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Pipelines
for Water Conveyance and Drainage

ASCE

Edited by
Roger W. Beieler, P.E.

EWRI ENVIRONMENTAL & WATER RESOURCES INSTITUTE

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Pipelines for Water Conveyance and Drainage

Prepared by
the Task Committee on Pipelines for Water Conveyance and Drainage of
the Irrigation Delivery and Drainage Systems Committee of
the Irrigation and Drainage Council of
the Environmental and Water Resources Institute of
the American Society of Civil Engineers

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PREFACE

This manual, ***Pipelines for Water Conveyance and Drainage***, includes a discussion of twenty topics for various pipe materials. The topics discussed include industry standards, available pipe sizes, standard lengths, allowable internal pressures, external load capabilities, protective linings, protective coatings, joints, fittings, hydraulic resistance factor, allowable leakage rates, repair methods, installation requirements, backfill requirements, special considerations, industry groups, and reference materials.

The need for a concise listing and description of the most commonly used types of pipe for water conveyance and drainage purposes was recognized by ASCE members in the late 1990s. Several new pipe materials were being introduced and new standards for these materials were being developed. Many of the new materials offered several advantages compared to the materials currently available, including reduced cost, longer life, improved flow characteristics, and ease of installation. In addition, manufacturers of existing pipe materials often modified and improved their products to make them more competitive.

The pipe materials discussed herein include concrete pipe, steel pipe, ductile iron pipe, polyvinyl chloride (PVC) pipe, molecularly oriented PVC pipe, high density polyethylene (HDPE) pipe, polyethylene profile wall pipe, PVC and polypropylene profile wall pipe, corrugated polyethylene pipe, vitrified clay pipe, clay drain tile, fiberglass pipe, and corrugated metal pipe. The intent of the manual is to provide design engineers, utility managers, educators, and planners a concise listing and description of the most commonly used types of pipe for water conveyance and drainage purposes.

Acknowledgments

Many individuals donated time and effort to prepare this manual since the need for such a manual was recognized in the late 1990s. The ASCE

and EWRI members who contributed include staff from the U.S. Bureau of Reclamation, industry groups, American Water Works Association (AWWA), Agricultural Research Service, pipe manufacturing companies, water supply agencies, and consulting firms.

This manual was prepared by a subcommittee of the Irrigation Delivery and Drainage Systems Technical Committee. The technical committee is one of several committees in the Irrigation and Drainage Council of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE).

CHAPTER 1
INTRODUCTION

PURPOSE AND SCOPE OF MANUAL

The purpose of this manual is to provide design engineers, utility managers, educators, and planners with a concise listing and description of the most commonly used types of water conveyance and drainage pipe that are commercially available in the United States. Also provided are listings of the most commonly used standards for manufacturing the pipe, useful publications pertaining to the design and installation of pipe, and industry groups that promote and distribute research data on their type of pipe.

During the preparation of this manual, the Pipeline Manual Task Committee obtained information from many sources. These sources include associations for standards and practices, governmental agencies, professional societies, educational institutions, consultants, pipe manufacturers, and industry groups.

Chapter 13, titled Resource Directory, is a compilation of the most active organizations involved with water conveyance pipe design and fabrication. Street addresses, phone and fax numbers, e-mail, and internet website addresses are listed. This information is current as of the date the manual was published (2013).

Before starting a pipeline construction project, managers and owners should make certain that the pipe installation crew has copies and are familiar with the latest pipe installation manuals.

This publication is disseminated under the sponsorship of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE). Neither EWRI nor ASCE assumes any liability for the contents or use of this manual and does not endorse any of the products mentioned herein. Trade or manufacturer's names appear solely because they help to make the manual more useful to the reader.

TYPES OF PIPE

The following types of pipe are discussed in this manual:

- Concrete pipe,
- Welded steel pipe,
- Ductile iron pipe,
- Solid wall polyvinyl chloride (PVC) pipe,
- Solid wall molecularly oriented polyvinyl chloride (PVCO) pipe,
- High density polyethylene (HDPE) pressure pipe,
- Polyethylene profile wall pipe,
- PVC profile wall pipe,
- Polypropylene profile wall pipe,
- Corrugated polyethylene pipe,
- Vitrified clay pipe,
- Clay drain tile,
- Fiberglass pipe,
- Corrugated steel pipe, and
- Corrugated aluminum pipe.

ALTERNATIVE PIPE MATERIALS

Recognizing that a variety of types of pipe may be suitable for a given situation, many water districts, municipalities, and other government agencies often prepare construction contract documents that allow a contractor to furnish one of several equivalent types of pipe for installation on a particular job. By allowing the contractor to choose the least costly type of pipe, the cost of the overall contract will be reduced. Note that the least cost for an installed pipeline is determined by several factors:

- Cost to manufacture the pipe,
- Cost to deliver the pipe to the job site,
- Ability of the manufacturer to deliver the pipe in a timely manner,
- Cost of labor and equipment to install the pipe,
- Types of suitable backfill material and relative degree of compaction required,
- Cost of corrosion control,
- Cost of locating and repairing any leaks that become evident during testing, and
- Cost to repair defects that become evident during the warranty period.

This manual should assist engineers in deciding which types of pipe will be equivalent for a particular circumstance.

TOPICS DISCUSSED

The following twenty topics are discussed for each pipe material:

1. Specifications and industry standards,
2. Available sizes,
3. Standard manufactured length,
4. Allowable internal pressure and factors of safety,
5. External load capabilities,
6. Description of pipe material,
7. Protective linings and coatings,
8. Joints,
9. Fittings,
10. Tapping methods,
11. Hydraulic resistance factor,
12. Wave speed (for hydraulic transient studies),
13. Allowable leakage rate,
14. Repair methods,
15. Water quality tolerances,
16. Installation, backfill, and protective requirements,
17. Special considerations,
18. Useful life,
19. Industry groups and committees, and
20. Reference materials.

SYSTEM OF UNITS

Dimensions cited herein are first expressed in metric units (S.I. –System International Units) with U.S. customary units shown in parenthesis. For discussion purposes, pipe diameters and other length dimensions in inches may be obtained by dividing millimeters by 25.4. Pressure is expressed herein as kilopascals (kPa). One kilopascal (kPa) equals approximately 0.145 pounds per square inch (psi).

References for metric units include the "Metric Guide for Federal Construction, Metric Design Guide, General Services Administration" and "Preferred Metric Numbers for Building Construction." These documents are available from the National Institute of Building Sciences. The website is www.nibs.org.

HYDRAULIC RESISTANCE FORMULAS

Many formulas have been used to determine flow resistance in pipes. Most are based on Chezy's 1775 premise that the head loss in a conduit varies with the square of the fluid velocity in the pipe. Although the Darcy-Weisbach formula is sometimes used for hydraulic design, the more common formulas are those of Hazen-Williams ("C" factor) or Manning ("n" value).

The reader should be cautioned that the roughness coefficients for the Hazen-Williams and Manning formulas vary with the pipe diameter and the interior surface roughness of the pipe. Interior surface roughness often increases as pipes age. Prudent engineering judgment must be used in choosing a roughness coefficient, regardless of the formula that is used for sizing of the pipe.

Excellent summaries of the history and derivation of the above formulas may be found in most hydraulic text books. Therefore, little additional discussion will be devoted to hydraulics in this manual.

CORROSION CONCERNS

Corrosion of the pipe wall and steel reinforcement is of great concern when specifying pipes that contain ferrous material. Requirements for controlling external corrosion on buried pipes that contain ferrous elements can be determined by corrosion surveys. These surveys should determine the soil resistivities and stray currents along the pipeline alignment. An assessment of corrosion histories of other pipelines in the area also should be made prior to design of the system. If necessary, auxiliary corrosion control systems should be specified.

Water quality tests should be made to determine whether interior pipe surfaces need protective coatings. Exterior coatings and interior linings are discussed in more detail under the individual type of pipe.

AWWA publications on this topic include *Manual M58—Internal Corrosion Control in Water Distribution Systems* and *Manual M27—External Corrosion: Introduction to Chemistry and Control.*

PIPE CROSSINGS

Pipelines frequently cross rivers and other bodies of water, wetlands, highways, railroads, streets, and known fault lines, as well as other pipelines. Several publications are available regarding planning, design, and construction of pipeline crossings.

The annual ASCE Publications Catalog and website (asce.org) contain many references to pipeline crossings. Several ASCE manuals and reports describe current design issues, construction methods, and economic considerations for the myriad types of crossings. Included are discussions on highway, railroad, and waterway crossings. In addition, the annual ASCE Pipeline Conference Proceedings often present specific project descriptions and new developments on pipeline crossings.

CLEANING METHODS

AWWA Manual M28 titled *Rehabilitation of Water Mains* describes current procedures, and presents an overview of different cleaning and lining practices.

ROUTE SELECTION

Selecting an appropriate route for a pipeline project is becoming increasingly complex. Environmental, regulatory, and public involvement issues play a more important role than in the past. An excellent summary of the route selection process is available in ASCE Manual and Report on Engineering Practice No. 46, *Pipeline Route Selection for Rural and Cross-Country Pipelines.*

REFERENCE MATERIALS

General information regarding pipeline design and installation is available in many reference materials, including the following:

ASCE has recently created a new tool for use on mobile internet devices. The ASCE Library Mobile Edition is available at ascelibrary.org and is useful for finding additional ASCE resources.

Howard, Amster. 1996. *Pipeline Installation*. Lakewood, CO: Relativity Publishing. Chapter 13 of this publication includes several pages listing useful handbooks, manuals, standards, organizations, and pipe manufacturers.

McAllister, E.W. 2009. *Pipeline Rules of Thumb Handbook, 7th ed.* Houston, TX: Gulf Publishing Co.

Descriptions of trenchless methods to install pipelines are available from several sources including the No-Dig Construction web site (www.nodig-construction.com).

Chapter 13 of this manual (titled Resource Directory) lists several organizations that provide reference materials for specific types of pipe.

PIPELINE COSTS

Because the cost for various pipeline materials differs significantly in geographical regions and depends on the demand for both pipeline products and the raw materials used to manufacturer them, this manual does not include a discussion of either the cost to purchase or the cost to install pipeline products.

SUPPLIERS OF VARIOUS PIPE PRODUCTS

Because the suppliers of pipe products frequently change as new manufacturers and suppliers enter the marketplace or companies are bought and sold, this manual does not list suppliers' or manufacturers' names. However, entering the common industry standard for a particular pipe product (such as AWWA C200 or ASTM C700) into an internet search engine will generally provide several names of pipe suppliers and manufacturers.

CHAPTER 2

CONCRETE PIPE

This chapter discusses several types of concrete pipe:

- Monolithic cast-in-place concrete pipe,
- Unreinforced concrete pipe,
- Reinforced concrete pipe,
- Reinforced concrete cylinder pipe,
- Concrete bar-wrapped cylinder pipe, and
- Prestressed concrete cylinder pipe.

The rugged construction, durability, and the natural corrosion resistance provided by embedment of the ferrous components in concrete or mortar make concrete pipe suitable for a wide range of applications.

Monolithic Cast-in-Place Concrete Pipe This type of pipe, which is constructed in-place, has been used in the diameter range of 300–3000 mm (12–120 in.) and consists of monolithic nonreinforced concrete for heads up to 4.5 m (15 ft). Some owners have used polypropylene fibers to strengthen the concrete.

Precast Unreinforced Concrete Pipe This type of pipe is used for applications with low pressures, typically under 75 kPa (25 ft) of head. The pipe consists of an unreinforced concrete shell with concrete joints.

Reinforced Concrete Pipe This type of pipe consists of reinforcement cages placed in a concrete shell to resist bursting pressures and external earth loads. The joints may be formed entirely of concrete or may include a circular steel joint ring. Reinforced concrete pipe is used for pressures up to 380 kPa (55 psi).

Reinforced Concrete Cylinder Pipe This type of pipe was developed to handle higher internal heads than reinforced concrete pressure pipe. This pipe consists of a steel cylinder with steel joint rings attached and around which a cage of reinforcing steel is placed. The cylinder comprises the inner layer of reinforcement, a second or outer reinforcement cage is provided, and concrete is cast around the reinforcement layers to form the pipe wall.

Concrete Bar-wrapped Cylinder Pipe This type of pipe has a composite design; the basic element of the pipe is a welded steel cylinder with steel joint rings welded to each end. The cylinder is lined with centrifugally placed cement mortar. Continuous reinforcing rod is then helically wound, under controlled tension, around the outside of the steel cylinder, and a mortar coating is placed by means of high velocity impact over the reinforcing rod.

Prestressed Concrete Pipe There are two types of prestressed concrete pipe: a steel cylinder lined with a concrete core (lined cylinder pipe), and a steel cylinder embedded in a concrete core (embedded cylinder pipe).

Lined Cylinder Pipe This type of pipe consists of a welded steel cylinder with steel joint rings attached to each end. The cylinder is then centrifugally lined with dense concrete to constitute the core. High-tensile wire reinforcement is helically wound under controlled tension, directly on the steel cylinder. The high-tensile wire and steel cylinder are protected by a cement mortar coating applied by a mechanical impact method. Concrete for lined cylinder pipe is generally centrifugally cast or placed within the steel cylinder by radial compression.

Embedded Cylinder Pipe This type of pipe consists of a welded steel cylinder with steel joint rings attached to each end and embedded in a concrete core. High-tensile wire reinforcement is helically wound under controlled tension in one or more layers around the outside of the concrete core containing the cylinder. The high-tensile wire is protected by a cement mortar coating. Concrete for embedded cylinder pipe is generally cast in vertical steel molds.

Detailed figures showing pipe cross sections and joint details are included in American Water Works Association (AWWA) Manual M9.

SPECIFICATIONS AND INDUSTRY STANDARDS

Several American Concrete Institute (ACI), AWWA and American Society for Testing and Materials (ASTM) standards are used for manufacturing concrete pipe. They include the following:

- ACI 346 Cast-in-Place Nonreinforced Concrete Pipe,
- ASTM C14 Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe,
- ASTM C118 Nonreinforced Concrete Pipe for Irrigation or Drainage,
- ASTM C505 Nonreinforced Concrete Irrigation Pipe with Rubber Gasket Joints,
- ASTM C985 Nonreinforced Concrete Culvert, Storm Drain, and Sewer Pipe,
- ASTM C76 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe,
- ASTM C361 Reinforced Concrete Low-Head Pressure Pipe,
- ASTM C302 Reinforced Concrete Noncylinder Pipe,
- AWWA C300 Reinforced Concrete Cylinder Pipe,
- AWWA C303 Concrete Bar-Wrapped Cylinder Pipe, and
- AWWA C301 Prestressed Concrete Cylinder Pipe.

AVAILABLE SIZES

Precast concrete pipe for water conveyance and drainage is available in sizes starting at 100 mm (4 in.) diameter. Other types of concrete pipe, such as embedded cylinder pipe have been manufactured in sizes larger than 6 m (20 ft) in diameter. The AWWA C300 and C302 standards include pipe up to 3,660 mm (144 in.) in diameter.

STANDARD MANUFACTURED LENGTH

Standard lengths of concrete pressure pipe are typically in the range of 2.4 to 12 m (8–40 ft). The ASTM C118 standard for low head irrigation and drainage pipe states that the maximum length of pipe shall not exceed 750 mm (30 in.) to 1,220 mm (48 in.) depending on the pipe diameter. Refer to the previously mentioned standards and manufacturer's literature for additional information regarding standard manufactured lengths.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

The allowable internal pressure for nonreinforced concrete pipe is based on empirical data for crack propagation. Nonreinforced concrete pipe is not recommended for high internal pressure applications. Recommended maximum pressures vary from zero (gravity flow only) to 9 m (30 ft) of head for nonreinforced pipe manufactured in accordance with

ASTM C505. The factor of safety is incorporated into the allowable stress for concrete. Tongue-and-groove shaped joints generally have been used. Rubber gaskets, mastic, mortar, and external bands are frequently used to seal the joints.

Reinforced concrete pipe and monolithic cast-in-place concrete pipe are designed based on a combination loading, which includes internal pressure, dead loads, and live loads. The maximum allowable internal pressure for reinforced concrete pipe manufactured to the AWWA C302 standard is 380 kPa (55 psi). The maximum allowable internal pressure for pipe manufactured to the ASTM C361 standard is stated as 375 kPa (125 ft of head or about 55 psi). The factor of safety is incorporated into the allowable stresses for concrete and reinforcing steel.

Reinforced concrete cylinder pipe uses a procedure that addresses external and internal loads individually, as well as in combination. The maximum allowable internal pressure depends on the pipe diameter, wall thickness, and cylinder thickness. The factor of safety is incorporated into the allowable stresses for concrete and reinforcing steel.

Bar-wrapped concrete cylinder pipe has been used with pressures as high as 2,760 kPa (400 psi). The pipe is custom designed to withstand the specific loading for each project. The recommended factor of safety is 2.0.

Embedded cylinder pipe and lined cylinder pipe are designed based on combination loadings and include surge pressures and live loads. Prestressed concrete cylinder pipe has been designed for operating pressures greater than 2,760 kPa (400 psi). The factor of safety is incorporated into the allowable stresses for concrete and steel.

EXTERNAL LOAD CAPABILITIES

Rigid pipe is designed to transmit applied external loads through the wall of the pipe down to the foundation. The pipe is the strongest when subjected to a uniform loading that is distributed all around the pipe, such as external hydrostatic pressure. The pipe is weakest when subjected to a line or point loading on top and a line or point reaction on the bottom.

Although most concrete pipe is considered rigid, with respect to external load analysis, AWWA Manual M9 recommends treating bar-wrapped concrete cylinder pipe as semi-rigid, because as it deflects, it develops its ability to support external loads both from the support of the surrounding soil and the inherent strength of the pipe.

Allowable depths of cover vary from 1.5 m (5 ft) for certain types of concrete pipe to more than 30 m (100 ft) for heavily reinforced, thick wall concrete pipe. Refer to the standards listed previously for specific limitations (both maximum and minimum) on external loading.

DESCRIPTION OF PIPE MATERIAL

The materials for nonreinforced concrete pipe include the aggregate, cement, water, and certain admixtures. Materials for reinforced concrete pipe and cylinder pipe also include the steel used for the reinforcing bars or mesh and the steel used for the cylinder.

PROTECTIVE COATINGS AND LININGS

A wide variety of protective coatings and linings are available for use with concrete pipe. PVC, epoxy, and rubberized linings are sometimes used on the inside of concrete pipe to prevent damage from scour if the water carries erosive materials or damage from hydrogen sulfide in wastewater applications.

The exterior of concrete pipe can also be coated to minimize damage from corrosive soils. AWWA Manual M9 includes a chapter on design considerations for corrosive environments. The information includes means for protection against high-chloride environments, high-sulfate environments, acid conditions, and stray current interference.

