United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 636 Structural Engineering
National Engineering Handbook

Chapter 52 Structural Design of Flexible Conduits

(210-VI-NEH, First Edition, June 2005)

Issued June 2005

Preface

Flexible conduits used on NRCS projects typically consist of corrugated metal pipe (CMP), various types of plastic pipe, steel pipe, or ductile iron pipe. The design of these conduits was completed by allowable fill height tables in various Conservation Practice Standards, guidance given in TR 77—Design and Installation of Flexible Conduits and the associated computer program, and multiple technical notes developed by NRCS staff.

NEH 636 chapter 52 updates the design procedure to current industry and government agency practice. Although symbols for conduit (pipe) design vary among types of materials and industry guidance, those used in chapter 52 are consistent within the document (see appendix 52A). Appendix 52B contains several design examples that were developed using the formulas and information in this chapter. A glossary of terms used within this chapter is included following the references and prior to the appendices.

Acknowledgments

The technical guidance in this document is a compilation of flexible conduit design guidance from the American Society of Testing Materials (ASTM), American Association of State Highway Transportation Officials (AASHTO), other Federal agencies, trade organizations, pipe manufacturers, and other text. This version was prepared by **Wade Anderson**, design engineer, National Design, Construction, and Soil Mechanics Center, Natural Resources Conservation Service (NRCS), Fort Worth, Texas.

Valuable review was provided by the following NRCS engineers:
Arvil Bass, Stillwater, Oklahoma
Benjamin Doerge, Fort Worth, Texas
Steve Durgin, Spokane, Washington
Andy Feher, Morgantown, West Virginia
Don Gilmore, Temple, Texas
Richard Koenig, Columbia, Missouri
Brian Lang, Salina, Kansas
Raymond Marine, Lakewood, Colorado
Jimmy Moore, Little Rock, Arkansas
Merlin Nelson, Bozeman, Montana
Chuck Schmitt, Casper, Wyoming
Lee White, Des Moines, Iowa
Rodney Yeoman, Columbus, Ohio

Valuable review was also provided by the following industry representatives:
Dan Edwards, National Corrugated Steel Pipe Association, Dallas, Texas
Dr. Glen Palermo, Plastic Pipe Institute, Washington, DC
Jeffrey Rash, Ductile Iron Pipe Research Association, Tyler, Texas

Guidance and direction in development of this document was provided by **William Irwin**, NRCS, Washington, DC, and **Lamont Robbins**, NRCS, Fort Worth, Texas.

Special thanks also to National Cartography and Geospatial Center's Technical Publishing Team members: **Mary Mattinson,** for her guidance and editing, **Suzi Self** for her desktop publishing, review, and editing, and **Wendy Pierce** for the graphic illustrations.

Chapter 52 Structural Design of Flexible Conduits

Contents:

Tables

Appendix 52–C

Chapter 52 Structural Design of Flexible Conduits

636.5200 Introduction

Pipe materials are generally considered to be rigid or flexible. A flexible pipe is one that will deflect at least 2 percent without structural distress (fig. 52–1). Materials that do not meet this criterion are generally considered rigid. Some pipe materials are described as semi-rigid based on their behavior and design procedures.

A flexible conduit derives its external load capacity from its flexibility. Under load, the pipe tends to deflect, developing soil support at the sides of the pipe. The ring deflection (fig. 52–1) relieves the pipe of the major portion of the vertical soil load, which is then transferred to the soil surrounding the pipe through the soil arching action over the pipe.

Flexible pipe materials consist of smooth-wall steel pipe, corrugated spiral rib or composite ribbed metal pipe (fig. 52–2), ductile iron pipe, and solid-wall, corrugated-wall, or profile-wall thermoplastic pipe (PVC, ABS, or PE) (fig. 52–3). Appendix 52B has design examples for various types of flexible pipes.

Figure 52–1 Deflected pipe

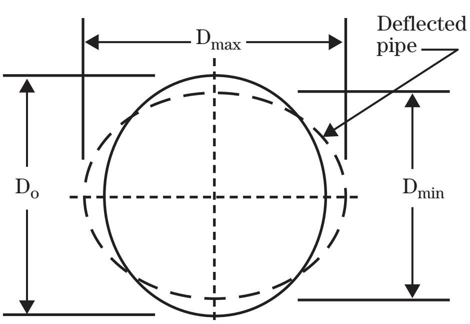


Figure 52–2 Corrugated metal pipe wall sections

636.5201 Internal pressure design

Conduits used in pressure applications must withstand the internal working pressure. The internal pressure is resisted by tensile stress (hoop stress) in the conduit wall (fig. 52–4).

Figure 52–3 Plastic pipe sections

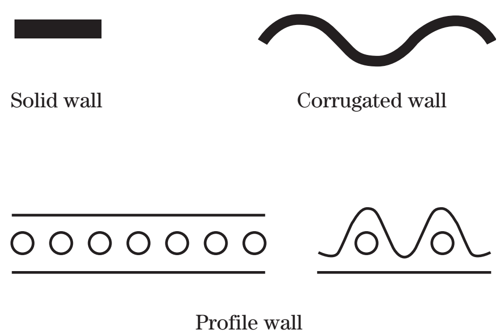
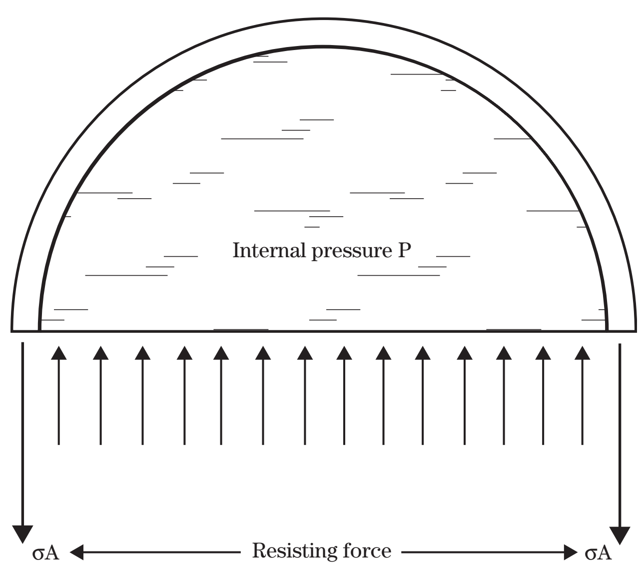


Figure 52–4 Internal pressure



(a) Plastic pipe

The internal pressure capacity of plastic pipe is given as a pressure rating for plastic pipe manufactured in accordance with ASTM standards and as a pressure class for pipe meeting AWWA standards.

The pressure capacity is time dependent and should be considered in the design of a pressure pipe system. The long-term strength (hydrostatic design basis) of plastic pipe governs the pressure capacity design; yet, plastic pipe is capable of withstanding higher short-term surge pressures.

The pressure rating or pressure class for solid-wall plastic pipe may be determined by one of the following formulas:

Outside diameter controlled pipe:

$$PC = PR = \frac{2 \times HDS}{SDR - 1} \qquad (52\text{–}1)$$

Inside diameter controlled pipe:

$$PC = PR = \frac{2 \times HDS}{SIDR + 1} \qquad (52\text{–}2)$$

AWWA C900 pressure class pipe:

$$PC = \frac{2 \times HDS}{SDR - 1} - P_{surge} \qquad (52\text{–}3)$$

where:
PR = pressure rating, lb/in^2
PC = pressure class, lb/in^2
P_{surge} = surge pressure based on an instantaneous velocity change of 2 ft/s, lb/in^2
HDS = hydrostatic design stress, lb/in^2
HDS = HDB/FS
HDB = hydrostatic design basis, lb/in^2
FS = factor of safety
= 2.5 (AWWA C900 pipe)
= 2.0 (all others)
SDR = D_o dimension ratio
SDR = D_o/t
D_o = pipe outside diameter, in
t = minimum wall thickness, in
SIDR = D_i dimension ratio
SIDR = D_i/t
D_i = pipe inside diameter, in

Pressure ratings or pressure class and pertinent dimensions for various plastic pipe materials are provided in appendix 52C. A complete description of HDB and HDS is available in ASTM D 2837.

The maximum design pressure for systems designed without a water hammer analysis should be limited to 72 percent of the pressure rating or pressure class of the pipe (ASAE, 1998, and ASTM 1176, 1993).

For plastic pipe systems subject to recurring or cyclic surge pressures, as described in 636.5202, the operating pressure plus the cyclic surge pressure should not exceed the pressure rating or pressure class of the pipe. If the number of cycles expected throughout the design life of the project is determined, design criteria using the short-term pressure rating and the number of cycles to failure found in Uni-Bell (2001) or recommended by the manufacturer may be used in selection of the pipe.

For occasional or infrequent pressure surges, as described in 636.5202, plastic pipe provides a higher short-term hoop strength. The pressure that corresponds to this elevated hoop stress is referred to as the quick-burst pressure or short-term strength (STS). A short-term pressure rating may be determined from the following equation:

$$STR = \frac{STS}{FS} \qquad (52\text{–}4)$$

where:
STR = short-term pressure rating, lb/in^2
STS = short-term strength (quick burst pressure), lb/in^2

$$= \frac{2 \times STHS}{SDR - 1}$$ (for outside diameter contı

$$= \frac{2 \times STHS}{SIDR + 1}$$ (for inside diameter contro

where:
STHS = short-term hoop strength, lb/in^2 (see appendix 52C)
SDR = D_o dimension ratio
SIDR = D_i dimension ratio
FS = 2.5 (AWWA C900 pipe)
= 2.0 (all others)

The design operating pressure plus the infrequent surge pressure should not exceed the short-term pressure rating.

Corrugated plastic pipe and profile wall plastic pipe are often not pressure rated. Because of the limited allowable pressure for watertight joints of corrugated or profile wall plastic pipe, the maximum allowable pressure shall be 10.8 pounds per square inch (lb/in^2) (25 feet).

The HDB is typically determined in a water environment of approximately 73 degrees Fahrenheit. As the operating temperature falls below 73 degrees Fahrenheit, the pressure capacity of plastic pipe increases. As the temperature of the environment or fluid increases, the pipe becomes more ductile. The pressure rating should be decreased by the factors shown in table 52–1 or by using the HDB determined by ASTM D 2837 at the desired elevated temperature in the pressure rating (or pressure class) calculations.

Table 52–1 Temperature factors

Temperature °F	PVC factor	ABS factor	PE factor
73.4	1.00	1.00	1.00
80	0.88	0.94	0.92
90	0.75	0.84	0.81
100	0.62	0.68	0.70
110	0.50	0.56	0.65
120	0.40	0.49	0.60
130	0.30	0.44	0.55
140	0.22	0.40	0.50

Source: Uni-Bell, 2001; ASTM 1176, 1993; and Plastic Pipe Institute, 2003

(b) Smooth wall steel and aluminum pipe

The pressure rating for steel and aluminum pipe shall be determined by the following formula:

$$PR = \frac{2 \times S \times t}{D_o} \qquad (52\text{–}5)$$

where:

PR = pressure rating, lb/in^2
S = allowable stress, lb/in^2 (50% of the yield strength of steel, 7,500 lb/in^2 for aluminum)
t = wall thickness, in
D_o = outside pipe diameter, in

Specification and grade of steel	Allowable stress 50% yield point lb/in^2
ASTM A 283	
Grade A	12,000
Grade B	13,500
Grade C	15,000
Grade D	16,500
ASTM A 1011 Structural steel	
Grade 30	15,000
Grade 33	16,500
Grade 36	18,000
Grade 40	20,000
Grade 45	22,500
Grade 50	25,000
Grade 55	27,500
ASTM A 53	
Grade A	15,000
Grade B	17,500
ASTM A 135	
Grade A	15,000
Grade B	17,500
ASTM A 139	
Grade A	15,000
Grade B	17,500
Grade C	21,000
Grade D	23,000
Grade E	26,000

The stress in a metal pipe may be allowed to increase from 50 percent of the yield strength to 75 percent for surge pressures. Therefore, the internal pipe pressure for working pressure plus surge pressure may be 1.5 times the pressure rating determined above.

(c) Corrugated metal

The maximum allowable pressure should be limited to 20 feet of head for annular pipe and 30 feet of head for helical pipe with lock or continuously welded seams, annular ends, and watertight couplings.

Corrugated bands (fig. 52–5) and gaskets (fig. 52–6) are necessary when watertightness is required. The ends of helical pipe should be reformed so the pipe may be coupled. Flat bands with sleeve or O-ring type gaskets, or hat/channel with mastic bands (fig. 52–5) are not considered watertight joints since they are susceptible to pulling apart. Bands with annular corrugations and rod and lug connectors, a band angle connector (fig. 52–7), or flanged connections are acceptable watertight couplings.

Figure 52–5 Standard band types

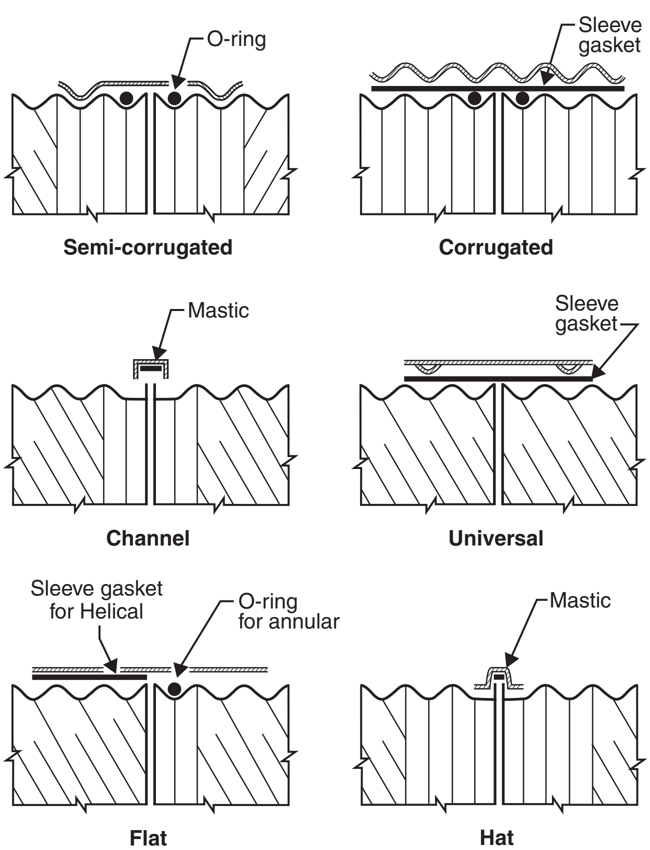
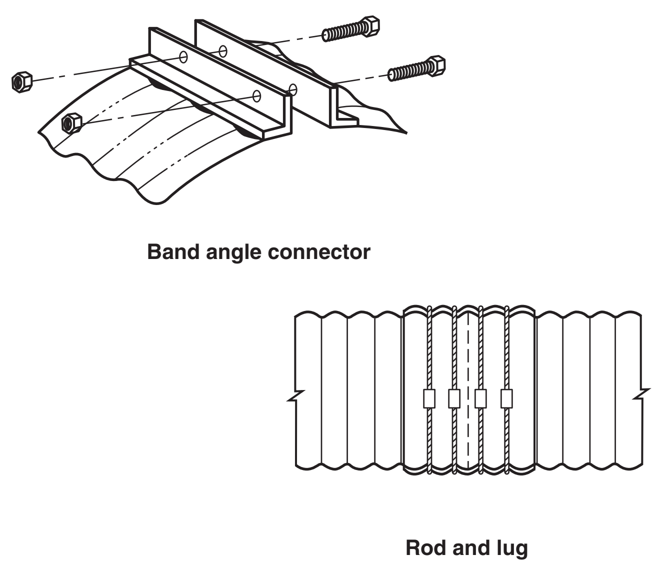


Figure 52–6 Standard corrugated pipe gaskets

Figure 52–7 Corrugated pipe watertight connectors



(d) Ductile iron pipe

The net thickness for internal pressure (static pressure plus surge pressure) may be determined from the following formula:

$$t = \left(\frac{P \times D_o}{2 \times S_y}\right) \quad (52–6)$$

where:
t = net pipe wall thickness, in
P = internal pressure, lb/in²
$P = 2.0\ (P_{work} + P_{surge})$ or static pressure
P_{work} = working pressure, lb/in²
P_{surge} = maximum surge pressure, lb/in²
D_o = outside pipe diameter, in
S_y = yield strength (42,000 lb/in² for ductile iron)

The standard surge allowance for ductile iron pipe is 100 lb/in². The pressure class designation signifies the allowable working pressure with a maximum surge pressure of 100 lb/in². If the anticipated surge pressure is different from 100 lb/in², the anticipated surge pressure should be used and the working pressure adjusted accordingly.

