ASCE 26-97

ASCE
STANDARD

American Society of Civil Engineers

Standard Practice for Direct Design of Buried Precast Concrete Box Sections

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This document uses both Système International (SI) units and customary units.

Published by the American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4400

ABSTRACT

This publication, *Standard Practice for Direct Design of Buried Precast Concrete Box Sections*, discusses the direct design of buried one-cell precast reinforced concrete box sections installed in accordance with Part III of this Practice intended for the conveyance of sewage, industrial wastes, storm water, and drainage. The publication also discusses these box sections as they are intended to serve as tunnels. Part II of this Practice presents the method of design for buried one-cell precast reinforced concrete box sections. Part III of this Practice presents construction requirements for precast reinforced concrete box sections designed in accordance with this Practice. The commentary provides supporting background data.

Library of Congress Cataloging-in-Publication Data

Standard practice for direct design of buried precast concrete box sections / American Society of Civil Engineers.
p. cm.— (ASCE Standard)
"ASCE 26-97."
Includes bibliographical references and index.
ISBN 0-7844-0472-0
1. Reinforced concrete construction. 2. Boxes—Design. 3. Precast concrete. 4. Soil-structure interaction. I. American Society of Civil Engineers.

TA683.2. S72 2000
624.1′83414—dc21

00-038955

Library of Congress Catalog Card No: 00-038955
ISBN 0-7844-0472-0
Manufactured in the United States of America.

STANDARDS

In April 1980, the Board of Direction approved ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by the Society. All such standards are developed by a consensus standards process managed by the Management Group F (MGF), Codes and Standards. The consensus process includes balloting by the balanced standards committee made up of Society members and nonmembers, balloting by the membership of ASCE as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding 5 years.

The following Standards have been issued.

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
ANSI/ASCE 2-91 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-99/ASCE 5-99/TMS 402-99) and Specifications for Masonry Structures (ACI 530.1-99/ASCE 6-99/TMS 602-99)
ASCE 7-98 Minimum Design Loads for Buildings and Other Structures
ANSI/ASCE 8-90 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
ANSI/ASCE 9-91 listed with ASCE 3-91
ASCE 10-97 Design of Latticed Steel Transmission Structures
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
ANSI/ASCE 12-91 Guideline for the Design of Urban Subsurface Drainage
ASCE 13-93 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE 14-93 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load and Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
ASCE 21-96 Automated People Mover Standards—Part 1
ASCE 21-98 Automated People Mover Standards—Part 2
SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
SEI/ASCE 24-98 Flood Resistant Design and Construction
ASCE 25-97 Earthquake-Actuated Automatic Gas Shut-Off Devices
ASCE 26-97 Standard Practice for Direct Design of Buried Precast Concrete Box Sections
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction

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FOREWORD

The material presented in this publication has been prepared in accordance with recognized engineering principles. This Standard and Commentary should not be used without first securing competent advice with respect to their suitability for any given application. The publication of the material contained herein is not intended as a representation or warranty on the part of the American Society of Civil Engineers, or of any other person named herein, that this information is suitable for any general or particular use or promises freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability from such use.

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ACKNOWLEDGMENTS

The American Society of Civil Engineers (ASCE) acknowledges the work of the Direct Design of Buried Concrete Pipe Standards Committee of the Management Group F, Codes and Standards. This group comprises individuals from many backgrounds including: consulting engineering, research, construction industry, education, government, design and private practice.

The Standard was prepared through the consensus standards process by balloting in compliance with procedures of ASCE's Management Group F, Codes and Standards. Those individuals who serve on the Standards Committee are:

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Standard Practice for Direct Design of Buried Precast Concrete Box Sections

PART I. GENERAL

1.0 SCOPE

1.1 This Standard Practice covers the direct design of buried one-cell precast reinforced concrete box sections installed in accordance with Part III of this Practice intended for the conveyance of sewage, industrial wastes, storm water, and drainage, and to serve as tunnels.

1.2 The precast reinforced concrete box sections designed under this Standard Practice are intended to be manufactured in accordance with ASTM Specifications C 789 and C 850 (AASHTO Standards M 259 and M 273) with exceptions as required by this Standard Practice.

1.3 Box sections with continuous pressure head above the top slab or unbalanced lateral loads other than from approaching wheels should not be designed in accordance with Practice.

1.4 When buried, precast reinforced concrete box sections are part of a composite system comprised of the box section and the surrounding soil envelope, which interact and contribute to the strength and structural behavior of the system.

1.5 Part II of this Standard Practice presents the method of design for buried one-cell precast reinforced concrete box sections. The design and analysis method accounts for the interaction between the box section and soil envelope in calculating loads, pressure distributions, moment, thrust, and shear in the box section, and includes a procedure for calculating the required reinforcement.

1.6 Part III of this Standard Practice presents construction requirements for precast reinforced concrete box sections designed in accordance with this Practice.

1.7 This Standard Practice may be used as a reference by the owner and the owner's engineer in preparing contract documents based on the direct design method.

1.8 The design procedures given in this Standard Practice are intended for use by engineers who are familiar with the installation characteristics and precast reinforced concrete box section characteristics that affect the structural behavior of buried one-cell precast reinforced concrete box section installations. Before applying the design procedures presented in Part II, the engineer should review the guidance and requirements given in other sections of this Standard Practice and its accompanying commentary.

1.9 The values of dimensions and quantities are expressed in inch-pound (English) units, which are to be regarded as standard. English unit values are converted to SI unit values, which are presented in parentheses or in a section following the English units. For clarity, Appendix A repeats the notation and contains the full translation of equations to SI units. The use of SI units is in accord with ASTM Practice E 380. SI units expressed in parentheses and in Appendix A are supplied for information only and are not a part of this Standard Practice.

Note 1: Some of the applicable standards referenced may have a double designation (Axxx/AxxxM) for separate inch-pound (English) and SI (metric) unit editions. Only the inch-pound unit edition of a standard is listed in this Standard Practice. If this Standard Practice is used in an SI unit design, the user should investigate whether separate SI unit editions of the referenced standards are available.

2.0 APPLICABLE DOCUMENTS

2.1 ASTM (AMERICAN SOCIETY FOR TESTING AND MATERIALS)

2.1.1 C 789 Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers

2.1.2 C 850 Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less than 2 ft of Cover Subjected to Highway Loadings

2.1.3 C 822 Definitions of Concrete Pipe and Related Products

2.1.4 D 698 Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5-lb Rammer and 12-in. Drop

2.1.5 E 380 Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)

2.2 AASHTO (AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS)

2.2.1 Standard Specifications for Highway Bridges and Structures

2.2.2 M 259 Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers

2.2.3 M 273 Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less than 2 ft of Cover Subjected to Highway Loadings

3.0 DEFINITIONS

3.1 For definitions of terms relating to precast concrete box sections, see ASTM Definitions C 822.

3.2 For terminology and definition of terms relating to structural design, see AASHTO Standard Specification for Highway Bridges and Structures.

3.3 Prism Load: Weight of column of earth over the outside span of the box section.

3.4 Fig. 3.4-1 illustrates the definitions and limits of the foundation, leveling course, sidefill or overfill, and box section as used in this Standard Practice.

3.5 For railroad loadings, the height of cover, H, is the distance from the top of the top slab to the bottom of the ties.

4.0 NOTATIONS

A = effective tension area of concrete surrounding the flexural tension reinforcement and having the same centroid as that reinforcement divided by the number of bars or wires, in.^{2} (mm^2)

A_s = area of tension reinforcement required in length b, in.^{2}/ft (mm^2/m)

A_{s1} = side wall outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s2} = top slab inside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s3} = bottom slab inside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s4} = side wall inside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s5a} = area of top slab inside face distribution reinforcement for traffic parallel to the box span, in.^{2}/ft (mm^2/m)

A_{s5b} = area of top slab inside face distribution reinforcement for traffic transverse to the box span, in.^{2}/ft (mm^2/m)

A_{s6} = top slab outside face distribution reinforcement area, in.^{2}/ft (mm^2/m)

A_{s7} = top slab outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s8} = bottom slab outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{vs} = area of stirrup reinforcement required to resist shear, in.^{2}/ft (mm^2/m) in each line of stirrups at circumferential spacing s_v

b = width of section that resists stress, in. (mm); taken as 12 in. (English units); and taken as 1,000 mm (SI units)

b = unit length of box section, ft (m); taken as 1 ft (English units); and taken as 1 m (SI units)

B_c = outside horizontal span of box, ft (m)

B_d = horizontal width of trench at top of box, ft (m)

B_1 = crack control coefficient for effect of concrete cover and spacing of reinforcement

C_d = load coefficient for trench installations

C_1 = crack control coefficient for type of reinforcement

d = distance from compression face to centroid of tension reinforcement, in. (mm)

d_b = diameter of tensile reinforcing bar, in. (mm)

d_c = thickness of concrete cover measured from extreme tension fiber to center of bar or wire located closest thereto, in. (mm)

f'_c = design compressive strength of concrete, lbs/in.^{2} (MPa)

f_s = maximum service load stress of reinforcing steel for crack control, lbs/in.^{2} (MPa)

f_v = maximum developable strength of stirrup material, lbs/in.^{2} (MPa)

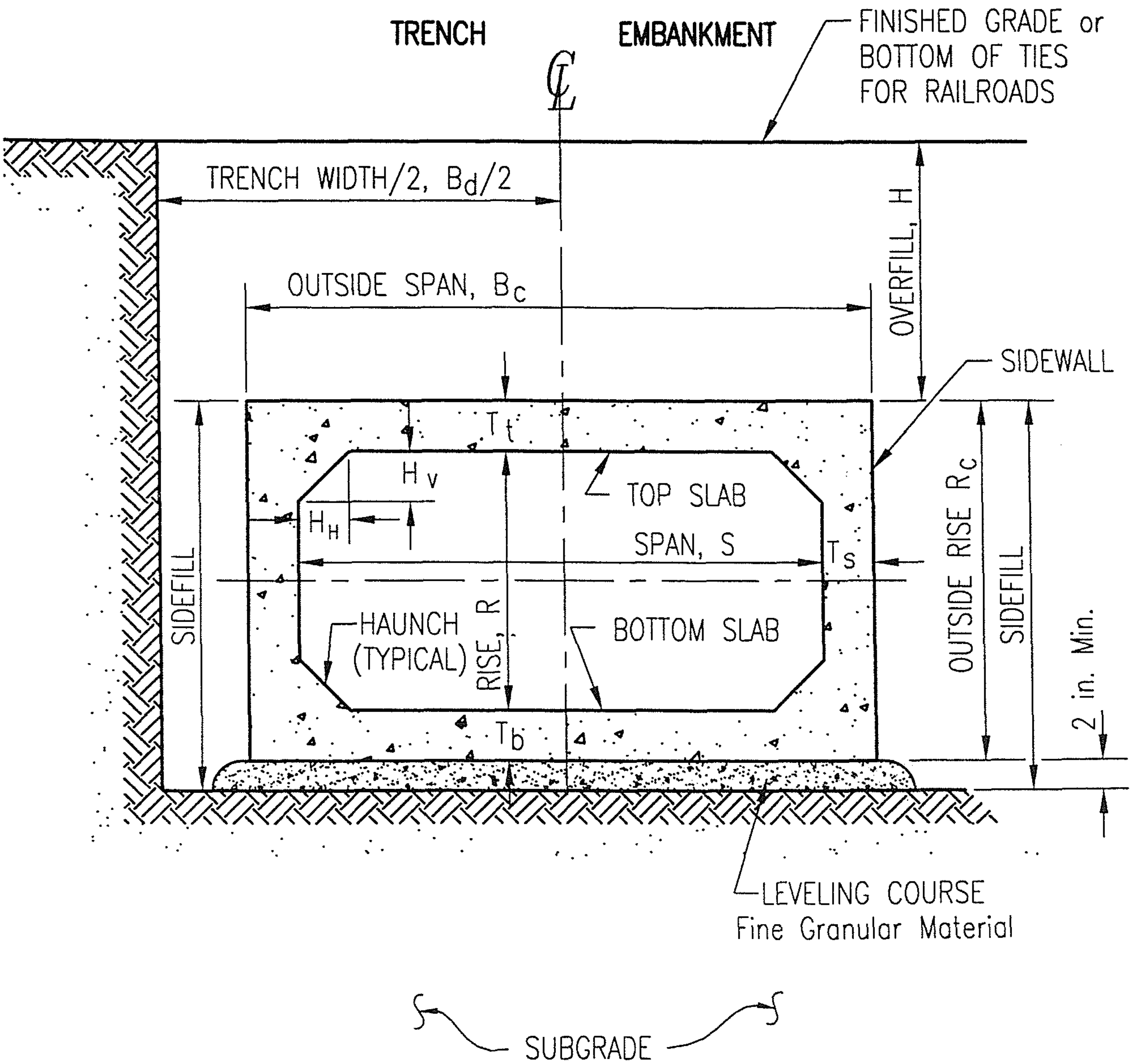


FIGURE 3.4-1. Box Section/Installation Terminology

f_y = design yield strength of reinforcement, lbs/in.^{2} (MPa)

F_{cr} = factor for adjusting crack control relative to average maximum crack width of 0.01 in. (0.3 mm) when F_{cr} = 1.0

F_d = factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing d

F_e = soil-structure interaction factor

F_{e1} = soil-structure interaction factor for embankment installations

F_{e2} = soil-structure interaction factor for trench installations

F_N = coefficient for effect of thrust on shear strength

h = overall thickness of member (wall thickness), in. (mm)

H = design height of earth cover above top of box section, ft (m)

H = for railroads, design height of cover above top of box section to bottom of the ties, ft (m)