JOINTS

The pipe joint is the weak link in any pipe installation. A good joint must be flexible enough to permit longitudinal movement owing to temperature changes and wetting and drying of the pipe, as well as vertical adjustments owing to settlement that sometimes occurs. Joints in pressure pipe that are located near fittings and valves are occasionally designed to be restrained against pullout.

Various types of joints are available for concrete pipe including tongue and groove, concrete bell and spigot, and steel bell and spigot rings. Some relatively low-pressure concrete pipe is assembled with a mastic compound in the joint to reduce leakage and infiltration, whereas joints for concrete pipe designed for higher pressure typically include rubber gaskets. Chapter 5 of the ACI *Concrete Pipe Handbook* includes detailed drawings of several pipe joint types and a discussion of joint gaskets and sealants.

The groove containing the gasket is constructed and shaped in such a way that the gasket is contained and is not required to support the weight of the pipe. When the pipe is centered, the gasket is compressed into the groove, forming a watertight seal. Gaskets come in different shapes depending on the manufacturer. Gaskets are generally installed at the construction site.

Some pipes with a steel cylinder require exterior grouting of the joint space. This is accomplished by using a fabric band placed around the pipe and held in place with steel straps. Portland cement grout is poured down one side and rises up on the other. The band should not be removed from the joint.

The interior of steel joints is generally protected by filling the gap between the pipe ends with cement mortar (a process referred to as "pointing").

Various methods and devices can be used to restrain joints for pipe containing a steel cylinder. The methods and devices include welding, flanges, clamp-type harnesses, bell-bolt-type harnesses, and snap-ring-type harnesses. AWWA Manual M9 includes a chapter on design of fittings and appurtenances.

FITTINGS

Bends can be made for relatively low-pressure concrete pipe by cutting an existing piece of pipe into two pieces with the bend angle desired. The two pieces are then rotated and encased in concrete to form the bend. Other fitting types, such as tees, can be made using a similar process. Concrete pipe suitable for higher pressures requires a steel fitting to form the bend. The steel fitting is generally lined and coated with concrete or mortar.

TAPPING METHODS

Tapping saddles are generally used to tap into an existing concrete pipeline. Outlets can be threaded or flanged. The AWWA Manual M9 includes a chapter on tapping procedures and describes two types of saddles. One type uses straps around the pipe and the other uses an attachment to the reinforcing.

HYDRAULIC RESISTANCE FACTOR

The most common method used for determining hydraulic losses in concrete pipelines designed for pressure applications is the Hazen-Williams formula. The *Concrete Pipe Handbook*, published by the American Concrete Pipe Association (ACPA), and the AWWA Manual M9 suggest using a roughness coefficient, "C", of 140 for pipe 400–1,200 mm (16–48 in.) in diameter, 145 for pipe 1,350–2,700 mm (54–108 in.) in diameter, and 150 for pipe 2,850 mm (114 in.) and larger.

For pipes flowing partially full, the Manning equation is frequently used to compute hydraulic resistance. ACPA's *Concrete Pipe Handbook* recommends that, even though laboratory tests on concrete pipe show an "n" value ranging from 0.009 to 0.010, a value more appropriate for design is 0.012 or 0.013. For pressure pipe, the AWWA Manual M9 suggests using an "n" value of 0.011 when the velocity is 1 m/s (3 ft/s), and 0.010 when the velocity is 1.5 m/s (5 ft/s).

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Chapter 3 in AWWA Manual M9 includes a detailed discussion of wave speed and hydraulic transients. It states that the calculated value of the surge wave speed for various types and classes of concrete pipe range from 900–1,220 m/s (2,950–4,000 ft/s).

ALLOWABLE LEAKAGE RATE

Different leakage allowances are specified for pipe with a steel cylinder versus noncylinder pipe. Reinforced and unreinforced concrete pipe do not have a steel cylinder, and the recommended allowable leakage rate according to AWWA Manual M9 is 2.3 L/mm of pipe diameter/km of pipeline/24 h (25 gal./in. of diameter/mi of pipeline/24 h). For pipes with a steel cylinder, the recommended allowable leakage rate is 1 L/mm of pipe/km of pipeline/24 h (10 gal./in. of diameter/mi of pipeline/24 h).

REPAIR METHODS

Joint failures can result from rolled or pinched gaskets or cracked bells and spigots. These can occur as a result of improper installation, settlement or heave, or excessive loading. Damage to the joint may require complete pipe removal and replacement. Joint leaks in low-pressure pipes occasionally can be repaired by injecting grout into the joint.

Uncontrolled corrosion can lead to failure in pipes that contain a steel cylinder. If undetected, corrosion can completely destroy the steel cylinder or reinforcing wire and rods. Corrosion can require extensive repair, up to and including replacement of entire sections of pipe.

Pipe damage during construction and installation generally can be repaired. Common methods for repair of low-pressure pipe include concrete collars and full circle repair clamps. For higher pressure pipelines with a steel cylinder, the size of the hole will determine the repair method.

For holes larger than 1 m (3 ft) the entire pipe section is generally removed and replaced. Otherwise a steel wrapper plate can be placed around the hole and welded. The steel reinforcement rod is welded to the cylinder on either side of the wrapper plate.

WATER QUALITY TOLERANCES

Groundwater quality, the quality of water being conveyed, and soil type can be important in determining if concrete pipe is suitable for a specific installation. Chlorides and sulfates will react with cementitious materials and could eventually erode the concrete pipe. Means of reducing the effect of chlorides and sulfates include using fly ash, using Type II or Type V cements in the concrete mix, or installing linings and coatings.

Hydrogen sulfide gas can also build up in sewer installations where the pipe is not flowing full. The pipe can be protected by using inner protective linings. An extensive discussion of hydrogen sulfide effects is included in the references mentioned at the end of this chapter.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

The ultimate performance of any pipe installation depends not only on the design of the pipe itself, but also on the proper excavation and backfill of the trench. This would include operations such as replacing the foundation material if required, placing the bedding materials, placing the pipe zone materials, and compacting backfill.

The bedding angle is defined as the angular portion of the pipe over which the vertical forces are distributed. Rigid pipe is designed for a bedding angle of 90°. Achieving a firm bedding and embedment is essential to the satisfactory performance of the pipe. Compaction of backfill around the bottom of the pipe to a depth of 0.37 of the outside diameter is required to obtain the proper embedment. To ensure that the 90° bedding angle is obtained, good compaction of the backfill material under the pipe haunches is essential. The haunch area is the portion of the trench from the bottom of the pipe to the horizontal centerline.

Larger restraint requirements are required from the surrounding soil for flexible pipe, such as concrete bar-wrapped cylinder pipe. For a flexible pipe to achieve its design strength and maintain circularity, the soil must provide side support for the pipe walls to resist the vertical loads. A high degree of compaction around the pipe to a height of 0.7 of the outside diameter is required to develop passive soil resistance and to prevent excessive deflection under long-term trench loads and live loads.

SPECIAL CONSIDERATIONS

In soils subject to wetting and drying cycles, a concentration of chloride ions and free oxygen can occur. These elements can damage the pipe. It may be necessary to install a barrier or a cathodic protection system.

USEFUL LIFE

The useful life of a properly installed concrete pipe can be up to 100 years or longer. The U.S. Army Corps of Engineers recommends a design life for precast concrete pipe of 70 to 100 years. Corrosion of the steel cylinder (occasionally referred to as the "can") or reinforcing rod is usually the cause of failure for these pipes. Use of cathodic protection systems is suggested for potentially corrosive soils to prevent early failure of the pipeline.

INDUSTRY GROUPS AND COMMITTEES

Industry groups and committees include the American Concrete Pipe Association, the AWWA Standards Committee on Concrete Pressure Pipe, and the American Concrete Pressure Pipe Association.

REFERENCE MATERIALS

American Concrete Institute (ACI) Committee 346. (2009). "Specification for Cast-In-Place Concrete Pipe." Farmington Hills, MI, ACI.

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CHAPTER 3
WELDED STEEL PIPE

This chapter discusses the use of welded steel pipe. Seamless wrought steel pipe is commonly used in high-pressure water, steam, and gas applications. Because it is seldom used for typical water conveyance projects, a discussion of wrought steel pipe is not included. Steel pipe with riveted seams was made prior to 1930 and is not discussed in this chapter.

Steel pipe has been used for water conveyance in the United States since the 1850s. Numerous manuals and guidelines are available for steel pipe design and installation. Two methods are in common use today for manufacturing steel pipe used for water conveyance. Spiral-seam pipe is made from coiled strips of steel by a continuous process. Straight-seam pipe is made from plate or sheet with edges parallel to each other. Other types of steel pipe are used for extremely high pressures, high temperatures, oil or gas transmission, or steam service and are not discussed in this manual.

SPECIFICATIONS AND INDUSTRY STANDARDS

The most common standard used for steel pipe associated with water conveyance projects is American Water Works Association (AWWA) C200. Field welding of steel pipe is covered by the AWWA C206 standard. The AWWA C604 standard covers installation of steel water pipe. The AWWA C207 standard covers flanges, and the C208 standard discusses fabricated fittings. Various types of couplings and expansion joints are discussed in the C219, C606, and C221 standards. Linings and coatings for steel pipe are discussed in several AWWA standards. AWWA Manual M11 includes several topics related to steel pipe and provides guidelines for design, testing, and installation. The American Iron and Steel Institute (AISI) has also published manuals discussing the merits of steel pipe, design standards, technical data, and references. Design criteria for welded steel pipe up to 6,000 mm (240 in.) in diameter are available in AISI's publication *Welded Steel Pipe Design Manual*.

AVAILABLE SIZES

Pipe sizes for water conveyance projects typically range from 100 mm (4 in.) in diameter to more than 3,660 mm (144 in.) in diameter. Standard sizes usually increase by 75 mm (3 in.) or 150 mm (6 in.) increments. However, for diameters greater than 450 mm (18 in.), essentially any diameter can be custom fabricated.

STANDARD MANUFACTURED LENGTH

Steel pipe for water conveyance projects is typically furnished with lengths in the range of 12–18 m (40–60 ft). However, the pipe can be cut to longer or shorter lengths as desired. Shorter lengths are frequently used if the pipe must be installed on an alignment with long radius curves. The curvature is made up by pulling or beveling the pipe at each joint.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

The allowable internal pressure is a function of the steel strength and thickness. Operating pressures as high as 2,760–3,450 kPa (400–500 psi) are not uncommon. Surge pressures can be significantly higher, depending on the hydraulics of the system.

Various safety factors have been used in the design of steel pipe. A design strength of 50 percent of the minimum yield strength is frequently used for normal operating pressures. Steel with a yield strength of 290 MPa (42,000 psi) is commonly used with an allowable design strength of 145 MPa (21,000 psi). The factor of safety could be considered as 2.0. If the pipe has a cement mortar coating, AWWA Manual M11 recommends limiting the allowable stress to 124.1 MPa (18,000 psi) to minimize cracking of the coating. Some designers limit the stress for normal operating pressures to the lesser of 50 percent of the minimum yield strength or the tensile strength divided by 2.4. Refer to the ASCE Manuals and Reports on Engineering Practice No. 79, *Manual on Steel Penstocks*, for additional information.

The factor of safety under extreme conditions, such as surge or a one-time hydrostatic test, is typically higher than the factor of safety for normal operating pressures. A design strength of 75 percent of the minimum yield strength is frequently used. This could be considered as a factor of safety of 1.33, if reaching the yield strength is considered as the point of failure.

EXTERNAL LOAD CAPABILITIES

Steel pipe is considered a flexible pipe and the Marston theory is frequently used to compute external soil loads. The external load capability depends on the degree of support provided by the backfill, the pipe wall thickness and material strength, and the type of lining and coating. Cement mortar lining and coating increases the strength of the pipe. However, to avoid cracking of the mortar, the allowable deflection of pipe with mortar lining or coating is generally limited to a lower value than pipe with flexible lining. Allowable deflections are commonly considered to be 2 percent of the diameter for mortar lined and coated pipe, 3 percent for mortar lined and flexible coated pipe, and 5 percent for pipe with flexible lining and coating. If the backfill material is well compacted, allowable burial depths in the range of 6–9 m (20–30 ft) are not uncommon.

DESCRIPTION OF PIPE MATERIAL

Steel used for manufacturing of pipe is classified as mild steel and is commonly designated by the American Society for Testing and Materials (ASTM) standards as A283, A572, A1011, and A1018. The steel material is available in various grades. A Grade 40 steel would have a minimum yield point of 276 MPa (40,000 psi). The AWWA C200 standard allows both structural steel (SS) and high strength low alloy steel (HSLAS).

PROTECTIVE LININGS AND COATINGS

Various linings and coatings are used to protect steel pipe. Common coatings include cement mortar, coal-tar enamel, liquid epoxy, cold-applied tape, and extruded polyolefin. Common linings include cement mortar, polyurethane, and epoxy. The majority of the lining and coating products are covered by the AWWA standards.

JOINTS

Commonly used joints for steel pipe include lap welded, butt strap, rolled groove rubber gasket, and Carnegie-shape rubber gasket. These joints are illustrated in Fig. 3-1. Bell-and-spigot joints with rubber gasket joints are relatively easy to assemble and do not damage any shop applied

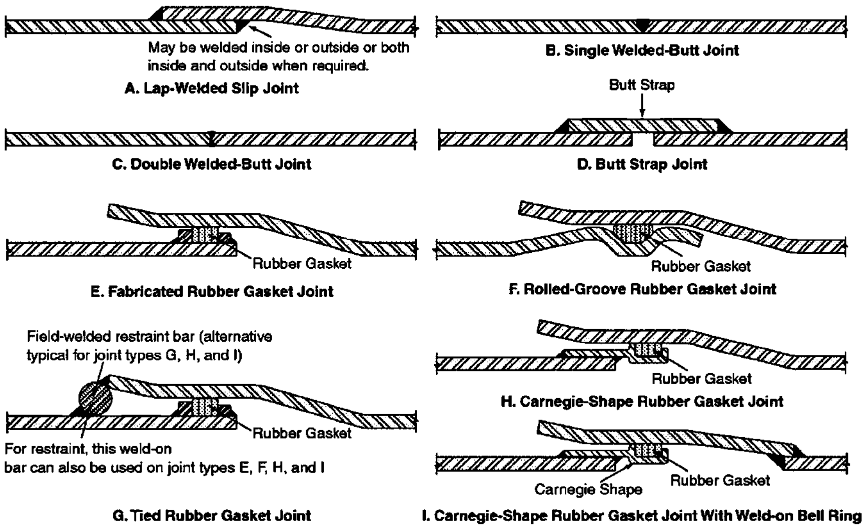

Fig. 3-1. Welded and Rubber-Gasketed Field Joints
Source: Reprinted from M11, Steel Pipe: A Guide for Design and Installation, by permission. Copyright © 2004, American Water Works Association

coating or lining. The rubber gasket joints are generally not used on pipe larger than 1,500 mm (60 in.) in diameter. Steel pipe joints 900 mm (36 in.) and larger in diameter are frequently field welded. The protective coating and lining at the joint is applied after welding. Several methods are available to test the welds (radiographic, magnetic particle, air test, and others).

Other methods of attaching pipe ends include bolted sleeve couplings, split-sleeve couplings, expansion joints, grooved couplings, shouldered couplings, and flanges. These methods are illustrated in Figs. 3-2, 3-3, and 3-4. Sleeve couplings consist of a sleeve slightly larger than the pipe, two flanges, two gaskets, and bolts. The gaskets are compressed by tightening the bolts. Split-sleeve couplings include two gaskets in captive grooves. The couplings are tightened with a minimal number of bolts to compress the sleeve. Grooved-and-shouldered couplings have a housing that encloses a rubber gasket. The housing fits into the groove or over the shoulder and locks the pipe ends together. Flanges are commonly used to connect the pipe to valves, fittings, or other types of pipe.

FITTINGS

Fabricated fittings for steel pipe are covered in AWWA Standard C208. The document provides a standard for the dimensions and fabrication

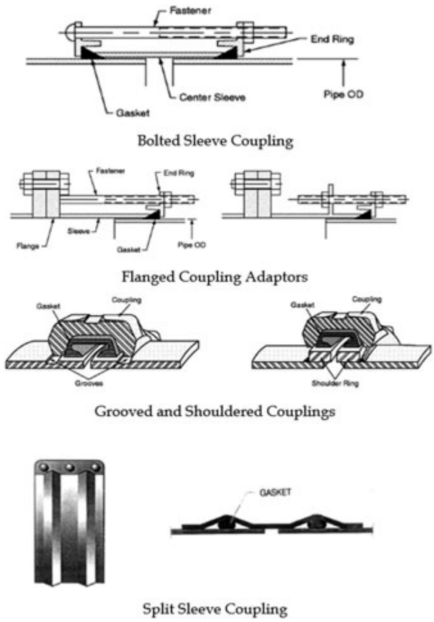

Fig. 3-2. Coupled Joints
Source: Portions Reprinted from M11, Steel Pipe: A Guide for Design and Installation, by permission. Copyright © 2004, American Water Works Association

details. Factory-made fittings are covered in ANSI Standard B16.9. Fittings can have flanged ends, welded ends, screwed ends, plain ends, or other end types.

TAPPING METHODS

Steel pipe can be tapped easily by cutting an opening and welding a flanged or threaded outlet to the pipe. Several companies also manufacture saddles with outlets that can be strapped to the pipe.

HYDRAULIC RESISTANCE FACTOR

Several formulas have been used to compute hydraulic friction losses in steel pipe. AWWA Manual M11 suggests that the most popular formula for computing friction loss in steel pipelines is the Hazen-Williams formula. Manual M11 states that for pipe with smooth interior linings in good condition, the "*C*" factor be computed by the equation

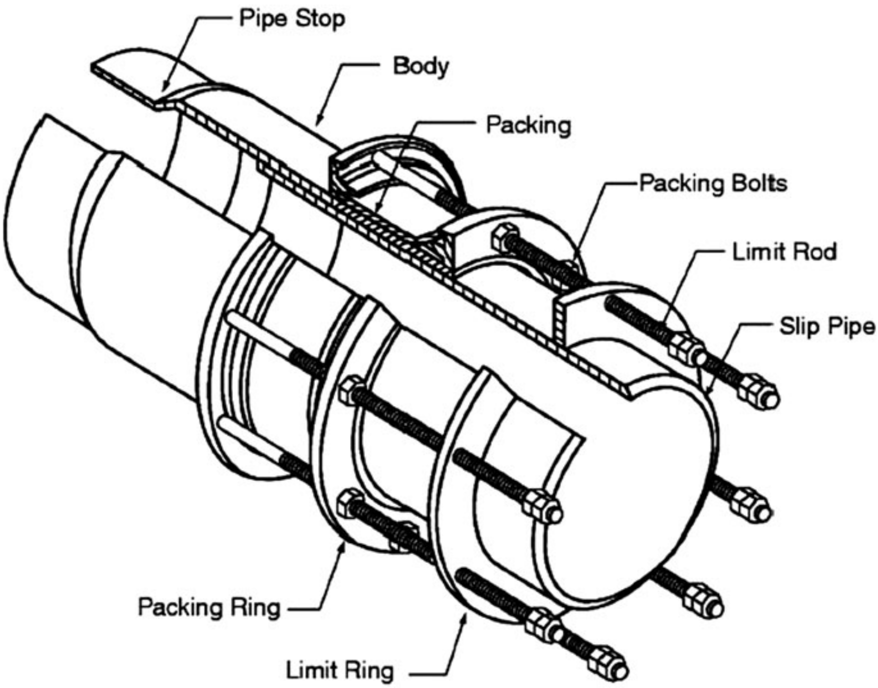

Fig. 3-3. Expansion Joint
Source: Reprinted from M11, Steel Pipe: A Guide for Design and Installation, by permission. Copyright © 2004, American Water Works Association

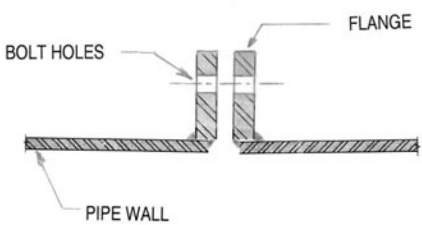

Fig. 3-4. Flanged Joint

$$C = 140 + 0.0067d \qquad (3\text{-}1)$$

where d = the nominal diameter of the pipe in millimeters.