Once the net pipe wall thickness is determined, an 0.08-inch service tolerance and the casting tolerance from appendix 52F, table 52F–1, are added to calculate the thickness, from which the appropriate pressure class is chosen.

636.5202 Water hammer/surge pressure

Water hammer (or surge pressure) occurs when the flow velocity in a pipe system is suddenly stopped or changed. When flow is suddenly changed, the mass inertia of the water is converted into a pressure wave or high static head on the pressure side of the pipeline. Some of the most common causes of water hammer are the opening and closing of valves, starting and stopping pumps, entrapped air, and poor pipe system layout.

For detailed surge analysis and to analyze flow changes other than instantaneous stoppage, a computer analysis is recommended. SURGE is one available computer program.

Surges may generally be divided into two categories: transient surges and cyclic surges. Transients are described as the intermediate conditions that exist in a system as it moves from one steady-state condition to another. Cyclic surging is a condition that recurs regularly with time. Surging of this type is often associated with the action of equipment, such as reciprocating pumps, pressure reducing valves, and float valves. Any piping material may eventually fatigue if exposed to continuous cyclic surging at sufficiently high frequency and stress.

Recurring surge pressures occur frequently and are inherent to the design and operation of the system (such as normal pump startup or shutdown and normal valve opening and closure).

Occasional surge pressures are caused by emergency operations and are usually the result of a malfunction, such as power failure or system component failure, which includes pump seize-up, valve-stem failure, and pressure-relief valve failure.

The pressure wave caused by the water hammer travels back and forth in the pipe getting progressively lower with each transition from end to end. The magnitude of the pressure change caused by the water hammer wave depends on the elastic properties of the pipe and liquid, as well as the magnitude and speed of the velocity change. The maximum surge pressure from water hammer is equal to:

$$H_{surge} = \frac{a \times \Delta V}{g} \qquad (52\text{–}7)$$

or

$$P_{surge} = \frac{a \times \Delta V}{g} \times \frac{\gamma_w}{144} \qquad (52\text{–}8)$$

or

$$P_{surge} = \frac{a \times \Delta V}{2.31 \times g} \text{ (for water)} \qquad (52\text{–}9)$$

where:

H_{surge} = surge pressure, ft of water
P_{surge} = surge pressure, lb/in²
a = velocity of the pressure wave, ft/s
ΔV = change in velocity of fluid, ft/s
g = acceleration due to gravity, 32.2 ft/s²
γ_w = unit weight of water, 62.4 lb/ft³

The maximum surge pressure results when the time required to stop or change the flow velocity is equal to or less than 2L/a such that:

$$T_{CR} \le \frac{2L}{a} \qquad (52\text{–}10)$$

where:

T_{CR} = critical time, seconds
L = distance within the pipeline that the pressure wave moves before it is reflected back by a boundary condition, ft
a = velocity of the pressure wave, ft/s

The velocity of the pressure wave, a, may be expressed as:

$$a = \frac{12 \times \sqrt{\frac{K_L}{\rho}}}{\sqrt{1 + \frac{K_L}{E} \times \frac{D_i}{t}}} \qquad (52\text{–}11)$$

or

$$a = \frac{12}{\sqrt{\frac{\gamma_w}{g}\left(\frac{1}{K_L} + \frac{D_i}{Et}\right)}} \qquad (52\text{–}12)$$

or

$$a = \frac{4{,}720}{\sqrt{1 + \frac{K_L}{E} \times \frac{D_i}{t}}} \text{ (for water)} \qquad (52\text{–}13)$$

For SDR pipe, the velocity of the pressure wave may be expressed as:

$$a = \frac{12 \times \sqrt{\frac{K_L}{\rho}}}{\sqrt{1 + \frac{K_L(SDR - 2)}{E}}} \qquad (52\text{–}14)$$

or

$$a = \frac{12}{\sqrt{\frac{\gamma_w}{g}\left(\frac{1}{K_L} + \frac{SDR - 2}{E}\right)}} \qquad (52\text{–}15)$$

or

$$a = \frac{4{,}720}{\sqrt{1 + \frac{K_L(SDR - 2)}{E}}} \text{ (for water)} \qquad (52\text{–}16)$$

where:

K_L = bulk modulus of liquid, lb/in²
= 300,000 lb/in² for water
E = modulus of elasticity of pipe material, lb/in² (as shown below)
SDR = standard dimension ratio
ρ = density of fluid, slugs/ft³
= 1.93 slugs/ft³ for water
γ_w = unit weight of water, 62.4 lb/ft³
g = acceleration due to gravity, 32.2 ft²/s
D_i = internal diameter of the pipe, in
t = pipe wall thickness, in

Material	Modulus of elasticity* (lb/in²)	
Steel	29,000,000	
Aluminum	10,000,000	
Ductile Iron	24,000,000	
PVC	400,000	(short term)
ABS	300,000	(short term)
Polyethylene	110,000	(short term)

*Short-term modulus of elasticity varies with the cell class of each plastic. Specific values may be obtained from the manufacturer.

636.5203 Loads on pipe

(a) Soil pressure

The soil pressure above flexible pipe is determined by the soil prism load theory (fig. 52–8). The soil pressure may be determined by the following equation:

$$P_s = \gamma_s \times h \qquad (52\text{–}17)$$

where:
P_s = pressure due to weight of soil at depth of h, lb/ft^2
γ_s = unit weight of soil, lb/ft^3
h = height of ground surface above top of pipe, ft

When groundwater is above the top of the pipe, P_s may be reduced for buoyancy by the factor, R_w:

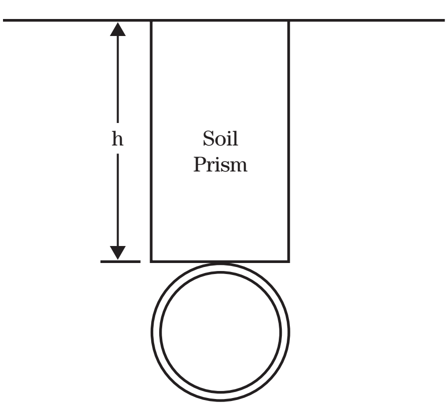
R_w = water buoyancy factor
= $1-0.33\, h_w/h$

where:
h = height of ground surface above top of pipe, ft
h_w = height of water above top of pipe, ft

The soil load per foot length of pipe may be determined by:

$$W_s = P_s \times \frac{D_o}{12} \qquad (52\text{–}18)$$

Figure 52–8 Soil prism



where:
W_s = soil load per linear foot of pipe, lb/ft
D_o = outside diameter of pipe, in

(b) Wheel loading

Underground pipes may be subjected to vehicular loads. The use of actual wheel/track loads is recommended. The magnitude of the wheel load may be estimated from the following:

Load class	P_L, lb
Field equipment	10,000
H15	12,000
H20	16,000

The effect of wheel loads at the surface reduces significantly with depth. When the wheel load is large, such as 20,000 pounds, the possibility of a similar load within a distance equal to the depth of consideration should be evaluated using special analysis.

The pressure distribution is based on the stress distribution theory (fig. 52–9) and may be expressed as follows:

When $D_o - t < 2.67h \times 12$:

$$W_L = \frac{0.48 P_L I_f \left(\frac{D_o - t}{12}\right)^2}{2.67h^3}\left[\frac{2.67h}{\left(\frac{D_o - t}{12}\right)} - 0.5\right] \qquad (52\text{–}19)$$

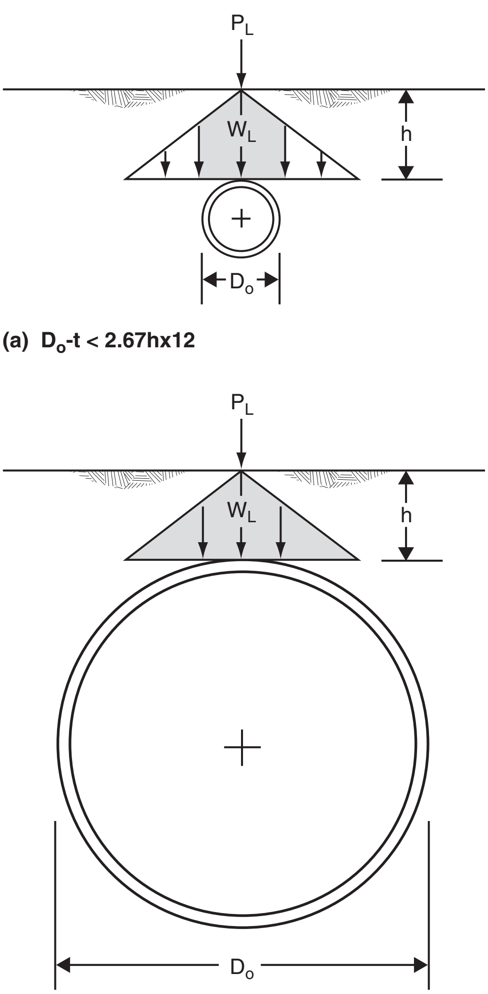
When $D_o - t \geq 2.67h \times 12$:

$$W_L = \frac{0.64 P_L I_f}{h} \qquad (52\text{–}20)$$

where:
W_L = wheel load per linear foot of pipe, lb/ft
P_L = wheel load at the surface, lb
I_f = impact factor (as described below)
h = height of ground surface above top of pipe, ft
D_o = outside diameter of pipe, in
t = pipe wall thickness, in

Depth of cover	Impact factor
< 1'0"	1.3
1'1" – 2'0"	1.2
2'0" – 2'11"	1.1
≥ 3'0"	1.0

Figure 52–9 Load pressure distribution



(a) D_o-t < 2.67hx12

(b) D_o-t ≥ 2.67hx12

The pressure on the pipe from the wheel load may be determined by:

$$P_W = \frac{W_L}{\left(\frac{D_o}{12}\right)} \tag{52–21}$$

where:
P_w = pressure on pipe from wheel load, lb/ft²
D_o = outside diameter of pipe, in

When the depth of fill is 2 feet or more, wheel loads may be considered as uniformly distributed over a square with sides equal to 1 3/4 times the depth of fill.

$$P_w = \frac{P_L}{(1.75h)^2} \tag{52–22}$$

(c) Vacuum pressure

Pipe may be subject to an effective external pressure because of an internal vacuum pressure, P_v. Sudden valve closures, shutoff of a pump, or drainage from high points within the system often create a vacuum in pipelines. Siphons will all be subject to negative pressures.

Vacuum pressure should be incorporated into the design of buried and aboveground pipes as described in this chapter. The vacuum pressure may be intermittent (short term), for long durations, or continuously (long term).

The vacuum load per length of pipe may be determined by:

$$W_V = P_V \times \frac{D_i}{12} \tag{52–23}$$

where:
W_v = vacuum load per linear foot of pipe, lb/ft
P_v = internal vacuum pressure, lb/ft²
D_i = inside pipe diameter, in

(d) Hydrostatic pressure

Pipe may be subject to external hydrostatic pressure if it is below the water elevation. The hydrostatic pressure may be determined by the following equation:

$$P_G = \gamma_w \times h_w \tag{52–24}$$

where:
P_G = external hydrostatic pressure, lb/ft^2
γ_w = unit weight of water, lb/ft^3
h_w = height of water above top of pipe, ft

636.5204 Buried pipe design

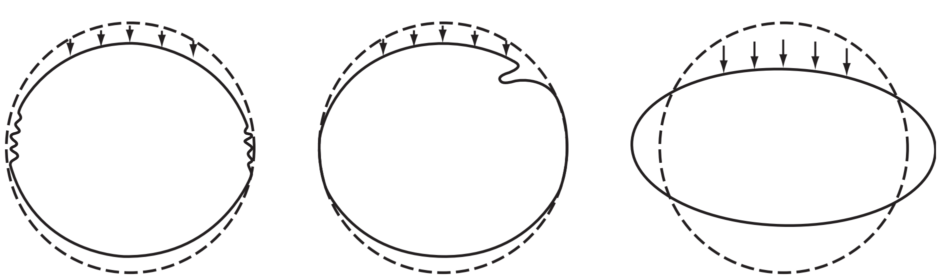
The typical modes of failure of buried flexible pipe include wall crushing (stress), local buckling, or excessive deflection (fig. 52–10).

Excessive wall stress may lead to wall crushing if the compressive strength of the pipe wall is exceeded.

Buckling may occur because of insufficient pipe stiffness and may control design for pipes subject to internal vacuum, external hydrostatic pressure, or pipe embedded in loose or poorly compacted soil.

Deflection of flexible pipe is a performance limit to prevent cracking of liners, avoid reversal of curvature, limit bending stress and strain, and avoid pipe flattening. Deflection of a nonpressure flexible pipe increases with time after construction is complete. The time is a function of the embedment and surrounding soil density. The deflection continues to increase as long as the soil around the pipe continues to consolidate (increase in density). A deflection lag factor, D_L, was included in the modified Iowa equation to account for the increase in deflection with time. A D_L value of 1.0 to 1.5 is often recommended. A D_L value of 1.0 is often used when the soil load is estimated by the soil prism load as illustrated in figure 52–8. A D_L value of 1.5 has historically been used by the NRCS and is recommended as the factor to be applied to only the soil load.

Figure 52–10 Modes of failure



(a) Wall crushing (b) Wall buckling (c) Excessive Deflection

(a) Plastic pipe

Plastic pipe materials consist of poly-vinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), and polyethylene (PE). Each type of material is supplied in several grades as shown in appendix 52C.

Design of buried plastic pipe includes analyses of the wall crushing, buckling resistance, allowable long-term deflection, and allowable strain.

At a constant load, the plastic modulus of elasticity of the plastic pipe decreases with time. With any increase in load, the plastic reacts with the short-term modulus of elasticity. The ratio of the short-term to long-term modulus of elasticity varies from approximately 3 for PVC to 5 for PE. The short-term modulus of elasticity is recommended for conditions that change through time, such as deflection. The pipe-soil interaction that occurs as discrete events is similar to a new load (Chevron Chemical, 1998). The long-term modulus of elasticity is often recommended for buckling since the loads and reaction of the pipe are considered static.

(1) Wall crushing

The design pressure and ring compression thrust in the pipe wall is determined by:

$$P = P_s + P_w + P_v \qquad (52–25)$$

where:

P = pressure on pipe, lb/ft²
P_s = pressure due to weight of soil, lb/ft²
P_w = pressure on pipe due to wheel load, lb/ft²
P_v = internal vacuum pressure, lb/ft²

$$T_{pw} = \frac{P \times \frac{D_o}{12}}{2} \qquad (52–26)$$

where:

T_{pw} = thrust in pipe wall, lb/ft
D_o = outside pipe diameter, in

The required wall cross-sectional area is determined by:

$$A_{pw} = \frac{\frac{T_{pw}}{12}}{\sigma} \qquad (52–27)$$

where:

A_{pw} = required wall area, in²/in
T_{pw} = thrust in pipe wall, lb/ft
σ = allowable long-term compressive stress, lb/in² (see appendix 52C, table 52C–1)

The area of a solid-wall pipe wall may be computed as:

$$A_{pw} = \frac{(D_o - D_i)}{2} \text{ or } t \qquad (52–28)$$

where:

A_{pw} = area of pipe wall, in²/in
D_o = outside pipe diameter, in
D_i = inside pipe diameter, in
t = pipe wall thickness, in

The average area of pipe wall for corrugated and profile wall pipe should be obtained from the manufacturer.

(2) Deflection

The Modified Iowa Equation may be transposed and rewritten to compute the percent deflection of each type of pipe. The properties of a pipe section are expressed as the standard dimension ratio (SDR) or standard inside dimension ratio (SIDR) for solid wall pipe, pipe stiffness (PS) for corrugated plastic pipe, and the ring stiffness constant (RSC) for profile wall pipe.