H_H = horizontal dimension of haunch, in. (mm)

H_V = vertical dimension of haunch, in. (mm)

K = ratio of active lateral unit pressure to vertical unit pressure
L_d = reinforcement lap or development length, in. (mm)
M_s = service load bending moment acting on length b, in.-lbs/ft (N-mm/m)
M_u = factored moment acting on length b, in.-lbs/ft (N-mm/m)
M_{nu} = factored moment acting on length b as modified for effects of compressive or tensile thrust, in.-lbs/ft (N-mm/m)
n = number of layers of reinforcement in a cage
N_s = service load axial thrust acting on length b (+ when compressive, − when tensile), lbs/ft (N/m)
N_u = factored axial thrust acting on length b (+ when compressive, − when tensile), lbs/ft (N/m)
PL = PL denotes the prism load (weight of the column of earth) over the box section's outside span, wB_cH, lbs/ft (N/m)
R = inside vertical rise of box section, ft (m)
R_c = outside vertical rise of box section, ft (m)
s_v = circumferential spacing of stirrups, in. (mm)
S = inside span of box section, ft (m)
t_b = clear cover over reinforcement, in. (mm)
T_b = thickness of bottom slab, in. (mm)
T_s = thickness of side wall, in. (mm)
T_t = thickness of top slab, in. (mm)
V_b = basic shear strength of length b at critical section where $M_{nu}/(V_u d) \geq 3.0$, lbs/ft (N/m)
V_c = nominal shear strength provided by concrete in length b, lbs/ft (N/m)
V_u = factored shear force acting on length b, lbs/ft (N/m)
w = unit weight of soil, lbs/ft^3 (N/m^3)
W_E = total earth load on box for length b, lbs/ft (N/m)
Z_b = extension of A_{s1} reinforcement into bottom slab, in. (mm)
Z_t = extension of A_{s1} reinforcement into top slab, in. (mm)
β = approximate ratio of distance from neutral axis to location of crack width divided by the distance from neutral axis to centroid of tensile reinforcing
μ = coefficient of internal friction of the soil
μ' = coefficient of friction between overfill and trench walls
ϕ_f = strength reduction factor for flexure
ϕ_v = strength reduction factor for shear
ρ = ratio of reinforcement area to concrete area

5.0 SUMMARY OF PRACTICE

5.1 The design and analysis method accounts for the interaction between the box section and soil envelope in determining loads and distribution of earth pressure on a buried one-cell precast reinforced concrete box section. The loads and pressure distributions are used to calculate moment, thrust, and shear in the box section top and bottom slabs, and side walls, which are then used to determine the required box section reinforcement.

5.2 Load effects are determined separately for each loading case.

5.3 The structural design of one-cell precast reinforced concrete box sections is based on a limits state design procedure that accounts for strength and serviceability criteria and is consistent with the procedures outlined in Section 17 of the AASHTO Standard Specifications for Highway Bridges. The design criteria include: structural aspects, such as flexure, thrust, and shear strengths; handling and installation; fatigue limits; and crack width control.

5.4 The design of a one-cell precast reinforced concrete box section is based on the assumption that specified design bedding and installation requirements will be achieved during construction of the installation.

PART II. DIRECT DESIGN METHOD

6.0 GENERAL

6.1 Design procedures and criteria shall conform to applicable sections of this Standard Practice.

6.2 DESIGN SUBMITTALS

6.2.1 This Practice permits the box sections to be designed and detailed by the manufacturer in accordance with design requirements furnished by the owner and installation requirements furnished by the jacking contractor. Shop drawings and design calculations are to be submitted to the owner and the jacking contractor for review and approval prior to manufacture.

6.2.2 When the owner provides the design, the box section manufacturer shall provide shop drawings for submittal to the owner and jacking contractor for approval.

6.2.3 When the owner prepares a design, the manufacturer may submit an alternate design to the owner for approval.

7.0 GENERAL DESIGN REQUIREMENTS

7.1 The following design requirements shall apply:

7.1.1 Load Factors

Dead and Earth Load Factor (Shear and Moment)	1.3
Dead and Earth Load Factor (Thrust)	
Reinforcement design	1.0
Concrete compression	1.3
Live Load Factor (Shear and Moment)	2.17
Live Load Factor (Thrust)	1.3
Intermittent Internal Pressure Load Factor (Thrust)	1.3

7.1.2 Strength Reduction (Phi) Factors

Flexure, and Combined Flexure and Thrust, ϕ_f	0.95
Shear, ϕ_v	0.9

7.1.3 Crack Control Factor

(unless modified by the owner)	1.0

8.0 DESIGN REQUIREMENTS BY OWNER

8.1 The owner shall establish the following criteria and requirements:

8.1.1 Intended use of box sections.

8.1.2 Inside span and rise of box sections. Dimensions shall conform to the standard dimensions specified in ASTM Specifications C 789 and C 850 (AASHTO Standards M 259 and M 273).

8.1.3 Plan and profile drawings of project with installation cross-sections as required.

8.1.4 Maximum and minimum design earth cover height above the top of the box sections.

8.1.5 Soil data sufficient to determine in situ conditions, and overfill or overfill weight.

8.1.6 Performance requirements for box section joints.

8.1.7 Any live load, surcharge, groundwater, internal hydrostatic pressure, or other loadings.

8.1.8 Location of ground water table with respect to bottom of box section.

8.1.9 Concrete cover over reinforcing, if different than standard.

8.1.10 Other requirements deemed necessary by the owner.

9.0 REQUIREMENTS OF MANUFACTURER

9.1 The manufacturer shall submit the following data to the owner for approval.

9.1.1 Wall Thickness

9.1.2 Concrete Strength

9.1.3 Reinforcement:

- specification,
- reinforcement Type 1, 2, or 3 as shown in Section 12, Table 12-1

- design yield strength,
- placement and design concrete cover,
- cross-sectional diameters,
- spacing,
- cross-sectional area,
- description of longitudinal members, and
- if stirrups used, developable stirrup design stress, stirrup shape, placement, and anchorage details.

9.1.3.1 The minimum design concrete cover for reinforcement in box sections shall be 2 1/2 times the reinforcement diameter but not less than 1 in. (25 mm), except that concrete cover need not exceed 1 1/2 in. unless otherwise specified. For boxes with less than 2 ft of cover subjected to highway loadings, the minimum design cover for reinforcement in the top of the top slab shall be 2 in. (50 mm).

9.1.3.2 The inside circumferential reinforcement shall extend into the tongue portion of the joint and the outside circumferential reinforcement shall extend into the groove portion of the joint. The clear distance of the end circumferential wires shall be not less than 1/2 in. nor more than 2 in. from the ends of the box section (see Section 12, Figs. 12-2, 12-3, and 12-4). Distribution reinforcement need not extend into the joints but the end cover shall be not more than 2 in. from the ends of the full thickness portion of the slab.

9.1.3.3 In certain loading conditions for 2 ft or more earth cover, A_{s7} and A_{s8} may not be required. In this case, joint reinforcement shall be placed in the groove (see Section 12, Fig. 12-3).

9.1.4 Box section laying length and joint information.

9.1.5 The yield strength and ultimate strength of the tension reinforcement used for design shall be as specified in Section 10.2.1 or 10.2.2.

10.0 MATERIALS

10.1 CONCRETE

10.1.1 Concrete shall conform to the requirements of ASTM Specifications C 789 or C 850 (AASHTO Standards M 259 or M 273).

10.2 REINFORCEMENT

10.2.1 Reinforcement shall consist of cold-drawn steel wire conforming to ASTM Specification A 82 or ASTM Specification A 496, or of cold-drawn steel welded wire fabric conforming to ASTM Specification A 185 or ASTM Specification A 497, or of hot-rolled steel bars conforming to ASTM Specification A 615.

10.2.2 The use of cold-drawn steel or cold-drawn steel welded wire fabric with strengths exceeding ASTM Specification values may be approved by the owner when the reinforcing manufacturer's mill test report certifies that a higher minimum yield and ultimate strength steel is being provided. The other requirements of the appropriate ASTM specifications listed in Section 10.2.1 (A 82, A 496, A 185, or A 497) shall be met by the higher minimum-strength steels. The yield strength shall not be taken greater than 86% of the ultimate strength, or 80 ksi (560 MPa), whichever is lower.

10.2.2.1 Section 10.2.2 does not apply to wire sizes having a nominal diameter of less than 0.080 in. (2 mm) or nominal cross-sectional area of less than 0.005 in.^{2} (3 mm^2). Section 10.2.2 does not apply to (any size of) hot-rolled steel manufactured in accordance with ASTM A615.

11.0 LOADS, LOAD COMBINATIONS, AND STRUCTURAL ANALYSIS

11.1 LOADS

11.1.1 Dead Loads

11.1.1.1 The dead load of the box section weight shall be considered in the design and based on a reinforced concrete density of 150 lbs/ft^3 (24 KN/m^3), unless otherwise specified.

11.1.1.2 The earth load from the fill over the box section shall be based on the design soil unit weight (mass) specified by the owner in Section 8.1.5, but not less than 110 lbs/ft^3 (17.6 KN/m^3), unless otherwise specified.

11.1.1.3 Fluid load in the box section shall be based on a unit weight of 62.4 lbs/ft^3 (10 KN/m^3), unless otherwise specified.

11.1.1.4 Uplift and lateral load caused by ground water, if any, above the bottom of the box section shall be considered as additional dead load.

11.1.2 Live Loads

11.1.2.1 Truck loads shall be either the AASHTO HS-series or the AASHTO Interstate Design load, or other truck loads as specified by the owner.

11.1.2.1.1 The static wheel loads shall be multiplied by the following AASHTO impact factors (see Table 11-1), which depend on the height of earth and pavement cover over the top of the box section:

TABLE 11-1. AASHTO Impact Factors

Earth and Pavement Cover Over Top of Box Section, ft	Impact Factor
0 to 1	1.3
Greater than 1 to 2	1.2
Greater than 2 to less than 3	1.1
3 and Greater	1.0

11.1.2.2 Railroad loads shall be as specified by the owner.

11.1.2.3 Aircraft loads shall be as required by the Federal Aviation Administration, or as specified by the owner.

11.1.2.4 Uniformly distributed surface surcharge or other live loads shall be as specified by the owner.

11.1.2.5 Special construction live loads shall be considered, if applicable.

11.2 LOAD APPLICATIONS

11.2.1 Pressure distributions for each load type are listed in Table 11-2 as Load Cases 1 through 10, and shown graphically in Fig. 11-1.

11.2.2 For purposes of computing maximum design forces at design locations, each load case is assigned as one or more of the following categories:

- **Permanent Dead Load**—Permanent dead loads are considered to be acting on the structure at all times.
- **Additional Dead Loads**—Additional dead loads are considered to be acting on the structure only if they increase the design force at the design section being considered.
- **Live Loads**—Live loads are considered to be acting on the structure only if they increase the design force at the design section being considered.

11.2.3 Load Case 1: Box Section Weight

Box section weight shall be computed based on the specified wall and slab thicknesses and concrete density.

11.2.4 Load Case 2: Vertical Soil Load

Vertical soil load shall be computed as the prism load modified by a soil structure interaction factor, F_e, that accounts for the conditions of installation, so that the earth load, W_E, on the box section is:

$$W_E = F_e w B_c H \qquad (11\text{-}1)$$

F_e may be determined by the Marston-Spangler Theory of earth loads, or by the simplified equations as follows.

11.2.4.1 For embankment installations (see Section 3, Fig. 3.4-1), F_{e1}

TABLE 11-2. Load Cases

Load Case	Load Category (1)	Description
1	P	Box section weight
2	P	Vertical soil weight
3	P	Lateral soil pressure
4	A	Additional lateral soil pressure
5	A	Internal fluid weight
6	L	Uniform highway, railroad, or aircraft load
7	L	Non-uniform highway, railroad, or aircraft load
8	L	Approaching highway, railroad, or aircraft load
9	P, A, L (2)	Uniform vertical surcharge load
10	P, A, L (2)	Linearly varying lateral surcharge load

Notes:
1. P = Permanent dead load
   A = Additional dead load
   L = Live load
2. Owner specifies load category for surcharge conditions.