Equivalent form in U.S. customary units is

$$C = 140 + 0.17d \qquad (3\text{-}2)$$

where d = the nominal diameter of the pipe in inches.

However, in consideration of long-term lining deterioration, slime build-up, and other conditions that may increase surface roughness, the use of a lower C factor is recommended as given by the equation

$$C = 130 + 0.0063d \qquad (3\text{-}3)$$

where d = the nominal diameter of the pipe in millimeters.

Equivalent form in U.S. customary units is

$$C = 130 + 0.16d \qquad (3\text{-}4)$$

where d = the nominal diameter of the pipe in inches.

For gravity flow conditions, AWWA Manual M11 recommends use of a Manning's "n" value of 0.011 for linings conforming to current AWWA standards.

WAVE SPEED (FOR HYDRAULIC TRANSIENT STUDIES)

The pressure wave velocity for steel pipe depends on the ratio of the pipe diameter to wall thickness and varies from approximately 600–1,000 m/s(2,000–3,300 ft/s). A graph of the wave speed and diameter wall thickness ratio is provided in several reference manuals including AWWA Manual M11.

ALLOWABLE LEAKAGE RATE

The allowable leakage rate for a steel pipeline depends on the type of joint used. A pipeline with welded joints, sleeve couplings, grooved-and-shouldered couplings, or flanged joints should have essentially no leakage. An allowable leakage rate of 38 L / 25.4 mm of diameter / 1.6 km of length / 24 h (10 gal / in. of diameter / mi of length / 24 h) is commonly used for a pipeline with rubber gaskets joints.

REPAIR METHODS

The method used to repair joints will depend on the type of joint. Welded joints are relatively easy to repair by the addition of a butt strap, additional welding, or the addition of a plate. Joint repair for sleeve couplings and grooved-and-shouldered couplings generally consists of removing and replacing the coupling. Bell-and-spigot joints with O-ring rubber gaskets frequently can be repaired by disassembling the joint and replacing the gasket or by welding the joint.

If an area of the pipe some distance from a joint is damaged, possible repair methods include welding a patch over the damaged area, using a repair band, or using a repair coupler.

WATER QUALITY TOLERANCES

The water quality tolerance of steel pipe depends on the type of protective lining used. Soft water can cause cement to leach from the cement mortar linings. An extra thick mortar lining may be used to offset leaching. An extra thickness of 3.2–6 mm (1/8–¼ in.) is typical. Liquid epoxy and fusion-bonded epoxy linings are not affected by the quality of water typically encountered in water conveyance projects.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Trenches should be excavated slightly deeper (50–150 mm, or equivalently 2–6 in.) than the planned pipe invert elevation and the excess excavation should be filled with loose material free from rocks. The pipe should be placed on the loose material using fabric slings. The pipe should not be rolled or dropped into the trench. Care should be taken to avoid damage to the coatings. The coating should be inspected after installation and areas of damaged coating should be repaired. The recommended type of backfill will depend on the pipe coating material used. The use of crushed rock with sharp edges should be avoided if the pipe is tape coated. The maximum size of backfill material should be specified to avoid damage to the coating and pipe. Compaction equipment should be carefully selected and operated to avoid excessive deflection of the pipe and damage to the coatings.

SPECIAL CONSIDERATIONS

The strength of steel allows steel pipe to be self-supporting; hence, it is ideally suited for aboveground applications. The allowable span length depends on the steel strength, pipe diameter, wall thickness, and type of support. The AWWA Manual M11 and other references include a table giving allowable spans for simply supported pipe in saddles. The manual also provides a recommended procedure for designing pipe supported by ring girders.

USEFUL LIFE

Metallic pipelines are subject to corrosion. Several methods of controlling corrosion are commonly used: 1) isolating the steel from the soil and water by means of protective coatings and linings, 2) separating the steel from other materials by means of isolating flange kits or special joints, 3) applying an electric current to counteract the external currents caused by soil conditions or other sources, and 4) providing sacrificial anodes that corrode before the steel pipe begins to corrode. With proper coating, linings, other forms of corrosion control, and proper maintenance, the useful life of steel pipelines can be in excess of 100 years.

INDUSTRY GROUPS AND COMMITTEES

AISI and the Steel Plate Fabricators Association are active in promoting the use of steel pipe and have published several design manuals.

Several technical committees have been established to develop standards and manuals for steel pipe. AWWA has technical committees for steel pipe, fittings, coatings, linings, and various types of joint systems. The American Society of Mechanical Engineers through Committees B16 and B36 prepares standards for steel pipe and fittings.

REFERENCE MATERIALS

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American Iron and Steel Institute (AISI). (2006). *Welded Steel Pipe Design Manual: Merits, Design Standards, Technical Data and References*. AISI, Washington, DC.

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CHAPTER 4
DUCTILE IRON PIPE

This chapter discusses the use of ductile iron pipe. Ductile iron pipe was introduced in 1948. It rapidly replaced the use of gray cast iron pipe. Several standards have been developed for ductile iron pipe and numerous publications regarding design are available.

SPECIFICATIONS AND INDUSTRY STANDARDS

Ductile iron pipe is a highly standardized pressure pipe for water and wastewater service. In the United States and Canada, it has American National Standards Institute (ANSI) and American Water Works Association (AWWA) standards for manufacturing, design, corrosion control, fittings, joints, and installation. There are American Society for Testing and Materials (ASTM) standards for corrosion control, culvert applications, and gravity sewer service.

AWWA and ASTM standards for ductile iron pipe are listed as follows:

- AWWA C104 Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water,
- AWWA C105 Polyethylene Encasement for Ductile-Iron Pipe Systems,
- AWWA C110 Ductile-Iron and Gray-Iron Fittings, 3 in. through 48 in., for Water and Other Liquids,
- AWWA C111 Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings,
- AWWA C115 Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges,

- AWWA C150 Thickness Design of Ductile-Iron Pipe,
- AWWA C151 Ductile-Iron Pipe, Centrifugally Cast, for Water,
- AWWA C153 Ductile-Iron Compact Fittings, 3 in. through 24 in. and 54 in. through 64 in., for Water Service,
- AWWA C600 Installation of Ductile-Iron Water Mains and Their Appurtenances,
- ASTM A377 Standard Index of Specification for Ductile-Iron Pressure Pipe,
- ASTM A674 Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids,
- ASTM A716 Ductile Iron Culvert Pipe, and
- ASTM A746 Ductile Iron Gravity Sewer Pipe.

AVAILABLE SIZES

Ductile iron pipe is available in nominal diameters of 80–1600 mm (3–64 in.) under the AWWA C151 standard.

STANDARD MANUFACTURED LENGTH

Nominal lengths are 5.5 m or 6 m (18 ft or 20 ft), depending on the manufacturer and the diameter of the pipe.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Ductile iron pipe is rated at working pressures of 1,034 to 2,413 kPa (150 to 350 psi) for standard applications, depending on the diameter of the pipe. Applications of greater than 2,413 kPa (350 psi) are possible but must be designed in consultation with the manufacturer of the pipe.

Ductile iron pipe is designated as a "pressure class" product, that is, the designation corresponds to the pressure capacity. This contrasts with previous "thickness class" designations that simply described an available thickness of pipe but did not give any guidance as to its capacity to sustain loads.

The most important part of designing a pipeline deals with determining the loads the conduit must support, both internally and externally, and designing the pipe wall to ensure they will be supported. There are many different approaches in the piping industry, all reflecting philosophies of design that differ from pipe material to pipe material. A conservative standard design approach for ductile iron pipe is given in the AWWA C150 standard. Since ductile iron pipe is considered to be a flexible conduit, internal pressure, and external load designs are accomplished separately.

Under AWWA C150 standard, ductile iron pipe wall thickness design based on internal pressure is a function of the rated water working pressure, a surge pressure, and a factor of safety. The Barlow hoop stress equation, as shown, is used in calculating the required wall thickness for internal pressure:

$$t = F_s(P_w + P_s)(D)/2S \qquad (4\text{-}1)$$

where:
t = pipe wall thickness in mm (in.)
F_s = factor of safety (2.0)
P_w = working pressure kPa (psi)
P_s = surge pressure in kPa (psi)
D = outside pipe diameter in mm (in.)
S = allowable stress of 289,590 kPa (42,000 psi)

Note that the design pressure ($P_w + P_s$) is a function of both the working and surge pressures. They are added together before applying a nominal factor of safety of 2.0. In doing so, the stress in the wall of the pipe that results from internal pressure is maintained at half or less of the tensile yield strength of ductile iron. Note also that a given "pressure class" of pipe is designated by the working pressure used to calculate the wall thickness required and that a nominal surge allowance of 689 kPa (100 psi) is added in design. Thus, a PN25 (pressure class 350) pipe has a wall thickness based on a working pressure of 25 bar (350 psi) and a surge pressure of 689 kPa (100 psi), the sum of which is multiplied by a safety factor of 2. The design pressure, then, with no safety factor is 6,204 kPa (900 psi).

This would be the basis for design for internal pressure; however, ductile iron pipe design also incorporates a "service allowance," which is simply an added 2 mm (0.08 in.) of wall thickness. Once the thickness is calculated using the hoop stress equation as stated, 2 mm (0.08 in.) is added to that result. Further, ductile iron pipe design, recognizing the fact that the centrifugal casting process is a dynamic process, adds an allowance for the casting tolerance. This is an additive allowance in order to ensure that if, on some portion of the pipe length the casting allowance is missing, that missing thickness does not negatively affect the thickness that is used to sustain a load. In other words, the casting process is not allowed to compromise the factor of safety.

EXTERNAL LOAD CAPABILITIES

Because ductile iron pipe is a flexible conduit, external loads are transferred through the wall of the pipe to the surrounding side-fill soil. The support the backfill is able to provide must be factored into calculations for the required wall thickness to sustain an external load.

The magnitude of the external load is determined using conservative models. All external load calculations are based on traffic and earth loads. The traffic load used is the American Association of State Highway and Transportation Officials (AASHTO) H-20 load, which assumes a 71,170 N (16,000 lb) point load at ground surface. This load is then distributed using the Boussinesq equation over a 3-ft length of pipe at pipe depth. The equation used to calculate the magnitude of the pressure that results is shown as

$$P_t = (CRPF)/(bD) \tag{4-2}$$

where:
P_t = the traffic load in kPa (psi)
C = surface load factor
R = a reduction factor, accounting for added support from adjacent pipe length
P = the wheel load of 71,170 N (16,000 lb force)
F = impact factor (1.5 at all depths)
b = effective pipe length of 0.914 m (36 in. at pipe depth)
D = pipe outside diameter in mm (in.)

The earth load is added to the traffic load. Ductile iron pipe design assumes a flexible conduit in a trench condition. In doing so, the most conservative model, the prism load, is used:

$$P_e = (wH)/a \tag{4-3}$$

where:
P_e = earth load in kPa (psi)
w = soil density of 18.85 kN /m^3 (120lbs/cu ft)
H = depth of cover in m (ft)
a = conversion factor of 1 for metric units (144 for U.S. customary units)

This model makes the assumption that the prism of soil above the outside diameter of the pipe is allowed to bear completely on the pipe without support offered by shear forces between this prism of soil and the soil immediately adjacent. Also, an assumption is made that the soil density will be 18.85 kN/m^3 (120 lb/ft^3) or less. This facilitates the development of tables found in AWWA C150 standard.

DESCRIPTION OF PIPE MATERIAL

Ductile iron pipe is manufactured using a centrifugal casting process. Casting machines rotate the pipe mold around its centerline axis while molten iron is introduced. Centrifugal force places the iron against the wall of the mold, forming the pipe. As the iron is poured into the mold, the point of introduction of the iron changes along the length of the mold, either by movement of the casting machine or by shifting the channel through which the iron is poured down the length of the mold.

Ductile iron is a derivative product of gray iron. After the scrap iron is melted but before the casting process begins, the gray iron is treated by introducing magnesium. The result is a violent reaction that causes an increase in the surface tension of the graphite within the iron. Thus, the graphite changes from a flake form in gray iron to a spheroidal or nodular form in ductile iron. The result is a strong, flexible material that, like steel, has a yield point and undergoes elongation before failing. The pipe manufactured under AWWA C151 has a minimum ultimate material strength of 413.7 MPa (60,000 psi), a minimum yield tensile strength of 289.6 MPa (42,000 psi) and undergoes a minimum elongation of 10 percent. This is designated as 60-42-10 ductile iron.

PROTECTIVE LININGS AND COATINGS

The standard lining for ductile iron pipe is the cement mortar lining in accordance with AWWA C104. This lining has proven to be an effective method of control of tuberculation and provides an improved hydraulic surface for water and wastewater flows. The lining may be cured by application of a seal coat of asphaltic paint. This 25 μm (1 mil) layer seals moisture in, thereby allowing the cement mortar to properly hydrate. According to the C104 standard, the seal coat is applied at the manufacturer's option, unless otherwise specified.

Special linings are also available for a variety of applications, including sewage pipelines where hydrogen sulfides are a concern. Such linings are not standardized but are proprietary. Their application should be discussed with pipe manufacturers prior to including these linings in the specification.

For external corrosion control, AWWA C105 standard provides for the application of loose polyethylene encasement of ductile iron pipe. This method was first applied in 1958 to pipe in an operating system.

JOINTS

There are several types of rubber gasketed joints available for ductile iron pipeline applications. The most prevalent joints are the push-on, mechanical, and flanged joints. In addition, many different proprietary restrained joints are available to control thrust forces, and other specialty joints, such as the ball and socket, grooved and shouldered joints, are available.

The most popular joint for underground ductile iron pipelines is the push-on joint. This joint, in conformance with AWWA C111, uses a single rubber gasket that is placed into an annular recess that is cast into the bell of the pipe. The joint is assembled by pushing the spigot end past the gasket, thus compressing the gasket and forming a tight seal. The push-on joint has a very high-pressure capacity, with the gasket and annular space designed so that the gasket is secured against displacement during assembly and pressurization.

Also available for underground use is the mechanical joint. This is a bolted stuffing-box type of joint whose popularity remains primarily with fittings. In pipe, it is generally available up through 600 mm (24 in.) in diameter. Compression of the gasket is accomplished by tightening bolts that draw a gland toward the bell of the joined pipe. This gland has a toe that pushes against the gasket, compressing it as the gland is tightened toward the bell. The mechanical joint is also manufactured in conformance with AWWA C111 standard.

Both of these joints are flexible joints that afford the ability to prevent stresses that may result from differential soil movement over time from building along the length of the pipeline. Since the gasket fits into the bell of the pipe, the spigot end may be cut in the field to fit as needed, eliminating the need for a laying schedule or drawing. Flexible joints also allow the possibility of deflecting joints during installation to gradually route the pipeline to avoid obstacles or follow long arcs without having to use fittings.

Various types of restrained joints are available from different manufacturers. Both push-on and mechanical joints can be made into restrained joints by the use of gripper gaskets or a gland with gripper devices.

FITTINGS

Elbows (bends), tees, reducers, and specials are all available in accordance with AWWA C110 and AWWA C153 standards. The former standardizes 80–1200 mm (3–48 in.) ductile or gray iron full-bodied fittings. The latter standardizes ductile iron compact fittings.

TAPPING METHODS

One feature of ductile iron pipe is the ease with which it can be tapped. Direct taps with 20 mm (3/4 in.) services in all diameters are possible at the minimum pressure class. Pipe 150 mm (6 in.) and larger may be direct tapped using 25 mm (1 in.) services. Depending on pipe size and class, larger direct service taps may be allowed. For other situations, tapping saddles and sleeves are available to install wet taps.

HYDRAULIC RESISTANCE FACTOR

The most popular formula used for calculating head loss in ductile iron pipelines is the Hazen-Williams formula. This formula was developed primarily for use in water pipelines and features a flow coefficient that was empirically derived. This flow coefficient is called the "C" factor. The cement-mortar lining used in ductile iron pipe presents a better hydraulic surface compared to unlined pipe. Tests on existing cement-mortar lined pipes, both ductile and gray cast iron, conducted by the Ductile Iron Pipe Research Association (DIPRA) suggest that an appropriate C factor for design is 140.

It should be noted that the inside diameter of ductile iron pipe is typically significantly larger than for other pipelines of the same nominal diameter. Since all modern pipes have comparable C factors (140–150) that are used in design, the hydraulic resistance is more a function of the inside diameter than the flow coefficient. Therefore, in calculating hydraulic resistance, the use of actual inside diameters is recommended. This typically results in lower hydraulic resistance through cement-mortar lined ductile iron pipe.

WAVE SPEED (FOR HYDRAULIC TRANSIENT STUDIES)

The modulus of elasticity of ductile iron is such that a rule of thumb regarding surge pressures is that 350 kPa (50 psi) of surge may be assumed for every 0.305 m/s (1 f/s) of instantaneous change in the velocity of flow.

The surge pressure may be calculated as follows:

$$H_s = \frac{\alpha \Delta V}{g} \tag{4-4}$$

where:

H_s = surge pressure head in m of head (ft of head)

α = wave velocity in m/s (f/s)

ΔV = velocity change in m/s (f/s)

g = acceleration due to gravity of 9.81 m/s^2 (32.2 ft/s^2)

The wave velocity, α, is calculated by:

$$\alpha = \frac{u}{\sqrt{1 + \frac{Kd}{Et}}} \tag{4-5}$$

where:

u = wave velocity of water of 1,420 m/s (4,660 f/s)

K = bulk modulus of elasticity of water of 2,030 MPa (294,000 psi)

d = pipe diameter in mm (in.)
E = modulus of elasticity of ductile iron of 165,500 MPa (24,000,000 psi)
t = thickness of pipe wall in mm (in.)