Solid-wall plastic pipe as:

$$\frac{\%\Delta X}{D} = \frac{(D_L P_S + P_w + P_V)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{2E}{3(SDR-1)^3}\right) + 0.061E'\right]} \qquad (52–29)$$

or

$$\frac{\%\Delta X}{D} = \frac{(D_L P_S + P_w + P_V)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{2E}{3(SIDR+1)^3}\right) + 0.061E'\right]} \qquad (52–30)$$

Corrugated-plastic pipe as:

$$\frac{\%\Delta X}{D} = \frac{\left(D_L P_S + P_w + P_V\right)\left(\frac{1}{144}\right)K(100)}{\left[0.149PS + 0.061E'\right]} \qquad (52\text{–}31)$$

Profile-wall pipe:

$$\frac{\%\Delta X}{D} = \frac{\left(D_L P_S + P_w + P_V\right)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{1.24(RSC)}{D_i}\right) + 0.061E'\right]} \qquad (52\text{–}32)$$

where:

$\frac{\%\Delta X}{D}$ = percent deflection
D_L = deflection lag factor (1.0 to 1.5)
K = bedding constant (0.1)
P_s = pressure on pipe from soil (lb/ft^2)
P_w = pressure on pipe from wheel load (lb/ft^2)
P_v = internal vacuum pressure (lb/ft^2)
E = modulus of elasticity of pipe material (as shown below)
SDR = D_o dimension ratio
  SDR = D_o/t
  D_o = pipe outside diameter, in
  t = minimum wall thickness, in
SIDR = D_i dimension ratio
  SIDR = D_i/t
  D_i = pipe inside diameter, in
  t = minimum wall thickness, in
PS = pipe stiffness
RSC = ring stiffness constant
D_i = inside pipe diameter, in
E' = modulus of soil reaction, lb/in^2 (see table 52–2)

Material	Modulus of elasticity* (lb/in^2)
PVC	400,000 (short term)
ABS	300,000 (short term)
Polyethylene	110,000 (short term)

* Short-term modulus of elasticity varies with the cell class of each plastic. Specific values may be obtained from the manufacturer.

The modulus of soil reaction, E', is an interactive modulus representing support of the soil in reaction to the lateral pipe deflection under load. Amster Howard of the Bureau of Reclamation (Howard, 1977) developed recommended E' values based on the soil prism load described above. The recommended values are provided in table 52–2.

The allowable deflections for plastic pipe typically are limited to 5 percent for a spillway/outlet conduit in embankment dam practice and 7.5 percent in water or liquid conveyance practice and drains in embankment dam practice.

(3) Wall buckling

Plastic pipe embedded in soil may buckle because of excessive loads and deformations. The total permanent pressure must be less than the allowable buckling pressure. The permanent load should consist of the soil pressure, groundwater pressure, and any internal long-term vacuum pressures. The allowable buckling pressure may be determined from:

$$q_a = \frac{1}{FS}\left(32R_w B'E'\frac{E_{long}I_{pw}}{D_o^{\,3}}\right)^{1/2} \qquad (52\text{–}33)$$

(Moser, 2001)

where:

q_a = allowable buckling pressure, lb/in^2
FS = design factor of safety
 = 2.5 for (h/(D_o/12) > 2
 = 3.0 for (h/(D_o/12) < 2
  where:
  h = height of ground surface above top of pipe, ft
  D_o = outside diameter of the pipe, in
R_w = water buoyancy factor
 = 1–0.33(h_w/h), 0<h_w<h
 where:
 h = height of ground surface above top of pipe, ft
 h_w = height of water above top of pipe, ft
B'= empirical coefficient of elastic support

$$= \frac{4\left(h^2 + \left(\frac{D_o}{12}\right)h\right)}{1.5\left(2h + \left(\frac{D_o}{12}\right)\right)^2}$$

E_{long} = long term modulus of elasticity, lb/in^2 (see table below)
The long term modulus of elasticity is recommended if the pipe is subject to the pressure in the normal operations. If the pipe is subject to the pressure for short time periods and infrequently, the use of the short-term modulus of elasticity is acceptable.

E' = modulus of soil reaction, lb/in^2 (table 52–2)

I_{pw} = pipe wall moment of inertia

$$= \frac{t^3}{12}, \text{in}^4/\text{in} \quad \text{(for solid wall pipe)}$$

where:
t = pipe wall thickness, in

D_o = outside pipe diameter, in

Material	Modulus of elasticity* (lb/in^2)
PVC	140,000 (long term)
ABS	65,000 (long term)
Polyethylene	22,000 (long term)

* Long-term modulus of elasticity varies with the cell class of each plastic. Specific values may be obtained from the manufacturer.

Pipes that are out-of-round or deflected increase in bending moment and have less allowable buckling pressure. The allowable buckling pressure should be reduced by the following factor:

$$C = \left[\frac{\left(1 - \frac{\%\Delta X}{D}\frac{1}{100}\right)}{\left(1 + \frac{\%\Delta X}{D}\frac{1}{100}\right)^2} \right]^3 \quad (52\text{–}34)$$

where:
C = reduction factor for buckling pressure

$\frac{\%\Delta X}{D}$ = percent deflection

Table 52–2 Average values of the modulus of soil reaction for the Modified Iowa Equation

Soil type – pipe bedding material (Unified Soil Classification – ASTM D2487)	E' for degree of compaction of bedding, lb/in^2 1/ Dumped	Slight, < 85% proctor, < 40% relative density	Moderate, 85-95% proctor, 40-70% relative density	High, > 95% proctor, > 70% relative density
Fine-grained soil (LL>50) 2/ Soil with medium to high plasticity CH, MH, CH-MH	No data available, use E' = 0 or consult with a geotechnical engineer			
Fine-grained soil (LL<50) soil with medium to no plasticity CL, ML, ML-CL, with less than 25% coarse-grained particles	50	200	400	1,000
Fine-grained soil (LL<50) soil with medium to no plasticity CL, ML, ML-CL, with more than 25% coarse-grained particles. Coarse-grained soil with fines GM, GC, SM, SC contains more than 12% fines	100	400	1,000	2,000
Coarse-grained soil with little or no fines GW, GP, SW, SP contains less than 12% fines	200	1,000	2,000	3,000
Crushed rock	1,000	3,000	3,000	3,000

1/ Source ASCE Journal of Geotechnical Engineering Division, January 1977
2/ LL = liquid limit

(4) Strain

Total strain in a pipe wall can be caused by two actions: (1) flexure of the pipe as it deforms, and (2) hoop stress caused by internal or external pressure in the pipe wall. If a homogeneous wall is assumed and pressure concentrations are neglected, the formula follows:

Hoop strain:

$$\varepsilon_h = \frac{\frac{P}{144}D}{2A_{pw}E} \qquad (52\text{–}35)$$

For solid wall pipe, the equation becomes:

$$\varepsilon_h = \frac{\frac{P}{144}D_M}{2tE} \qquad (52\text{–}36)$$

where:

ε_h = maximum strain in pipe wall because of ring bending, in/in
P = pressure on/in pipe (may be internal and/or external pressure with the appropriate sign), lb/ft^2
D_M = mean pipe diameter, in
A_{pw} = area of pipe wall, in^2/in
E = modulus of elasticity of the pipe material, lb/in^2
t = pipe wall thickness, in

Maximum strains because of deflection or flexure may be determined by assuming the pipe remains an ellipse during deflections. The resulting equations are:

$$\varepsilon_f = \frac{t}{D_M}\left(\frac{\frac{3\Delta Y}{D_M}}{1-2\frac{\Delta Y}{D_M}}\right) = \frac{1}{SDR}\left(\frac{\frac{3\Delta Y}{D_M}}{1-2\frac{\Delta Y}{D_M}}\right)$$

(solid wall pipe)
(52–37)

or

$$\varepsilon_f = 6\frac{t}{D_M}\frac{\Delta Y}{D_M}$$

(corrugated or profile wall pipe)
(52–38)

where:

ε_f = maximum strain in pipe wall because of ring deflection, in/in
ΔY = vertical decrease in diameter, in
D_M = mean pipe diameter, in
$\Delta Y/D_M = \Delta X/D$ = percent deflection expressed as a decimal
t = pipe wall thickness, in
SDR = standard dimension ratio

In a buried pipeline, these strain components act simultaneously. The maximum combined strain in the pipe wall can be determined by summing both components.

$$\varepsilon = \varepsilon_f \pm \varepsilon_h \qquad (52\text{–}39)$$

where:

ε = maximum combined strain in pipe wall, in/in

In calculating the maximum combined strain, the hoop strain, ε_h, resulting from applied internal pressure, if any, should be added to the maximum strain due to deflection, ε_f. If the hoop strain is due to external load or internal vacuum pressure, the ring hoop strain should be substracted to obtain the maximum combined strain, ε.

The maximum combined strain in the pipe should be limited to:

$$\varepsilon \le \varepsilon_{all} \qquad (52\text{–}40)$$

where:

ε_{all} = allowable strain for the pipe material

The allowable strain should be no more than 5 percent for polyethylene and ABS pipes.

The allowable deflection for PVC pipe limits strain in standard PVC pipes to an acceptable value. Therefore, computation of strain and comparison to an allowable strain limit is not required for PVC pipe.

In polyethylene pressure pipe with pressure near the pipe pressure rating, the strain may be limited by limiting the deflection to the values shown in table 52–3.

(b) Steel

Design of steel pipe includes an analysis of the deflection and the buckling pressure.

(1) Deflection

The Modified Iowa Equation may be used to compute the deflection as:

$$\Delta X = \left(\frac{\left(D_L W_S + W_L + W_V\right)\left(\frac{1}{12}\right)Kr^3}{EI_{pw} + 0.061E'r^3} \right) \quad (52–41)$$

where:

ΔX = deflection, in
D_L = deflection lag factor (1.0 to 1.5)
W_s = soil load per linear foot of pipe, lb/ft
W_L = wheel load per linear foot of pipe, lb/ft
W_v = vacuum load per linear foot of pipe, lb/ft
K = bedding constant (0.1)
r = radius of pipe, in
EI_{pw} = pipe wall stiffness, in-lb*
where:
E = modulus of elasticity (29,000,000 lb/in^2 for steel and 4,000,000 lb/in^2 for cement mortar)
I_{pw} = pipe wall moment of inertia = $\frac{t^3}{12}$, in^4/in
t = wall thickness, in
E' = modulus of soil reaction, lb/in^2 (table 52–2)

* Under load, the individual elements; i.e., mortar lining, steel shell, and mortar coating. work together as laminated rings ($E_S I_S + E_I I_I + E_C I_C$) – shell, lining, coating). Structurally, the combined elements increase the moment of inertia of the pipe section, above the shell alone, thus increasing its ability to resist loads. The pipe wall stiffness EI of these individual elements is additive. (AWWA 1995)

Table 52–3 Safe deflection of polyethylene pressure pipe

SDR	Safe deflection as % of diameter
32.5	8.5
26.0	7.0
21.0	6.0
17.0	5.0
13.5	4.0
11.0	3.0
9.0	2.5

Source: ASTM F 714

The percent deflection may be determined by:

$$\% \frac{\Delta X}{D} = \frac{\Delta X}{D_o} \times 100 \quad (52–42)$$

Allowable deflections for various lining and coating systems are:

Steel pipe	= 5 percent
Flexible lined and coated steel pipe	= 5 percent
Mortar-lined and flexible coated steel pipe	= 3 percent
Mortar-lined and coated steel pipe	= 2 percent

(2) Buckling

Steel pipe embedded in soil may buckle because of excessive loads and deformations. The total permanent pressure must be less than the allowable buckling pressure. The permanent pressure should consist of the soil pressure, hydrostatic pressure, and any long-term vacuum pressure. The allowable buckling pressure may be determined from:

$$q_a = \frac{1}{FS}\left(32R_w B'E' \frac{EI_{pw}}{D_o^{\ 3}}\right)^{1/2} \quad (52–43)$$

where:

q_a = allowable buckling pressure, lb/in^2
FS = design factor of safety
= 2.5 for $(h/(D_o/12) > 2$
= 3.0 for $(h/(D_o/12) < 2$
where:
h = height of ground surface above top of the pipe, ft
D_o = outside diameter of the pipe, in
R_w = water buoyancy factor
= $1–0.33(h_w/h)$, $0<h_w<h$
where:
h = height of ground surface above top of the pipe, ft
h_w = height of water above top of pipe, ft
B' = empirical coefficient of elastic support
= $\frac{1}{1+4e^{(-0.065h)}}$ (AWWA, 1989)
where:
h = height of ground service above top of pipe, ft
E' = modulus of soil reaction, lb/in^2 (table 52–2)
E = modulus of elasticity, lb/in^2 (29,000,000 for steel)

I_{pw} = transverse moment of inertia = $\frac{t^3}{12}$, in^4/in
t = pipe wall thickness, in
D_o = outside pipe diameter, in

(c) Corrugated and spiral rib metal pipe

Design of corrugated and spiral rib metal pipe includes analysis of the wall strength, buckling strength, seam strength, and handling stiffness. Section properties of corrugated and spiral rib metal pipe are included in appendix 52D.

The strength requirements may be determined by either the allowable stress design (ASD) method or the load and resistance factor design (LRFD) method. Both methods are presented in ASTM B 790 for corrugated aluminum pipe and ASTM A 796 for corrugated steel pipe. The ASD method is presented next.

(1) Thrust

The design pressure and ring compression thrust in the pipe wall are determined by:

$$P = P_S + P_W + P_v \tag{52–44}$$

where:
P = design pressure, lb/ft^2
P_s = pressure due to weight of soil, lb/ft^2
P_w = pressure on pipe due to wheel load, lb/ft^2
P_v = internal vacuum pressure, lb/ft^2

$$T_{pw} = \frac{P \times \left(\frac{D_i}{12}\right)}{2} \tag{52–45}$$

where:
T_{pw} = thrust in pipe wall, lb/ft
D_i = inside pipe diameter, in

The required wall cross-sectional area is determined by:

$$A_s = \frac{T_{pw} \times (FS)}{f_y} \tag{52–46}$$

where:
A_s = required area of section, in^2/ft
T_{pw} = thrust in pipe wall, lb/ft
FS = safety factor, 2.0 for wall area
f_y = minimum yield strength, lb/in^2
33,000 lb/in^2 for steel
24,000 lb/in^2 for aluminum
20,000 lb/in^2 for aluminum alloy 3004-H32

(2) Buckling

The selected corrugated pipe section with the required wall area shall be checked for possible buckling. If the critical buckling stress, f_c, is less than the minimum yield stress, f_y, the required wall area must be recalculated using f_c instead of f_y.

When: $$D_i < \frac{r}{k}\sqrt{\frac{24E}{f_u}} \tag{52–47}$$

$$f_c = f_u - \frac{f_u^{\,2}}{48E}\left(\frac{kD_i}{r}\right)^2 \tag{52–48}$$

When: $$D_i \geq \frac{r}{k}\sqrt{\frac{24E}{f_u}} \tag{52–49}$$

$$f_c = \frac{12E}{\left(\frac{kD_i}{r}\right)^2} \tag{52–50}$$

where:
D_i = inside pipe diameter, in
r = radius of gyration of corrugation, in
k = soil stiffness factor = 0.22 for good fill material compacted to 90% of standard density based on ASTM D 698 or $\phi > 15°$
= 0.44 for soils with $\phi < 15°$ (Contech, 2001)
E = modulus of elasticity of pipe material, lb/in^2
f_u = minimum tensile strength of material, lb/in^2
45,000 lb/in^2 for steel
34,000 lb/in^2 for aluminum
27,000 lb/in^2 for aluminum alloy 3004-H32
f_c = critical buckling stress, lb/in^2

(3) Seam strength

For pipe fabricated with longitudinal seams (riveted, spot-welded, or bolted), the seam strength shall be sufficient to develop the thrust in the pipe wall. The required seam strength shall be:

$$SS = T_{pw} \times FS \qquad (52\text{–}51)$$

where:
- SS = required seam strength, lb/ft
- T_{pw} = thrust in pipe wall, lb/ft
- FS = safety factor, 3.0 for seam strength

Since helical lockseam and welded-seam pipe do not have longitudinal seams, seam strength criteria are not valid for these types of corrugated pipe.