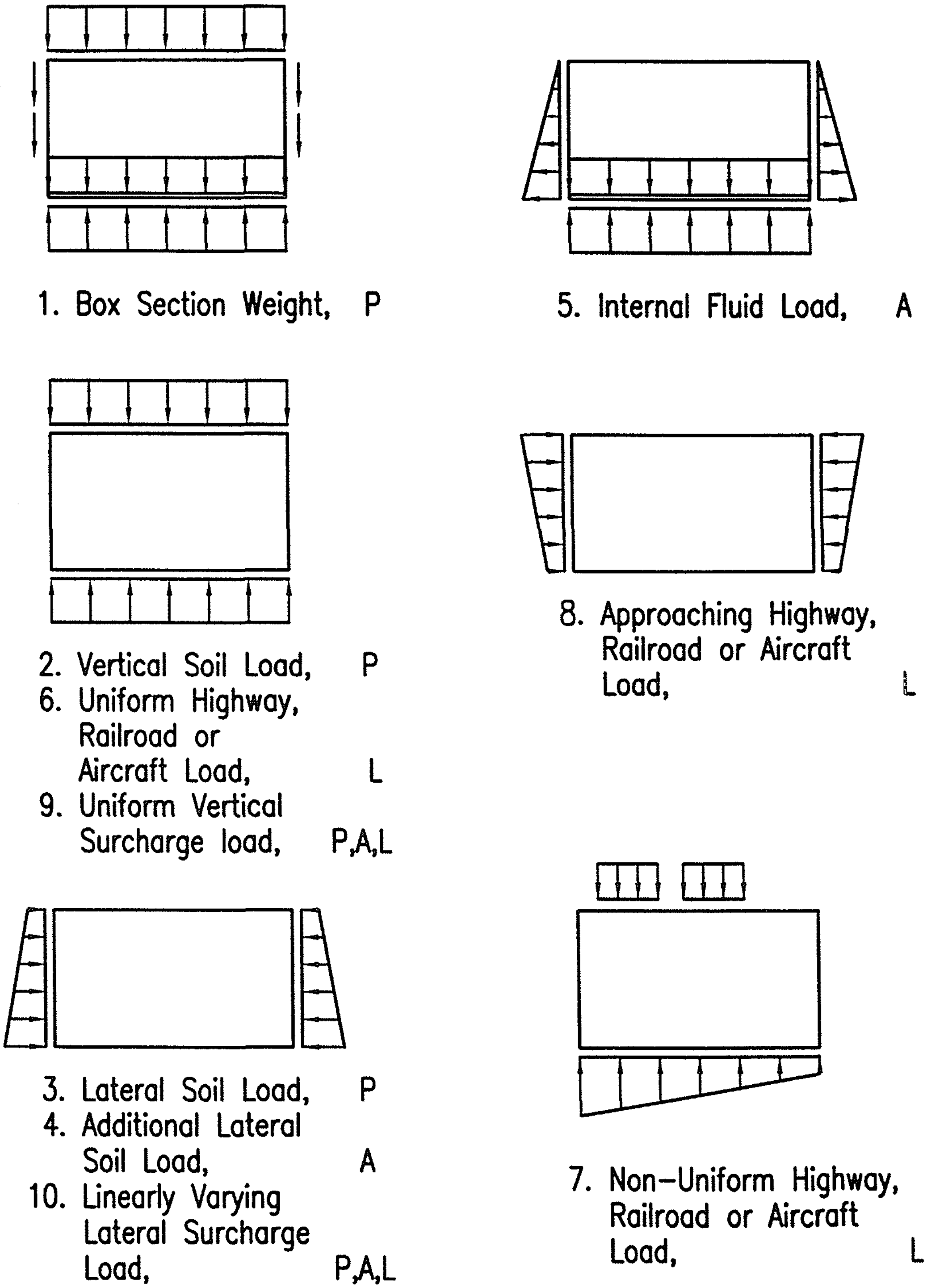


FIGURE 11-1. Load Cases

$$F_{e1} = 1 + 0.20\frac{H}{B_c} \qquad (11\text{-}2)$$

F_{e1} need not be greater than 1.15 for installations with compacted fill at the sides of the box section conforming to requirements given in Section 20.0, and need not be greater than 1.4 for installations with uncompacted fill at the sides of the box section.

11.2.4.2 For trench installations (see Section 3, Fig. 3.4-1), F_{e2}

$$F_{e2} = \frac{C_d B_d^2}{HB_c} \qquad (11\text{-}3)$$

Values of C_d can be obtained from Fig. 11-2 for normally encountered soils. The maximum value of F_{e2} need not exceed F_{e1}.

11.2.5 Load Cases 3 and 4: Lateral Soil Loads

Lateral soil loads shall be taken as the vertical soil pressure times a lateral soil pressure coefficient. Designs shall consider the maximum stress resultants produced by the range of lateral soil pressure coefficient values between 0.25 and 0.5. Load Case 4 is the additional lateral soil load above the 0.25 minimum pressure coefficient, and shall be treated as an additional dead load.

For railroads and airports, lateral soil loads shall be as specified by the owner.

11.2.6 Load Case 5: Internal Fluid Weight

Internal fluid weight shall be computed based on the specified depth and density of fluid in the box section.

11.2.7 Load Case 6: Uniform Highway, Railroad, or Aircraft Load

For box sections where the load distribution length, as determined in Sections 11.2.13 through 11.2.15, is equal to or greater than the outside span of the box section, a highway, railroad, or aircraft load shall be distributed as a uniform load.

11.2.8 Load Case 7: Non-Uniform Highway, Railroad, or Aircraft Load

For box sections where the load distribution length, as determined in Sections 11.2.13 through 11.2.15, is less than the outside span of the box section, a highway, railroad, or aircraft load shall be placed and analyzed at critical locations.

11.2.9 Load Case 8: Approaching Highway, Railroad, or Aircraft Load

The effects of approaching highway, railroad, or aircraft loads shall be analyzed as a lateral load pressure. For AASHTO highway loads (Fig. 11-3), the lateral pressure shall be equal to 800 psf (38.3 kPa) for earth cover depths to 1 ft (0.3 m); and for depths of fill greater than 1 ft (0.3 m), the lateral pressure shall be equal to 700/H psf (33.5/H kPa). For railroad loads and aircraft loads, the lateral pressure shall be as specified by the owner.

11.2.10 Load Case 9: Uniform Vertical Surcharge Load

Vertical surcharge loads shall be as specified by the owner and shall be considered uniformly distributed over the top slab of the box section.

11.2.11 Load Case 10: Linearly Varying Lateral Surcharge Load

Lateral surcharge loads shall be as specified by the owner and shall be considered as varying linearly with top and bottom magnitudes as specified by the owner.

11.2.12 Intermittent Internal Fluid Pressure Load

When loads from intermittent internal fluid pressures are considered, a separate design shall be made with the pressure taken as a negative "permanent dead load." This separate design shall be compared to the design without internal fluid pressure, and the controlling conditions used in the final design.

11.2.13 Highway Load Distribution through Earth Cover

The earth pressure caused by a concentrated surface load from truck wheels shall be assumed to decrease with increasing depth at an angle of about 41° with the vertical in each direction, as shown in Fig. 11-4. This angle increases the length of the sides of the load area 1.75 ft (m) for every ft (m) of depth below the surface.

The loaded area is also a function of the tire contact area, as shown in Fig. 11-5. The tire contact area shall be $0.01P$, where P is the wheel load; and the ratio of tire width to tire contact chord length, W/L, shall be 2.5. For an HS 20 truck, the tire footprint is 20 in. (500 mm) in width, W, by 8 in. (200 mm) in contact chord length, L, as shown in Fig. 11-5. A design wheel load is obtained by multiplying the nominal wheel load by a β factor of 1.67. Therefore,