ALLOWABLE LEAKAGE RATE

AWWA C600 presents an equation for use in calculating an allowable leakage in testing a given length of pipeline. The equation used is

$$L = \frac{SD\sqrt{P}}{794{,}797} \qquad (4\text{-}6)$$

where:
L = allowable leakage in L/h
S = length of pipe being tested (m)
D = nominal diameter of pipe (mm)
P = average test pressure during leakage test (kPa)

Equivalent form in U.S. customary units is

$$L = \frac{SD\sqrt{P}}{133{,}200} \qquad (4\text{-}7)$$

where:
L = allowable leakage in gal./h
S = length of pipe being tested (ft)
D = nominal diameter of pipe (in.)
P = average test pressure during leakage test (psi)

When testing against closed metal-seated valves, an additional leakage of 1.2 mL/h/mm (0.0078 gal./h/in.) of nominal valve size per valve being tested against should be included. AWWA C600 also discusses a procedure to follow in conducting a leakage test for newly installed water mains. Generally, the leakage test involves the addition of water to maintain a test pressure. The need for this added water may be caused by air in the system, but it is considered as leakage for purposes of the formula. The test pressure must be maintained to within 35 kPa (5 psi) of the specified test pressure after the air in the pipeline has been expelled. Regardless of the amount of leakage, all visible leaks must be repaired.

REPAIR METHODS

Split sleeve bell repair clamps as well as other products are available to repair leaking joints.

WATER QUALITY TOLERANCES

The cement-mortar lining in ductile iron pipe is appropriate for use in treated and raw waters and for use in domestic sanitary sewage if the pipe is flowing full. Where soft or acidic waters are found, the seal coat should be specified for the standard cement-mortar lining. Where septic sewage is a concern, special linings are available.

Additionally, all pipe manufacturers' standard products have been tested and found to be in compliance with NSF 61, "Drinking Water System Components–Health Effects."

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Ductile iron pipe should be installed in accordance with the AWWA C600 standard. Where external corrosion is a concern, the pipe should be encased in polyethylene in accordance with AWWA C105.

Backfill requirements for ductile iron pipe are described in AWWA Manual M41. Five laying condition types are described with various materials and degrees of compaction.

Ductile iron pipe can be placed on supports using push-on type joints. Recommendations are to provide support for each pipe length directly behind the bell of the pipe. For pressurized pipe placed on hangers, lateral support should be provided.

For longer spans, manufacturers have extended span products available. These are proprietary products and the manufacturers should be consulted for application details.

SPECIAL CONSIDERATIONS

Soil environments should be evaluated for corrosivity to ductile iron pipe, either by record of performance of other iron pipe in the area or by field testing. Appendix A of AWWA C105 provides a soil testing method for evaluating corrosivity. In addition, the Ductile Iron Pipe Research Association (DIPRA) provides field service for evaluating corrosivity both for soil and for stray direct currents that may result from existing cathodic protection systems in the vicinity.

USEFUL LIFE

By controlling corrosion, the useful life of ductile iron pipe can be significantly increased. However, if corrosive conditions are found, they should be mitigated. Since the advent of ductile iron pipe in 1948, DIPRA has detailed service records that are available upon request.

INDUSTRY GROUPS AND COMMITTEES

DIPRA is an association of manufacturers of ductile iron pipe. DIPRA staff is available for consultation and assistance in all aspects of the application of ductile iron pipelines. In addition, field regional engineers provide the services of DIPRA to consultants and utilities, including soil investigations for corrosivity, technical information, and in-house training. The services of DIPRA are available at no charge (www.dipra.com).

Ductile iron pipe and fittings standards are developed and maintained by AWWA Standards Committee A21.

REFERENCE MATERIALS

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CHAPTER 5

POLYVINYL CHLORIDE (PVC) PIPE

This chapter discusses the use of solid wall polyvinyl chloride (PVC) pipe. Corrugated, ribbed, and closed profile PVC pipe are discussed in a subsequent chapter. The desirable combination of corrosion and chemical resistance, strength to weight ratio, flexibility, long-term tensile strength, watertight joints, abrasion resistance, relatively low coefficient of friction, and effective cost have made solid wall PVC pipe a popular material for both pressure and nonpressure pipe applications.

PVC pipe has been used for water conveyance, wastewater conveyance, and drainage in the United States since the 1950s. The major markets for PVC pipe are irrigation and drainage, sanitary sewer, industrial/municipal pressure water distribution, gravity storm sewer, and highway drainage.

Manufacturing of PVC pipe involves an extrusion process using both heat and pressure to extrude the pipe through a die. PVC pipe is typically manufactured with either a bell and spigot gasketed joint or a bell and spigot solvent joint. An alternative butt fusible-type joint was recently introduced. The extrusion formulation used for fusible PVC has certain narrowed ranges of key ingredients. Another fairly recent product is molecular oriented PVC pipe, referred to as PVCO pipe. This pipe was first installed in North America in 1991. The pipe is manufactured by a process that reorients the molecules of conventionally extruded PVC pipe. The unique material structure of the pipe gives it a burst strength in excess of conventional PVC pipe. This allows use of a thinner wall for a given pressure class.

SPECIFICATIONS AND INDUSTRY STANDARDS

The wide use of PVC pipe within different industries has created different pressure standards and pipe diameter standards. The use of PVC pipe in different industries, with different standards, should not be a limitation, except for using nonpressure pipe for pressure applications. For simplicity of installation and maintenance, using one industry standard type of pipe throughout a project is preferred. This avoids potential problems with matching and joining pipes with a slightly different diameter basis.

Testing in the PVC pipe industry may be divided into three general categories: qualification testing, quality control testing, and assurance testing. Throughout the manufacturing process, the product is sampled on a predetermined frequency and subjected to quality control destructive and nondestructive tests. Quality assurance testing is completed on finished lots to assure the product meets a multitude of industry standards.

PVC pipe is an outside diameter (O.D.) pipe, which means that for a given type and size, the pipe O.D. is maintained constant and the pressure rating (wall thickness) is established by varying the inside diameter. This allows standard sized pipe fittings to be used on pipes with different pressure ratings. However, as will be discussed for the various standards, the O.D. can vary depending on whether it is meant to approximate one of the iron or steel pipe standards.

The ratio of the outside diameter to the wall thickness is referred to as the Dimension Ratio (DR). Certain ratios are considered standard and are known as SDR or Standard Dimension Ratios. Common SDRs include 21, 26, 32.5, and 41.

Table 5-1 contains the most common types of PVC pipe, the size ranges covered in the standard, and their associated standards organizations.

PVC pipe is available in different colors. Most pipes used for conveyance of potable water are white or blue. Most pipes used for conveyance of irrigation water are white. Green pipe is frequently used for force main, sewer and, drainage applications; and purple pipe is frequently used for reclaimed (nonpotable) water.

AVAILABLE SIZES

Note that PVC pipes may not be manufactured in all the sizes covered in the standards identified in Table 5-1. Local pipe suppliers should be contacted to confirm availability.

The differences in outside diameters of the various types of PVC pipe with the same nominal size can cause compatibility problems. For example, a nominal 300 mm (12 in.) diameter pipe manufactured in accordance with American Water Works Association (AWWA) C900 has an outside diameter of 335.28 mm (13.20 in.) (same as ductile iron pipe), a nominal 300 mm (12 in.) diameter pipe manufactured in accordance

Table 5-1. Common Types of Solid Wall PVC Pipe, Size Ranges, and Associated Standards

Pipe Type	Size Range	Standards
Water Distribution PVC	100–300 mm (4–12 in.)	AWWA C900
Water Transmission PVC	350–1,200 mm (14–48 in.)	AWWA C905
Molecularly Oriented PVC	100–600 mm (4–24 in.)	AWWA C909
Plastic Irrigation Pipe (PIP)	100–900 mm (4–36 in.)	ASTM D2241, NRCS 430, ASAE S376
Fusible PVC	100–900 mm (4–36 in.)	No current standard (outside diameters are in accordance with AWWA C900 and C905)
PVC gated pipe	150–300 mm (6–12 in.)	NRCS 443
PVC gravity sewer and drainage pipe	100–1,200 mm (4–48 in.)	ASTM D3034, ASTM F679

Source: Table was developed by the committee authors based on review of the available standards for PVC pipe.

with American Society for Testing and Materials (ASTM) D2241 has an outside diameter of 323.85 mm (12.75 in.) (based on IPS, or iron pipe size), and a nominal 300 mm (12 in.) diameter pipe manufactured in accordance with ASTM D3034 has an outside diameter of 317.50 mm (12.50 in.).

Many manufacturers can furnish adaptors or transition gaskets to allow connection of various pipes to standard fittings and pipes of other diameters.

STANDARD MANUFACTURED LENGTH

PVC pipe for pressure applications is typically furnished in 6 m (20 ft) laying lengths. PVC pipe for gravity and drainage is generally furnished in either 4 m (14 ft) or 6 m (20 ft) laying lengths. Some manufacturers will fabricate pipe to other lengths on special orders.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

The allowable internal pressure is a function of the PVC strength and thickness. Pipe manufactured in accordance with AWWA C900 with a dimension ratio (DR) of 14 has an allowable working pressure of 2,100 kPa (305 psi). Allowable surge pressures can be significantly higher.

The hydrostatic pressure capacity of PVC pipe is derived through long-term hydrostatic pressure testing conducted to establish long-term strength. Pressure surges of infrequent short duration can be withstood on a long-term basis. PVC piping system design should be based on the pressure class or pressure rating. The testing methods for determining the time to failure under long-term hydrostatic pressure are contained in AWWA Manual M23.

The general formula for determining the pipe pressure class or pressure rating is

$$\text{PC or PR} = \frac{2}{\text{DR}-1} + \frac{\text{HDB}}{\text{F}} \tag{5-1}$$

where:

PC = Pressure Class
PR = Pressure Rating
DR = Dimension Ratio
HDB = Hydrostatic Design Basis
F = Safety Factor

Standard PVC pressure pipe material has a hydrostatic design basis of 27.6 MPa (4,000 psi). Molecularly oriented PVC pipe material has a hydrostatic design basis of 49 MPa (7,100 psi).

PVC pressure pipe meeting the requirements of AWWA C900, AWWA C905, and ASTM D2241 has a factor of safety of 2.0, whereas the pressure classes of AWWA C909 have a factor of safety of 2.5 and a surge allowance of 0.61 m/s (2.0 ft/s). Dimension ratios (DR) and standard dimension ratios (SDR) define a constant ratio between outer diameter and wall thickness; they provide a simple means of specifying product dimensions to maintain constant mechanical properties regardless of size. For a given dimension ratio, pressure capacity and pipe stiffness remain constant independent of pipe size. This is in contrast to the older standard of schedule pipe, such as Schedule 40 or Schedule 80, where the pressure rating changes with each diameter change in the pipe size.

PVC pressure pipe is rated for an internal hydrostatic pressure at 23°C (73.4°F). As operating temperature rises above 23°C (73.4°F), the pressure capacity of PVC pipe decreases. For additional information regarding the effect of temperature on pressure rating, refer to the manuals or handbooks listed at the end of this chapter. Temperature also affects expansion and contraction of PVC pipe. The coefficient of thermal expansion is 5.4 $\times 10^{-5}$/°C (3.0 $\times 10^{-5}$/°F), which is equivalent to 0.95 cm/30.5 m/5.4°C (3/8 in./100 ft/10°F). Difficulties can be encountered when the pipe installation temperature is significantly different from normal operating temperature, particularly for pipe with solvent weld- or butt-fused joints. Techniques used to minimize problems with thermal expansion include backfilling the trenches during the coolest part of the day, installing the pipe in an "S" shape in the trench, and installing rubber gasket or expansion joints at regular intervals.

PVC pipe used for nonpressure applications (manufactured to ASTM D3034 and ASTM F679 standards) is tested in accordance with ASTM D3212 (Joints for Drain and Sewer Pipe Using Flexible Elastomeric Seals). This test requires that the joints can withstand 75 kPa (25 ft of head) and 75 kPa (22 in. of mercury) vacuum.

EXTERNAL LOAD CAPABILITIES

PVC pipe is considered a flexible pipe and the Marston theory is frequently used to compute external soil loads. Basic concept of the theory is that the load owing to the weight of the column of soil above a buried pipe is modified by the response of the pipe. The ability to deflect causes the soil directly over the pipe to settle more than the soil adjacent to the trench wall producing a shearing force that reduces the load on the pipe. Under soil load, the pipe deflects developing passive soil support at the sides of the pipe. The ring deflection relieves the major portion of the vertical soil load creating a soil arching action over the pipe. The reference materials listed at the end of this chapter provide a wealth of information regarding external load capabilities. The *Uni-Bell Handbook of PVC Pipe* and the ASTM D3034 standard recommend a maximum allowable deflection of 7.5 percent.

DESCRIPTION OF PIPE MATERIAL

PVC resin, the basic building block of PVC pipe, is derived essentially from natural gas or petroleum, salt water, and air. Most manufacturers purchase PVC resin and commence their manufacturing processes with blend of PVC resin, stabilizers, pigments, lubricants, processing aids, and modifiers. ASTM established Standard Specifications for Rigid Poly(Vinyl Chloride) (PVC) and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds ASTM D1784. PVC pipe is an engineered product for a specific end use. Cell classes of PVC pipe with higher modulus properties are better suited for external loading (sewer and drainage) applications, and cell classes with higher tensile properties are better suited for internal pressure applications. The PVC cell classification is an eight-digit number. The classification system is fairly complex. It is described in the ASTM D4216 standard.

For molecular oriented PVC pipe, the longitudinal molecular structure of PVC is reoriented to a circumferential direction using heat and pressure. By a process involving circumferentially expanding the starting stock piece, a new molecular orientation is achieved. The new molecular orientation increases the physical and mechanical properties of PVCO pipe. Additional information regarding the description of the pipe material is provided in the forward section of the AWWA C909 standard.

PROTECTIVE LININGS AND COATINGS

PVC pipes do not require protective linings or coatings for water conveyance. PVC is a homogeneous thermoplastic compound that is nonconductive and is immune to electrochemical reactions. The chemical resistance quality of PVC makes it useful as a liner for other types of pipes. PVC is susceptible to discoloration from ultraviolet (UV) radiation. A common method to protect exposed PVC pipe is painting with a latex (water-based) paint. The discoloration process is time dependent and can be slowed by the addition of UV absorbers in the PVC compound. Additional information regarding the effect of sunlight exposure is available in a publication by the Uni-Bell PVC Pipe Association titled "The Effects of Ultraviolet Aging on PVC Pipe."

JOINTS

The most commonly used joints for PVC pipe are gasketed, solvent welded, and mechanical joints. PVC pipe is manufactured in a gasketed bell and spigot in most sizes. Some of the advantages of gasketed joints are allowance for expansion and contraction, reliable assembly in poor weather conditions, ease of installation, and consistent reliability in the joint. Solvent cement bell and spigot joints are formed using a three-step process of cleaning, priming, and cementing. The advantages of solvent jointed pipe are that the cost of the pipe is generally less than gasketed pipe, and the solvent joint is "welded" together. Solvent joint PVC pipe is available in iron pipe sizes up to 300 mm (12 in.) diameter and somewhat scarcer in irrigation pipe sizes up to 500 mm (20 in.) diameter. Mechanical joints are commonly used on ductile iron fittings and are suitable for use with PVC pipe that is manufactured to the same outside diameter as ductile iron pipe. Butt-fused joints are joined using a fusion machine consisting of an electronically controlled heating element. The element simultaneously heats both ends of the pipe to be joined. After the pipe ends have been heated and the proper bead has developed, the heater plate is removed, and the pipe ends are brought together and held in place under pressure until the joint cools. This provides a monolithic, fully restrained pipe system. Pipe with butt-fused joints is most commonly used for trenchless applications, such as horizontal directional drilling, slip lining, or pipe bursting. It has also been used for open trench applications.

Sleeve compression couplings consist of a sleeve slightly larger than the pipe, two rings, two gaskets, and bolts. Flange coupling adaptors can be used to connect a plain end PVC pipe to a flanged end. The gaskets are compressed by tightening the bolts. Flanges or mechanical joints are most commonly used to connect the pipe to valves, fittings, or other types of pipe.

Methods to restrain PVC gasketed joints are available. They include clamps and external rods, gripper teeth or set screws, gripper rings, and gripper gaskets.

FITTINGS

The PVC fittings used with PVC pipe are manufactured in gasket and solvent (slip) type joints. The AWWA C907 standard covers injection-molded PVC fittings with push-on, rubber gasketed joints, 100 mm (4 in.)–300 mm (12 in.). The standard includes elbows, tees, plugs, reducers, line couplings, repair couplings, plugs, adapters, and caps. Fabricated fittings for larger diameter pipe with cast iron diameters are covered by the AWWA C905 standard. Fittings for plastic irrigation pipe (PIP) are manufactured from a compound meeting the requirements of ASTM D1784, gasket bells conform to ASTM D3139, and gaskets conform to ASTM F477.

Fittings for PVC pipe used for sewer and drain applications are covered by several ASTM standards including D3139, F477, D3212, F913, and F1336.

Injection molded fittings (elbow and tees) for PVC pipe are formed in mold cavities in which the inner surfaces are defined by the core and the outer surfaces are defined by the cavity. Fabricated PVC fittings are manufactured from straight lengths of pipe welded or butt fused together and sometimes overwrapped with fiberglass for additional mechanical strength. Because most pipe failures occur in the fittings, not in the pipe, using a fitting with a higher pressure rating than the adjacent pipe is a common practice. For example, a designer may choose to use fittings rated for 690 kPa (100 psi) with a pipeline rated for 550 kPa (80 psi).

Gasketed fittings are generally more costly than slip fittings. Some designers use a combination of gasketed pipe and slip fittings. This practice combines the advantages of gasketed joints and the economy of solvent joint fittings. Fabricated epoxy-coated steel fittings with gasketed bells are common for PVC pipe sizes greater than 300 mm (12 in.). Ductile iron fittings with mechanical joints or push-on joints are commonly used on pressure pipelines.

TAPPING METHODS

Saddle taps or sleeve taps are commonly used for tapping PVC pipe. The saddle or sleeve is bolted in place, and the tap can be made hot or cold. For some applications, a PVC saddle can be solvent welded to the pipe and then tapped with a hole-saw. Procedures and limitations for saddle tapping are described in AWWA Manual M23 and the AWWA C605 standard.

PVC pipe of certain diameters and with adequate wall thickness can be direct tapped. Procedures and limitations for direct tapping are described in AWWA Manual M23, the AWWA C605 standard, and many of the installation guides furnished by the pipe manufacturers.