(4) Flexibility factor

The metal pipe must have sufficient stiffness to withstand temporary loads that occur during shipping, handling, and installation. Relationships referred to as the flexibility factor have been developed that relate the required pipe wall stiffness to the pipe diameter. The flexibility factor is determined as:

$$FF = \frac{D_i^2}{EI_{pw}} \qquad (52\text{–}52)$$

where:
- FF = flexibility factor, in/lb
- D_i = inside diameter of the pipe, in
- E = modulus of elasticity of pipe material, lb/in^2
- I_{pw} = moment of inertia of pipe wall, in^4/in

The flexibility factor shall not exceed the allowable flexibility factors in appendix 52E.

(d) Ductile iron

The required wall thickness for ductile iron pipe under external load is based on two design considerations: ring bending stress and ring deflection. Thicknesses for standard pressure classes are provided in appendix 52F.

(1) Ring bending stress

The design ring bending stress, f, of 48,000 pounds per square inch provides a factor of safety of at least 1.5 on the minimum ring yield strength and 2.0 on the ultimate ring strength. The pressure due to soil, wheel, and vacuum loads required to develop a bending stress of 48,000 pounds per square inch at the pipe invert may be determined by:

$$P_{bs} = \frac{f}{3\left(\frac{D_o}{t}\right)\left(\frac{D_o}{t}-1\right)\left[K_b - \frac{K_x}{\frac{8E}{E'\left(\frac{D_o}{t}-1\right)^3}+0.732}\right]} \qquad (52\text{–}53)$$

where:
- P_{bs} = pressure to develop maximum ring bending stress, lb/in^2
- f = design maximum bending stress (48,000 lb/in^2)
- D_o = outside diameter of pipe, in
- t = net pipe wall thickness
  = t_n – service allowance – casting tolerance
  where:
  - t_n = nominal thickness from appendix 52F
  - service allowance = 0.08 in (AWWA, 2002)
  - casting tolerance from appendix 52F
- K_b = bending moment coefficient (table 52–4)
- K_x = deflection coefficient (table 52–4)
- E = modulus of elasticity (24,000,000 lb/in^2)
- E' = modulus of soil reaction, lb/in^2 (table 52–4)

The total pressure on the buried pipe is:

$$P = P_S + P_w + P_v \qquad (52\text{–}54)$$

where:
- P = design pressure, lb/ft^2
- P_s = pressure from weight of soil, lb/ft^2
- P_w = pressure on pipe because of wheel load, lb/ft^2
- P_v = internal vacuum pressure, lb/ft^2

The total pressure on the buried pipe, P, must be less than the design pressure to develop the maximum ring bending stress, P_{bs}:

$$P \le P_{bs} \times 144 \qquad (52\text{–}55)$$

where:
- P = design pressure, lb/ft^2
- P_{bs} = pressure to develop ring bending stress, lb/in^2

(2) Ring deflection

Maximum allowable ring deflection for unlined ductile iron pipe is 5 percent of the outside diameter. The maximum allowable ring deflection for cement-mortar-lined ductile iron pipe is 3 percent of the outside diameter. Research has shown that 3 percent deflection provides a safety factor of at least 2.0 against failure of the cement-mortar lining. The following equation may be used to determine the allowable design pressure at the allowable deflection:

$$P_{bs} = \frac{f}{3\left(\frac{D_o}{t}\right)\left(\frac{D_o}{t}-1\right)\left[K_b - \frac{K_x}{\frac{8E}{E'\left(\frac{D_o}{t}-1\right)^3}+0.732}\right]} \qquad (52\text{–}56)$$

where:

P_{rd} = pressure to develop allowable ring deflection, lb/in^2

$\frac{\Delta X}{D}$ = percent deflection
= 5% (0.05) for unlined pipe
= 3% (0.03) for mortar-line pipe

K_x = deflection coefficient (see table 52–4)

D_o = outside diameter of pipe, in

t_1 = minimum manufacturing thickness, in (t_n – casting tolerance)
t_n = nominal pipe wall thickness from appendix 52F

E = modulus of elasticity (24,000,000 lb/in^2)

E' = modulus of soil reaction, lb/in^2 (table 52–4)

The total pressure on the buried pipe, P, must be less than the design pressure to develop acceptable deflection, P_{rd}:

$$P \le P_{rd} \times 144 \qquad (52\text{–}57)$$

where:

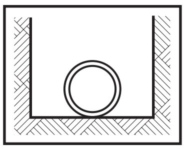
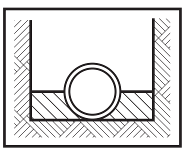
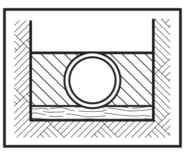
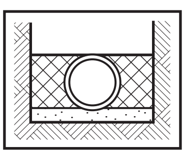
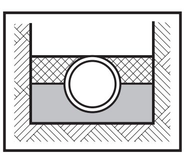
P = design pressure, lb/ft^2

P_{rd} = pressure to develop ring deflection, lb/in^2

A required net thickness, t, is determined using both the ring bending stress and allowable deflection equations above. The larger of the two net thicknesses, t, is selected. The nominal thickness is determined by adding the service allowance and casting tolerance. The nominal thickness is typically specified.

Although backfill around the pipe should be well compacted, design values of laying condition type 3 (table 52–4) are recommended for ductile iron pipes used in embankments for dams and ponds.

Table 52–4 Design values for standard laying conditions

Laying Condition	Description	E' psi[B]	Bedding Angle	K_b	K_x
 Type 1	Flat bottom trench[C] loose backfill.[D]	150	30	0.235	0.108
 Type 2	Flat bottom trench[C] Backfill lightly consolidated to centerline of pipe.	300	45	0.210	0.105
 Type 3	Pipe bedded in 4 inch (102 mm) minimum loose soil[E] Backfill lightly consolidated to top of pipe.	400	60	0.189	0.103
 Type 4	Pipe bedded in sand, gravel, or crushed stone to depth of 1/8 pipe diameter. 4 inch (102 mm) minimum. Backfill compacted to top of pipe. (Approximately 80 percent standard proctor, AASHTO T-99.)	500	90	0.157	0.096
 Type 5	Pipe bedded in compacted granular material to centerline of pipe, 4 inch (102 mm) minimum under pipe. Compacted granular or select[E] material to top of pipe. (Approximately 90 percent standard proctor, AASHTO T-99.)	700	150	0.128	0.085

A Consideration of the pipe-zone embedment conditions included in this table may be influenced by factors other than pipe strength. For additional information see ANSI/AWWA C600. Standard for installation of Ductile-Iron Water Mains and their Appurtenances.
B 1 lb/in^2 = 6.894757 kPa.
C Flat-bottom is defined as undisturbed earth.
D For pipe 14 inch (350 mm) and larger, consideration should be given to use of laying conditions other than Type 1.
E Loose soil or select material is defined as native soil excavated from the trench free of rocks, foreign materials, and frozen earth.

636.5205 Expansion and contraction

All pipe products expand and contract with changes in temperature. Approximate coefficients of thermal expansion for pipe materials is presented in table 52-5. Buried pipe used in NRCS applications will not typically experience significant changes in temperature, and thermal stress or dimension change will be minimal. However, changes in the ambient temperature prior to backfilling around the pipe may lead to excessive expansion or contraction. Therefore, the backfill should be placed as construction progresses.

Unrestrained pipe will experience a length change with changing temperature. The length may be estimated by:

$$\Delta L = L_{ur}\alpha\Delta T \qquad (52–58)$$

where:
ΔL = change in length, in
L_{ur} = length of unrestrained pipe, in
α = coefficient of thermal expansion, in/in/°F
ΔT = change in temperature, °F

A pipe restrained or anchored at both ends will experience a change in stress with changing temperature because of expansion and contraction. The longitudinal stress in the pipe wall caused by temperature changes may be estimated by:

$$S_{EC} = E\alpha\Delta T \qquad (52–59)$$

where:
S_{EC} = stress due to temperature change, lb/in^2
E = short term modulus of elasticity, lb/in^2
α = coefficient of thermal expansion, in/in/°F
ΔT = change in temperature, °F

The modulus of elasticity of plastic pipe is a function of the temperature. Since the temperature change does not occur rapidly, the average temperature is recommended for use in determining the appropriate modulus of elasticity. The modulus of elasticity should be adjusted for temperature by the factors shown in table 52–1.

Various pipe joints that allow some movement because of expansion and contraction are available. Gasketed pipe joints (such as bell and spigots) for plastic, steel, or ductile iron pipe and expansion joints for steel pipe allow some movement at the joint. The allowable movement at the joint should be obtained for the particular joint and compared to the length change caused by a change in temperature. Welded steel or plastic pipes or solvent cemented plastic pipes do not allow movement at the joint.

Table 52–5 Coefficients of thermal expansion

Pipe material	Coefficient (in/in/°F)
PVC	$3.0x10^{-5}$
HDPE	$1.2x10^{-4}$
ABS	$5.5x10^{-5}$
Aluminum	$1.3x10^{-5}$
Ductile Iron	$5.8x10^{-6}$
Steel	$6.5x10^{-6}$

Source: AWWA, 2002

636.5206 Aboveground pipe design

Aboveground applications frequently require noncontinuous support. These applications include pipe support from a saddle, rack, or stand supported by an adequate foundation or suspended from an overhead structure (figs. 52–11, 52–12, and 52–13). The equations shown apply to uniformly loaded and simply supported pipe. Lower bending moment and deflection will result for continuous rigidly joined and multiple span pipe.

(a) Bending stress

The maximum bending stress in the pipe wall of an unsupported pipe is:

$$S_b = \frac{MD_o}{2I} \qquad (52–60)$$

where:
S_b = bending stress, lb/in²
M = bending moment, in-lb
I = moment of inertia, in⁴

$$= \frac{\pi}{64}\left(D_o^4 - D_i^4\right), \text{in}^4 \quad \text{(plastic or ductile iron pipe)}$$

$$= \frac{\pi}{8}\left(D_o^3 t\right) \quad \text{(steel pipe)}$$

D_o = outside pipe diameter, in
D_i = inside pipe diameter, in
t = pipe wall thickness, in

The moment for an end-supported simple beam with a single span may be calculated by:

$$M = \frac{wL_{span}^2}{8} \qquad (52–61)$$

where:
M = bending moment, in-lb
w = load of pipe filled with liquid, lb/in
L_{span} = span length, in

The above two equations may be combined to determine the bending stress at center span of the pipe or an allowable support spacing of a uniformly loaded, simply supported pipe.

$$S_b = \frac{0.0625wL_{span}^2 D_o}{I} \qquad (52–62)$$

and

$$L_{span} = 4.0\sqrt{\frac{S_{ball} I}{wD_o}} \qquad (52–63)$$

where:
S_b = bending stress, lb/in²
S_{ball} = allowable bending stress, lb/in²
(50% of yield strength for steel, 48,000 lb/in² for ductile iron, and 7,500 lb/in² for aluminum)
= HDS = HDB/FS for plastic
HDS = hydrostatic design stress
HDB = hydrostatic design basis
FS = factor of safety (2.5 for AWWA C900 pipe, 2.0 for others)

Figure 52–11 Pipeline hanger

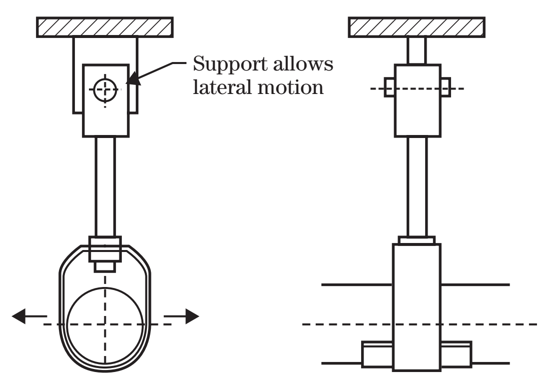
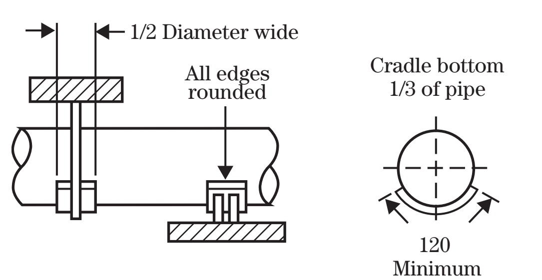


Figure 52–12 Pipeline support



w = load of pipe filled with liquid, lb/in
L_{span} = span length, in
I = moment of inertia, in^4

$= \frac{\pi}{64}\left(D_o^{\,4} - D_i^{\,4}\right)$, in^4 (plastic and ductile iron pipe)

$= \frac{\pi}{8}\left(D_o^{\,3} t\right)$ (steel and aluminum pipe)

D_o = outside pipe diameter, in
D_i = inside pipe diameter, in
t = pipe wall thickness, in

(b) Deflection

The length of the span between pipe supports shall be such that the deflection between supports is limited to an acceptable value. A maximum deflection of 1/360 of the span is recommended for steel pipe, 1/120 for ductile iron pipe, 0.5 percent of span for PVC pipe, and 1-inch for other plastic pipe. The maximum theoretical deflection for a uniformly loaded, simply supported pipe may be determined by:

$$y = 0.0130\left(\frac{WL_{span}^3}{E_{long} I}\right) \qquad (52\text{–}64)$$

or

$$y = \frac{0.0130\, wL_{span}^4}{E_{long} I} \qquad (52\text{–}65)$$

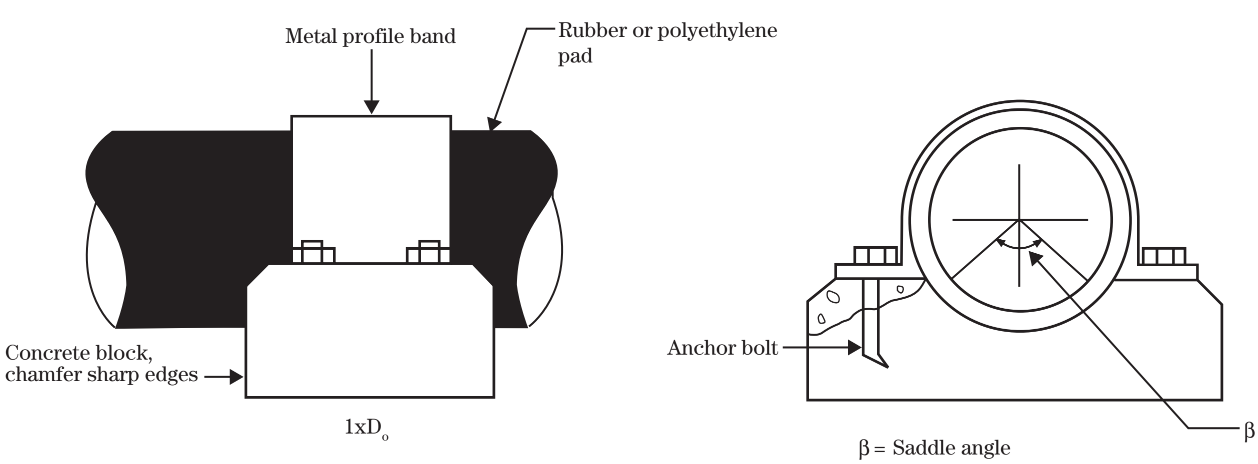
where:
y = maximum deflection at center of span, in
W = total load on span, lb
w = weight of pipe filled with liquid, lb/in
L_{span} = span length, in
E_{long} = long-term modulus of elasticity, lb/in² (see below)
I = transverse moment of inertia

$= \frac{\pi}{64}\left(D_o^{\,4} - D_i^{\,4}\right)$, in^4 (plastic or ductile iron pipe)

$= \frac{\pi}{8}\left(D_o^{\,3} t\right)$ (steel pipe)

D_o = outside diameter, in
D_i = inside diameter, in
t = pipe wall thickness, in, in^4

Figure 52–13 Typical saddle details



Note: This equation for I does not apply to corrugated, ribbed, or profile wall pipe. The appropriate values should be obtained from ASTM specifications or the manufacturer.