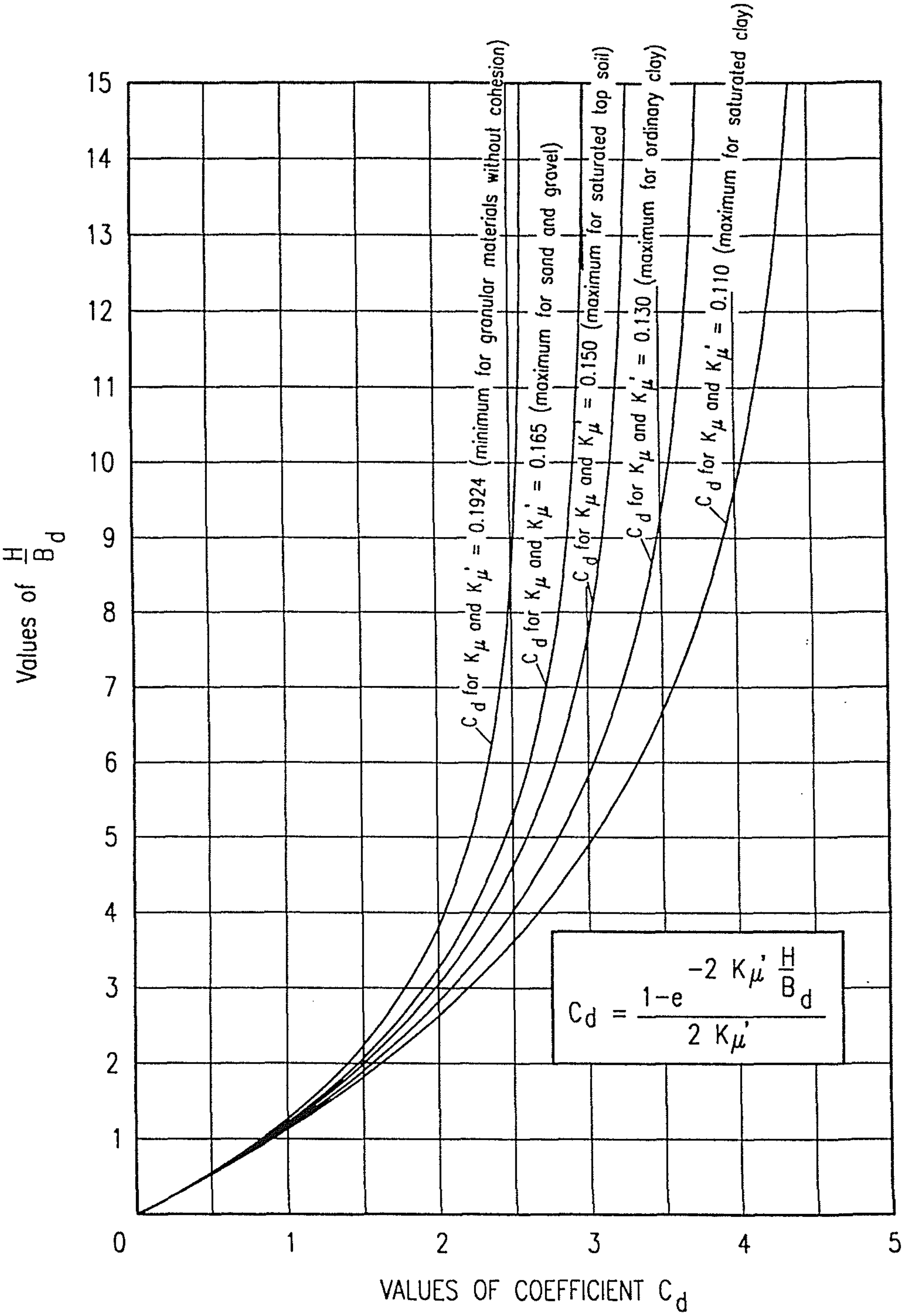


FIGURE 11-2. Coefficient C_d—Load Coefficient for Trench Installations

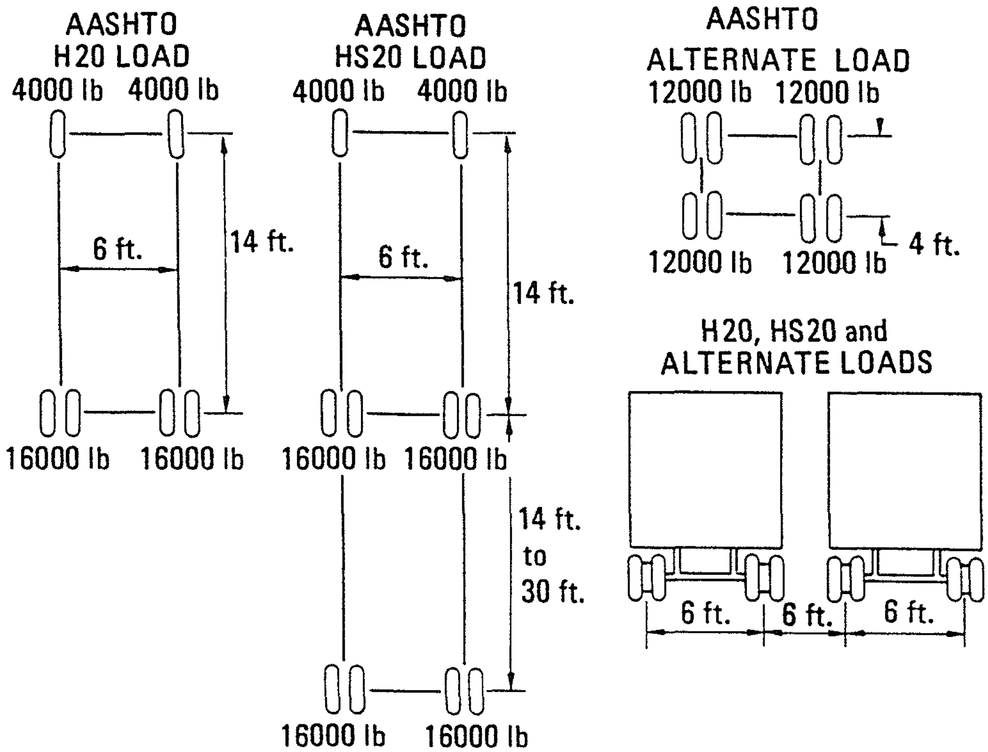


FIGURE 11-3. AASHTO Live Loads

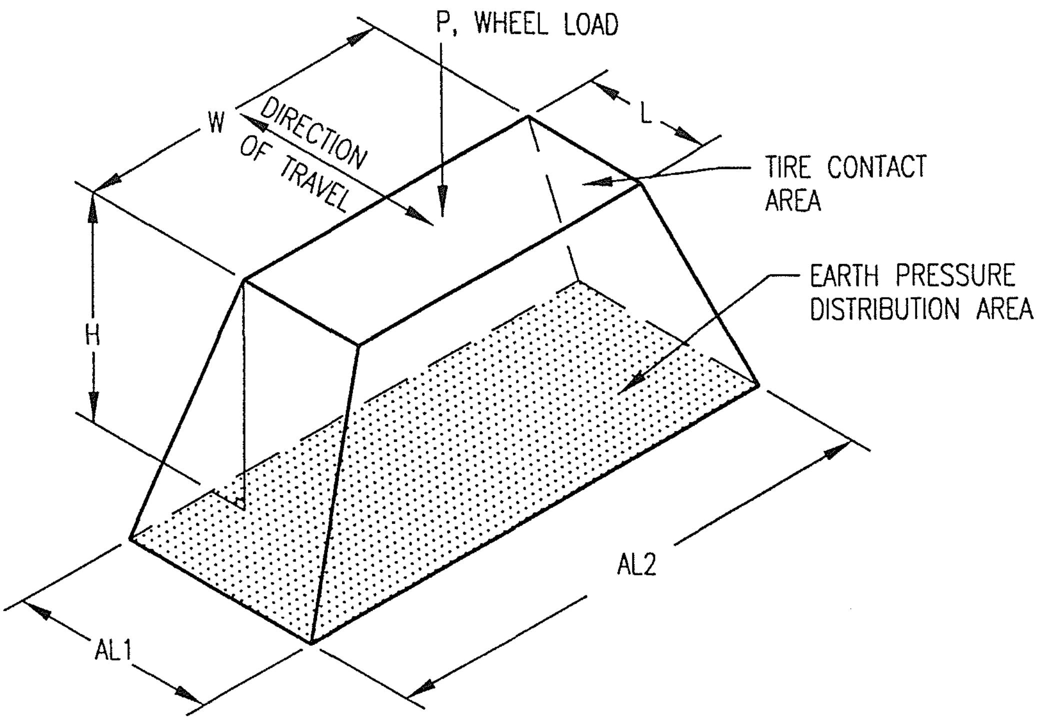


FIGURE 11-4. Earth Pressure Distribution Area at Depth of Earth Cover

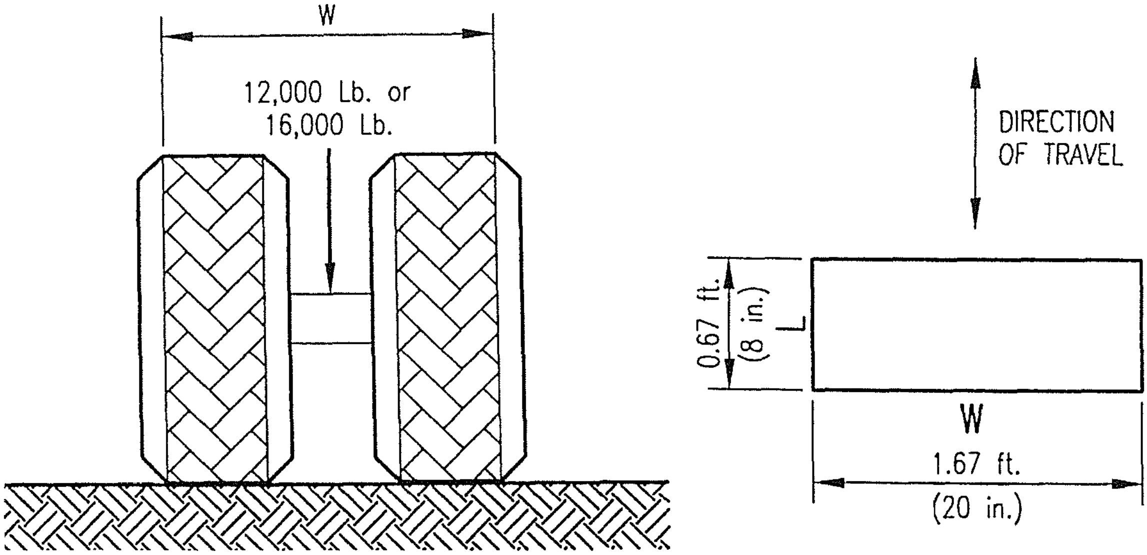


FIGURE 11-5. AASHTO Tire Contact Area for HS20 Dual Wheels

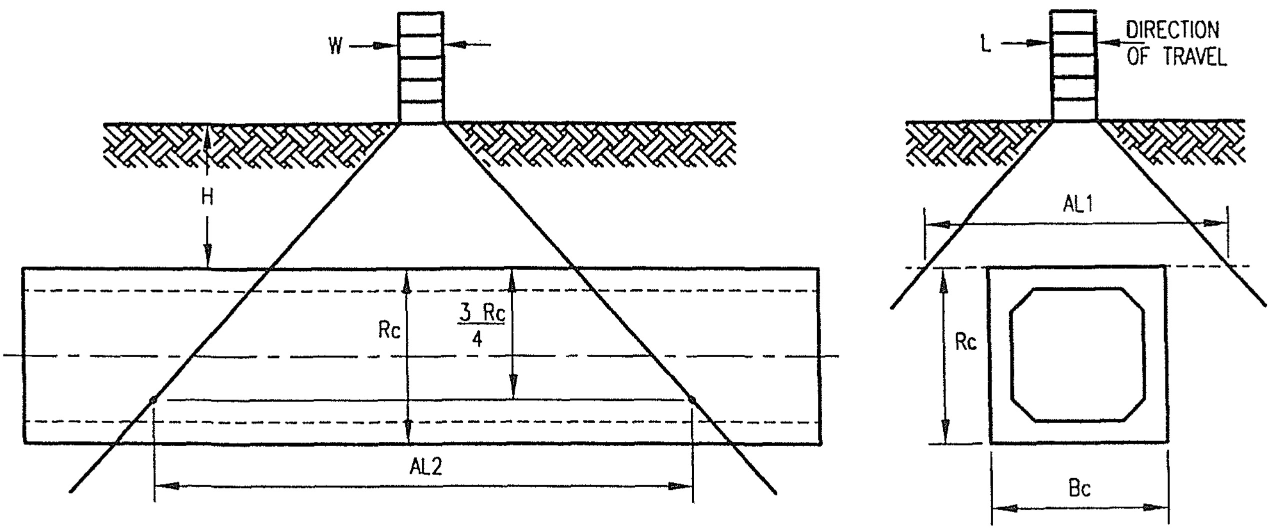


FIGURE 11-6. Additional Distribution of Effective Earth Pressure due to Longitudinal Beam Stiffness

to develop the increased load, the contact chord length is increased to βL.

The attenuated surface load shall be considered as that acting on the top of the box section's top slab, and reaction to the top loading shall be considered as acting on the bottom of the bottom slab, which provides additional distribution of effective earth pressure due to longitudinal beam stiffness, as shown in Fig. 11-6.

When the direction of travel is perpendicular to the axis of the box section, the equivalent earth pressure, w_L, produced by a single wheel over a box section with an outside span, B_c, and a height of earth cover, H, over its top slab (Fig. 11-6) is:

$$w_L = \frac{P \times I_f}{AL2 \times AL1} \tag{11-4}$$

$$AL1 = L + 1.75H \tag{11-5}$$

$$AL2 = L + 1.75[H + 0.75R_c] \tag{11-6}$$

Overlapping pressures from adjacent wheels shall be considered, including adjacent wheels on a single truck and on passing trucks in one or more travel lanes. The more severe of the following two conditions shall be considered as the design load combination:

(1) A single overloaded truck with nominal wheel loads multiplied by β. If this load combination produces more severe strength requirements than combination (2), it shall be used for strength criteria, but not for service criteria (cracking and fatigue).
(2) Multiple trucks in four lanes with nominal wheel loads not multiplied by β. If this load combination produces more severe strength requirements than combination (1), it shall be used for strength criteria. It shall always be used as service criteria.

The total live load on the box section shall be determined from the effective live load pressure and the spread distance, $AL1$. If the spread distance is less than the outside span of the box section, the portion of the total live load that acts on a unit length of box section, W_L, is:

$$W_L = w_L \times AL1 \qquad (11\text{-}7)$$

If the spread distance is greater than the outside span of the box section, the portion of the total live load that acts on a unit length of box section is:

$$W_L = w_L B_c \qquad (11\text{-}8)$$

The reactive earth pressures acting on the bottom slab of the box section caused by the effective portion of the surface live load acting on the top slab of the box section shall be assumed to have the distribution as shown in Fig. 11-1, Load Case 7 for non-uniform load distribution and Load Case 6 for uniform load distribution.

11.2.14 Railroad Load Distribution through Ballast and Earth

Railroad load distribution through ballast and earth shall be as specified by the owner.

11.2.15 Aircraft Load Distribution through Pavement and Earth

Aircraft wheel load distribution through earth shall be as specified by the owner. If no requirements are specified or required, aircraft wheel loads may be distributed through pavement and earth in accordance with the provisions of Section 11.2.13 on highway loads.

11.3 STRUCTURAL ANALYSIS

11.3.1 Stress Resultants for Design

The design of box sections shall be based on an analysis for moments, thrusts, and shears at locations in the structure that govern requirements for concrete and reinforcement crack control and strength.

11.3.2 Assumptions for Analysis

Moments, thrusts, and shears may be determined using an elastic analysis with the slabs, walls, and haunches of the box section assumed to be uncracked concrete members. If a box section contains haunches, the stiffness of the haunches shall be included in the analysis.

11.3.3 Combined Effects of Stress Resultants

The design of a box section for serviceability and strength shall be based on the combined effects of the moment, thrust, and shear that govern the concrete and reinforcement crack control and strength requirements at all locations in the box section.

Moments, thrusts, and shears in the transverse direction for the permanent dead load cases given in Section 11 shall be combined with moments, thrusts, and shears in the transverse direction for the "additional dead load" and "live load" cases, when the "additional dead load and live load" cases increase the structural effects produced by the combined moment, thrust, and shear at each design section that governs the required concrete and reinforcement design.

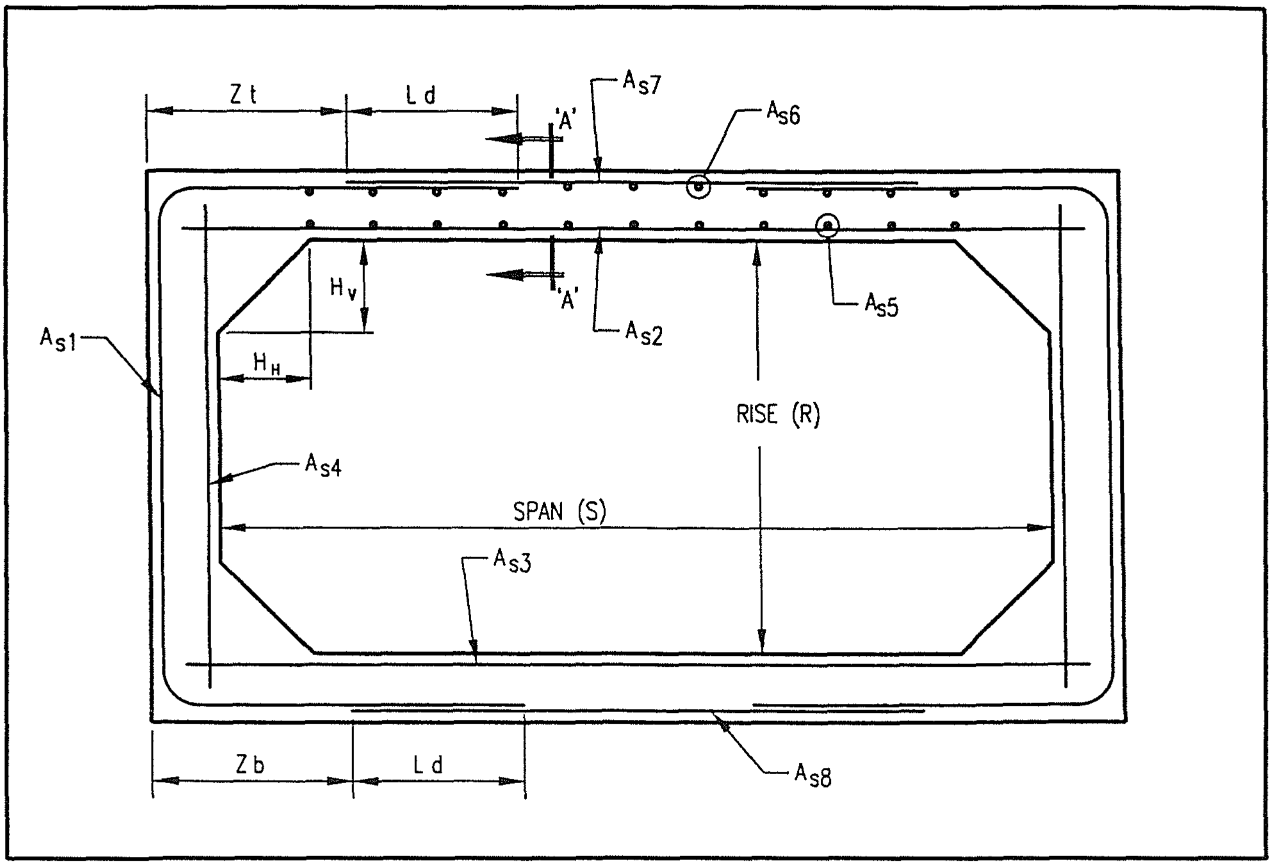
12.0 REINFORCEMENT

12.1 REINFORCEMENT DETAILS

12.1.1 Reinforcement details for precast reinforced concrete box sections shall be as shown in Figs. 12-1 through 12-4.

12.2 REINFORCEMENT DESIGN

12.2.1 Reinforcement for flexural strength shall be not less than A_s where



Notes:

1. Reinforcement anchorage/development and splices shall be in accordance with the AASHTO Bridge Standards or ACI 318.
2. In certain loading conditions for two ft. or more earth cover, A_S7 and A_S8 may not be required. In this case, joint reinforcement shall be placed in the groove in accordance with Section 9.1.3.3.
3. Distribution reinforcement A_S5 and A_S6 is required for AASHTO truck loadings when earth cover is less than 2 ft.
4. See Figures 12-2 and 12-3 for Section 'A'–'A'.