HYDRAULIC RESISTANCE FACTOR

Research and analysis have established that flow conditions in PVC pressure pipe systems can be evaluated using the Hazen-Williams equation. The Hazen-Williams equation flow equation is the most widely used in calculating PVC pressure pipe conditions. AWWA Manual M23 recommends using a flow coefficient ("C" factor) for PVC pipe of 150. The manual states that research has established that C factors for both new and previously used PVC pipe range from 155–165. If the portion of pipe being analyzed includes a large number of fittings, the friction loss in the fittings should be considered. Field experience indicates the flow characteristics of PVC pipe do not change significantly with age.

For gravity sewer and drainage pipe, the Manning equation is frequently used to calculate hydraulic resistance. According to the Uni-Bell *Handbook of PVC Pipe*, studies in the laboratory and actual installations have found the value for "n" to range from 0.007 to 0.011. The Uni-Bell handbook recommends a design value for Manning's "n" equal to 0.009.

The Manning's "n" value for plastic pipe with a smooth interior based on ANSI/ASCE Standard 12-05 is a range of 0.010 to 0.013.

WAVE SPEED (FOR HYDRAULIC TRANSIENT STUDIES)

Surge pressures (commonly called water hammer) are generated in any pressurized piping system when the flowing liquid changes velocity. The pressure wave velocity in PVC pipe depends on the ratio of the diameter to wall thickness and varies from approximately 250–450 m/s (800–1,500 ft/s). A technical discussion of surge pressure is beyond the scope of this chapter; the section titled "Reference Materials" includes documents that provide more information on pressure surge. One of the variables in the wave speed equation is the modulus of elasticity. Note that the modulus of elasticity for PVC pipe, 2,760 MPa (400,000 psi) is different than the modulus of elasticity for PVCO pipe 3,210 MPa (465,000 psi).

Appendix B of the AWWA C900 standard includes figures and a design example for selection of pressure class to withstand recurring (cyclic) surges.

The following strategies have been used to manage surge in PVC pipe systems: reducing the working pressure to a certain percentage of the pressure rating; limiting the maximum velocity; using gear operators on all valves and operating valves slowly; using a bypass line with a valve for starting and stopping pumps; installing sufficient air relief and air vacuum valves; and installing surge tanks, surge chambers, or flywheels.

ALLOWABLE LEAKAGE RATE

Regardless of the joint system, a PVC pipeline should have essentially no leakage. The purpose of the leakage test is to establish that the section of pipeline tested, including all joints, fittings, and other appurtenances do not leak. An allowable leakage rate commonly used for a pipeline with bell-and-spigot rubber gasket joints is expressed by the equation

$$Q = \frac{LD(P)^{1/2}}{795,000} \tag{5-2}$$

where:
Q = allowable leakage in L/h
L = length of pipe being tested in m
D = pipe nominal diameter in mm
P = average test pressure in kPa

Equivalent equation in U.S. customary units is

$$Q = \frac{LD(P)^{1/2}}{148,000} \tag{5-3}$$

where:
Q = allowable leakage in gal./h
L = length of pipe being tested in ft

D = pipe nominal diameter in in.
P = average test pressure in psi

Nonpressure PVC pipe used for sewers is commonly tested using a low-pressure air test. Hydrostatic testing involving installation of pipe plugs and filling of manholes with water is occasionally required. When the groundwater level is above the installed pipe, infiltration testing is frequently performed. The reference materials listed at the end of the chapter include recommended testing methods and criteria.

REPAIR METHODS

A common method used to repair PVC pipe is a repair coupler, which has gasketed joints on both ends. Some couplers have a gasketed sleeve that allows the coupler to be extended, whereas others are simply a double-belled coupling that is large enough to completely slide onto one end of the pipe. Typically the damaged pipe and fittings are replaced, and a gap large enough to bring the pipe ends into alignment is provided. The repair coupler is extended to close the joint. Other types of steel compression fittings or clamps can be used to make closure, but the PVC repair coupler is the most common.

WATER QUALITY TOLERANCES

The water quality tolerance of PVC pipe is excellent. PVC is a homogeneous thermoplastic compound that is nonconductive and is immune to electrochemical reactions.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

PVC pipe is a flexible pipe and derives its soil load carrying capacity from its flexibility. Under soil load, the pipe tends to deflect, thereby developing passive soil support at the sides of the pipe. Compacting the backfill along the sidewall increases the soil support. At the same time, the ring deflection relieves the top of the pipe from the major portion of the vertical soil load, which is then carried by the surrounding soil through the mechanism of an arching action over the pipe. Supporting the earth load is a design trade-off between stiffer pipe and better compacted backfill supporting the pipe sidewall. The subject of buried pipe design and installation are discussed in the Uni-Bell *Handbook of PVC Pipe*.

AWWA Manual M23 also includes information on joint assembly, pipe cutting, pipe bending, casings, valving, thrust restraint, and testing.

SPECIAL CONSIDERATIONS

As mentioned previously, PVC pipe used in aboveground applications is susceptible to discoloration from ultraviolet radiation. PVC pipe exposed to very cold temperatures becomes brittle and requires extra care in handling during cold weather. Pipe bedding material should be selected to avoid damage to the pipe. If the temperature of the water being conveyed exceeds 23°C (73.4°F), both the pressure rating and the strength to resist external loads should be evaluated. If the pipe will be subjected to large variations in temperature, and the joints are not rubber gasketed, consideration should be given to allowances for thermal expansion and contraction.

USEFUL LIFE

PVC piping systems are not susceptible to attack from chemicals found in typical water and sewer systems. Once PVC pipe has been installed underground in normal water and sewer systems, it is not susceptible to the normal processes of deterioration found in nature. PVC pipe has not been in use an adequate length of time to determine definitively its useful life, but field research by industry groups would indicate a life expectancy of at least 100 years.

INDUSTRY GROUPS AND COMMITTEES

Industry groups and committees include the Uni-Bell PVC Pipe Association (www.uni-bell.org), the AWWA Standards Committee on PVC Pressure Pipe and Fittings, and the Plastics Pipe Institute.

REFERENCE MATERIALS

American Society of Agricultural and Biological Engineers (ASABE). (2006). "Design, Installation and Performance of Underground, Thermoplastic Irrigation Pipelines." ASABE, St. Joseph, MI.

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CHAPTER 6

HIGH DENSITY POLYETHYLENE (HDPE) PRESSURE PIPE

This chapter discusses extruded solid wall high density polyethylene pipe (HDPE). Light weight, corrosion resistance, and flexibility make polyethylene an ideal material for many subsurface applications.

Corrugated polyethylene pipe and profile wall polyethylene pipe are discussed in a subsequent chapter.

SPECIFICATIONS AND INDUSTRY STANDARDS

The most common standards used for 100 mm (4 in. diameter) and larger HDPE pipe associated with water conveyance projects are

- AWWA C906 Polyethylene (PE) Pressure Pipe and Fittings, 4 in. (100 mm) through 63 in. (1,575 mm) for Water Distribution and Transmission, and
- ASTM F714 Standard Specification for Polyethylene (PE) Plastic Pipe Based on Outside Diameter.

In addition to these two standards, there are several other ASTM standards covering the materials, testing, and manufacturing of HDPE.

AVAILABLE SIZES

Polyethylene pressure pipe is available in O.D. (outside diameter) sizes from 15–1,600 mm (0.5–63 in.) diameters for extruded solid wall pipe. The size of pipe available for any given pressure rating may not cover the entire range.

STANDARD MANUFACTURED LENGTHS

Standard manufacturing lengths varies with the manufacturer and pipe diameter. Small diameter pipe is produced in coils up to 450 m (1,500 ft). Diameters up to 8 in. can be coiled. Standard lengths for larger diameter pipe are 6–12 m (20–40 ft).

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Allowable internal pressure for extruded solid wall pipe is proportional to the ratio of the outside diameter to the wall thickness. The ratio of the outside diameter to wall thickness is known as the Dimension Ratio (DR), and certain ratios are considered standard and are known as SDR or Standard Dimension Ratio. The allowable internal pressure is calculated by using the following equation:

$$PC = (2(HDB)(DF))/(DR - 1) \tag{6-1}$$

where:
PC = Pressure Class
HDB = Hydrostatic Design Basis
DF = Design Factor (inverse of the safety factor)
DR = Dimension Ratio

The procedure to develop the hydrostatic design basis (HDB) is described in several publications including AWWA Manual M55: *PE Pipe—Design and Installation*.

The design factor (DF) most commonly used for water conveyance is 0.5, which converts to a factor of safety of 2.0. For the polyethylene materials described in AWWA Standard C906, the effective factor of safety against transient and sustained pressures is at least 2:1.

EXTERNAL LOAD CAPABILITIES

HDPE pipe is flexible and the Marston theory is used to calculate external soil loads. Marston theory takes into account the affect of the arching of the soil over a flexible pipe. The arching of the soil and the stress relaxation of the HDPE keep the pipe from experiencing the full prism load when installed in a ditch. The external load capacity depends on the wall thickness and configuration.

The recommended procedure for external load design is provided in AWWA Manual M55. It includes a discussion of dead loads, live loads, surcharge loads, ring deflection, and wall buckling.

DESCRIPTION OF PIPE MATERIAL

High density polyethylene is a polymer prepared by the polymerization of ethylene. Properties, such as density, melt index, crystallinity, degree of branching and cross linking, molecular weight, and molecular weight distribution can be regulated over a wide range by varying the catalysts and methods of polymerization.

ASTM D3350 classifies polyethylene pipe and fittings materials using a series of cells that designate material physical properties. Cell designation includes density, melt index, flexural modulus, tensile strength, environmental stress crack resistance, hydrostatic design basis, and color and UV stabilizer. Extruded solid wall HDPE pipe uses pressure-rated resins that meet the ASTM D3350 standard and are listed by the Plastics Pipe Institute (PPI) Report No. TR-4 (www.plasticpipe.org).

PROTECTIVE LININGS AND COATINGS

Polyethylene is a corrosion resistant material and does not require protective coatings or linings. However, if appropriate stabilizers are not added to the polyethylene, ultraviolet (UV) light can cause degradation to the product by long-term exposure. The most common stabilizer is carbon black. Alternative, nonblack, UV stabilization systems have been developed for pipe that is not black in color.

JOINTS

Joints may be joined by butt fusion, socket fusion or, for branches, saddle fusion. Butt-fused joints are made by heating the pipe ends with a metal plate at a specific temperature for a specific amount of time and then bringing the pipe ends into contact with each other and applying a specific amount of pressure. This is usually done with the assistance of a butt fusion machine to ensure proper alignment of the pipe ends and produce consistent fusion joints. Butt-fused joints are as strong as the pipe itself. Since heating time, temperature, and fusion pressures vary, the pipe manufacturer or fusion equipment manufacturer should be consulted for the proper procedures.

HDPE pipe and fittings may also be joined to other pipe and fittings, to pipe appurtenances, such as valves, or to other pipe materials by mechanical compression couplings, flanges, mechanical joint adaptors, and transition fittings. A description of these products is included in the AWWA Manual M55. Internal pipe stiffeners may be necessary with certain products.

FITTINGS

Typically, fittings for HDPE pipe are made of the same material as the pipe. HDPE fittings can be molded or fabricated. They are available in a wide variety of configurations including reducers, saddles, wyes, tees, end caps, and elbows. Fittings manufactured from other materials, such as ductile iron or steel, can also be used assuming appropriate transition products are provided.

TAPPING METHODS

Tapping can be accomplished with saddle-fused tapping tees or mechanical tapping saddles. Standard tees and saddles are available in sizes to meet the curvature of the different outside diameters.

HYDRAULIC RESISTANCE FACTOR

Several formulas have been used to calculate the hydraulic friction losses in HDPE pipe. A Hazen-Williams "C" factor of 150 is commonly accepted. The Manning's "n" value for smooth interior HDPE given in ANSI/ASCE Standard 12-05 is a range of 0.010 to 0.013. Field experience indicates the flow characteristics of HDPE pipe do not change significantly with age.

WAVE SPEED (FOR HYDRAULIC TRANSIENT STUDIES)

The pressure wave velocity for HDPE pipe depends on the stiffness of the pipe as well as the pipe dimensions. Pipe with lower dimension ratios (DR) exhibits faster wave velocities. Manufacturer's design manuals contain information specific to wave speed for various pipe products. AWWA Manual M55 also describes the procedure for estimating the surge pressures and uses the terms "recurring surge pressure" and "occasional surge pressure."

ALLOWABLE LEAKAGE RATES

The allowable leakage rate for properly fused HDPE pipe joints is zero. The hydrostatic leak testing procedure is complicated by the fact that the pipe gradually expands under pressure and requires make-up water to maintain a constant pressure. For prudence and test integrity, make-up water should be documented to verify pipe expansion and/or leakage of the system. A description of the recommended testing procedure is provided in AWWA Manual M55 and ASTM F2164 (Standard Practice for Field Leak Testing of Polyethylene Pressure Piping Systems Using Hydrostatic Pressure).

REPAIR METHODS

Several repair methods are available for HDPE pipe that has been damaged or improperly fused. The methods include mechanical repair sleeves, sidewall fusion saddles, electrofusion saddles, mechanical saddles, and replacement of the leaking section with a new section of pipe joined by electrofusion couplings.

WATER QUALITY TOLERANCES

Polyethylene is not subject to corrosion associated with the compounds commonly found in water or wastewater.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Trenches should be excavated and backfilled as described in AWWA Manual M55 and similar publications. In addition to trench applications, extruded solid wall polyethylene pipe is also commonly used for slip lining existing pipelines, horizontal directional drilling, and pipe bursting applications. When HDPE pipe is used in nontrench applications where the pipe is pulled into place, the maximum safe pull force must be considered. Various pipe manufacturers publish the recommended safe pull forces. New construction techniques and equipment for accomplishing these procedures constantly are being developed.

SPECIAL CONSIDERATIONS

HDPE pipe has a specific gravity that is slightly less than water and is hence susceptible to floatation in high groundwater situations if the pipe is empty and there is not adequate ground cover to restrain it. Another situation where floatation is a concern is in crossings of water bodies, where the pipe is usually weighted down with concrete weights. The weights have an elastomeric material between the pipe and the concrete to keep them from gouging the polyethylene.

Extruded solid wall polyethylene is flexible and can be laid around curves to avoid obstacles or provide access to structures. The recommended minimum cold bending radius depends on the wall thickness and is provided in AWWA Manual M55 as well as the installation guides provided by most pipe manufacturers. HDPE pipe will typically bend without great effort to about a 70-pipe diameter or greater bend radius. However, considerable force may be required if the pipe is cold or if a tighter radius is desired. The pipe may tend to spring back with considerable force when the restraints are removed, either intentionally or inadvertently.

HDPE pipe has a relatively high coefficient of expansion 2.2×10^{-4} m/m/°C (1.2×10^{-4} in./in./°F). Thermal expansion and contraction effects must be considered in the design of pipes that will experience significant temperature changes. Anchoring methods should be considered where pipes join to structures.

The pressure rating of the pipe is based on a temperature of 23°C (73.4°F). At higher temperatures, the hydrostatic design basis is reduced and this reduction should be considered in selection of a pressure class.

Because HDPE pipe is nonmetallic, it is generally not detectable by use of standard magnetic locating equipment. If the ability to locate the pipe in the future is important, a tracer wire or metallic locating tape can be installed above the pipe.

Other considerations include high-static electricity charges under certain conditions, bounce-back concerns if the pipe is struck with a blunt instrument, and the stored energy in pipe that is coiled.

USEFUL LIFE

The useful life of a polyethylene pipe system is dependent on many things including proper installation, stress applied to the pipe, maintenance, and the environment. Polyethylene pipe is corrosion-resistant in water and wastewater applications. While the useful life of any pipeline system is difficult to predict, experience has shown that polyethylene pressure pipes in service for more than 40 years have not suffered any significant problems. Research indicates that the useful life is in excess of 100 years.

INDUSTRY GROUPS AND COMMITTEES

PPI is the primary industry group for HDPE pipe. The Polyolefin Pressure Pipe and Fittings Committee of AWWA assists with development of standards.

REFERENCE MATERIALS

American Water Works Association (AWWA). (2006). Manual M55: *PE Pipe–Design and Installation*. AWWA, Denver, CO.

Plastics Pipe Institute (PPI). (2012). Report No. TR-4: HDB/HDS/SDB/PDB/MRS. PPI, Irving, TX.

CHAPTER 7

POLYETHYLENE PROFILE WALL PIPE

This chapter discusses polyethylene profile wall pipe. The term "profile wall" refers to pipe in which strength is gained through the geometry of the pipe wall. Profile wall pipe is typically low head design. Profile wall pipes all have a smooth interior wall while the exterior may be ribbed, corrugated, or smooth. The wall may contain hollow cores.

SPECIFICATIONS AND INDUSTRY STANDARDS

Polyethylene profile wall pipe is manufactured under the following standards:

- AASHTO M252 Corrugated Polyethylene Drainage Pipe,
- AASHTO M294 Corrugated Polyethylene Pipe, 300- to 1500-mm Diameter,
- ASTM F894 Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe,
- ASTM F2306 Standard Specification for 12–60 in. Annular Corrugated Profile-Wall Polyethylene Pipe and Fittings for Gravity-Flow Storm Sewer and Subsurface Drainage Applications, and
- ASTM F2648 Standard Specification for 12–60 in. Annular Corrugated Profile-Wall Polyethylene Pipe and Fittings for Land Drainage Applications.

In addition to the ASTM standards listed, there are similar AASHTO standards that cover the same products.

AVAILABLE SIZES

ASTM F894 profile wall polyethylene pipe is manufactured in a wide variety of sizes varying from 450–3,000 mm (18–120 in.) inside diameters. AASHTO M252 is profile wall pipe manufactured from 100–250 mm (4–10 in.) nominal diameters. AASHTO M294, ASTM F2306 and ASTM F2648 profile wall pipe is manufactured in sizes varying from 300–1,500 mm (12–60 in.) nominal diameters.

STANDARD MANUFACTURED LENGTH

Profile wall pipe is general available in standard lengths of 6 m (20 ft). Other lengths can be special ordered.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Profile wall pipe can withstand limited amounts of internal pressure. Refer to the manufacturers' brochures for the allowable internal pressure for specific types of pipe.

EXTERNAL LOAD CAPABILITIES

Polyethylene profile wall pipe is flexible and the Marston theory is used to calculate external soil loads. Marston theory takes into account the arching affect of the soil over a flexible pipe. The external load capacity depends on the wall thickness and configuration. Profile wall pipe gains strength through the geometry of the pipe wall.

The external load capacity of pipe manufactured to the AASHTO M252, AASHTO M294, ASTM F2306, and ASTM F2648 standards is provided by the pipe manufacturers in their guidelines.