Material	Modulus of elasticity (lb/in)*
Steel	29,000,000
Aluminum	10,000,000
Ductile iron	24,000,000
PVC	140,000 (long term)
ABS	65,000 (long term)
Polyethylene	22,000 (long term)

* Long-term modulus of elasticity varies with the cell class of each plastic. Specific values may be obtained from the manufacturer.

(c) Hoop stress

The hoop stress caused by internal pressure may be estimated by:

$$S_p = \frac{P \times D_i}{2 \times t} \qquad (52\text{–}66)$$

where
S_p = stress from internal pressure, lb/in^2
P = pressure in the pipe, lb/in^2
D_i = inside diameter of the pipe, in
t = pipe wall thickness, in

(d) Localized stress at supports

An unstiffened pipe resting in saddle supports has high local stresses, longitudinal and circumferential, adjacent to the tips of the saddles. The localized stresses are less for a larger saddle angle (β) than for a small angle, and are practically independent of the thickness of the saddle (saddle dimension parallel to the pipe axis). Saddle angles of 90 degrees to 120 degrees are recommended. Ductile iron pipe research shows that little benefit is gained by increasing the saddle angle above 120 degrees, yet the maximum stress increases rapidly with saddle angle less than 90 degrees. For a pipe that fits the saddle well, the maximum longitudinal or circumferential localized stress probably does not exceed

$$S_l = k_{support} \frac{R_{support}}{t^2} \ln\left(\frac{R_o}{t}\right) \qquad \text{(Roark, 1975)} \qquad (52\text{–}67)$$

where:
S_l = local stress at the saddle, lb/in^2
$R_{support}$ = total saddle reaction, lb
= $\frac{wL_{span}}{2}$ (single span)
= wL_{span} (multiple span)
where:
w = weight of pipe filled with liquid, lb/in
L_{span} = span length, in
R_o = outside radius of pipe, in
t = pipe wall thickness, in
$k_{support}$ = coefficient
= 0.02 – 0.00012 (β-90)
= 0.03 – 0.00017(β-90) (ductile iron pipe) (DIPRA, 2001)
β = saddle angle, degrees

Theories and data differ on the importance of the saddle support width. Some test data indicate little effect on the maximum local stress when the support width is a minimum of:

$$b = \sqrt{2D_o t} \qquad (52\text{–}68)$$

where:
b = saddle width, in
D_o = outside diameter of pipe, in
t = pipe wall thickness, in
= net pipe wall thickness, in (ductile iron)

Some polyethylene pipe manufacturers recommend the support width be at least equal to the outside pipe diameter.

(e) Total stress at the saddle support

The total stress at the saddle is a combination of the longitudinal stresses in the pipe wall. In the case of a pipe with internal pressure, the Poisson ratio effect of the hoop stress, which produces a lateral tension, must be added to determine the total beam stress in the pipe wall (Barnard, 1948). The total stress may be computed as

$$S_T = vS_p + S_b + S_l + S_{EC} \qquad (52\text{–}69)$$

where:
S_T = total stress at the saddle, lb/in^2
v = Poisson's ratio
(0.30 for steel and ductile iron, 0.33 for aluminum, 0.38 for PVC, 0.40 for PE, 0.50 for ABS)
S_p = hoop stress from internal pressure, lb/in^2
S_b = bending stress, lb/in^2
S_l = local stress at saddle, lb/in^2
S_{EC} = stress from expansion and contraction (if restrained), lb/in^2

The total stress must be less than the allowable stress.

$$S_T < S_{all} \qquad (52\text{–}70)$$

where:
S_T = total stress at saddle, lb/in^2
S_{all} = allowable stress, lb/in^2 (50% of yield strength for steel, 48,000 lb/in^2 for ductile iron, and 7,500 lb/in^2 for aluminum)

$$= \frac{HDB \times T_f}{FS} \quad \text{for plastic}$$

HDB = hydrostatic design basis
T_f = temperature factor from table 52–1.
FS = factor of safety (2.5 for AWWA C900 pipe, 2.0 for others)

(f) Buckling

For aboveground pipe subject to external hydrostatic pressure or internal vacuum pressure, the critical collapse pressure may be determined by the following equations:

$$P_{CR} = \frac{3EI_{pw}}{\left(1 - v^2\right)r^3} \quad \text{for all pipe} \qquad (52\text{–}71)$$

$$P_{CR} = \frac{0.447PS}{\left(1 - v^2\right)} \quad \text{for corrugated plastic pipe} \qquad (52\text{–}72)$$

$$P_{CR} = \frac{2E}{\left(1 - v^2\right)}\left(\frac{1}{SDR - 1}\right)^3 \qquad (52\text{–}73)$$

or

$$P_{CR} = \frac{2E}{\left(1 - v^2\right)}\left(\frac{1}{SIDR + 1}\right)^3 \quad \text{for solid-wall pipe} \qquad (52\text{–}74)$$

where:
P_{CR} = critical external collapse pressure, lb/in^2
E = modulus of elasticity, lb/in^2
The long-term modulus of elasticity is recommended if the pipe is subject to the presssure in the normal operations. If the pipe is subject to the pressure for short time periods and infrequently, the use of the short-term modulus of elasticity is acceptable.
I_{pw} = pipe wall moment of inertia, in^4
v = Poisson’s ratio (0.30 for steel and ductile iron, 0.33 for aluminum, 0.38 for PVC, 0.40 for PE, 0.50 for ABS)
r = mean pipe radius, in
PS = pipe stiffness, lb/in^2
SDR = D_o dimension ratio
SIDR = D_i dimension ratio

636.5207 Thrust block design

The internal pressure of a pipe acts perpendicular to any plane with a force equal to the pressure, P, times the area of the pipe, A. The radial forces within the pipe are balanced by the tension in the pipe wall. The axial components of pressure through a straight section are balanced by the same pressure in the opposite direction. An unbalanced thrust force will exist in other configurations (fig. 52–14).

The internal pressure used in thrust block design is the working pressure for a pumped system or static pressure head in a gravity system.

Abrupt changes in pipeline grade, horizontal alignment, or reduction in pipe size normally require an anchor or thrust blocks (fig. 52–15) to absorb any axial thrust of the pipeline. Thrust control may also be needed at the end of the pipeline and at inline control valves.

Thrust blocks and anchors must be large enough to withstand the forces tending to move the pipe, including those of momentum and pressure, as well as forces from expansion and contraction.

The positioning of the thrust blocks must consider whether connections adjacent to the thrust block are capable of movement, as well as the anticipated direction of movement.

The vector sum of the pressure forces is shown as T, a thrust force, for various configurations in figure 52–14. The area of the thrust block may be determined by the following:

$$A_T = \frac{T}{q_{all}} \qquad (52\text{-}75)$$

where:
A_T = area of thrust block required, ft^2
T = thrust force, lb
q_{all} = allowable soil bearing pressure, lb/ft^2

If adequate soil tests are not available, the soil pressure may be estimated from table 52–6.

Table 52–6 Allowable soil bearing pressure

Natural soil material	Depth of cover to center of thrust block 2 ft	3 ft	4 ft	5 ft
	(lb/ft^2)			
Sound bedrock	8,000	10,000	10,000	10,000
Dense sand and gravel mixture (assumed Ø = 40°)	1,200	1,800	2,400	3,000
Dense fine to coarse sand (assumed Ø = 35°)	800	1,200	1,650	2,100
Silt and clay mixture (assumed Ø = 25°)	500	700	950	1,200
Soft clay and organic soils (assumed Ø = 10°)	200	300	400	500

Figure 52–14 Thrust forces

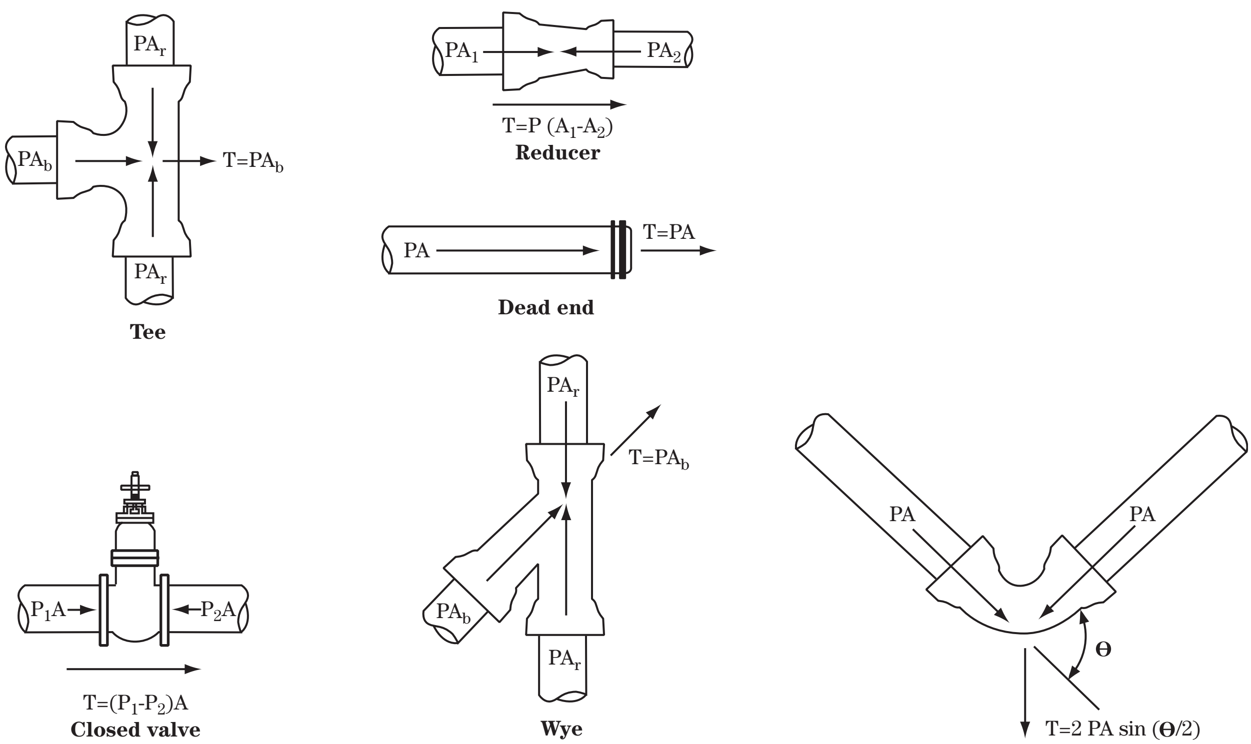
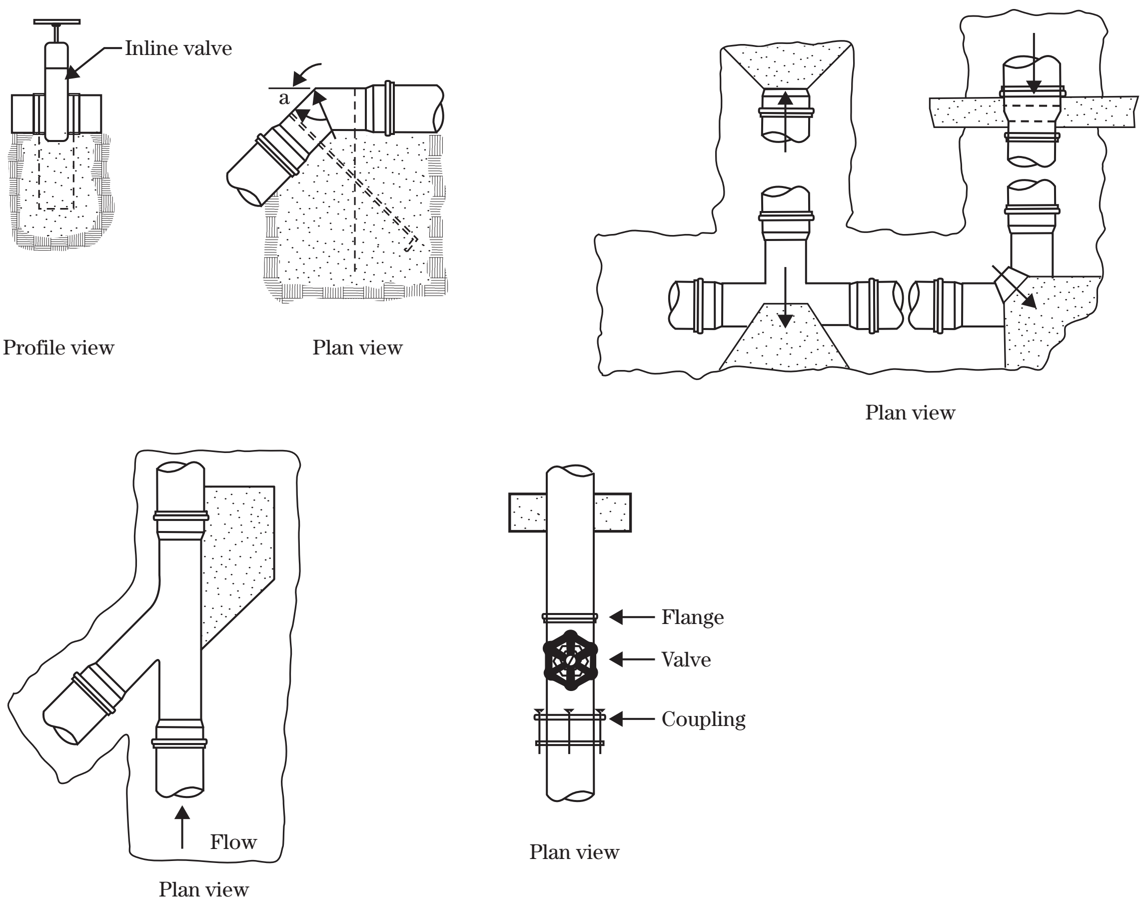


Figure 52–15 Thrust block types



636.5208 Longitudinal bending

Flexible plastic pipe is often installed in conditions that require longitudinal bending. Steel, corrugated metal pipe, and ductile iron pipe will withstand minimal longitudinal bending. Controlled longitudinal bending of the pipe within acceptable limits can be accommodated by the flexibility of the pipe itself. Additional longitudinal deviation must be accomplished by joint deflection or the use of special fittings. Joint deflection limits may be obtained from the manufacturer. Acceptable bending may be expressed in terms of the minimum bending radius calculated by:

$$R_b = \frac{ED_o}{2S_{ball}} \qquad (52\text{–}76)$$

where:
R_b = minimum bending radius, in
E = short-term modulus of elasticity, lb/in^2
D_o = outside pipe diameter, in
S_{ball} = allowable bending stress, lb/in^2

$$= \frac{HDB \times T_f}{FS}$$ (nonpressure or gasketed pressure plastic pipe)

$$= \frac{\left(HDB - \frac{HDB}{2}\right) \times T_f}{FS}$$

HDB = hydrostatic design basis
T_f = temperature factor from table 52–1.
FS = factor of safety (2.5 for AWWA C900 pipe, 2.0 for others)

= $S_{all} - S_p$ (for steel, aluminum, corrugated metal, and ductile iron pipe)

where:
S_{all} = allowable stress, lb/in^2 (50% of yield strength for steel, 48,000 lb/in^2 for ductile iron, and 7,500 lb/in^2 for aluminum)
S_p = stress caused by internal pressure, lb/in^2

$$= \frac{PD_o}{2t}$$

where:
P = maximum working pressure or static pressure, lb/in^2
D_o = outside pipe diameter, in
t = pipe wall thickness, in
= net pipe wall thickness, in (for ductile iron)

Some bending may be accomplished by axial joint deflection in gasketed pipe joints. The amount of joint deflection may be obtained from the pipe manufacturer. Solvent cemented or welded joints do not allow joint deflection.

636.5209 References

American Association of State Highway and Transportation Officials. 2000. Standard specifications for highway bridges, 17th ed. Washington, DC.

American Iron and Steel Institute. 1980. Modern sewer design. Washington, DC.

American Iron and Steel Institute. 1983. Handbook of steel drainage and highway construction products. Washington, DC.