FIGURE 12-1. Typical Box Section Reinforcement Layout

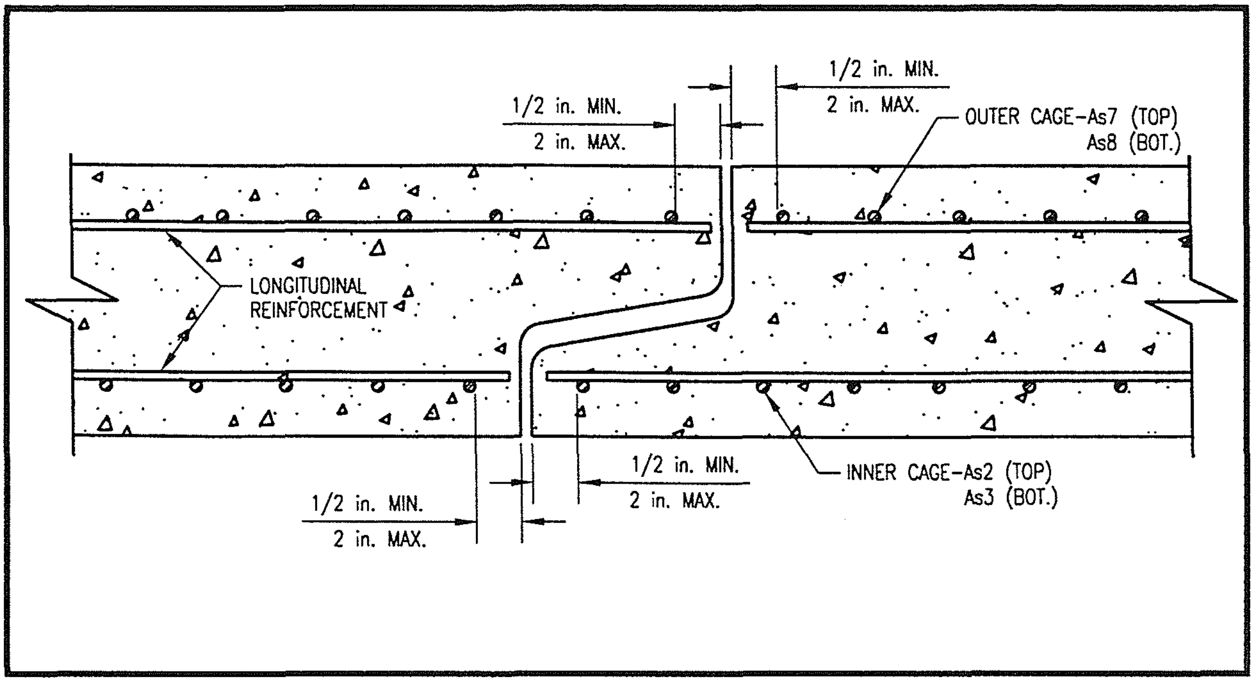


FIGURE 12-2. Reinforcement Placement at Ends of Box when As7 and As8 Cages Are Used

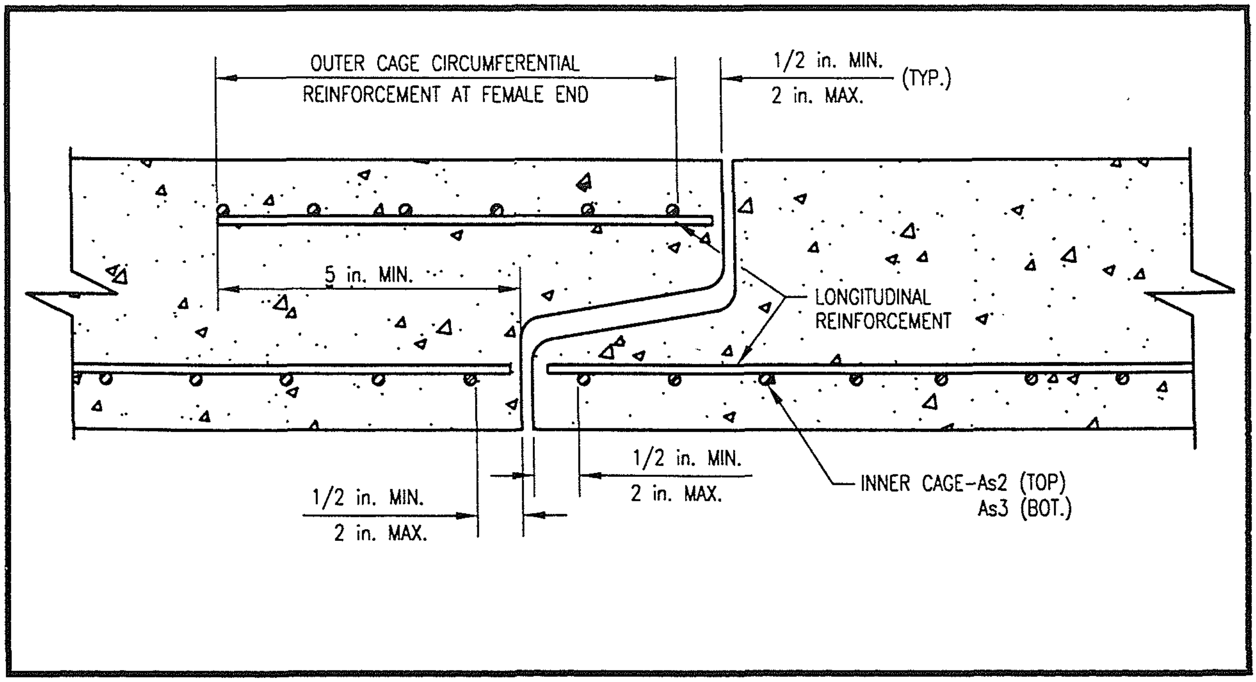


FIGURE 12-3. Reinforcement Placement at Ends of Box when As7 and As8 Cages Are Not Used

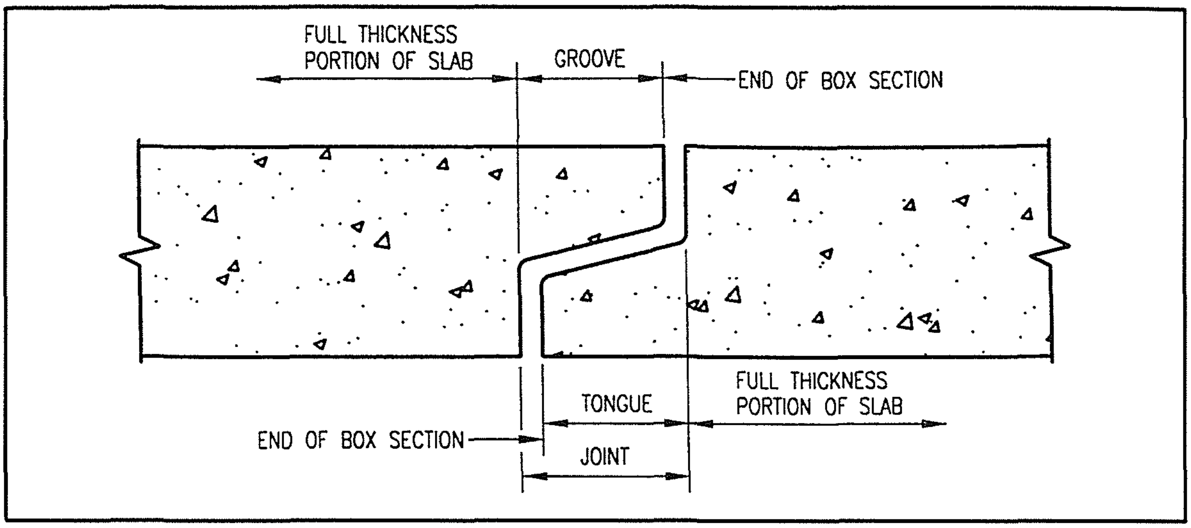


FIGURE 12-4. Typical Box Section Joint (Top Slab Shown)

$$A_s = (g\phi_f d - N_u - \sqrt{g[g(\phi_f d)^2 - N_u(2\phi_f d - h) - 2M_u]})/(f_y) \quad (12\text{-}1)$$

where

$g = 0.85bf'_c$
$b = 12$ in.

12.2.2 Minimum Reinforcement

12.2.2.1 Where tensile steel reinforcement is required, the minimum reinforcement area shall be:

$$A_{s\,\min} = 0.002bh \quad (12\text{-}2)$$

12.2.3 Maximum Flexural Reinforcement Limited by Concrete Compression

$$A_{s\,\max} = \left(\left[\frac{5.5 \times 10^4 g'\phi_f d}{(87{,}000 + f_y)}\right] - 0.75N_u\right) \Big/ (f_y) \quad (12\text{-}3)$$

$$g' = bf'_c\left[0.85 - 0.05\,\frac{(f'_c - 4{,}000)}{1{,}000}\right] \quad (12\text{-}4)$$

where

$b = 12$ in.
$g'_{\max} = 0.85bf'_c$
$g'_{\min} = 0.65bf'_c$

12.2.4 Crack Control

12.2.4.1 Crack control is assumed to be at 1 in. (25 mm) from the tension reinforcement.

12.2.4.2 For welded wire fabric with spacing of circumferential wires of 4 in. (100 mm) or less, and hot rolled bars with bar diameters 1/2 in. (13 mm) or less, the Crack Control Factor, F_{cr}, shall not exceed that specified, where:

$$F_{cr} = \frac{B_1}{30{,}000\phi_f d A_s}\left[\frac{M_s + N_s\left(d - \frac{h}{2}\right)}{ij} - C_1 bh^2\sqrt{f'_c}\right] \quad (12\text{-}5)$$

where

C_1 = see Table 12-1
$b = 12$ in.

TABLE 12-1. Crack Control Coefficients

Type of Reinforcement	C_1
1. Smooth wire or plain bars	1.0
2. Welded smooth wire fabric, 8 in. (200 mm) maximum spacing of longitudinals or welded deformed wire fabric and deformed wire	1.5
3. Deformed bars or any reinforcement with stirrups anchored thereto	1.9

$$j \cong 0.74 + 0.1e/d \quad (12\text{-}6)$$

$$j_{max} = 0.9$$

$$i = \frac{1}{1 - \frac{jd}{e}} \quad (12\text{-}7)$$

$$e = \frac{M_s}{N_s} + d - \frac{h}{2}, \text{ in.} \quad (12\text{-}8)$$

if $e/d < 1.15$ *crack control will* not *govern*

$$B_1 = \sqrt[3]{t_b s_l / 2n} \quad (12\text{-}9)$$

where

s_l = spacing of circumferential reinforcement, in.
n = 1, when tension reinforcement is a single layer
n = 2, when tension reinforcement is made of multiple layers

12.2.4.3 Hot rolled deformed bar reinforcement larger than 1/2 in. (13 mm) shall be designed so that the service load steel stress, f_s, does not exceed that specified, where

$$f_s = \frac{155}{\beta \sqrt[3]{d_c A}} \leq 36 \text{ ksi} \quad (12\text{-}10)$$

$$\beta = 1 + \frac{d_c}{0.7d} \quad (12\text{-}11)$$

$$\max d_c = 0.5 d_b + 2 \quad (12\text{-}12)$$

12.2.5 Shear Strength (Diagonal Tension)

The box section wall shall be designed so that for each region requiring inner or outer flexural tensile reinforcement in accordance with Sections 12.2.1 and 12.2.4, the shear strength of the concrete, V_c, shall be greater than the maximum factored shear force, V_u, in each region.

12.2.5.1 Shear Strength, V_c, at Sections where $M_{nu}/V_{ud} \geq 3.0$

The shear strength of the concrete, V_c, is equal to the basic shear strength, V_b, where:

$$V_b = b\phi_v d\sqrt{f'_c}\,(1.1 + 63\rho)(F_d F_N) \quad (12\text{-}13)$$

where

b = 12 in.
$f'_{c\,max}$ = 7,000 psi

$$\rho = \frac{A_s}{bd} \quad (12\text{-}14)$$

where

b = 12 in.
ρ_{max} = 0.02

$$F_d = 0.8 + \frac{1.6}{d} \leq 1.3 \quad (12\text{-}15)$$

For compressive thrust ($+N_u$):

$$F_N = 1 + \frac{N_u}{2{,}000bh} \quad (12\text{-}16)$$

where b = 12 in.

For tensile thrust ($-N_u$):

$$F_N = 1 + \frac{N_u}{500bh} \quad (12\text{-}17)$$

where b = 12 in.

$$M_{nu} = M_u - N_u\left[\frac{(4h - d)}{8}\right] \quad (12\text{-}18)$$

12.2.5.2 Shear Strength, V_c, at Sections where $M_{nu}/V_u d < 3.0$

$$V_c = \frac{4V_b}{\frac{M_{nu}}{V_u d} + 1} \quad (12\text{-}19)$$

$$\max V_c = 3.0\phi_v bd\sqrt{f'_c} \quad (12\text{-}20)$$

$$\max \frac{M_{nu}}{V_u d} = 3.0 \quad (12\text{-}21)$$

12.2.5.3 If V_c is less than V_u, the area of tensile reinforcement may be increased up to $\rho_{max} bd$ to increase shear strength, or stirrups shall be provided as required by Section 12.2.6.

12.2.5.4 Sections located less than a distance, d, from the face of a support may be designed for the same shear, V_u, as that computed at a distance, d, provided that:

(1) The support reaction, in the direction of the applied shear, introduces compression into the end regions of the member, and
(2) No concentrated load occurs between the face of the support and the location of the critical section at d.

