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.

American Water Works Association (AWWA). (2003). Manual M23, *PVC Pipe—Design and Installation*. AWWA, Denver, CO.

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

Natural Resources Conservation Service (NRCS). (2011). Conservation Practice Standard, Code 430, "Irrigation Water Conveyance Pipeline." NRCS, Washington, DC.

Uni-Bell PVC Pipe Association. (1980). "The Effects of Ultraviolet Aging on PVC Pipe." PVC Pipe Association, Dallas, TX.

Uni-Bell PVC Pipe Association. (2012). *Handbook of PVC Pipe: Design and Construction*. PVC Pipe Association, Dallas, TX.

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.