American Society of Agricultural Engineers. 1998. ASAE S376.2, Design, installation and performance of underground thermoplastic irrigation pipelines. ASAE, St. Joseph, MI.

American Society of Testing and Materials International. 2001. ASTM A 53, Standard specification for pipe, steel, black and hot-dipped, zinc-coated, welded and seamless. West Conshohocken, PA.

American Society of Testing and Materials International. 2001. ASTM A 135, Standard specification for electric-resistance-welded steel pipe. West Conshohocken, PA.

American Society of Testing and Materials International. 2001. ASTM A 139, Standard specification electric-fusion (Arc)-welded steel pipe (NPS 4 and over). West Conshohocken, PA.

American Society of Testing and Materials International. 2000. ASTM A 283, Standard specification for low and intermediate tensile strength carbon steel plates. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM A 746, Standard specification for ductile iron gravity sewer pipe. West Conshohocken, PA.

American Society of Testing and Materials. 2001. ASTM A 796, Standard practice for structural design of corrugated steel pipe, pipe-arches, and arches for storm and sanitary sewers, and other buried applications. West Conshohocken, PA.

American Society of Testing and Materials International. 2003. ASTM A 1011, Standard specification for steel, sheet and strip, hot-rolled, carbon, structural, high-strength low-alloy and high-strength low-alloy with improved formability. West Conshohocken, PA.

American Society of Testing and Materials. 2000. ASTM B 790, Standard practice for structural design of corrugated aluminum pipe, pipe-arches, and arches for culverts, storm sewers, and other buried conduits. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM D 1527, Standard specification for acrylonitrile-butadiene-styrene (ABS) plastic pipe, schedules 40 and 80. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM D 1785, Standard specification for poly(vinyl chloride) (PVC) plastic pipe, schedules 40, 80, and 120. West Conshohocken, PA.

American Society of Testing and Materials. 2001. ASTM D 2104, Standard specification for polyethylene (PE) plastic pipe, schedule 40. West Conshohocken, PA.

American Society of Testing and Materials. 2001. ASTM D 2239, Standard specification for polyethylene (PE) plastic pipe (SIDR-PR) based on controlled inside diameter. West Conshohocken, PA.

American Society of Testing and Materials. 2000. ASTM D 2241, Standard specification for poly(vinyl chloride) (PVC) pressure-rated pipe (SDR-series). West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM D 2282, Standard specification for acrylonitrile-butadiene-styrene (ABS) plastic pipe (SDR-PR). West Conshohocken, PA.

American Society of Testing and Materials. 2001. ASTM D 2447, Standard specification for polyethylene (PE) plastic pipe, schedules 40 and 80, based on outside diameter. West Conshohocken, PA.

American Society of Testing and Materials. 2001. ASTM D 2737, Standard specification for polyethylene (PE) plastic tubing. West Conshohocken, PA.

American Society of Testing and Materials International. 2001. ASTM D 2837, Standard test method for obtaining hydrostatic design basis for thermoplastic pipe materials. West Conshohocken, PA.

American Society of Testing and Materials. 2000. ASTM D 3034, Standard specification type PSM poly(vinyl chloride) (PVC) sewer pipe and fittings. West Conshohocken, PA.

American Society of Testing and Materials. 2001 ASTM D 3035, Standard specification for polyethylene (PE) plastic pipe (DR-PR) based on controlled outside diameter. West Conshohocken, PA.

American Society of Testing and Materials. 2001 ASTM F 679, Standard specification for poly(vinyl chloride) (PVC) large-diameter plastic gravity sewer pipe and fittings. West Conshohocken, PA.

American Society of Testing and Materials International. 2000. ASTM F 714, Standard specification for polyethylene (PE) plastic pipe (SDR-PR) based on outside diameter. West Conshohocken, PA.

American Society of Testing and Materials. 1995. ASTM F 758, Standard specification for smooth-wall poly(vinyl chloride) (PVC) plastic underdrain ssytems for highway, airport, and similar drainage. West Conshohocken, PA.

American Society of Testing and Materials. 1995. ASTM F 789, standard specification for type PS-46 and type PS-115 poly(vinyl chloride) (PVC) plastic gravity flow sewer pipe and fittings. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM F 794, standard specification for poly (vinyl chloride) (pvc) profile gravity sewer pipe and fittings based on controlled inside diameter. West Conshohocken, PA.

American Society of Testing and Materials. 1995. ASTM F 892, standard specification for polyethylene (PE) corrugated pipe with smooth interior and fittings. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM F 894, standard specification for polyethylene (PE) profile large diameter profile wall sewer and drain pipe. West Conshohocken, PA.

American Society of Testing and Materials. 1999. ASTM F 949, standard specification for poly (vinyl chloride) (PVC) corrugated sewer pipe with smooth interior and fittings. West Conshohocken, PA.

American Society of Testing and Materials. 1993. ASTM F1176, standard practice for design and installation of thermoplastic irrigation systems with maximum working pressure of 63 psi. West Conshohocken, PA.

American Water Works Association. 1980. PVC pipe - design and installation. AWWA Manual M23. Denver, CO.

American Water Works Association. 1989. Steel pipe – a guide for design and installation. AWWA Manual M11, 3rd ed. Denver, CO.

American Water Works Association. 1997. AWWA standard for coal-tar protective coatings and linings for steel water pipelines—enamel and tape—hot applied. AWWA C203. Denver, CO.

American Water Works Association. 2000(a). AWWA standard for cement-mortar protective lining for steel water pipe—4" and larger—shop applied. AWWA C205, Denver, CO.

American Water Works Association. 2000(b). AWWA standard for cold applied tape coatings for the exterior of special sections, connections, and fittings for steel water pipelines. AWWA C209, Denver, CO.

American Water Works Association. 1997. AWWA standard for liquid-epoxy coating systems for the interior and exterior of steel water pipelines. AWWA C210, Denver, CO.

American Water Works Association. 2000. AWWA standard tape coating systems for the exterior of steel water pipelines. AWWA C214, Denver, CO.

American Water Works Association. 2002. American national standard for thickness design of ductile iron pipe. AWWA C150. Denver, CO.

American Water Works Association. 1997. AWWA standard for polyvinyl chloride (PVC) pressure pipe and fabricated fittings, 4 inch through 12 inch, for water distribution. AWWA C900. Denver, CO.

American Water Works Association. 1997. AWWA standard for polyvinyl chloride (PVC) pressure pipe and fabricated fittings, 14 inch through 48 inch, for water transmission and distribution. AWWA C905. Denver, CO.

Barnard, R.E. 1948. Design standards for steel water pipe. J. American Waterworks Assoc., Vol. 40, pp. 24-87, Denver, CO.

Chevron Chemical Company. 1998. The Plexco/Spirolite engineering manual. Performance Pipe Div., Chevron Chemical Co., Bensenville, IL.

Contech Construction Products. 2001. Contech tunnel liner plate. Middletown, OH.

Ductile Iron Pipe Research Association. 2000. Design of ductile iron pipe. Ductile Iron Pipe Research Assoc., Birmingham, AL.

Ductile Iron Pipe Research Association. 2001. Design of ductile iron pipe on supports. Birmingham AL.

Howard, A.K. 1977. Modulus of soil reaction values for buried flexible pipe. J. Geotechnical Eng., Amer. Soc. Civil Eng., Vol. 103, pp. 33-43, New York, NY.

Moser, A.P. 2001. Buried pipe design. McGraw-Hill, New York, NY.

Plastic Pipe Institute. 2003. Comments from Dr. Gene Palermo.

Roark, R.J., and W.C. Young. 1975. Formulas for stress and strain. McGraw-Hill, New York, NY.

Uni-Bell PVC Pipe Association. 2001. Handbook of PVC pipe design and construction. Dallas, TX.

United States Army Corps of Engineers. 1998. Conduits, culverts, and pipes. Engineer Manual EM 1110-2902. Office Chief of Engineers, Washington, DC.

Glossary

Buckling. Failure by lateral or torsional instability of a structural member, occurring with stresses below the yield strength.

Collapse pressure (critical buckling pressure). The negative pressure at which the pipe collapses caused by water column separation from valve closure, sudden air evacuation, surge pressures, or other causes.

Critical time. Longest elapsed time before final flow stoppage that will still allow the maximum pressure surge to occur.

Deflection. The decrease in the vertical diameter of a pipe due to load, divided by the nominal diameter, expressed as a percent.

Gage. Reference system for thickness of metal sheets or wire.

Hoop stress. The tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure.

Hydrostatic design basis. One of a series of established stress values specified in ASTM D 2837 for a plastic compound obtained by categorizing the long-term hydrostatic strength determined in accordance with Test Method D 2837.

Hydrostatic design stress. The recommended maximum hoop stress that can be applied continuously with a high degrees of certainty that failure of the pipe will not occur.

Modulus of soil reaction, E prime (E´). Measure of the stiffness of the embedment material that surrounds the pipe.

Out-of-roundness. The allowed difference between the maximum measured diameter and the minimum measured diameter (stated as an absolute deviation).

Pipe stiffness. For plastic pipe, a term to describe the stiffness of the pipe from a parallel plate test, which defines the pipe's resistance to load.

Pressure rating or pressure class. The maximum internal water pressure that can be exerted continuously in a pipe without damage at a specific temperature (73 ºF).

Standard dimension ratio (SDR) or dimension ratio (DR). A specific ratio of the average specified outside diameter to the minimum specified wall thickness for outside diameter-controlled plastic pipe.

Standard inside dimension ratio (SIDR). A specific ratio of the average specified inside diameter to the minimum specified wall thickness for inside diameter-controlled plastic pipe.

Static head. The height of water above any plane or reference point.

Static pressure. The internal pressure when no flow is occurring in the pipe.

Surge pressure. The maximum pressure increase greater than working pressure (sometimes called water hammer) that is anticipated in the system as a result of change in velocity in the water. Some causes of surge include the opening and closing (full or partial) of valves, starting and stopping of pumps, changes in reservoir elevation, liquid column separation, and entrapped air.

Thrust in a pipe wall. The circumferential compressive force in the conduit walls, per unit length of pipe.

Total system pressure. The sum of working pressure plus surge pressure.

Water hammer. A pressure surge in a pipeline caused by a sudden change in water velocity. Typical causes include the sudden starting or stopping of a pump, sudden valve movement, or air movement in a pipeline. The surge may damage or destroy pipelines and pumps if severe.

Working pressure. The maximum anticipated sustained operating pressure for the system.

Appendix 52A Symbols Used in NEH 636, Chapter 52

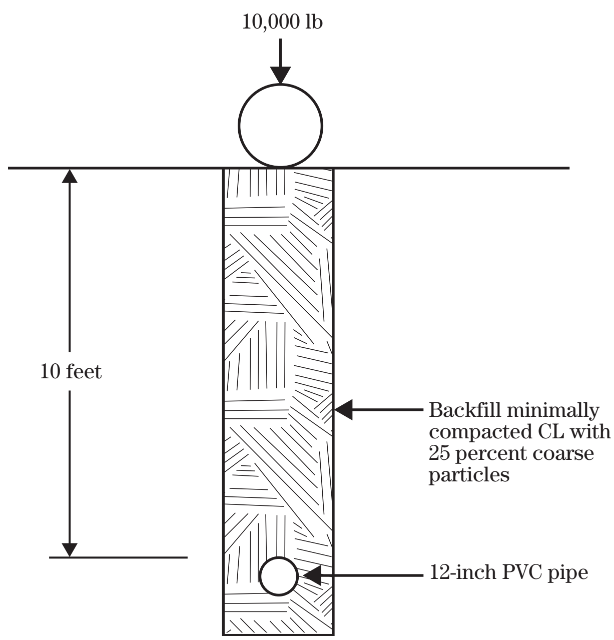
A	pipe cross section area, in^2
A_{pw}	area of pipe wall, in^2/in
A_s	area of section, in^2/ft
A_T	area of thrust block required, ft^2
a	velocity of pressure wave, ft/s
B'	empirical coefficient of elastic support
b	aboveground pipe saddle width, in
C	reduction factor for buckling pressure
D_L	deflection lag factor
D_M	mean pipe diameter, in
D_o	outside pipe diameter, in
D_i	inside pipe diameter, in
E	modulus of elasticity of pipe material, lb/in^2
E_{long}	long-term modulus of elasticity, lb/in^2
E'	modulus of soil reaction, lb/in^2
EI	pipe wall stiffness, in-lb
e	base of neutral logs, 2.71828
FF	flexibility factor, in/lb
FS	factor of safety
f	design maximum bending stress, lb/in^2
f_c	critical buckling stress, lb/in^2 (CMP)
f_u	minimum tensile strength of material, lb/in^2 (CMP)
f_y	minimum yield strength, lb/in^2 (CMP)
g	acceleration of gravity, 32.2 ft/s^2
H	maximum working pressure, ft
HDB	hydrostatic design basis, lb/in^2
HDS	hydrostatic design stress, lb/in^2
H_{surge}	surge pressure, ft of water
h	height of ground surface above top of pipe, ft
h_w	height of water above top of pipe, ft
I	moment of inertia, in^4
I_{pw}	pipe wall moment of inertia, in^4
I_f	impact factor
K	bedding constant
K_b	bending moment coefficient
K_L	bulk modulus of liquid, lb/in^2
K_x	deflection coefficient
k	soil stiffness factor = 0.22 for good fill material compacted to 90% of standard density based on ASTM D 698
$k_{support}$	coefficient for saddle support
L	distance within the pipeline that the pressure wave moves before it is reflected back by a boundary condition, ft
L_{span}	span length, in
L_{ur}	length of unrestrained pipe, in
M	bending moment, in-lb
P	pressure in or on pipe, lb/ft^2
PC	pressure class, lb/in^2
PR	pressure rating, lb/in^2
PS	pipe stiffness
PCR	critical collapse pressure, lb/in^2 (aboveground pipe)
P_G	external hydrostatic pressure, lb/ft^2
P_L	wheel load at the surface, lb
P_S	pressure on pipe from weight of soil, lb/ft^2
P_V	internal vacuum pressure, lb/ft^2
P_W	pressure on pipe from wheel load, lb/ft^2
P_{bs}	pressure to develop maximum ring bending, lb/in^2 (ductile iron pipe)
P_{rd}	pressure to develop allowable ring deflection, lb/in^2 (ductile iron pipe)
P_{surge}	surge pressure, lb/in^2
P_{work}	working pressure, lb/in^2
q_a	allowable buckling pressure, lb/in^2
q_{all}	allowable soil bearing pressure of the soil, lb/ft^2
RSC	ring stiffness constant
R_b	minimum bending radius, in
R_o	outside radius of pipe, in
$R_{support}$	aboveground pipe support reaction, lb
R_w	water buoyancy factor
r	radius of gyration of corrugation, in
S	allowable stress, lb/in^2
SDR	standard dimension ratio (same as DR)
SIDR	standard inside diameter dimension ratio (same as IDR)
SS	required seam strength, lbf/ft
STHS	short-term hoop strength, lb/in^2
STR	short-term pressure rating, lb/in^2
STS	short-term strength (quick burst pressure), lb/in^2
S_{all}	allowable stress, lb/in^2
S_b	bending stress, lb/in^2
S_{ball}	allowable bending stress, lb/in^2
S_{EC}	stress because of expansion or contraction, lb/in^2
S_l	local stress at a saddle support, lb/in^2
S_P	stress from internal pressure, lb/in^2
S_T	total stress at saddle support, lb/in^2
S_y	yield strength, lb/in^2
T	thrust force, lb
T_{PW}	thrust in pipe wall, lb/ft
T_{CR}	critical time, second
T_f	temperature factor
t	wall thickness, in
t	net pipe wall thickness, in (ductile iron pipe)
t_1	minimum manufacturing thickness, in (ductile iron pipe)
t_n	nominal pipe wall thickness, in (ductile iron pipe)

W	total load on span, lb
$\mathbf{W_L}$	wheel load per linear foot of pipe, lb/ft
$\mathbf{W_S}$	soil load per linear foot of pipe, lb/ft
$\mathbf{W_V}$	vacuum load per linear foot of pipe, lb/ft
w	load of pipe filled with liquid, lb/in
y	maximum deflection at the center of span, in
α	coefficient of thermal expansion, in/in/°F
β	saddle angle, degrees
Δ**/D**	percent deflection expressed as a decimal
Δ**T**	change in temperature, °F
Δ**V**	change in velocity of fluid, ft/s
Δ**Y**	vertical change in diameter, in
ε	maximum combined strain in pipe wall because of ring bending
$\varepsilon/_{\mathbf{all}}$	allowable strain in pipe wall
$\varepsilon_{\mathbf{h}}$	strain in the pipe wall caused by hoop stress
$\varepsilon_{\mathbf{f}}$	strain in the pipe wall caused by bending or flexure
$\varepsilon_{\mathbf{h}}$	strain in the pipe wall caused by hoop stress
$\gamma_{\mathbf{s}}$	unit weight of soil, lb/ft^3
$\gamma_{\mathbf{w}}$	unit weight of water, 62.4 lb/ft^3
ρ	density of fluid, slugs/ft^3
θ	angle of pipe bed, degrees
σ	allowable long-term compressive stress, lb/in^2
ν	Poisson's ratio
Δ**L**	change in length, in
Δ**X/D**	percent deflection expressed as a decimal
Δ**y**	Vertical decrease in diameter, in
%Δ**X/D**	percent deflection

Appendix 52B Flexible Conduit Design Examples

Design Example 1 — Plastic Pipe

Problem: 12-inch diameter PVC pipe will be installed for an irrigation pipeline system. The pipe will be buried under 10 feet of soil. The maximum pressure (including surge pressure) in the pipe will be 110 pounds per square inch. The pipe is subject to farm equipment with wheel loads of 10,000 pounds. The excavation will be backfilled and minimally compacted with CL soils that have less than 25 percent coarse particles.