12.2.5.5 The tips of haunches with an inclination 45° or steeper may be taken as the face of a support.

12.2.6 Stirrups

If stirrups are required for shear by Section 12.2.5, they shall meet the following requirements:

12.2.6.1 Area of Stirrups

$$A_{vs} = \frac{1.1 s_v}{f_v \phi_v d} [V_u - V_c] \qquad (12\text{-}22)$$

$$V_c = \frac{4V_b}{\dfrac{M_{nu}}{V_u d} + 1} \qquad (12\text{-}23)$$

$$V_{c\max} = 2\phi_v bd\sqrt{f'_c} \qquad (12\text{-}24)$$

where b = 12 in.

$f_{v\max} = f_y$, or anchorage strength, whichever is less

$$s_{v\max} = 0.75\phi_v d \qquad (12\text{-}25)$$

12.2.6.2 Extent of Stirrups

(1) Stirrups shall be provided in all locations where V_u is greater than V_c plus an additional minimum distance equal to the wall or slab thickness, h, beyond this region.
(2) The stirrups required at a point of critical shear shall be extended to the face of the support members. In box sections with 45° or steeper haunches, the stirrups used in the slab shall be extended to a point one-third the wall thickness, h, from the start of the haunch toward the inside face of the wall.

12.2.6.4 Stirrup Anchorage

When stirrups are required, the stirrups shall be anchored around circumferentials that are in tension due to any of the required loading combinations. Anchorage of both ends of the stirrup shall be sufficient to develop the factored stress in the stirrup. The maximum factored tensile stress in the stirrup shall be the yield stress or the stress that can be developed by anchorage, whichever is less.

12.2.7 Welds, Splices, and Development of Reinforcement

Welds, splices, and development of welded wire fabric reinforcement shall conform to the requirements of ASTM C 789 or C 850 (AASHTO M 259 or M 273) (see Fig. 12-1). The AASHTO Standard Specifications for Highway Bridges or ACI 318 shall apply for reinforcement other than welded wire fabric.

12.3 DISTRIBUTION REINFORCEMENT

12.3.1 Design of Reinforcement

Box sections having less than 2 ft (0.6 m) of earth cover thickness shall have distribution reinforcement placed in the top slab perpendicular to the box section span (see Fig. 12-1).

12.3.1.1 Inside face distribution reinforcement for traffic parallel to the box section span, A_{s5a}, shall have an area at least equal to:

$$A_{s5a} = \frac{100}{\sqrt{S}} A_{s2} \geq 0.5A_{s2} \qquad (12\text{-}26)$$

Inside face distribution reinforcement for traffic perpendicular to the box section span, A_{s5b}, shall have an area at least equal to:

$$A_{s5b} = \frac{220}{\sqrt{S}} A_{s2} \geq 0.67A_{s2} \qquad (12\text{-}27)$$

12.3.1.2 Outside face distribution reinforcement, A_{s6}, shall have an area at least equal to one-half the amount of distribution reinforcement required in Section 12.3.1.1. Top slabs that are overlaid by a cast-in-place concrete slab need not contain outside face distribution reinforcement, A_{s6}.

12.3.2 Minimum Area of Distribution Reinforcement

12.3.2.1 When distribution reinforcement is required in the top slab, the minimum area of distribution reinforcement perpendicular to the principal transverse reinforcement shall be the amount specified in Section 12.3.1.1 for the inside face of the top slab and one-half the amount specified in Section 12.3.1.1 for the outside face of the top slab.

12.4 FATIGUE LIMIT

The maximum stress range of reinforcement in box sections that are expected to be subject to 1,000,000 or more repetitive load applications shall be limited to:

$$f_r = f_{sf} - 0.33\, f_{min} \qquad (12\text{-}28)$$

where

f_r = live load stress range, psi
f_{sf} = 23,000 psi
f_{min} = algebraic minimum live load stress level, tension positive, compression negative, psi

PART III. CONSTRUCTION OF PRECAST CONCRETE BOX SECTION SYSTEMS

13.0 GENERAL

13.1 The soil/precast reinforced concrete box section system shall be constructed to conform to the dimensions and requirements specified or shown on the plans and to this Practice. The owner is advised to provide or require, adequate inspection of the box section installation at the construction site.

14.0 WORKING DRAWINGS AND MARKING

14.1 When complete details are not provided on the plans, or when required by provisions in the contract documents, the contractor shall prepare and submit to the owner working drawings of the installation system proposed for use. Installation of the box sections shall not begin until the owner has approved the drawings. The working drawings shall show complete details and substantiating calculations of the box sections, equipment, and installation methods the contractor proposes to use.

14.2 Working drawings shall be submitted sufficiently in advance of the start of the affected work to allow time for review and approval by the owner, and correction of the submittal by the contractor without delaying the work. Approval by the owner shall not relieve the contractor of any responsibility under the contract documents for the successful completion of the work.

14.3 The following information shall be legibly marked on each box section with waterproof paint or indented:

14.3.1 Box Section Designation

The box section designation shall be indicated as follows:

S________ R________ H________ – ________

where

S = designated box section span, ft (mm)
R = designated box section rise, ft (mm)
H = min.–max. height of cover, ft (m)

14.3.2 Date of Manufacture

14.3.3 Name or Trademark of the Manufacturer

14.3.4 Plant Identification

14.3.5 One end of each box section designed to be installed with the top slab up shall be legibly marked during the process of manufacturing or immediately thereafter on the inside and outside of the top slab, or shall have the top identified by the location of one or more lift holes or devices.

15.0 SAFETY

15.1 Safety requirements for construction shall be in accordance with the applicable federal, state, and local regulations.

15.2 Open ends of installed box sections shall be covered during overnight or longer periods of suspended work to prevent access by animals, personnel, and accumulation of soil and debris. Covers shall be braced or fastened to prevent movement. These covers need not be watertight.

Note 3: If the box section is plugged watertight when empty, the possibility of box flotation should be investigated, and, if necessary, appropriate measures shall be taken to prevent flotation.

16.0 EXCAVATION

16.1 Trenches shall be excavated to the dimensions and grade specified on the plans or as ordered by the owner. The width of trenches shall be kept to the minimum required for installation of the box sections.

16.2 When a trench is used and $F_{e2} < F_{e1}$ according to Section 11.2.4, the maximum trench width, measured at the top of the box section, used to calculate F_{e2} shall not be exceeded.

16.3 When ledge rock, compacted rocky, or other unyielding foundation material is encountered, it shall be removed to the requirements shown on the plans. Overexcavated areas shall be backfilled with approved materials and compacted to the Standard Proctor density specified for the leveling course.

16.4 The contractor shall make such provisions as required to ensure adequate drainage of the trench to protect the leveling course during the construction operations. Where surface water or groundwater conditions exist, the site and trench shall be dewatered.

17.0 FOUNDATION

17.1 Preparation of foundation, placement of foundation material where required, and placement of the leveling course shall precede the installation of the box sections.

17.2 The foundation shall be moderately firm to hard in situ soil, stabilized soil, or compacted fill material.

17.3 When unsuitable or unstable material is encountered, the foundation shall be stabilized or removed and replaced with firm and stable leveling course material.

17.4 Where groundwater and soil characteristics may contribute to the migration of soil fines into or out of the foundation, leveling course, or overfill materials, methods to prevent migration shall be provided.

17.5 Box sections installed over an unyielding foundation shall be cushioned so as to prevent blasting shock when future blasting is anticipated in the area.

18.0 LEVELING COURSE

18.1 When in the opinion of the owner, the natural soil does not provide a suitable leveling course, a leveling course, as shown in Fig. 3.4-1, shall be constructed of sand or selected sandy soil. All material shall pass a U.S. Standard 3/8-in. sieve, and not more than 10% shall pass a U.S. Standard No. 200 sieve. The leveling course shall be constructed, as required, for the full length of the box section to distribute the load-bearing reaction uniformly on the box section over its full length, and to maintain the required box section grade. Care shall be taken that the leveling course is flat and not high in the center area of the box section as this could cause high stresses in the box section floor.

18.2 If rock strata or boulders are encountered under the box section within the limits of the required leveling course, the rock or boulders shall be removed and replaced with additional leveling course material.

19.0 BOX SECTION PLACEMENT AND JOINING

19.1 Box sections shall be installed to the line and grade shown in the contract documents. Joining shall be in accordance with the box section manufacturer's recommendations.

Note 4: Where practical, work should be started at lowest end of the box section line, and with the spigot or tongue end pointing downstream.

19.2 Adjustments in grade by exerting force on the box section with excavating equipment or by lifting and dropping the box section shall be prohibited. If the installed box section is not on grade, the box section shall be completely unjoined, the grade corrected, and the box section then rejoined.

19.3 Proper facilities shall be provided for hoisting and lowering the box sections without disturbing the leveling course and the sides of the excavation.

19.4 The ends of the box sections shall be cleaned before sections are jointed.

19.5 The box section shall be fitted and matched so that when laid on the leveling course, it shall form a smooth, uniform line of sections.

19.6 Multiple box sections in parallel installations require positive lateral bearing between the sides of adjacent box sections. Compacted earth fill, granular backfill, or grouting between the sections are considered means of providing positive bearing.

19.7 Precast reinforced concrete box sections shall be handled with reasonable care and shall not be dragged over gravel or rock, and care shall be taken to prevent box sections from striking rock or other hard objects during placement.

19.8 Each joint shall be sealed to prevent migration of soil fines.

19.9 If required by the contract documents, each joint shall meet the specified infiltration and exfiltration requirements.

19.10 Unless otherwise approved by the owner, loads from construction equipment transferred to a box section before, during, or after fill placement, either directly or through the fill, shall not be greater than the loads assumed in the design.

20.0 SIDEFILL

20.1 When the design, using the soil-structure interaction factor, F_{e1} in Section 11.2.4.1, is based on compacted fill at the sides of the box, the sidefill shall be as required by the contract documents, but not less than select granular fill compacted to at least 90% Standard Proctor (ASTM D 698), or native sandy silty granular fill compacted to at least 95% of Standard Proctor (ASTM D 698).

20.2 When the design, using the soil-structure interaction factor in Section 11.2.4.1 is not based on compacted fill at the sides of the box section, the side fill soil shall be compacted as required in the contract documents.

21.0 OVERFILL

21.1 Overfill shall be constructed as specified. Overfill material shall be placed in layers with no greater than the maximum thickness specified and compacted to obtain the required density. The material shall be brought up evenly and simultaneously on both sides of the box section.

21.2 Ponding or jetting to compact overfill shall be permitted only where soil conditions permit free drainage and only with the approval of the owner.

21.3 The soil shall be approved material containing no debris, organic matter, frozen material, large stones with a diameter greater than one-half the thickness of the compacted layers being placed.

21.4 When impact or vibratory equipment is used for compaction, care shall be taken to avoid damaging the box sections.

22.0 SHEATHING REMOVAL AND TRENCH SHIELD ADVANCEMENT

22.1 Unless sheathing is to be left in place, it shall be pulled out in vertical increments to permit placement and compaction of fill material for the full width of the trench.

22.2 When trench shields or boxes are moved, the previously placed box section shall not be disturbed. It may be necessary to restrain the installed box section by use of deadman anchors or other means. Voids in the sidefill that are created by movement of a shield or box shall be filled and compacted.

23.0 PRECAST CONCRETE APPURTENANCES

23.1 Manholes shall be installed in a manner that will minimize differential settlement between the box section and manhole.

23.2 Precast concrete fittings, such as tees and wyes, shall be bedded, installed, and overfilled with the same material and in the same manner as the precast concrete box sections to prevent differential settlement between box section and fittings.

24.0 MINIMUM COVER FOR CONSTRUCTION LOADS

24.1 If the passage of construction equipment over an installed box section is necessary during project construction, compacted overfill in the form of a ramp shall be constructed to a minimum elevation of 3 ft (0.9 m) over the top of the box section or higher, if necessary, such that the equipment load on the box section does not exceed the box section design strength. In an embankment installation, the overfill shall extend a minimum of one box section span or 3 ft (0.9 m), whichever is greater, beyond each side of the box section to prevent possible lateral displacement of the box section. If a large volume of construction traffic must cross an installed line of box sections, the point of crossing shall be changed occasionally to minimize the possibility of lateral displacement.

APPENDIX

APPENDIX A: SI UNITS FOR NOTATION AND EQUATIONS

A1.0 SCOPE

A1.1 This Appendix repeats the notation and contains the full translation of equations contained in the Standard Practice from English unit values to SI unit values. In addition, English unit values in the text are converted to SI unit values, which are presented in parentheses. The values of dimensions and quantities expressed in English (inch-pound) units shall be regarded as standard. The SI unit values are supplied for information only and are not a part of this Standard Practice.

Note 1: Some of the applicable standards referenced may have a double designation (Axxx/AxxxM) or separate inch-pound (English) and SI (metric) unit editions. Only the inch-pound unit edition of a standard is listed in this Practice. If the Practice is used in an SI unit design, the user should investigate whether separate SI unit editions of the referenced standards are available.

A1.2 The section and equation numbering systems used in the Standard Practice are maintained in this Appendix to facilitate comparisons.

