



Pipelines

for Water Conveyance and Drainage



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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

Edited by
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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).

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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 web-site 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 pipes.

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 manufacture 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.

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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.



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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.



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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 surcharges.

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.
- ACI. (1990). “Recommendations for Cast-In-place Non-reinforced Concrete Pipe.” Farmington Hills, MI, ACI.
- American Concrete Pipe Association (ACPA). (1980). *Concrete Pipe Handbook*. Irving, TX, ACPA.
- ACPA. (2011). *Concrete Pipe Design Manual*. Irving, TX, ACPA.
- American Water Works Association (AWWA). (2008). *Manual M9, Concrete Pressure Pipe*. Denver, CO, AWWA.

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

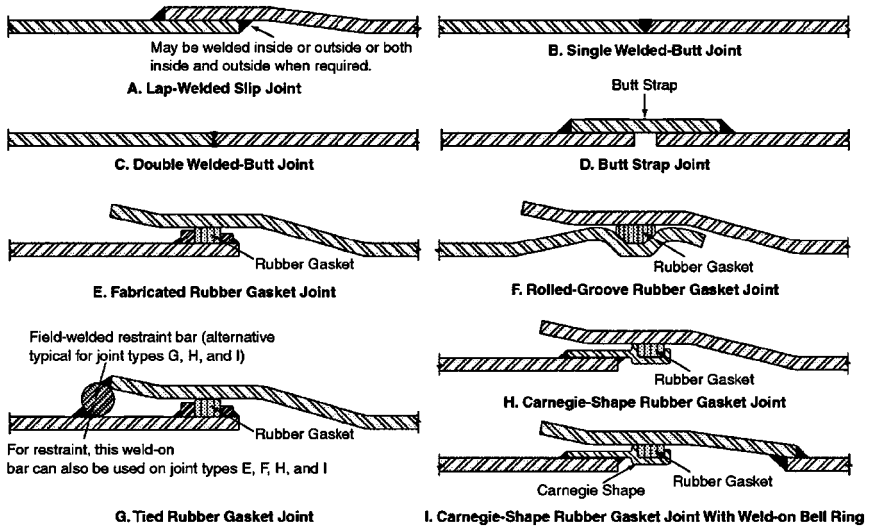


Fig. 3-1. Welded and Rubber-Gasketed Field Joints

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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

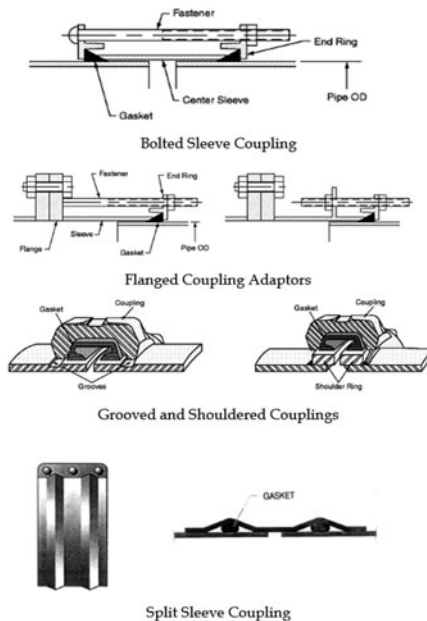


Fig. 3-2. Coupled Joints

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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

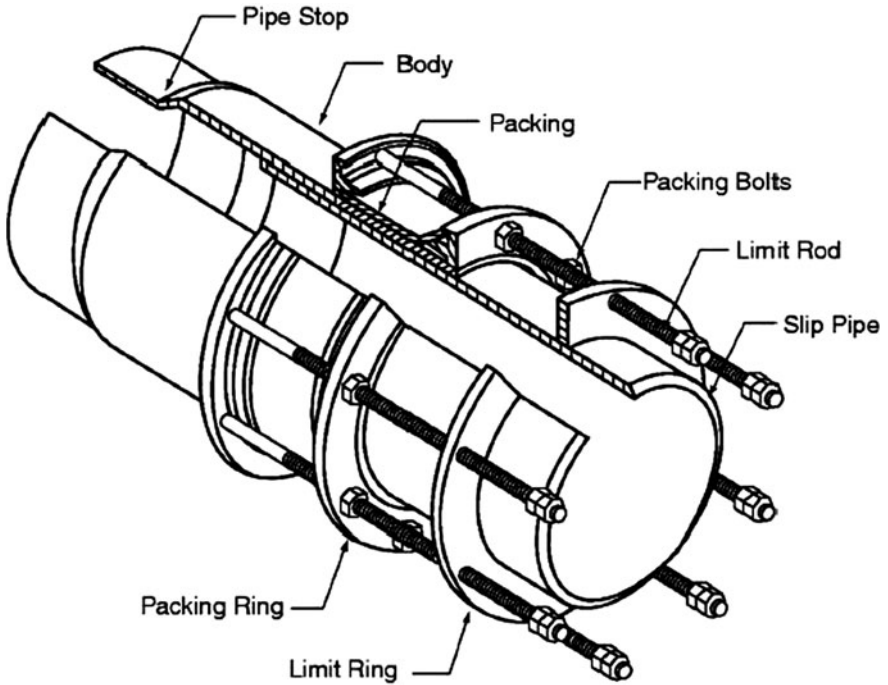


Fig. 3-3. Expansion Joint

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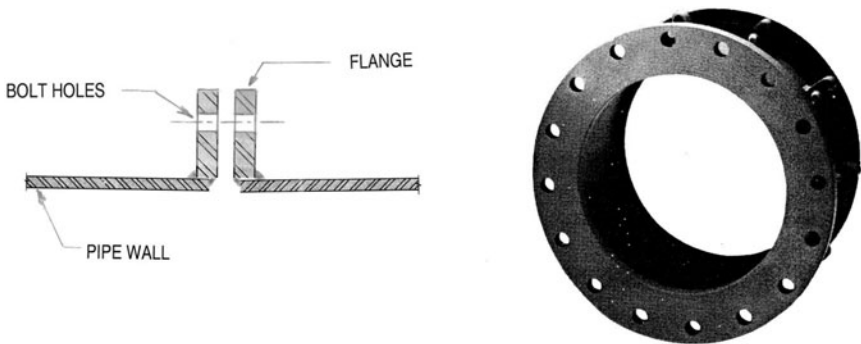


Fig. 3-4. Flanged Joint

$$C = 140 + 0.0067d \quad (3-1)$$

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

Equivalent form in U.S. customary units is

$$C = 140 + 0.17d \quad (3-2)$$

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

$$C = 130 + 0.0063d \quad (3-3)$$

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

Equivalent form in U.S. customary units is

$$C = 130 + 0.16d \quad (3-4)$$

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.