The ASTM F894 standard covers six standard ring stiffness constant (RSC) classifications: 40, 63, 100, 160, 250, and 400. The design of polyethylene profile wall pipe for subsurface applications is typically based on three performance criteria: wall crush strength, constrained buckling resistance, and pipe deflection. Selection of an appropriate wall thickness should follow the guidelines in ASTM D2321 and the pipe manufacturer's recommendations. Note that not all manufacturers produce pipe in each of the standard ring stiffness constant classifications. Common design practice is to limit the long-term deflection to no more than 7.5 percent.

DESCRIPTION OF PIPE MATERIAL

High density polyethylene is a polymer prepared by the polymerization of ethylene as the sole monomer. There are certain properties that the designer should consider in specifying polyethylene pipe. Properties, such as density, melt index, crystallinity, degree of branching and cross linking, molecular weight, and molecular weight distribution, can be regulated over a wide range by varying the catalysts and methods of polymerization.

ASTM D3350 classifies polyethylene pipe and fittings materials using a series of cells that designate material physical properties. Cell class designates, in order: density, melt index, flexural modulus, tensile strength, environmental stress crack resistance, hydrostatic design basis, and color and UV stabilizer. Corrugated pipe has a cell class of 335420 C or E. F-894 profile pipe uses a pressure rated resin that is made to the ASTM D3350 specification to improve long-term performance without cracking and has a cell classification of 334433C and is listed by the Plastics Pipe Institute (PPI) TR-4.

High density polyethylene material is resistant to many abrasive chemicals, such as road salt, motor oils and fuels, and alkaline soils.

PROTECTIVE COATINGS AND LININGS

The chemical and corrosion of polyethylene profile wall pipe makes it ideal for sanitary sewer and a wide variety of industrial waste disposal applications. It will not rust, decay, or support bacteriological growth, and is not subject to electrolytic or galvanic corrosion. No protective coatings or linings are required.

JOINTS

Lengths of polyethylene profile wall pipe can be joined by a variety of methods including bell and spigot, heat fusion, extrusion welded, and electrofusion joints. For the bell-and-spigot arrangement, an elastomeric gasket is fit into a groove on the spigot end of the pipe and then the bell of the next piece slides over the spigot end of the other until it is fully seated. The joint is water tight and meets the specification for drain and plastic sewer plastic pipes, ASTM D3212.

FITTINGS

A wide variety of fittings (manholes, bends, tees, reducers, and so on) can be fabricated for use with polyethylene profile wall pipe.

TAPPING METHODS

Polyethylene pipe is usually tapped by cutting out a section of pipe and replacing it with the desired fitting. Tees with polymeric gaskets, which are able to conform to uneven surfaces, are available for insertion into the wall of the profile pipe.

HYDRAULIC LOSS FACTORS

ANSI/ASCE 12-05 Standard "Guidelines for the Design of Urban Subsurface Drainage" recommends a Manning's "n" value of 0.010 to 0.013 for plastic pipe with a smooth interior.

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Because polyethylene profile wall pipe is not used as a pressure pipe, wave speed does not apply.

ALLOWABLE LEAKAGE RATE

Profile wall pipe joints made to ASTM standard D3212 (Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals) can be laboratory tested at an internal and external pressure of 75 kPa (10.8 psi or about 25 ft of head). The standard requires a 10-minute test with no leakage under conditions of shear and angular deflection. The ASTM F2487 document (Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Corrugated High Density Polyethylene Pipelines) provides guidance with the allowable leakage rate.

REPAIR METHODS

There are several methods to repair joints and damaged pipe sections:

- If sections of the pipe are damaged, the damaged section can be removed and replaced, then new couplers are placed at both ends of the repair.
- Split band couplers can be installed to repair a damaged section if the damaged area is less the about 10 percent of the pipe diameter.

- If the damaged area is less than 25 percent of the pipe diameter, the areas can be repaired by wrapping the pipe with a geotextile fabric, strutting or bracing the damaged section, then encasing it in a concrete collar.
- Occasionally, the damaged areas can be repaired by use of a mastic material wrapped around the pipe and held in place by a combination of the tacky mastic surface and straps that are tightened after the mastic material is in place.
- For repair of pipe with improperly assembled joints, chemical grouting can be used.
- For repair of pipe large enough for entry by personnel, an internal seal can be placed inside the pipe. The seals usually comprise a metal band with a rubber gasket, which expands to conform to the inner wall of the pipe.

WATER QUALITY TOLERANCES

Polyethylene is not subject to corrosion and is ideal for potable water systems, wastewater systems, and irrigation or drainage systems.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Polyethylene profile wall pipe should be installed in accordance with ASTM Practice D2321 (Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications). This practice provides recommendations for the installation of buried thermoplastic pipe used in sewers and other gravity-flow applications. The recommendations are intended to ensure a stable underground environment for thermoplastic pipe under a wide range of service conditions.

The scope of the practice does not include product performance criteria, such as minimum pipe stiffness, maximum service deflection, or long-term strength. The product manufacturer, specifier, or project engineer should verify that the pipe specified for an intended application, when installed according to procedures outlined in this practice, will provide a long-term, satisfactory performance according to criteria established for that application. A commentary on factors important in achieving a satisfactory installation is included in the appendix to ASTM D2321.

SPECIAL CONSIDERATIONS

Polyethylene profile wall pipe is a light-weight material, and designs should be checked for flotation when the pipe is installed below the groundwater level and may not be flowing full.

Welding of the joints should be performed only by qualified personnel. The material has a high coefficient of thermal expansion and contraction. If the pipe is installed during hot weather, and especially if it has been exposed to sunlight for a long period of time, the forces associated with thermal contraction must be considered during design.

Hard or sharp objects in the trench adjacent to the pipe should be removed. Where differential conditions of pipe support exist, such as near structures or manholes, a transition support region should be provided to ensure uniform support and avoid development of concentrated shear loading on the pipe. Occasionally, controlled density fill or controlled low-strength material are used to fill excavated areas adjacent to structures. These materials exhibit little to no settlement and stabilize the transition zone where the depth of fill material varies.

USEFUL LIFE

The useful life of a polyethylene profile wall pipe system is dependent on many variables, including proper installation, stress applied to the pipe, and maintenance. Polyethylene pipe is corrosion resistant in water pipeline applications. While the useful life of any pipeline system is difficult to predict, lifetimes in storm drainage and sanitary sewer applications of 100 years are not unreasonable.

INDUSTRY GROUPS AND COMMITTEES

Technical committees of ASTM, PPI, and AASHTO have developed standards for polyethylene profile wall pipe and fittings.

REFERENCE MATERIALS

American Society for Testing and Materials (ASTM). (2011). D2321, “Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications.” ASTM, West Conshohocken, PA.

Plastics Pipe Institute (PPI). (2006). TN-37, “Standard Practice for Installation of Annular Corrugated Profile Wall Polyethylene Pipe for Agricultural Drainage or Water Table Control.” PPI, Irving, TX.

PPI. (2012). Report No. TR-4: HDB/HDS/SDB/PDB/MRS. PPI, Irving, TX.

CHAPTER 8

PVC AND POLYPROPYLENE PROFILE WALL PIPE

This chapter discusses polyvinyl chloride (PVC) and polypropylene (PP) profile wall pipe. Whereas polyvinyl chloride (PVC) and polypropylene (PP) are different materials, they are both used to produce profile wall pipe and are both discussed in this chapter. The term "profile wall" refers to pipe in which strength is gained through the geometry of the pipe wall. PVC and PP profile wall pipes all have a smooth interior wall, whereas the exterior may be ribbed or smooth. The wall may contain hollow cores. Profile wall pipe is typically for low head design.

SPECIFICATIONS AND INDUSTRY STANDARDS

Several ASTM standards cover the manufacturing of PVC profile wall pipe including

- F794 Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter,
- F949 Standard Specification for Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe with a Smooth Interior and Fittings,
- F1803 Standard Specification for Poly (Vinyl Chloride)(PVC) Closed Profile Gravity Pipe and Fittings Based on Controlled Inside Diameter,
- F2736 Standard Specification for Polypropylene (PP) Corrugated Single Wall Pipe and Double Wall Pipe, and
- F2764 Standard Specification for Polypropylene (PP) Triple Wall Pipe and Fittings for Non-Pressure Sanitary Sewer Applications.

AVAILABLE SIZES

The ASTM F794 standard includes pipe in sizes 100–1,200 mm (4–48 in.). The ASTM F949 standard includes pipe in sizes 100–1,200 mm (4–48 in.). The ASTM F1803 standard includes pipe in sizes 450–1,500 mm (18–60 in.). The ASTM F2736 standard includes pipe in sizes 150–750 mm (6–30 in.). The ASTM F2764 standard includes pipe in sizes 750–1500 mm (30–60 in.). Not all these sizes may be available. Check with the pipe manufacturers to confirm availability.

STANDARD MANUFACTURED LENGTH

For PVC profile wall pipe, a review of manufacturer's literature indicates the most common laying length is 4.3 m (14 ft). For PP profile wall pipe, a review of the manufacturers' literature indicates the most common laying length is 6 m (20 ft).

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

PVC and PP profile wall pipe can withstand limited amounts of internal pressure and must meet an internal pressure laboratory test of 75 kPa (10.8 psi or about 25 ft of head) per ASTM D3212.

EXTERNAL LOAD CAPABILITIES

PVC and PP profile wall pipes are flexible, and the Marston theory is used to calculate external soil loads. The Marston theory takes into account the arching effect of the soil over a flexible pipe. The external load capacity depends on the wall thickness and configuration. Profile wall pipe gains strength through the geometry of the pipe wall.

A review of manufacturers' literature indicates the typical pipe stiffness at 5 percent deflection is 317 kPa (46 psi) when the pipe is tested in accordance with ASTM D2414 (External Loading Properties of Plastic Pipe by Parallel Plate Loading).

The manufacturers' guidelines and design manuals provide information on the allowable external load and depth of burial. Soil conditions, the material used for backfill, and the degree of compaction all play a part in determining the allowable depth of burial. Common design practice is to limit the long-term deflection to no more than 7.5 percent.

DESCRIPTION OF PIPE MATERIAL

PVC profile wall pipe is manufactured from PVC resin, compounded to meet the physical and chemical requirements of ASTM D1784 Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds.

PP profile wall pipe is manufactured from polypropylene resin, meeting the requirements of ASTM D4101 Standard Specification for Polypropylene Injection and Extrusion Materials.

PROTECTIVE COATINGS AND LININGS

The chemical and corrosion resistance of PVC and PP profile wall pipes makes them ideal for sanitary sewer and a wide variety of industrial waste disposal applications. They will not rust, decay, or support bacteriological growth, and are not subject to electrolytic or galvanic corrosion. No protective coatings or linings are required.

JOINTS

Lengths of PVC and PP profile wall pipes are joined by a rubber-gasketed bell and spigot. For the bell-and-spigot arrangement, an elastomeric gasket is fit into a groove on the spigot end of the pipe, and then the bell of the next piece slides over the spigot end of the other until it is fully seated. The joint is water tight and meets the specification for drain and plastic sewer plastic pipes, ASTM D3212.

FITTINGS

A wide variety of fittings (bends, tees, reducers, and so on) can be fabricated for use with PVC and PP profile wall pipe.

TAPPING METHODS

PVC and PP profile wall pipes can be tapped by cutting out a section of pipe and replacing it with the desired fitting. Depending on the shape of the pipe exterior, special saddle gaskets should be used. For PVC, silicone can be applied to make the connection water tight.

HYDRAULIC LOSS FACTORS

The range of Manning's "n" value for PVC and PP profile wall pipes varies from 0.009 to 0.013. ANSI/ASCE 12-92 Standard Guidelines for the Design of Urban Subsurface Drainage recommends a Manning's "n" value of 0.010 to 0.013 for plastic pipe with a smooth interior. Some manufacturers recommend the use of 0.009 for the "n" value based on testing with clean water.

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Because PVC and PP profile wall pipes are not used as a pressure pipes, hydraulic transient studies are not normally performed.

ALLOWABLE LEAKAGE RATE

ASTM F794, F2736, F2764 profile wall pipe joints are made to ASTM standard D3212 (Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals), which requires that the joints withstand an internal and external pressure laboratory test of 75 kPa (10.8 psi or about 25 ft of head) for 10 minutes without leaking under conditions of vertical and angular deflection.

ASTM F1417 (Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air) is an industry standard for conducting low-pressure air tests in the field.

REPAIR METHODS

Repair of joints or pipe sections is usually accomplished by replacing the damaged portion with a repair coupling. Some minor repairs, such as a small hole caused by a backhoe bucket, can be repaired in the trench. Consult with the pipe supplier for the proper repair procedures.

WATER QUALITY TOLERANCES

PVC and PP are not subject to corrosion and are ideal for potable water systems, wastewater systems, and irrigation/drainage systems.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

As with polyethylene profile wall pipe, PVC and PP profile wall pipe should be installed in accordance with ASTM Practice D2321

(Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications) and the manufacturer's instructions.

The scope of the practice does not include product performance criteria, such as minimum pipe stiffness, maximum service deflection, or long-term strength. The product manufacturer, specifier, or project engineer should verify that the pipe specified for an intended application, when installed according to procedures outlined in this practice, will provide a long-term, satisfactory performance according to criteria established for that application. A commentary on factors important in achieving a satisfactory installation is included in the appendix to ASTM D2321.

SPECIAL CONSIDERATIONS

PVC and PP profile wall pipes are constructed with a light-weight material, and designs should be checked for flotation when the pipe is installed below the groundwater level and may not be flowing full.

Hard or sharp objects in the trench adjacent to the pipe should be removed. Where differential conditions of pipe support exist, such as near structures or manholes, a transition support region should be provided to ensure uniform support and avoid development of concentrated shear loading on the pipe.

As with most PVC products, as the temperature approaches or drops below freezing, the flexibility and impact resistance is reduced. Extra care should be used in handling PVC profile wall pipe during cold weather.

USEFUL LIFE

The useful life of a PVC or PP profile wall pipe system is dependent on many factors, including proper installation, stress applied to the pipe, and maintenance. PVC and PP profile wall pipe are corrosion resistant in water pipeline applications. While the useful life of any pipeline system is difficult to predict, lifetimes in storm drainage and sanitary sewer applications of 100 years are not unreasonable.

INDUSTRY GROUPS AND COMMITTEES

Technical committees of ASTM and the Plastics Pipe Institute have developed standards for PVC and PP profile wall pipes and fittings.

REFERENCE MATERIALS

American National Standards Institute (ANSI)/ASCE. (1992). "Standard Guidelines for the Design of Urban Subsurface Drainage." ANSI, Washington, DC; ASCE, Reston, VA.

American Society for Testing and Materials (ASTM). (2011). Practice D2321, "Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications." ASTM, West Conshohocken, PA.

CHAPTER 9

CORRUGATED POLYETHYLENE PIPE

This chapter discusses the use of single wall corrugated polyethylene pipe for use primarily for drainage applications, and to a lesser degree, for conveyance of storm water. For subsurface drainage, the pipe is generally perforated with openings small enough in size to inhibit the surrounding envelope or soil from entering the pipe. In leach fields, the pipe is generally smooth wall with larger perforations.

Corrugated polyethylene pipe has come into use, primarily for land drainage, over the past 30 or 40 years. At first only small diameter pipe was produced. As that became accepted, "large diameter" pipe from 250–450 mm (10–18 in.) diameter was introduced in response to demand by consumers. Over the last 10 to 15 years diameters up to 1,500 mm (60 in.) have been produced.

The corrugations of small diameter pipe are usually concentric, whereas larger diameters may be concentric or spiral wound, depending on the manufacturer.

SPECIFICATIONS AND INDUSTRY STANDARDS

The most common standards used for corrugated polyethylene pipe are

- ASTM F405 Standard Specification for Corrugated Polyethylene (PE) Pipe and Fittings,
- ASTM F667 Standard Specification for Large Diameter Corrugated Polyethylene (PE) Pipe and Fittings,
- NRCS PS 606 Subsurface Drain, and
- NRCS Material Specification 548 Corrugated Polyethylene Tubing.

AVAILABLE SIZES

Corrugated polyethylene pipe is manufactured in sizes 80–1,500 mm (3–60 in.) in diameter.

STANDARD MANUFACTURED LENGTH

The corrugated pipe is extruded in continuous lengths and can be provided in long coils up to 200 mm (8 in.) in diameter or cut to shipping lengths of 4 or 6 m (13 or 20 ft) for diameters of 200 mm (8 in.) or larger.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Gravity flow corrugated polyethylene pipe is not designed to operate under internal pressure heads. Incidental heads of a few feet of water generally will not harm the pipe, but standard design practice is to consider internal pressure to be zero.

EXTERNAL LOAD CAPABILITIES

The external load capacity is highly influenced by the type of backfill installed around the pipe, or in the case of a pipe that is installed by plowing, the type of native soil. Refer to the manufacturers' guidelines for the allowable depth of burial.

Single wall corrugated pipe is subject to stretch during installation and external load capacity drops significantly as the degree of stretch approaches 10 percent. Therefore, specifications should restrict stretch to 5 percent or less. Damage to the corrugations also reduces the external load capacity.

DESCRIPTION OF PIPE MATERIAL

High density polyethylene is a polymer prepared by the polymerization of ethylene as the sole monomer. Properties, such as density, melt index, crystallinity, degree of branching and cross linking, molecular weight, and molecular weight distribution can be regulated over a wide range by varying the catalysts and methods of polymerization.

ASTM D3350 classifies polyethylene pipe and fittings materials using a series of cells that designate material physical properties. Cell class designates, in order: density, melt index, flexural modulus, tensile strength, environmental stress crack resistance, hydrostatic design basis, and color and UV stabilizer. Corrugated pipe has a cell class of 335420 C or E. F-894 profile pipe uses a pressure rated resin that is made to ASTM D3350 specification to ensure long-term performance without cracking, has a cell classification of 334433C, and is listed by the Plastics Pipe Institute (PPI) TR-4.

HDPE is resistant to many abrasive chemicals, such as road salt, motor oils and fuels, and alkaline soils.

PROTECTIVE LININGS AND COATINGS

Polyethylene is a corrosion resistant material and does not require protective coatings. Since UV light is present in sunlight, 2 or 3 percent carbon black is compounded into the material to prevent or delay UV degradation. Long-term storage should provide shelter from sunlight. This protection is often provided by wrapping the pipe in opaque disposable plastic bags.

JOINTS

Joints for corrugated polyethylene pipe are made with bells or couplers that are formed to match the corrugations of the pipe. Couplers are available with or without gaskets. The gaskets limit particle infiltration in fine soils.

FITTINGS

Fittings are made of the same material as the pipe and are available in a wide variety of configurations including reducers, wyes, tees, end caps, and elbows. The fittings are fastened to the pipe using the same methods described in the Joints section.