Assumptions:
1. The pipe is outside diameter controlled.
2. The PVC pipe will be PVC 2116 with a hydrostatic design basis of 3,200 pounds per square inch (see appendix 52C)
3. Assume unit weight of soil = 120 lb/ft^3
4. Slightly compacted CL soils, E' = 200 lb/in^2

Determine:
A. Dimension ratio (SDR for outside diameter controlled pipe) for the maximum pressure (including surge pressure)
B. External soil and wheel loads
C. Required wall area for external load
D. Deflection
E. Allowable buckling
F. Strain

Design example 1—Plastic pipe (continued)

Solution:

A. Dimension ratio (SDR for outside diameter controlled pipe) for maximum pressure (including surge pressure
Water pressure—From table 52C–3 of appendix 52–C, an SDR of 26 is required since a 12-inch PVC 2116 pipe with SDR of 26 has a working pressure of 125 lb/in^2, which is greater than the 110 lb/in^2 maximum pressure (including surge pressure).

B. External soil and wheel loads
From equation 52–17, soil pressure is

$$P_s = \gamma_s \times h$$

$$= 120 \times 10 = 1{,}200 \text{ lb/ft}^2$$

Wheel loading: From table 52C–3 of appendix 52–C, 12-inch PVC pipe with a SDR of 26 has a thickness, t=0.49 in. From equations 52–19 and 52–21:
Since $D_o - t < 2.67h \times 12$
$12.75 - 0.49 < 2.67\ (10) \times 12$
$12.26 < 320.4$

$$W_L = \frac{0.48 P_L I_f \left(\frac{D_o - t}{12}\right)^2}{2.67h^3}\left[\frac{2.67h}{\left(\frac{D_o - t}{12}\right)} - 0.5\right]$$

$$W_L = \frac{0.48(10{,}000)(1.0)\left(\frac{12.75 - 0.49}{12}\right)^2}{2.67(10)^3}\left[\frac{2.67(10)}{\left(\frac{12.75 - 0.49}{12}\right)} - 0.5\right]$$

$$W_L = 48 \text{ lb/ft of pipe}$$

$$P_w = \frac{W_L}{\left(\frac{D_o}{12}\right)} = \frac{48}{12.75/12} = 45 \text{ lb/ft}^2$$

Design pressure: $P = P_S + P_W + P_v$

$$= 1{,}200 + 45 + 0 = 1{,}245 \text{ lb/ft}^2$$

From equation 52–26:
Thrust:

$$T_{pw} = \frac{P \times \left(\frac{D_o}{12}\right)}{2}$$

$$T_{pw} = \frac{1{,}245 \times \frac{12.75}{12}}{2}$$

$$T_{pw} = 661 \text{ lb/ft of pipe}$$

Design example 1—Plastic pipe (continued)

C. Required wall area for external load
From equation 52–27:

$$A_{pw} = \frac{\left(\frac{T_{pw}}{12}\right)}{\sigma}$$

$$A_{pw} = \frac{\left(\frac{661}{12}\right)}{1{,}600}$$
, σ = 1,600 lb/in² from appendix 52C, table 52C, table 52C–1

A_{pw} = 0.034 in²/in

Wall area of 12-inch pipe with SDR of 26 using equation 52–28:

$$A_{pw} = \frac{(D_o - D_i)}{2} \quad \text{or t}$$

$$A_{pw} = t$$

$$A_{pw} = 0.49\ \text{in}^2/\text{in} > 0.034\ \text{in}^2/\text{in} \quad \text{O.K.}$$

D. Deflection
From equation 52–29, percent deflection for solid wall pipe is

$$\frac{\%\Delta X}{D} = \frac{(D_L P_S + P_L + P_V)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{2E}{\cdots}\right) + 0.061E'\right]}$$

$$\frac{\%\Delta X}{D} = \frac{\frac{[1.5(1{,}200) + 45 + 0]}{144}(0.1)(100)}{\left[\left(\frac{2(400{,}000)}{3(26-1)^{3'}}\right) + 0.061(200)\right]}$$

$$\frac{\%\Delta X}{D} = 4.38\% < \left(\frac{\%\Delta X}{D}\right)_{allowable} = 7.5\% \qquad \text{O.K.}$$

E. Allowable buckling pressure
From equation 52–33:

$$q_a = \frac{1}{FS}\left(32 R_w B' E' \frac{E_{long} I_{pw}}{D_o^{\ 3}}\right)^{1/2}$$

Design example 1—Plastic pipe (continued)

$$\frac{h}{\left(\frac{D_o}{12}\right)} = \frac{10}{\left(\frac{11.75}{12}\right)} = 9.41 > 2$$

where:

FS = 2.5

$R_w = 1.0$

$$B' = \frac{4\left(h^2 + \frac{D_o}{12}h\right)}{1.5\left(2h + \frac{D_o}{12}\right)^2} = \frac{4\left(120^2 + \left(\frac{12.75}{12}\right)10\right)}{1.5\left(2(10) + \frac{12.75}{12}\right)^2} = 0.66$$

$$I_{pw} = \frac{t^3}{12} = \frac{(0.49)^3}{12} = 0.0098 \text{ in}^4/\text{in}$$

From equation 52–34, the reduction factor for the allowable buckling pressure from the deflection of the pipe is

$$C = \left[\frac{\left(1 - \frac{\%\Delta X}{D}\frac{1}{100}\right)}{\left(1 + \frac{\%\Delta X}{D}\frac{1}{100}\right)^2}\right]^3$$

$$= \left[\frac{\left(1 - 4.38\frac{1}{100}\right)}{\left(1 + 4.38\frac{1}{100}\right)^2}\right]^3$$

$$= 0.676$$

The reduced allowable buckling pressure is

$$q_a C = 3{,}045 \times 0.676$$

$$= 2{,}058 \text{ lb/ft}^2 > 1{,}245 \text{ lb/ft}^2 \qquad \text{O.K.}$$

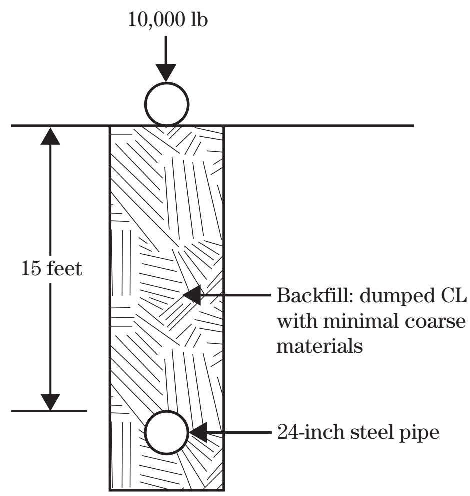
F. Strain

The allowable deflection for PVC pipe limits strain in PVC pipes. Therefore, computation of strain and comparison to an allowable strain limit is not required for PVC pipe.

Conclusion: A PVC pipe of PVC 2116 plastic with a DR of 26 should be installed and the backfill at least slightly compacted.

Design Example 2 — Steel Pipe

Problem: A 24-inch-diameter steel pipe will be installed for an irrigation pipeline system. The pipe will be buried under 15 feet of soil. The maximum pressure (including surge pressure) in the pipe will be 150 pounds per square inch. The pipe is subject to farm equipment with wheel loads of 10,000 pounds. The excavation will be backfilled with dumped CL soils with minimal coarse particles.



Assumptions:

1. The pipe is ASTM A-139 Grade A Steel, with a design stress at 50 percent of the yield stress of 15,000 lb/in^2
2. Assume unit weight of soil = 120 lb/ft^3
3. E' = 50 lb/in^2

Determine:

A. Required wall thickness of the pipe for the internal pressure
B. External soil and wheel loads
C. Deflection
D. Allowable buckling

Solution:

A. Internal pressure—The working pressure rating equation can be revised to compute the required thickness. From equation 52–5:

$$PR = \frac{2 \times S \times t}{D_o}$$

$$t = \frac{P \times D_o}{2 \times S}$$

$$t = \frac{150 \times 24}{2 \times 15,000} = 0.12 \text{ in}$$

Use 1/8- or 0.125-inch thick steel.

Design example 2—Steel pipe (continued)

B. External loads

From equations 52–17 and 52–18, soil pressure is

$$P_s = \gamma_s \times h$$
$$= 120 \times 15 = 1,800 \text{ lb/ft}^2$$
$$W_s = P_s \times \frac{D_o}{12}$$
$$= 1,800 \times \frac{24}{12} = 3,600 \text{ lb/ft} = 300 \text{ lb/in of pipe}$$

From equation 52–19 and 52–21, wheel loading is calculated using the following:

Since $D_o - t < 2.67h \times 12$
$24 - 0.125 < 2.67\ (15) \times 12$
$23.875 < 480$

$$W_L = \frac{0.48 P_L I_f \left(\frac{D_o - t}{12}\right)^2}{2.67h^3}\left[\frac{2.67h}{\frac{D_o - t}{12}} - 0.5\right]$$

$$W_L = \frac{0.48(10,000)(1.0)\left(\frac{24 - 0.125}{12}\right)}{2.67(15)^3}\left[\frac{2.67(15)}{\frac{24-0.125}{12}} - 0.5\right]$$

$$W_L = 41.4 \text{ lb/ft of pipe}$$

Design load:

$$W = W_s + W_L + W_V$$
$$= 3,600 + 41 + 0 = 3,641 \text{ lb/ft}$$
$$P_w = \frac{W_L}{\frac{D_o}{12}} = \frac{3,641}{\left(\frac{24}{12}\right)} = 1,820 \text{ lb/ft}^2$$

Design example 2—Steel pipe (continued)

C. Deflection of the steel pipe

From equation 52–41

$$\Delta X = \left(\frac{\left(D_L W_S + W_L + W_V\right)\left(\frac{1}{12}\right) K r^3}{E I_{pw} + 0.061 E' r^3} \right) \text{ and}$$

$$I_{pw} = \frac{t^3}{12} = \frac{0.125}{12}$$

$$= .000162 \text{ in}^4 / \text{in}$$

$$\Delta X = \left(\frac{\left[1.5(300) + 3.4 + 0\right]\left(\frac{1}{12}\right)(0.1)\left(\frac{24}{2}\right)^3}{(29{,}000{,}000)(.000162) + 0.061(50)\left(\frac{24}{2}\right)^3} \right)$$

$$= 7.8 \text{ in}$$

Percent deflection:

$$\% \frac{\Delta X}{D} = \frac{\Delta X}{D_0} \times 100 = \frac{7.8}{24} \times 100 = 32.7\% > 5\% \text{ for unlined pipe}$$

Since the deflection is excessive, try a wall thickness, t, of 3/16 in

$$I_{pw} = \frac{t^3}{12} = \frac{0.1875^3}{12} = 0.000549 \text{ in}^4 / \text{in}$$

$$\Delta X = \left[\frac{\left[1.5(3{,}600) + 41 + 0\right]\left(\frac{1}{12}\right)(0.1)\left(\frac{24}{2}\right)^3}{(29{,}000{,}000)(0.000549) + 0.061(50)\left(\frac{24}{2}\right)^3} \right]$$

$$= 3.69 \text{ in}$$

$$\% \frac{\Delta X}{D_o} = \frac{\Delta X}{D_o} \times 100$$

$$= \frac{3.69}{24} \times 100$$

$$= 15.4 > 5\% \quad \text{for an unlined pipe}$$

Design example 2—Steel pipe (continued)

Since the deflection is still excessive, try a wall thickness, t of 5/16 in

$$I_{pw} = \frac{t^3}{12}$$
$$= \frac{0.3125^3}{12}$$
$$= 0.00254 \text{ in}^4/\text{in}$$

$$\Delta X = \left[\frac{(1.5(3,600)+4.1+0)\left(\frac{1}{12}\right)(0.1)\left(\frac{24}{2}\right)^3}{(29,000,000)(0.00254)+0.061(50)\left(\frac{24}{2}\right)^3} \right]$$
$$= 0.99 \text{ in}$$

$$\%\frac{\Delta X}{D_o} = \frac{\Delta X}{D_o} \times 100$$
$$= \frac{0.99}{24} \times 100$$
$$= 4.1 < 5\%$$

for an unlined pipe, therefore $t = \frac{5}{16}$ is OK

D. Allowable buckling pressure
From equation 52–43:

$$q_a = \frac{1}{FS}\left(32R_w B'E' \frac{EI_{pw}}{D_o^{\,3}}\right)^{1/2}$$

where:

$$\frac{h}{\left(\frac{D_o}{12}\right)} = \frac{15}{12} = 7.5 \geq 2, \text{ so F.S. } 2.5$$

$$R_w = 1.0$$

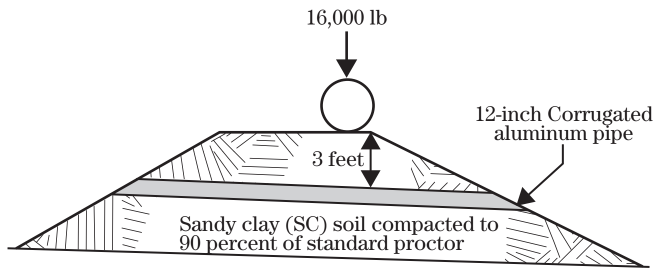
$$B' = \frac{1}{1+4e^{(-0.065h)}} = \frac{1}{1+4e^{(-0.065 \times 15)}} = 0.398$$

$$q_a = \frac{1}{2.5}\left(32(1.0)(0.398)(50)\frac{(29,000,000)(0.00254)}{(24)^3}\right)^{1/2}$$
$$= 23.3 \text{ lb/in}^2 = 3,355 \text{ lb/ft}^2 > 1,820 \text{ lb/ft}^2 \quad \text{O.K.}$$

Conclusion: The 24-inch steel pipe should be made of ASTM A 53, grade A steel or stronger with a minimum wall thickness of 5/16 inch.

Design Example 3—Corrugated Metal Pipe

Problem: A 12-inch corrugated aluminum pipe will be installed as outlet pipe in an earthen dam. The top of the pipe will be 3 feet below the top of the dam. The dam will be constructed of an SC material compacted to 90 percent of standard Proctor. Heavy traffic with wheel loads up to 16,000 pounds will cross the embankment.