A2.0 STANDARD PRACTICE— SI CONVERSIONS

4.0 NOTATIONS

A = effective tension area of concrete surrounding the flexural tension reinforcement and having the same centroid as that reinforcement divided by the number of bars or wires, in.^{2} (mm^2)

A_s = area of tension reinforcement required in length b, in.^{2}/ft (mm^2/m)

A_{s1} = side wall outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s2} = top slab inside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s3} = bottom slab inside face reinforcement area, in.^{2}/ ft (mm^2/m)

A_{s4} = side wall inside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s5a} = area of top slab inside face distribution reinforcement for traffic parallel to the box span, in.^{2}/ft (mm^2/m)

A_{s5b} = area of top slab inside face distribution reinforcement for traffic transverse to the box span, in.^{2}/ft (mm^2/m)

A_{s6} = top slab outside face distribution reinforcement area, in.^{2}/ft (mm^2/m)

A_{s7} = top slab outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{s8} = bottom slab outside face reinforcement area, in.^{2}/ft (mm^2/m)

A_{vs} = area of stirrup reinforcement required to resist shear, in.^{2}/ft (mm^2/m) in each line of stirrups at circumferential spacing s_v

b = width of section that resists stress, in. (mm); taken as 12 in. (English units); taken as 1,000 mm (SI units)

b = unit length of box section, ft (m); taken as 1 ft (English units); taken as 1 m (SI units)

B_c = outside horizontal span of box, ft (m)

B_d = horizontal width of trench at top of box, ft (m)

B_1 = crack control coefficient for effect of concrete cover and spacing of reinforcement

C_d = load coefficient for trench installations

C_1 = crack control coefficient for type of reinforcement

d = distance from compression face to centroid of tension reinforcement, in. (mm)

d_b = diameter of tensile reinforcing bar, in. (mm)

d_c = thickness of concrete cover measured from extreme tension fiber to center of bar or wire located closest thereto, in. (mm)

f'_c = design compressive strength of concrete, lbs/in.^{2} (MPa)

f_s = maximum service load stress of reinforcing steel for crack control, lbs/in.^{2} (MPa)

f_v = maximum developable strength of stirrup material, lbs/in.^{2} (MPa)

f_y = design yield strength of reinforcement, lbs/in.^{2} (MPa)

F_{cr} = factor for adjusting crack control relative to average maximum crack width of 0.01 in. (0.3 mm) when F_{cr} = 1.0

F_d = factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing d

F_e = soil-structure interaction factor

F_{e1} = soil-structure interaction factor for embankment installations

F_{e2} = soil-structure interaction factor for trench installations

F_N = coefficient for effect of thrust on shear strength
h = overall thickness of member (wall thickness), in. (mm)
H = design height of earth cover above top of box section, ft (m)
H = for railroads, design height of cover above top of box section to bottom of the ties, ft (m)
H_H = horizontal dimension of haunch, in. (mm)
H_V = vertical dimension of haunch, in. (mm)
K = ratio of active lateral unit pressure to vertical unit pressure
L_d = reinforcement lap or development length, in. (mm)
M_s = service load bending moment acting on length b, in.-lbs/ft (N-mm/m)
M_u = factored moment acting on length b, in.-lbs/ft (N-mm/m)
M_{nu} = factored moment acting on length b as modified for effects of compressive or tensile thrust, in.-lbs/ft (N-mm/m)
n = number of layers of reinforcement in a cage
N_s = service load axial thrust acting on length b (+ when compressive, − when tensile), lbs/ft (N/m)
N_u = factored axial thrust acting on length b (+ when compressive, − when tensile), lbs/ft (N/m)
PL = PL denotes the prism load (weight of the column of earth) over the box section's outside span, wB_cH, lbs/ft (N/m)
R = inside vertical rise of box section, ft (m)
R_c = outside vertical rise of box section, ft (m)
s_v = circumferential spacing of stirrups, in. (mm)
S = inside span of box section, ft (m)
t_b = clear cover over reinforcement, in. (mm)
T_b = thickness of bottom slab, in. (mm)
T_s = thickness of side wall, in. (mm)
T_t = thickness of top slab, in. (mm)
V_b = basic shear strength of length b at critical section where $M_{nu}/(V_u d) \geq 3.0$, lbs/ft (N/m)
V_c = nominal shear strength provided by concrete in length b, lbs/ft (N/m)
V_u = factored shear force acting on length b, lbs/ft (N/m)
w = unit weight of soil, lbs/ft^3 (N/m^3)
W_E = total earth load on box for length b, lbs/ft (N/m)
Z_b = extension of A_{s1} reinforcement into bottom slab, in. (mm)
Z_t = extension of A_{s1} reinforcement into top slab, in. (mm)
β = approximate ratio of distance from neutral axis to location of crack width divided by the distance from neutral axis to centroid of tensile reinforcing
μ = coefficient of internal friction of the soil
μ' = coefficient of friction between overfill and trench walls
ϕ_f = strength reduction factor for flexure
ϕ_v = strength reduction factor for shear
ρ = ratio of reinforcement area to concrete area

11.2.4 Load Case 2: Vertical Soil Load

Vertical soil load shall be computed as the prism load modified by a soil structure interaction factor, F_e, that accounts for the conditions of installation, so that the earth load, W_E, on the box section is:

$$W_E = F_e w B_c H \qquad (11\text{-}1)$$

F_e may be determined by the Marston-Spangler Theory of earth loads, or by the simplified equations as follows:

11.2.4.1 For embankment installations (see Fig. 3.4-1), F_{e1}

$$F_{e1} = 1 + 0.20\frac{H}{B_c} \qquad (11\text{-}2)$$

F_{e1} need not be greater than 1.15 for installations with compacted fill at the sides of the box section, and need not be greater than 1.4 for installations with uncompacted fill at the sides of the box section.

11.2.4.2 For trench installations (see Fig. 3.4-1), F_{e2}

$$F_{e2} = \frac{C_d B_d^2}{H B_c} \qquad (11\text{-}3)$$

Values of C_d can be obtained from Fig. 11-2 for normally encountered soils. The maximum value of F_{e2} need not exceed F_{e1}.

12.0 REINFORCEMENT

12.1 REINFORCEMENT DETAILS

12.1.1 Reinforcement details for precast reinforced concrete box sections shall be as shown in Figs. 12-1 through 12-4.

12.2 REINFORCEMENT DESIGN

12.2.1 Reinforcement for flexural strength shall be not less than A_s where

$$A_s = (g\phi_f d - N_u - \sqrt{g[g(\phi_f d)^2 - N_u(2\phi_f d - h) - 2M_u]})/(f_y) \quad (12\text{-}1)$$

where

$g = 0.85bf'_c$
$b = 1{,}000$ mm

12.2.2 Minimum Reinforcement

12.2.2.1 Where tensile steel reinforcement is required, the minimum reinforcement area shall be:

$$A_{s\,\min} = 0.002bh \quad (12\text{-}2)$$

12.2.3 Maximum Flexural Reinforcement Limited by Concrete Compression

$$A_{s\,\max} = \left(\left[\frac{380g'\phi_f d}{(600 + f_y)}\right] - 0.75N_u\right) \Big/ (f_y) \quad (12\text{-}3)$$

$$g' = bf'_c\left[0.85 - 0.5\,\frac{(f'_c - 27.6)}{6.9}\right] \quad (12\text{-}4)$$

where

$b = 1{,}000$ mm
$g'_{\max} = 0.85bf'_c$
$g'_{\min} = 0.65bf'_c$

12.2.4 Crack Control

12.2.4.1 Crack control is assumed to be at 1 in. (25 mm) from the tension reinforcement.

12.2.4.2 For welded wire fabric with spacing of circumferential wires of 4 in. (100 mm) or less, and hot rolled bars with bar diameters 1/2 in. (13 mm) or less, the Crack Control Factor, F_{cr}, shall not exceed that specified, where:

$$F_{cr} = \frac{B_1}{525{,}000\phi_f d A_s} \cdot \left[\frac{M_s + N_s\left(d - \frac{h}{2}\right)}{ij} - 0.083C_1 bh^2\sqrt{f'_c}\right] \quad (12\text{-}5)$$

where

C_1 = see Table 12-1
$b = 1{,}000$ mm

$$j \cong 0.74 + 2.54e/d \quad (12\text{-}6)$$

$$j_{\max} = 0.9$$

$$i = \frac{1}{1 - \frac{jd}{e}} \quad (12\text{-}7)$$

$$e = \frac{M_s}{N_s} + d - \frac{h}{2},\ \text{mm} \quad (12\text{-}8)$$

if $e/d < 1.15$ *crack control will* not *govern*

$$B_1 = \sqrt[3]{25.4t_b s_l/2n} \quad (12\text{-}9)$$

where

s_l = spacing of circumferential reinforcement, mm
$n = 1$, when tension reinforcement is a single layer
$n = 2$, when tension reinforcement is made of multiple layers

12.2.4.3 Hot rolled deformed bar reinforcement larger than 1/2 in. (13 mm) shall be designed so that the service load steel stress, f_s, does not exceed that specified, where

$$f_s = \frac{140{,}000}{\beta\sqrt[3]{d_c A}} \le 248\ \text{MPa} \quad (12\text{-}10)$$

$$\beta = 1 + \frac{d_c}{0.7d} \quad (12\text{-}11)$$

$$\max d_c = 0.52d_b + 50 \quad (12\text{-}12)$$

12.2.5 Shear Strength (Diagonal Tension)

The box section wall shall be designed so that for each region requiring inner or outer flexural tensile reinforcement in accordance with Sections 12.2.1

and 12.2.4, the shear strength of the concrete, V_c, shall be greater than the maximum factored shear force, V_u, in each region.

12.2.5.1 Shear Strength, V_c, at Sections where $M_{nu}/V_ud \geq 3.0$

The shear strength of the concrete, V_c, is equal to the basic shear strength, V_b, where:

$$V_b = 0.083b\phi_v d\sqrt{f'_c}\,(1.1 + 63\rho)(F_d F_N) \quad (12\text{-}13)$$

where

$b = 1{,}000$ mm
$f'_{c\max} = 48.3$ MPa

$$\rho = \frac{A_s}{bd} \quad (12\text{-}14)$$

where

$b = 1{,}000$ mm
$\rho_{\max} = 0.02$

$$F_d = 0.8 + \frac{41}{d} \leq 1.3 \quad (12\text{-}15)$$

For compressive thrust ($+N_u$):

$$F_N = 1 + \frac{N_u}{14bh} \quad (12\text{-}16)$$

where $b = 1{,}000$ mm

For tensile thrust ($-N_u$):

$$F_N = 1 + \frac{N_u}{3.5bh} \quad (12\text{-}17)$$

where $b = 1{,}000$ mm

$$M_{nu} = M_u - N_u\left[\frac{(4h - d)}{8}\right] \quad (12\text{-}18)$$

12.2.5.2 Shear Strength, V_c, at Sections where $M_{nu}/V_ud < 3.0$

$$V_c = \frac{4V_b}{\dfrac{M_{nu}}{V_d d} + 1} \quad (12\text{-}19)$$

$$\max V_c = 0.249\phi_v bd\sqrt{f'_c} \quad (12\text{-}20)$$

$$\max \frac{M_{nu}}{V_u d} = 3.0 \quad (12\text{-}21)$$

12.2.5.3 If V_c is less than V_{uc}, the area of tensile reinforcement may be increased up to $P_{\max}bd$ to increase shear strength, or stirrups shall be provided as required by Section 12.2.6.

12.2.5.4 Sections located less than a distance, d, from the face of a support may be designed for the same shear, V_u, as that computed at a distance, d, provided that:

(1) The support reaction, in the direction of the applied shear, introduces compression into the end regions of the member, and
(2) No concentrated load occurs between the face of the support and the location of the critical section at d.

12.2.5.5 The tips of haunches with an inclination 45° or steeper may be taken as the face of a support.

12.2.6 Stirrups

If stirrups are required for shear by Section 12.2.5, they shall meet the following requirements:

12.2.6.2 Area of Stirrups

$$A_{vs} = \frac{1.1s_v}{f_v\phi_v d}[V_u - V_c] \quad (12\text{-}22)$$

$$V_c = \frac{4V_b}{\dfrac{M_{nu}}{V_u d} + 1} \quad (12\text{-}23)$$

$$V_{c\max} = 0.166\phi_v bd\sqrt{f'_c} \quad (12\text{-}24)$$

where $b = 1{,}000$ mm

$f_{v\max} = f_y$, or anchorage strength, whichever is less

$$s_{v\max} = 0.75\phi_v d \quad (12\text{-}25)$$

12.3 DISTRIBUTION REINFORCEMENT

12.3.1 Design of Reinforcement

Box sections having less than 2 ft (0.6 m) of earth cover thickness shall have distribution reinforcement placed in the top slab perpendicular to the box section span (see Fig. 12-1).

12.3.1.1 Inside face distribution reinforcement for traffic parallel to the box section span, A_{s5a}, shall have an area at least equal to:

$$A_{s5a} = \frac{55}{\sqrt{S}} A_{s2} \leq 0.5A_{s2} \qquad (12\text{-}26)$$

Inside face distribution reinforcement for traffic perpendicular to the box section span, A_{s5b}, shall have an area at least equal to:

$$A_{s5b} = \frac{120}{\sqrt{S}} A_{s2} \leq 0.67A_{s2} \qquad (12\text{-}27)$$

12.3.1.2 Outside face distribution reinforcement, A_{s6}, shall have an area at least equal to one-half the amount of distribution reinforcement required in Section 12.3.1.1. Top slabs that are overlaid by a cast-in-place concrete slab need not contain outside face distribution reinforcement, A_{s6}.

12.3.2 Minimum Area of Distribution Reinforcement

12.3.2.1 When distribution reinforcement is required in the top slab, the minimum area of distribution reinforcement perpendicular to the principal transverse reinforcement shall be the amount specified in Section 12.3.2.1 for the inside face of the top slab and one-half the amount specified in Section 12.3.2.1 for the outside face of the top slab.