TAPPING METHODS

Polyethylene pipe is usually tapped by cutting out a section of pipe and replacing it with the desired fitting.

HYDRAULIC RESISTANCE FACTOR

ANSI/ASCE 12-05 Standard Guidelines for the Design of Urban Subsurface Drainage lists the following recommended design values of friction coefficients (Manning's "n") for plastic pipe with corrugations:

75–250 (3–8 in.) mm diameter	0.014–0.016
250–300 mm (10–12 in.) diameter	0.016–0.018
Larger than 300 mm (12 in.)	0.019–0.021

The recommended "n" value for single wall pipe is relatively high owing to the interior corrugations.

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Wave speed is not a factor in low head pipe design.

ALLOWABLE LEAKAGE RATE

Because single wall corrugated polyethylene pipe is not intended for pressure use and is frequently perforated, there is no assigned allowable leakage rate.

REPAIR METHODS

There are several methods to repair joints and damaged pipe sections:

- If sections of the pipe are damaged, the damaged section can be removed and replaced, then new couplers are placed at both ends of the repair.
- Split-band couplers can be installed to repair a damaged section if the damaged area is less than about 10 percent of the pipe diameter.
- If the damaged area is less than 25 percent of the pipe diameter, the areas can be repaired by wrapping the pipe with a geotextile fabric, strutting or bracing the damaged section, then encasing it in a concrete collar.
- Occasionally, the damaged areas can be repaired by use of a mastic material wrapped around the pipe and held in place by a combination of the tacky mastic surface and straps that are tightened after the mastic material is in place.

WATER QUALITY TOLERANCES

Single wall corrugated polyethylene is not subject to corrosion and is suitable for drainage systems and other similar uses.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Single wall corrugated polyethylene pipe should be installed in accordance with ASTM Practice D2321 (Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications). This practice provides recommendations for the installation of buried thermoplastic pipe used in sewers and other gravity flow applications. The recommendations are intended to ensure a stable underground environment for thermoplastic pipe under a wide range of service conditions.

The scope of the practice necessarily excludes product performance criteria, such as minimum pipe stiffness, maximum service deflection, or long-term strength. Thus, it is incumbent upon the product manufacturer, specifier, or project engineer to verify and assure that the pipe specified for an intended application, when installed according to procedures outlined in this practice, will provide a long-term, satisfactory performance according to criteria established for that application. A commentary on factors important in achieving a satisfactory installation is included in the appendix to ASTM D2321.

The structural performance of polyethylene pipe depends on the interaction between the embedment, or backfill envelope, and the pipe and is commonly referred to as soil pipe interaction. The backfill envelope must provide structural and drainage characteristics appropriate for the application. The combination of the type of material and compaction level (standard Proctor density, AASHTO T-99, ASTM D698) determines the overall strength of the backfill envelope.

The width of the trench depends on the diameter, backfill material, and the method of compaction. Trench widths should be no wider than is necessary to place the pipe and install backfill around it. As a practical matter, the trench width is often governed by standard excavator bucket sizes, trench box dimensions, and soil conditions.

SPECIAL CONSIDERATIONS

Polyethylene pipe is a light-weight material and designs should be checked for flotation when the pipe is installed below the groundwater level and may not be flowing full. Hard or sharp objects in the trench adjacent to the pipe should be removed. Filter material or pea gravel is occasionally used around perforated polyethylene pipe to minimize infiltration of soil particles.

USEFUL LIFE

The useful life of a polyethylene pipe system is dependent on many things, including proper installation, stress applied to the pipe, and maintenance. Polyethylene pipe is corrosion resistant in water pipeline applications. While the useful life of any pipeline system is difficult to predict, lifetimes in storm drainage and land drainage of 100 years are not unreasonable.

INDUSTRY GROUPS AND COMMITTEES

Technical committees of ASTM (www.astm.org), PPI, and AASHTO have developed standards for corrugated polyethylene pipe and fittings.

REFERENCE MATERIALS

Corrugated Polyethylene Pipe Association (CPPA). (1997). "Recommended Installation Practices for Corrugated Polyethylene Pipe and Fittings." CPPA, Sweetwater, TN.

Natural Resources Conservation Services (NRCS), (2001). *National Engineering Handbook*, Section 650.1427. NRCS, Washington, DC.

Plastic Pipe Institute (PPI). (2006). TN-37, "Standard Practice for Installation of Annular Corrugated Profile Wall Polyethylene Pipe for Agricultural Drainage or Water Table Control." PPI, Irving, TX.

CHAPTER 10

VITRIFIED CLAY PIPE AND CLAY DRAIN TILE

This chapter discusses the use of vitrified clay pipe for water or sewage conveyance and the use of clay drain tile in general drainage applications. For drainage applications, infiltration is required through joints between pipe sections or through perforations in the pipe or tile.

Vitrified clay pipe is specified where higher field supporting strengths are required. The pipe may have centering lugs in the bell end, or prefabricated joints may be specified. Standard Strength and Extra Strength perforated pipe are available under the same standard specification as pipe for sewer application. Vitrified clay pipe is commonly used in both open cut trench and microtunneling applications.

Clay drain tile is often specified for agricultural drainage, foundation drainage, under drainage, filter fields, leaching fields, and similar subdrainage applications.

SPECIFICATIONS AND INDUSTRY STANDARDS

Separate specifications and testing criteria are available for vitrified clay pipe and clay drain tile.

The following ASTM standards are applicable to vitrified clay pipe:

- ASTM C700 Standard Specification for Vitrified Clay pipe Extra Strength, Standard Strength, and Perforated,
- ASTM C12 Standard Practice for Installing Vitrified Clay pipe Lines (Note: See Appendix X. 1 Installation Criteria for Perforated Vitrified Clay pipe),
- ASTM C301 Standard Test Methods for Vitrified Clay pipe.

- ASTM C425 Standard Specification for Compression Joints for Vitrified Clay pipe and Fittings,
- ASTM C896 Standard Terminology Relating to Clay Products,

The following ASTM standards are applicable to Clay Drain Tile:

- ASTM C4 Standard Specification for Clay Drain Tile and Perforated Drain Tile,
- ASTM C12 Standard Practice for Installing Vitrified Clay pipe Lines, and
- ASTM C896 Standard Terminology Relating to Clay Products.

ASTM standards for vitrified clay pipe and clay drain tile are under the jurisdiction of ASTM Committee C-4 on vitrified clay pipe and are the direct responsibility of Subcommittee C.04.20 on Methods of Test and Specifications.

AVAILABLE SIZES

Vitrified clay pipe manufactured in accordance with ASTM C700 is available from 100–300 mm (4–12 in.) in diameter in 50 mm (2 in.) increments, and from 375–1,050 mm (15–42 inches) in diameter in 75 mm (3 in.) increments.

Clay drain tile manufactured in accordance with ASTM C4 is available in standard strength in 100, 125, 150, 200, 250, 300, and 375 mm (4, 5, 6, 8, 10, 12, and 15 in.) diameter; in extra quality and heavy duty in 100, 125, 150, 200, 250, 300, 350, 375, 400, 450, and 525 mm (4, 5, 6, 8, 10, 12, 14, 15, 16, 18, and 21 in.) diameter, and extra strength in 100, 125, 150, 200, 250, 300, 350, 375, 400, and 450 mm (4, 5, 6, 8, 10, 12, 14, 15, 16 and 18 in.) diameter.

STANDARD MANUFACTURED LENGTH

Vitrified clay pipe manufactured in accordance with ASTM C700 is available in various lengths depending on the pipe diameter and manufacturer. Common lengths for smaller diameters in the 100–300 m (4–12 in.) range are 0.6–1.8 m (2–6 ft) and for larger diameters—larger than 300 mm (12 in.)—are 1.8–3 m (6–10 ft).

Clay drain tile manufactured in accordance with ASTM C4 has a length not less than the diameter in sizes 300–750 mm (12–30 in.). Smaller sizes of clay drain tile are commonly manufactured in 1 ft lengths.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Vitrified clay pipe and clay drain tile are not used as pressure pipe in drainage or wastewater applications.

EXTERNAL LOAD CAPABILITIES

The minimum bearing strengths of vitrified clay pipe are defined in ASTM C700. The field supporting strength is a function of three-edge bearing strength and class of bedding, which is defined in ASTM C12.

Depths of cover in excess of 6 m (20 ft) are not unusual for vitrified clay pipe. The minimum crushing strengths of clay drain tile are defined in ASTM C4. Depths of cover up to 6 ft are not unusual for clay drain tile.

The *Clay Pipe Engineering Manual* published by the National Clay Pipe Institute provides tables for determining the load on pipes based on the diameter, depth of cover, and soil conditions.

DESCRIPTION OF PIPE MATERIAL

Vitrified clay pipe is manufactured from fire clay, shale, surface clay, or a combination of these materials. When formed into pipe and fired to a suitable temperature, the product must meet the minimum strength requirements of ASTM C700. Vitrified clay pipe is pipe made from materials that have been subjected to vitrification, a process that fuses the clay particles into a very hard, inert, glass-like state.

Clay drain tile is also manufactured from fire clay, shale, surface clay, or a combination of these materials. When formed into tile and fired to a suitable temperature, the product must meet the strength requirements of ASTM C4.

PROTECTIVE COATINGS AND LININGS

Both vitrified clay pipe and clay drain tile are a chemically inert material that is resistant to internal and external attack from solvents, acids, alkalis, gases, and others. They do not require a protective coating or lining.

JOINTS

Vitrified clay pipe may be supplied with or without prefabricated compression joints, couplings, or centering lugs in the bell. In past years, some organizations have required that a hot joint compound be poured to seal the joints. Clay drain tile is furnished with butt-ends unless otherwise specified by the purchaser.

FITTINGS

A complete range of fittings and adapters is available for vitrified clay pipe and clay drain tile. Types of fittings and adapters include tees, wyes, elbows, double tees and wyes, reducers, and increasers.

TAPPING METHODS

Generally, fittings should be used for new construction. Vitrified clay pipe may be tapped by the use of diamond core drills and adapters or by cutting out a section of pipe and inserting a fitting with adapters. Connections are generally made to clay drain tile by the use of fittings rather than tapping.

HYDRAULIC RESISTANCE FACTOR

ANSI/ASCE 12-05 Standard Guidelines for the Design of Urban Subsurface Drainage recommends a friction coefficients (Manning's "n") for vitrified clay pipe of between 0.011 and 0.015, depending on the flow deposition of foreign material and the alignment of the pipeline. A value of "n" of 0.013 is commonly used in the design of clay drain tile.

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Because clay pipe is not used as a pressure pipe, wave speed does not apply.

ALLOWABLE LEAKAGE RATE

Vitrified clay pipe fitted with compression joints is tested by air (ASTM C828 Standard Test Method for Low Pressure Air Test of Vitrified Clay pipe Lines) or by water (ASTM C1091 Standard Test Method for Hydrostatic Infiltration and Exfiltration Testing of Vitrified Clay Pipe Lines). Clay drain tiles are not tested for leakage.

REPAIR METHODS

The method used to repair vitrified clay pipe and clay drain tile depends on the type of repair required and the type of joint provided. Couplings may be used to insert fittings. Saddles and repair clamps fitted with straps are also available.

WATER QUALITY TOLERANCES

Because the material used to manufacture vitrified clay pipe and clay drain tile is an inert material, it is not affected by poor water quality. The inert nature of clay pipe allows it to be used for agricultural drains, storm water drains, and sanitary sewers.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

Vitrified clay pipe and clay drain tile should be installed in accordance with the methods described in ASTM C12 Standard Practice for Installing Vitrified Clay Pipe Lines. Four types of bedding and two types of encasement (concrete or crushed stone) are recommended. It is important that the bedding material be true to line and grade to provide uniform and continuous support of the pipe barrel.

SPECIAL CONSIDERATIONS

ASTM C12 mentions extreme care should be exercised in placement and compaction of backfill. It also discusses the use of filter fabric, position of perforations, and other items somewhat unique to clay pipe.

Sections of clay pipe should be checked for out-of-roundness to confirm they are within the specification tolerance. Pipe sections that do not meet the criteria should be rejected, because they are susceptible to breaking the bells during installation.

USEFUL LIFE

Both vitrified clay pipe and clay drain tile are considered to have an extended life span (in the range of 100 years) if properly installed and left undisturbed.

INDUSTRY GROUPS AND COMMITTEES

The ASTM standards, specifications and practices for vitrified clay pipe and clay drain tile are under the jurisdiction of ASTM Committee C4 on clay pipe.

The industry group associated with clay pipe is the National Clay Pipe Institute. The website is ncpi.org. The institute is actively involved in promoting the use of clay pipe by providing engineering guides, design aids, software programs, and technical literature.

REFERENCE MATERIALS

American Society for Testing and Materials (ATSM). (2003). C1091, "Standard Test Method for Hydrostatic Infiltration and Exfiltration Testing of Vitrified Clay Pipe Lines." ATSM, West Coshohocken, PA.

ATSM. (2011). C828, "Standard Test Method for Low Pressure Air Test of Vitrified Clay pipe Lines." ATSM, West Coshohocken, PA.

National Clay Pipe Institute (NCPI). (2006). *Clay Pipe Engineering Manual*. NCPI, Elkhorn, WI.

CHAPTER 11

FIBERGLASS PIPE

This chapter discusses fiberglass pipe. Fiberglass pipe was first used in 1948 and was originally used primarily in the oil and chemical process industries. In the 1960s, fiberglass pipe became more common in the water and sewage markets. Because of its corrosion resistance, the pipe does not require linings, coatings, or cathodic protection.

SPECIFICATIONS AND INDUSTRY STANDARDS

There are several standard covering the manufacturing of fiberglass pipe. They include

- ASTM D3262 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe,
- ASTM D3517 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe,
- ASTM D3754 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe,
- ASTM D4161 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals, and
- AWWA C950 Fiberglass Pressure Pipe.

AVAILABLE SIZES

Fiberglass pipe is available in sizes ranging from 25–3,660 mm (1–144 in.) in diameter. It is available in standard round shape, or in oval, elliptical, arch, and other custom shapes. Some manufacturers do not produce fiberglass pipe in the full range of sizes. For water and wastewater conveyance, the most commonly produced sizes are from 450–2,550 mm (18–102 in.) diameter.

STANDARD MANUFACTURED LENGTH

Lengths of 6 m (20 ft) are common, but other lengths can be fabricated. At least one manufacturer offers special lengths up to 12 m (40 ft).

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

The AWWA C950 standard includes nine pressure classes, which range from 50–450 psi. The pipe is factory tested to twice the rated pressure class. A design factor of 4.0 is used on the initial hydrostatic strength, and a design factor of 1.8 is used for the long-term hoop strength.

EXTERNAL LOAD CAPABILITIES

The AWWA C950 standard includes four stiffness classes: 62, 124, 248, and 496 kPa (9, 18, 36, and 72 psi). The external load capability is a function of the pipe class, the material surrounding the pipe, and the degree of compaction. The recommended method to determine the external load capability is described in AWWA Manual M45 Fiberglass Pipe Design and ASTM D3839 Standard Guide for Underground Installation of Fiberglass (Glass-Fiber Reinforced Thermosetting-Resin) Pipe.

DESCRIPTION OF PIPE MATERIAL

Fiberglass pipe is manufactured from glass fiber reinforcements embedded in, or surrounded by, cured thermosetting resin. The composite structure may contain fillers, certain agents, and pigments. Depending on the materials used to manufacture the pipe, it has been referred to as fiberglass reinforced polymer mortar pipe, reinforced thermosetting resin pipe, and others.

PROTECTIVE COATINGS AND LININGS

Resistance to corrosive soils, water, and wastewater is one of the advantages of fiberglass pipe. No protective coatings and linings are necessary.

JOINTS

Several types of joints are available for fiberglass pipe. The most common types include fiberglass couplings, bell and spigot joints, mechanical coupling joints, and wrapped joints. Joints with a rubber gasket can be furnished with one gasket or two. Restrained joints using a key system are available. For microtunneling or slip-lining applications, a flush joint should be used. For connections to valves or other types of pipe, a flanged joint can be furnished.

FITTINGS

Fittings and specials for fiberglass pipe are available in a wide range of configurations. Fittings and specials are typically manufactured by compression molding, contact molding, filament winding, and cutting and mitering. Fittings and specials include elbows, wyes, tees, and reducers. Pipe outside diameters match ductile iron dimensions, so standard saddles, taps, fittings, couplings, clamps, joints, and others are compatible and readily available.

TAPPING METHODS

Outlets or nozzles may be added to an existing pipe or fitting using cutting and lamination techniques. These items also may be incorporated by other means. In nonpressure systems, laterals are frequently connected using special fittings or expandable boot accessories. Taps on pressure lines can be accomplished using 360° tapping sleeves.

HYDRAULIC LOSS FACTORS

For pipes flowing full, AWWA Manual M45 recommends use of a Hazen Williams "C" coefficient of 150 for fiberglass pipe. For gravity flow applications where the pipe may be flowing partially full, AWWA Manual M45 recommends use of a Manning roughness coefficient "n" of 0.009 for fiberglass pipe.

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

The wave speed for fiberglass pipe is a function of the modulus of elasticity of the pipe wall, the pipe diameter, and the wall thickness.

AWWA Manual M45 includes a section describing the formula for computing the wave velocity and includes example calculations.

ALLOWABLE LEAKAGE RATE

Neither the AWWA Manual M45 nor the ASTM D3839 standard includes a recommended allowable leakage rate. Properly installed fiberglass pipe and joints will have no leakage. In order to allow some tolerance for air trapped in the pipe system, a formula for allowable leakage commonly used in specifications for fiberglass pipe in metric units is

$$Q = \frac{LD\sqrt{P}}{795{,}000} \tag{11-1}$$

where:
Q = allowable leakage in L/h
L = length of pipe being tested in m
D = pipe nominal diameter in mm
P = average test pressure in kPa

Equivalent equation in U.S. customary units is

$$Q = \frac{LD\sqrt{P}}{148{,}000} \tag{11-2}$$

where:
Q = allowable leakage in gal./h
L = length of pipe being tested in ft
D = pipe nominal diameter in in.
P = average test pressure in psi

REPAIR METHODS

Typically, fiberglass pipe with minor damage can be repaired at the job site. Pipe that is significantly damaged should be replaced. The pipe manufacturer should be consulted for guidance before beginning repair work, particularly for pressure pipe. Repair techniques include patching of small areas using factory-supplied materials (typically a resin, catalyst, and glass mat), use of repair clamps, and use of flexible steel couplings.

Damaged pipe ends may be simply cut off and the pipes assembled using couplings or special closure pieces. For damage away from the ends, a segment containing the affected area may be cut from the pipe and the remaining sections joined with couplings or special closure pieces.

WATER QUALITY TOLERANCES

Fiberglass pipe is resistant to corrosion resulting from minerals and substances commonly found in water and wastewater.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

AWWA Manual M45 describes the best practices for shipping, handling, storing, and installing fiberglass pipe. When the pipe will be stored outdoors for long periods of time, consult with the manufacturer to determine if any precautions are necessary. As with any flexible pipe, proper backfilling of the trench, and particularly the area under the pipe haunches, is extremely important.

The maximum particle size for the pipe embedment zone should be limited to avoid damage to the pipe. AWWA Manual M45 suggests a rule of limiting the maximum particle size to no more than three times the pipe wall thickness. Pipe manufacturers should be consulted for specific recommendations.

When a fiberglass pipe is used for microtunneling or slip-lining applications, the maximum safe jacking load must be considered. Various pipe manufacturers publish data identifying the recommended safe jacking loads.

SPECIAL CONSIDERATIONS

If a fiberglass pipe will be subject to unusual installation or service conditions, special consideration should be given to the design. These conditions include

- Broad temperature fluctuations (not common for a buried pipe),
- Elevated temperature service (not common with pipes used for water conveyance, wastewater conveyance, and drainage),
- Shallow burial depth (less than 1.2 m [4 ft] of cover),
- Uneven bending or differential settlement because of unstable soil conditions,
- Narrow trenches to tight spaces where adequate placement and compaction of backfill is difficult,
- Unusually high construction loads, and

- Aboveground installations (AWWA Manual M45 includes a chapter on aboveground installation and the unique design considerations).

USEFUL LIFE

Fiberglass piping systems are not susceptible to attack from chemicals found in typical water and sewer systems. Once the pipe has been installed underground in normal water and sewer systems, it is not susceptible to the normal processes of deterioration found in nature. Fiberglass pipe has not been in use long enough to definitively determine a useful life, but field research would indicate a life expectancy greater than 100 years.

INDUSTRY GROUPS AND COMMITTEES

Industry groups include the Fiberglass Tank and Pipe Institute. Technical committees include the AWWA Standards Committee on Thermosetting Fiberglass Reinforced Plastic Pipe.

REFERENCE MATERIALS

American Society for Testing and Materials (ASTM). (2008). D3839, "Standard Guide for Underground Installation of Fiberglass (Glass-Fiber Reinforced Thermosetting-Resin) Pipe." ASTM¸ West Conshocken, PA.

American Water Works Association (AWWA). (2005). Manual M45 *Fiberglass Pipe Design*. AWWA, Denver, CO.

ASCE. (2007) Manuals and Reports on Engineering Practice No. 60, "Gravity Sanitary Sewer—Design and Construction." ASCE, Reston, VA.

Fowles, D. T. (1992). "Pressure Pipeline Design for Water and Wastewater," ASCE, New York.

CHAPTER 12
CORRUGATED METAL PIPE

This chapter discusses the use of corrugated metal pipe. Both steel and aluminum materials are used to manufacture corrugated metal pipe.

SPECIFICATIONS AND INDUSTRY STANDARDS

The most common specification used for corrugated steel metal pipe associated with water conveyance projects is ASTM A760 Standard Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains. This specification has also been adopted by the American Association of State Highway and Transportation Officials as AASHTO M36.

Design of corrugated steel metal pipe products is covered by ASTM A796 Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications.

The most common specification used for corrugated aluminum pipe is ASTM B745 Specification for Corrugated Aluminum Pipe for Sewers and Drains. The material specification most commonly used for corrugated aluminum pipe is AASHTO M197 Aluminum Alloy Sheet for Corrugated Metal Pipe. This material is also covered in AASHTO M196. Design of corrugated aluminum pipe is covered by ASTM B790 Structural Design of Corrugated Aluminum Pipe, Pipe Arches, and Arches for Culverts, Storm Drain, and other Buried Conduits.

The USDA's Natural Resource Conservation Service (NRCS) also has specifications for corrugated metal pipe. Material Specification 551 describes requirements for coated, corrugated steel pipe, and Material Specification 552 describes requirements for aluminum corrugated pipe.

AVAILABLE SIZES

Corrugated metal pipe is available in diameters 150–3,660 mm (6–144 in.). Common uses for circular corrugated metal pipe include culverts, low head water conveyance, sewers, and drainage pipe. In addition to circular shapes, corrugated conduits are available in pipe-arch shapes.

STANDARD MANUFACTURED LENGTH

Standard manufacturing length for corrugated metal pipe is 6 m (20 ft), although lengths of up to 12 m (40 ft) are available in most sizes.

ALLOWABLE INTERNAL PRESSURE AND FACTORS OF SAFETY

Corrugated metal pipe is not generally used as a pressure pipe, hence, no allowable internal pressure or factor of safety have been established. Standard pipe is capable of withstanding a meter or so of head (about 3 ft), provided the joints are installed with gaskets. Welded seam, helical corrugated steel pipe is occasionally used for low-pressure conduits in irrigation and other applications. Joints must be compatible with the pressure requirements.

EXTERNAL LOAD CAPABILITIES

The shape of corrugated metal pipe allows it to withstand significant external loads. The safe load depends on the diameter, material thickness, and size of corrugations. Tables showing the safe loads are available in several references. External earth loads of over 30.5 m (100 ft) are possible.

DESCRIPTION OF PIPE MATERIAL

Two materials are commonly used to manufacture corrugated metal pipe: steel and aluminum. Zinc coated steel sheets and coils are specified in AASHTO M218 and ASTM A444. Aluminum coated coils are specified in AASHTO M274 and ASTM A819. Several other coatings for steel pipe with separate AASHTO and ASTM specifications are available. Corrugated aluminum pipe is typically produced from the Alclad 3004-H34 alloy.

Several types of corrugations are used for pipe products. The corrugations are described by pitch, depth, and inside forming radius. Pitch is measured at right angles to the corrugations from crest to crest. Corrugated steel pipe with circumferential (annular) seams commonly has corrugations with a pitch of 67.8 mm × 1.5 mm depth and 75 mm × 25 mm (a pitch of 2.67 in. × ½ in. depth and 3 in. × 1 in.). Corrugations with a pitch up to 375 mm × 139.7 mm depth and 75 mm radius (a pitch up to 15 in. × 5.5 in. depth and 3 in. radius) are available in larger diameter sizes. The corrugations and seams for lock seam pipe run helically (or spirally) around the pipe. Corrugations for lock seam pipe above 300 mm (12 in.) diameter generally vary from 50 mm × 12.5 mm depth to 125 mm × 25 mm depth (2 in. × ½ in. depth to 5 in. × 1 in. depth).

Corrugated aluminum pipe is available as helical pipe, riveted pipe, or perforated pipe. Corrugations for helical pipe are available in either the 37.5 mm × 6.25 mm, 67.8 mm × 12.5 mm, 75 mm × 25 mm, or 150 mm × 25 mm sizes (1.5 in. × ¼ in., 2.67 in. × ½ in., 3 in. × 1 in., or 6 in. × 1 in. sizes). Corrugations for riveted aluminum pipe are available in 67.8 mm × 12.5 mm, 75 mm × 25 mm, or 150 mm × 25 mm (2.67 in. × ½ in., 3 in. × 1 in., or 6 in. × 1 in.). Perforated pipe using either 67.8 mm × 12.5 mm or 75 mm × 25 mm (2.67 in. × ½ in. or 3 in. × 1 in.) corrugation is also available for drainage applications.

A unique corrugation is used with spiral rib pipe. The corrugations are rectangularly formed ribs between flat wall areas. This pipe was developed to provide smoother flow characteristics. Two profile configurations are commonly used: 18.75 mm × 18.75 mm × 190.5 mm and 18.75 mm × 25 mm × 292.1 mm (¾ in. × ¾ in. × 7.5 in. and ¾ in. × 1 in. × 11.5 in.).

Common material thicknesses range from 1.016–4.267 mm (0.040–0.168 in.) for helical corrugations. Thicknesses up to 9.652 mm (0.380 in.) are available for larger diameter pipe with annular corrugations.

PROTECTIVE LININGS AND COATINGS

Several protective coatings and linings are available for steel corrugated metal pipe. They include zinc coating, polymer coating, aluminum coating, asphalt coating, and cold applied bituminous coatings.

JOINTS

The most common type of joint is a metal coupling band. The band is drawn and secured on the pipe by bolts or wedges. Gaskets can be used to minimize leakage. Three types of gaskets are commonly used: o-ring type, sleeve type, or mastic type. Flanged joints and other specialized joint types are available.

FITTINGS

Standard fittings are available including bends, elbows, crosses, tees, reducers, laterals, and wyes. Fittings for other applications can be shop fabricated.

TAPPING METHODS

Saddle branches can be used to connect small branch lines to corrugated metal pipe. The saddle branches can be installed after the pipe is placed or can be factory installed. A universal type of saddle branch is available to connect corrugated metal pipe to any other type of pipe. The adjoining pipe is placed inside the branch and mastic is used to make the connection water tight.

HYDRAULIC RESISTANCE FACTOR

The most commonly used hydraulic resistance formula for corrugated metal pipe is the Manning formula. The coefficient of roughness ("n" value) depends on the pipe diameter, size of corrugations, and type of lining. Recommended values vary from 0.011–0.027.

ANSI/ASCE 12-05 Standard Guidelines for the Design of Urban Subsurface Drainage lists the following recommended design values for the friction coefficient Manning's "n":

Plain annular	0.022–0.027
Plain helical	0.011–0.023
Paved invert	0.018–0.022
Spun asphalt lined	0.011–0.015
Spiral rib metal pipe (smooth)	0.012–0.015

WAVE SPEED (HYDRAULIC TRANSIENT STUDIES)

Because corrugated metal pipe is typically not used for pressure applications, wave speeds have not been developed.

ALLOWABLE LEAKAGE RATE

Because corrugated metal pipe is typically used for water conveyance applications with low head or a free water surface, an allowable leakage rate does not generally apply. If the pipe will be used in a pressure application, the type of joint and gasket must be selected to meet the project's specified leakage requirements.

REPAIR METHODS

Banded joints are normally repaired by replacing or tightening the band. Repair of damaged sections not adjacent to joints can be made by the use of couplings.

If a corrugated metal pipe has deteriorated, repair is possible by a number of methods including slip lining with a smaller diameter pipe, cured-in-place lining of the pipe using an inversion method, shotcrete lining, and cement mortar lining.

WATER QUALITY TOLERANCES

According to the American Iron and Steel Institute, there is little difference in the durability of steel in still, natural waters in the pH range of 4.5–9.5. However, moving water increases the level of dissolved gases. Increasing levels of dissolved oxygen and carbon dioxide can accelerate corrosion. Dissolved salts can increase durability by decreasing oxygen solubility but can increase corrosion if they ionize and decrease resistivity. The portion of the pipe most susceptible to corrosion is the invert. With proper linings and coatings, water quality tolerance concerns can be minimized. Abrasion caused by sediment-laden water can be minimized by applying a bituminous paving to the bottom 25 percent of the circumference.

Aluminum has good corrosion resistance, primarily owing to the thin oxide film that forms on the surface when exposed to air. If the film is damaged, a new layer of film will form. The film has a grayish-white color and gives the pipe a tendency to "self-heal." The Aluminum Association provides the following recommendations to minimize corrosion concerns:

- Soil and water pH should be between 4 and 9.
- Soil and water resistivities should be 500 ohm-cm or greater.
- There should be no dissimilar metals bonded to pipes.

- Clay-muck backfill materials should be avoided if they contain organic materials.
- The pipe should be isolated from stray electrical currents.

INSTALLATION, BACKFILL, AND PROTECTIVE REQUIREMENTS

As with any pipe product, proper base preparation is essential. The bedding requirements for pipe arches are unique. The bedding should be shaped to the approximate contour of the pipe. Corrugated metal pipe installed under fills may need to be installed with a camber (i.e., the section where settlement is anticipated will be installed at a higher elevation) to allow for future settlement. The preferred backfill is a granular material, although cohesive materials can be used if careful attention is given to moisture content and proper compaction. The minimum recommended cover for most pipes is 30 cm (12 in.). In the case of structural plate pipes, a common recommendation for minimum cover is the span divided by 8 or 45 cm (18 in.) whichever is greater.

SPECIAL CONSIDERATIONS

Corrugated metal pipe can be used to span ravines or streams. Tables showing safe spans for various pipe sizes, wall thickness, and corrugation types are included in most reference handbooks for corrugated metal pipe.

Various end treatments are available for corrugated metal pipe used as culverts. The end treatment design must consider unbalanced soil loads because of skewed installations and consider hydraulic action owing to flow forces.

Pipes with circumferential seams should be installed with the inside sheet laps pointing downstream. Joints should be designed with several considerations in mind: shear strength requirements, moment requirements, tensile strength, necessary joint overlap, necessary soil tightness, and necessary water tightness.

The relatively light weight of aluminum products makes them easier to handle, load, unload, and place in the trench.

USEFUL LIFE

Several studies regarding durability of corrugated metal pipe have been performed by various state and industry groups, generally with respect to culverts. The studies include a comparison of numerous types of protective coatings and linings. The useful life is highly dependent on the soil conditions and coating products used. Additional information regarding the useful life of corrugated metal pipe is available in the references listed in a subsequent section.

INDUSTRY GROUPS AND COMMITTEES

ASTM A05.17 and B07.08 have technical committees that deal with the design and installation of corrugated steel and aluminum pipe.

Industry groups involved with corrugated metal pipe include the American Iron and Steel Institute, the National Corrugated Steel Pipe Association, and the Aluminum Association.

REFERENCE MATERIALS

Aluminum Association. (1983). AA67, *Aluminum Drainage Products Manual*. Aluminum Association, Arlington, VA.

Corrugated Steel Pipe Institute (CSPI). (2007). *Handbook of Steel Drainage and Highway Construction Products*. CSPI, Cambridge, ON.

National Corrugated Steel Pipe Association (NCSPA). (2011). *Installation Manual for Corrugated Steel Drainage Structures*. NCSPA, Washington, DC.

CHAPTER 13

RESOURCE DIRECTORY

This chapter includes a listing of organizations associated with pipeline products. The listing includes the organization name, address, phone number, and web address. Several of the organizations (ASABE, ASCE, AWWA, ASTM, and NACE for example) provide general information and publications relating to numerous pipeline products. Other organizations promote only one type of pipe and have information available relating to the application, design, installation, and maintenance of pipeline systems.

ORGANIZATIONS AND AGENCIES

Organizations and agencies with useful information and publications include the following:

Aluminum Association, 1525 Wilson Blvd., Suite 600, Arlington, VA 22209. Phone: (703) 358-2960. www.aluminum.org

American Association of State Highway Transportation Officials (AASHTO), 444 North Capitol St. NW, Suite 249, Washington, DC 20001. Phone: (202) 624-5800. www. info@aashto.org

American Concrete Pipe Association (ACPA), 222 W. Las Colinas Blvd., Suite 641, Irving, TX 75039-5423. Phone: (972) 506-7216. www.concrete-pipe.org

American Concrete Pressure Pipe Association (ACPPA), 11800 Sunrise Valley Dr., Suite 309, Reston, VA 20191. Phone: (703) 391-9135. www.acppa.org

American Iron and Steel Institute, 1101 17th St. NW, Suite 1300, Washington, DC 20036-4700. Phone: (202) 452-7100. www.steel.org

American National Standards Institute (ANSI), 1899 L St., NW, 11th Floor, Washington, DC 20036. Phone: (202) 293-8020. www.ansi.org

American Society for Testing and Materials (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959. Phone: (610) 832-9585. www.astm.org

American Society of Agricultural and Biological Engineers (ASABE), 2950 Niles Road, St. Joseph, MI 49805-9659. Phone: (616) 429-0300. www.asabe.org

American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191-4400. Phone: (800) 548-2723. www.asce.org

American Society of Mechanical Engineers (ASME), 3 Park Ave., New York, NY 10016-5990, Phone: 800-843-2763. www.asme.org

American Water Works Association (AWWA), 6666 West Quincy Ave., Denver, CO 80235. Phone: (303) 794-7711. www.awwa.org

Corrugated Polyethylene Pipe Association, A Division of the Plastics Pipe Institute, 105 Decker Ct., Suite 825, Irving, TX 75062. Phone: (469) 499-1044. www.plasticpipe.org

Corrugated Steel Pipe Institute, 652 Bishop St. North, Unit 2A, Cambridge, ON N3H 4V6. Phone: (519) 650-8080. www.cspi.ca

Ductile Iron Pipe Research Association (DIPRA), 245 Riverchase Pkwy, East, Suite O, Birmingham, AL 35244. Phone: (205) 988-9870. www.dipra.com

Fiberglass Tank and Pipe Institute, 11150 S. Wildcrest Dr., Suite 101, Houston, TX 77099-4343. Phone: (281) 568-4100. www.fiberglasstankandpipe.com

NACE International (formerly National Association of Corrosion Engineers), 1440 South Creek Dr, Houston, TX 77084-4906. Phone: (281) 228-6200. www.nace.org

National Clay Pipe Institute, PO Box 759, Lake Geneva, WI 53147. Phone: (262) 248-9094. www.ncpi.org

National Corrugated Steel Pipe Association, 1255 Twenty-Third Street, NW, Washington, DC 20037-1174. Phone: (202) 452-1700. www.ncspa.org

Natural Resource Conservation Service (formerly Soil Conservation Service), Central National Technology Support Center, 501W. Felix St., FWFC, Bldg. 23, Fort Worth, TX 76115. Phone: (817) 509-3302. www.nrcs.usda.gov

North American Society for Trenchless Technology (NASTT), 7445 Morgan Road, Liverpool, NY 13090. Phone: (703) 351-5252. www.nastt.org

Plastic Pipe and Fittings Association, Building C, Suite 20, 800 Roosevelt Road, Glen Ellyn, IL 60137. Phone: (630) 858-6540. www.ppfahome.org

Plastics Pipe Institute (PPI), 105 Decker Ct., Suite 825, Irving, TX 75062. Phone: (469) 499-1044. www.plasticpipe.org

Steel Plate Fabricators Association, 11315 Reed Hartman Hwy., Suite 104, Cincinnati, OH 45241. Phone: (513) 469-0500. www.spfa.org

Uni-Bell PVC Pipe Association, 2655 Villa Creek Dr., Suite 155, Dallas, TX 75234. Phone: (972) 243-3902. www.uni-bell.org

USEFUL PUBLICATIONS

Useful publications for the pipeline industry include the following:

- **American Water Works Association**, Opflow Online, www.awwa.org/publications
- **Municipal Sewer and Water Magazine**, www.mswmag.com
- **No Dig Newsletter**, www.no-dig-construction.com
- **Public Works Magazine**, www.pwmag.com
- **Stormwater Journal**, www.stormh2o.com
- **Trenchless Technology Magazine**, www.trenchlessonline.com
- **Water Efficiency Magazine**, www.water efficiency.net
- **Water World Magazine and Newsletter**, www.waterworld.com

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