12.4 FATIGUE LIMIT

The maximum stress range of reinforcement in box sections that are expected to be subject to 1,000,000 or more repetitive load applications shall be limited to:

$$f_r = f_{sf} - 0.33f_{min} \qquad (12\text{-}28)$$

where

f_r = live load stress range, psi
f_{sf} = 159 MPa
f_{min} = algebraic minimum live load stress level, tension positive, compression negative, psi

COMMENTARY

PART I. GENERAL

C1.0 SCOPE

The ASCE Standard Practice for Direct Design of Buried Precast Concrete Box Sections, hereinafter referred to as the Practice, provides for the direct design of buried one-cell precast concrete box sections.

Direct design requires determining the earth loads and pressure distributions on the box section, based on installation design, soil properties (type, unit weight, and level of compaction), analysis to determine moments, thrusts and shears, and design to determine required reinforcement areas. Analysis and design procedures are similar to those used for other reinforced concrete structures.

C3.0 DEFINITIONS

For consistent application, it is necessary that terms be defined where they have particular meanings in the Practice. The definitions given or referenced are for use in application of this Practice only and may not always correspond to ordinary usage.

C4.0 NOTATIONS

For consistent application, it is necessary that notations be defined where they have particular meanings in the Practice. The notations given are for use in application of this Practice only and may not always correspond to ordinary usage.

PART II. DESIGN

C6.0 GENERAL

It is not possible to predict all possible field situations or to cover them in this Practice and Commentary. Therefore, it is imperative that the precast concrete box section system design be reviewed by a qualified engineer.

C6.1 Although designs may be hand-calculated, the microcomputer program BOXCAR (Reference Document C1) will greatly facilitate designs and analyses. BOXCAR is available from the Center for Microcomputers in Transportation (McTrans), University of Florida. BOXCAR was developed by Simpson Gumpertz and Heger Inc. (SGH) for FHWA and uses the design method presented in the Practice.

BOXCAR designs the box-reinforcement requirements to conform to the AASHTO design method (Document 2.2.1). Precast reinforced concrete box sections are normally manufactured with the standard dimensions listed in ASTM Specifications C 789 and C 850 (AASHTO Standards M 259 and M 273). Dimensions other than these standard dimensions may be available. When non-standard dimensions are required, the owner should contact the manufacturers in the project area.

C6.2 This section clarifies that the owner may do designs, but that the preferred method is the manufacturer doing the design based on the owner's requirements and submitting this design to the owner for approval. In either case, the manufacturer shall prepare shop drawings for submission to the owner.

The various manufacturers of precast concrete box sections use individual methods and materials for manufacture that are unique to their particular manufacturing plants. Common variations are steel type, cage shape and fabrication method, concrete strength, laying length, and joint details. There are many different combinations that will meet the requirements of this Practice. Because certain methods and materials may not be economically available to all manufacturers, the preferred method of the owner and manufacturer sharing the design responsibility is recommended. This method tends to promote the most economical designs.

C7.0 GENERAL DESIGN REQUIREMENTS

C7.1.1 Load Factors

Load factors are taken from the AASHTO Bridge Specification (Document 2.2.1).

C7.1.2 Strength Reduction Factors

Strength reduction (phi) factors are used to account for possible variation in strength due to manufacturing variables.

C7.1.3 Crack Control Factor

The Crack Control Factor is applied to designs using welded wire fabric and to designs using hot rolled bars with diameters of 1/2 in. or less to control the crack width per Section 12.2.4.2 of the Practice. Crack control when using hot rolled bars 1/2 in. in diameter or greater is covered in Section 12.2.4.3 of the Practice. Cracks are expected to occur in box sections designed using this Practice, just as cracks are expected in most reinforced-concrete structures that are subject to their design service loads. The 0.01-in. (0.3-mm) crack was originally selected arbitrarily as a test criterion and was then, and is now, not intended as an indication of structurally distressed or failed box sections in the installed condition. When crack widths exceed 0.01 in. (0.3 mm), the box section should be appraised, considering structural integrity, environmental conditions, and service life. Section 27.4.1 of the AASHTO Bridge Specification provides guidance for acceptance and repair of cracks in precast concrete culvert and storm drain box sections.

Most box section designs are controlled by ultimate flexure or ultimate shear. Fewer designs are controlled by service load cracking. Depending on design criteria, crack control may govern a greater or lesser range of heights of earth cover.

F_{cr}, the Crack Control Factor, defines the service load average maximum crack width limit at 1 in. (25 mm) from the tension reinforcement. If crack control governs the design, a Crack Control Factor of 1.0 indicates that there is a 50% probability that cracks in excess of but close to 0.01 in. (0.3 mm) in width will occur at the design service load.

If Equation (8) is rearranged to solve for the area of steel required (A_s), it can be seen that F_{cr} is a divisor of the stress required for the desired crack width control. F_{cr} of 1.1 will allow more 0.01-in. (0.3-mm) cracks and some slightly larger cracks. F_{cr} of 0.9 will restrict crack width and allow very few 0.01-in. (0.3-mm) cracks.

The crack control equations were developed from test specimens with approximately 1 in. (25 mm) of cover on the tension reinforcement. Therefore, designs with more than 1 in. (25 mm) cover and F_{cr} of 1.0 are predicted to reach a 0.01-in. (0.3-mm) crack approximately 1 in. (25 mm) from the tension steel and reach a wider crack at the surface of the concrete.

For box sections with more than 1 in. (25 mm) of cover over the tension reinforcement, the crack width limit at the surface of the concrete may be estimated relative to the calculated crack width limit at 1 in. (25 mm) from the tension reinforcement. The two crack width limits may be assumed to be proportional to their distance from the neutral axis. For this purpose the neutral axis may be assumed to be at $3d/8$ from a compression face of the box section.

When two or more layers of reinforcing are used to make a single line of tension reinforcement (n = 2), crack control is improved. However, because there is insufficient information about cracking behavior with more than two layers, it is recommended that no more than two layers be assumed for design, even if more layers are used in the box section.

C11.0 LOADS

C11.1 The load cases shown in Fig. 11-1 of the Practice are assumed to be balanced, as shown, so as not to cause side sway. Designs for significant unbalanced loads are not within the scope of the program BOXCAR and may require special calculations. Significant unbalanced loads may occur where box sections are installed close to and parallel or on a skew to the edge of a fill, or in a wide trench that runs perpendicular or on a skew to a steep side slope, or other cases where the loads may be applied at an angle to the vertical.

C11.1.2.1 Truck Loads

AASHTO truck loads are considered as applied by a tire print rather than a point load. Each tire print is assumed to be a 10-in. (250-mm) square, such that the print of a dual-tire assembly is 10 by 20 in. (250 by 500 mm). In some cases, the Interstate Truck load may produce greater pipe stresses than the HS-series.

AASHTO specifications suggest that truck loads may be ignored for burial depths greater than 8 ft (2.4 m). For box section designs, truck loads should be considered at all depths and not arbitrarily eliminated.

In multiple-lane roadways, the maximum wheel loads on the trucks passing in adjacent lanes are assumed to be aligned at the same location in the center of four adjacent 12-ft (3.6-m) lanes. For this load case, the live load factor is reduced to the load factor used for dead and earth loads, effectively eliminating a live load overload factor for this extremely unlikely case of up to four fully loaded trucks passing with maximum wheel loads at the same locations.

C11.2.4.1 See Section 20 and Commentary C20 for the requirements and discussion of the requirements for use of maximum F_{c1} = 1.15, rather than 1.4, or more.

C11.2.12 Designs covered by this Practice are not intended to be used for box sections that will be subject to continuous internal pressure. Designs including intermittent internal fluid pressure loads may be made. The program, BOXCAR combines live loads and additional dead loads with permanent loads only if they increase stresses. However, there is no provision in BOXCAR Version 1.0, to add internal pressure above the inside top of the box section and handle it as an additional dead load that is applied only if it increases stresses. Therefore a separate design must be made and compared to the design without internal pressure and the controlling conditions used. When internal pressure is sufficiently high to cause significant tension in the inside reinforcing at the corners of the box section, special detailing may be required. Joint leakage should be considered.

C12.0 REINFORCEMENT

The reinforcement design equations were developed based on accepted structural engineering limit states design practice and evaluations of many tests on specimens and slabs as a part of the American Concrete Pipe Association's long-range research program. The basis of these equations is explained in References C3, C4, C5, and C6.

C12.2.4.3 Equation (12-10) limits the maximum stress at service load to control cracking and place a limit on maximum strain (as related to 36 Ksi). The procedure in this section applies to hot rolled deformed bars larger than 1/2 in. in diameter. Designs using such reinforcement are usually closer to the type of components tested in research to establish crack control limits for typical reinforced concrete components whose designs are based on Reference C2. The β factor is included in this equation to reflect the differences in crack control between flexural members over the range of thickness that occurs with box sections of moderate size and burial depths up to large, deeply buried, cast-in-place box sections. The stress limit of 36 Ksi is also a limit for box sections in Reference C2.

The limiting service load stress of 36 Ksi for Grade 60 deformed bar reinforcement is consistent with limits of $0.6F_y$ and 60 Ksi maximum F_y in the AASHTO Specifications for Highway Bridges and Structures. Although cracking is limited by strain, the strain associated with 36 Ksi maximum is considered adequate for design. When Grade 40 deformed bar reinforcement is used, service load stress of 36 Ksi will not control unless a Load Factor for ultimate flexure of less than 1.11 is used. A Load Factor of 1.3 is specified for ultimate flexure in this Practice.

Calculations for the service load stress, f_s, should account for both the effects of bending and thrust (usually compressive) at the governing section for crack width control. A suitable approximate equation from Reference C1 for determining f_s is:

$$f_s = \frac{M + N\left(d - \frac{h}{2}\right)}{A_s jid} \tag{C1}$$

where

$e = MN + d - h/2$
e/d min. = 1.15
$i = 1/(1 - jd/e)$
$j = 0.74 + 0.1\ (e/d) \leq 0.9$

C12.2.7 Welds, Splices, and Development of Reinforcement

Sections 7.4 of ASTM C789, ASTM C850, AASHTO M259, and AASHTO M273 and Fig. 12-1 of this Practice define acceptable splice types and locations. Splices at locations of high stress are specified to be lapped splices of welded wire fabric. The AASHTO Bridge Specifications (Referenced Document C2) contain splice requirements for splices of reinforcement other than welded wire fabric.

ASTM C789 and C850 require that splices be made by lapping and allows these laps to be connected by welding. Tack welding of reinforcement by the box section manufacturer during fabrication of cages is a typical and necessary practice in the manufacture of precast box sections. This Practice enhances the rigidity of the cage to assist in proper placement of the reinforcement. However, the manufacturer should be aware that some agencies do not allow welding on box section cages.

Tests of welded splices show that overheating of the wire during welding can help make a strong weld but it also tends to weaken the wire. It is important not to overheat the wire. It is also important not to undercut the wire. Good practice is to "strike the arc" and "tail off" on the free ends of the wires to avoid undercutting in critical areas.

When the box section manufacturer welds to circumferential or distribution reinforcement, care should be taken not to damage this reinforcement, particularly in zones that will be subject to high stress. The most critical zones of high stress for the circumferentials are in the middle third of the span of the inside cages in the slabs and approximately 1/4 of the span or rise from the corners to the corners of the outside cages. No welds should be made to the inside circumferentials in slabs in the middle third of the span. The least amount of welding consistent with adequate cage rigidity is preferred.

Cage rigidity is enhanced by appropriate welding by the box section manufacturer. Welds to circumferentials by the box section manufacturer should be made only on circumferentials in the same plane not less than 18 in. apart along the longitudinal axis of the box section. When spacers are welded to circumferentials they should be placed only on these circumferentials. This confines possible welding damage to these few circumferentials while enhancing cage rigidity.

When individual rods or wires are used for distribution reinforcement, they should be welded to longitudinal wires only near the ends of the box section and may be tied at any location.

If welds are made to Grade 60 reinforcing bars, weldable bars conforming ASTM A706 should be used.

PART III. CONSTRUCTION OF PRECAST CONCRETE BOX SECTION SYSTEMS

C18.0 LEVELING COURSE

The leveling course is used in the installation of precast concrete box culverts to ensure uniform bearing pressures on the bottom of the sections for structural considerations and so that individual box sections do not tilt or rotate relative to adjacent box sections.

C20.0 SIDEFILL

When the design earth load on box sections is determined using the F_{e1} limiting value of 1.15, the earth fill on each side of the box should be of the soil type and minimum compaction level specified in Section 20.1 in order to preclude excessive earth overfill load due to settling sidefill. Also, settling sidefill reduces the lateral soil pressure, affecting the magnitude of moments and shears in the box wall. When earth fill on the sides of the box section does not meet the soil type and compaction levels specified in Section 20.1, the higher earth loads obtained using Equation (11-2) with an upper limit of 1.4 accounts for the increased earth load for most installation conditions. A special soil-structure interaction analysis should be made for cases where the soil within a distance of one outside box section span, B_c, adjacent to each side of the box is extremely soft and susceptible to high differential settlement relative to the box from the weight of the overfill above the box and side soil.

C21.0 OVERFILL

In order to reduce the load on the box culvert, it is recommended that the soil immediately over the top of the box not be compacted for a depth of about 1/3 the outside height of the box above the top unless the Contract Documents require compaction in this area.

REFERENCED DOCUMENTS

[C1] *BOXCAR User and Programmer Manual*, Federal Highway Administration, Hydraulic Computer Program HY-10, Publication No. FHWA-1P-89-018.

[C2] *Standard Specifications for Highway Bridges*, 1992, AASHTO (American Association of State Highway and Transportation Officials).

REFERENCES

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