Assumptions:
1. The pipe is made of aluminum with a minimum yield stress of 24,000 lb/in^2
2. Assume unit weight of soil = 120 lb/ft^3
3. E' = 400 lb/in^2
4. Assume D_o and D_i = 12 in

Determine:
A. External soil and wheel loading
B. Thrust
C. Required cross sectional area of 2 2/3 by 1/2 corrugated pipe
D. Check buckling
E. Check seam strength
F. Check flexibility factor

Solution:
A. External loads

From equation 52–17, soil pressure is

$$P_s = \gamma_s \times h$$

$$120 \times 3 = 360 \ lb/ft^2$$

Design example 3—Corrugated metal pipe (continued)

From equation 52–19 and 52–21, and assuming t=0.060 inch,

since $D_o - t < 2.67h \times 12$

$12 - 0.060 < 2.67\,(3) \times 12$

$11.94 < 96.1$

wheel loading is

$$W_L = \frac{0.48 P_L I_f \left(\frac{D_o - t}{12}\right)^2}{2.67h^3}\left[\frac{2.67(h)}{\left(\frac{D_o - t}{12}\right)} - 0.5\right]$$

$$W_L = \frac{0.48(16{,}000)(1.0)\left(\frac{12 - 0.060}{12}\right)^2}{2.67(3)^3}\left[\frac{2.67(3)}{\left(\frac{12 - 0.060}{12}\right)} - 0.5\right]$$

$$= 796 \text{ lb/ft of pipe}$$

$$P_W = \frac{W_L}{\left(\frac{D_o}{12}\right)} = \frac{796}{\frac{12}{12}} = 796 \text{ lb/ft}^2$$

Design pressure: $P = P_S + P_W + P_v$

$= 360 + 796 + 0 = 1{,}156 \text{ lb/ft}^2$

B. Thrust

From equation 52–45:

$$T_{pw} = \frac{P \times \frac{D_i}{12}}{2}$$

$$T_{pw} = \frac{1{,}156 \times \frac{12}{12}}{2}$$

$$T_{pw} = 578 \text{ lb/ft of pipe}$$

C. Required cross-sectional area from equation 52–46

$$A_s = \frac{T_{pw} \times FS}{f_y}$$

$$A_s = \frac{578 \times 2}{24{,}000}$$

$$A_s = 0.048 \text{ in}^2/\text{ft} < 0.775 \text{ in}^2/\text{ft for a 16 gage } (0.060 \text{ in thick})\ 2\frac{2}{3} \times \frac{1}{2} \text{ corrugations} \quad \text{O.K.}$$

Design example 3—Corrugated metal pipe (continued)

D. Buckling

From equation 52–47 and 52–48:

Since

$$D_i < \frac{r}{k}\sqrt{\frac{24E}{f_u}} = \frac{0.1712}{0.22}\sqrt{\frac{(24)10,000,000}{34,000}} = 65$$

$$f_c = f_u - \frac{f_u^{\,2}}{48E}\left(\frac{kD_i}{r}\right)^2$$

$$= 34,000 - \frac{34,000^2}{48(10,000,000)}\left(\frac{(0.22)12}{0.1712}\right)^2$$

$$= 33,427 \text{ lb/in}^2 > f_y \text{ of } 24,000 \text{ lb/in}^2 \text{ so wall area is O.K.}$$

E. Seam strength

From section 636.5204(c)(3), if helical lockseam or welded-seam (for steel) pipe is used, this criterion does not apply. For riveted corrugated pipe, using equation 52–51,

$SS = T_{pw} \times FS$

$SS = 578 \times 3.0 = 1{,}734$ lbf/ft < 9,000 lb/ft for single rivets
(from appendix 52D, table 52D–4)

F. Flexibility factor

From section 636.5204(c)(4):

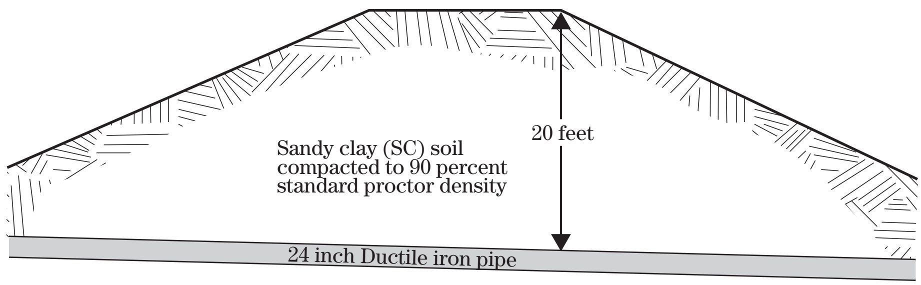
$$FF = \frac{D_i^{\,2}}{EI_{pw}} = \frac{12^2}{(10,000,000).001892}$$

$$= 0.0076 < 0.031 \text{ from appendix 52-E}$$

Conclusion: A 12-inch diameter, 16-gage, corrugated aluminum pipe with 2 2/3 x 1/2 corrugation is acceptable.

Design Example 4 — Ductile Iron Pipe

Problem: A 24-inch ductile iron pipe will be installed as the primary outlet pipe in an earthen dam. The top of the pipe will be 20 feet below the top of the dam. The dam will be constructed of an SC material compacted to 90 percent of the standard Proctor density.



Assumptions:

1. Assume unit weight of soil = 120 lb/ft^3.
2. Since the pipe will be installed in an embankment dam of SC soils, the design values for laying condition 3 will be used, E' = 400 lb/in^2, K_b = 0.189, and K_x = 0.103.
3. A nominal pipe thickness of 0.33 inch will be assumed since this is the minimum pipe thickness for 24-inch pipe as shown in appendix 52F.
4. The allowable ring deflection is 5 percent.

Determine:

A. External soil load
B. Check ring bending stress
C. Check ring deflection

Solution:

A. External loads

From equation 52–17, soil pressure is

$$P_s = \gamma_s \times h$$

$$120 \times 20 = 2{,}400 \text{ lb/ft}^2$$

From equation 52–18, design pressure is

$$P = P_S + P_W + P_v$$

$$= 2{,}400 + 0 + 0 = 2{,}400 \text{ lb/ft}^2$$

B. Ring bending stress

t_n = nominal thickness from appendix 52F – service allowance – casting tolerance

= 0.33 – 0.08 – 0.07 = 0.18 in.

Design example 4—Ductile iron pipe (continued)

From equation 52–53:

$$P_{bs} = \frac{f}{3\left(\frac{D_o}{t}\right)\left(\frac{D_o}{t}-1\right)\left[K_b - \frac{k_x}{\frac{8E}{E'\left(\frac{D_o}{t}-1\right)^3}+0.732}\right]}$$

$$P_{bs} = \frac{48,000}{3\left(\frac{24}{0.18}\right)\left(\frac{24}{0.18}-1\right)\left[0.189 - \frac{0.103}{\frac{8(24,000,000)}{400\left(\frac{24}{0.18}-1\right)^3}+0.732}\right]}$$

$$\begin{aligned} P_{bs} &= 11.43 \text{ lb/in}^2 \\ &= 11.43 \times 144 \\ &= 1,645 \text{ lb/ft}^2 \end{aligned}$$

Since 2,400 lb/ft² > 1,645 lb/ft², a thicker pipe wall is required. Assume a nominal pipe wall thickness of 0.43 in.

t_n = 0.43 – 0.08 – 0.07 = 0.28 in

$$P_{bs} = \frac{48,000}{3\left(\frac{24}{0.28}\right)\left(\frac{24}{0.28}-1\right)\left[0.189 - \frac{0.103}{\frac{8(24,000,000)}{400\left(\frac{24}{0.28}-1\right)^3}+0.732}\right]}$$

$$\begin{aligned} P_{bs} &= 18.16 \text{ lb/in}^2 \\ &= 18.16 \times 144 \\ &= 2,615 \text{ lb/ft}^2 \end{aligned}$$

Since 2,615>2,400 lb/ft² O.K.

C. Ring deflection

t_1 = nominal thickness from appendix 52–F (t_n) – casting tolerance
= 0.43 – 0.07
= 0.36 in

Design example 4—Ductile iron pipe (continued)

From equation 52–56:

$$P_{rd} = \frac{\frac{\Delta X}{D_o}}{12K_x}\left[\frac{8E}{\left(\frac{D_o}{t_1}-1\right)^3}+0.732E'\right]$$

$$P_{rd} = \frac{.05}{12(0.103)}\left[\frac{8(24,000,000)}{\left(\frac{24}{0.36}-1\right)^3}+0.732(400)\right]$$

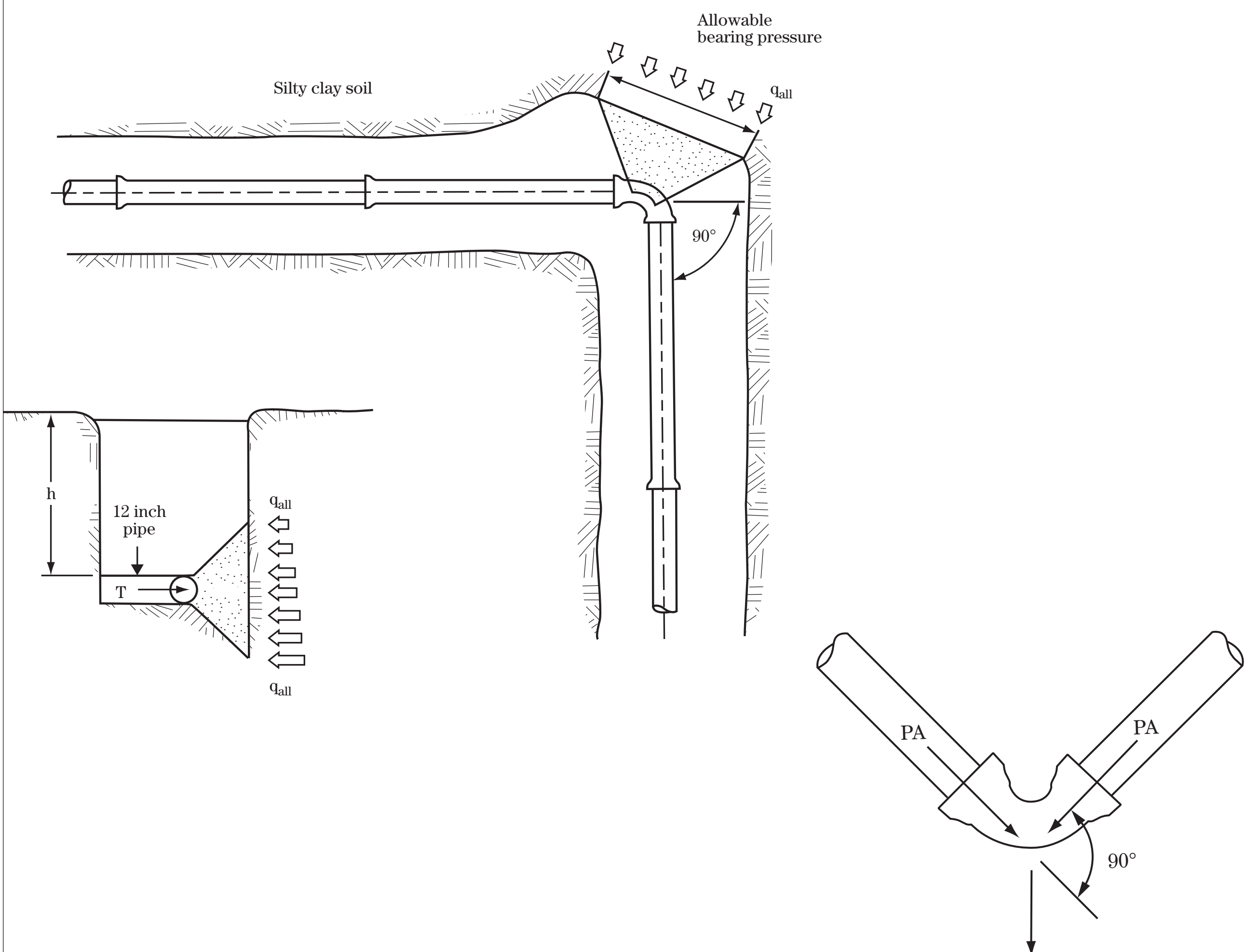
$$P_{rd} = 39\ \text{lb/in}^2 = 39\times 144 = 5,655\ \text{lb/ft}^2$$

$$P \le P_d \times 144$$

$$2,400 < 5,655\ \text{lb/ft}^2 \qquad \text{O.K.}$$

Design Example 5 — Thrust Block

Problem: A 12-inch diameter pipe will be installed for an irrigation pipeline system. The pipe will be buried under 4 feet of soil and include 90 degree bends. The working pressure in the pipe will be 50 pounds per square inch. The soil surrounding the trench consists of silty clay.



Assumptions:
1. The allowable bearing capacity will be estimated.
2. The center of the thrust block will be at the centerline of the pipe.

Determine:
A. Thrust force on the pipe bend
B. Allowable soil bearing pressure
C. Area of thrust block required

Design example 5—Thrust block (continued)

Solution:

A. Thrust force on the pipe bend
From figure 52–14, the thrust force on a bend may be estimated by:

$$T = 2PA\sin\left(\frac{\theta}{2}\right) = 2\times 50\times\frac{\pi\times 12^2}{4}\sin\left(\frac{90}{2}\right) = 7,993\text{ lb}$$

B. Allowable soil bearing pressure
The depth to the center of the thrust block is

$$h + \frac{D_o}{2} = 4 + \frac{12}{12\times 2} = 4.5\text{ ft}$$

From table 52–6 the allowable bearing capacity for silty clay soil at a depth of 4 feet is 950 lb/ft^2 and 1,200 lb/ft^2 at 5. The allowable bearing capacity at 4.5 feet may be determined by an average.

$$\frac{950 + 1,200}{2} = 1,075\text{ lb/ft}^2$$

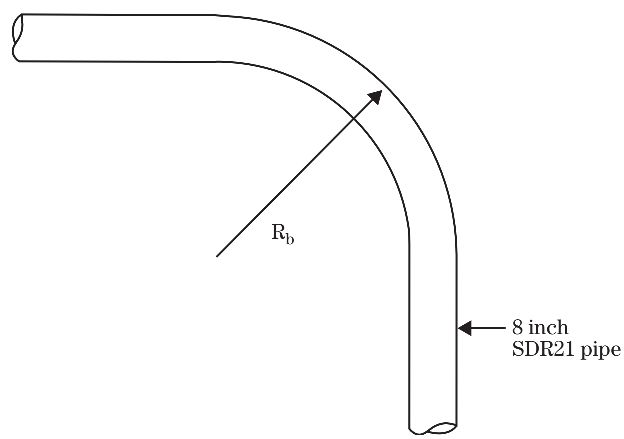
C. Area of thrust block required
From equation 52–75, the area of the thrust block required is:

$$A_T = \frac{T}{q_{all}} = \frac{7,993}{1,075} = 7.43\text{ ft}^2$$

Conclusion: The thrust block should be a minimum of 7.43 square feet. A block 2.75 feet by 2.75 feet would be sufficient to resist the thrust force at the 90 degree bends.

Design Example 6 — Longitudinal Bending

Problem: An 8-inch diameter HDPE pipe will be installed for an irrigation pipeline system. The alignment of the pipe requires a change of direction. It is desired to accomplish the change of direction by using the allowable longitudinal bending of the pipe. The pipe will have an internal pressure (including surge pressure) in the pipe of 80 pounds per square inch.



Assumptions:
1. The pipe material will be PE3408.
2. Since this is pressure pipe, it is fusion welded.
3. The pipe meets ASTM D 3035 and has a SDR of 21 to provide a pressure rating of 80 lb/in².
4. The modulus of elasticity of the HDPE is 110,000 lb/in².

Determine:
A. Allowable bending stress for the pipe
B. Minimum bending radius of the pipe

Solution:
A. Allowable bending stress
From table 52C–1, the hydrostatic design basis (HDB) is 1,600 lb/in².
From section 636.5208, the allowable bending stress is

$$S_{ball} = \frac{\left(HDB - \frac{HDB}{2}\right) \times T_f}{FS}$$

$$S_{ball} = \frac{\left(1{,}600 - \frac{1{,}600}{2}\right) \times 1}{2.0} = 400 \text{ lb/in}^2$$

Design example 6—Longitudinal bending (continued)

B. Minimum bending radius
From equation 52–76, the minimum bending radius is

$$R_b = \frac{ED_o}{2S_{ball}}$$

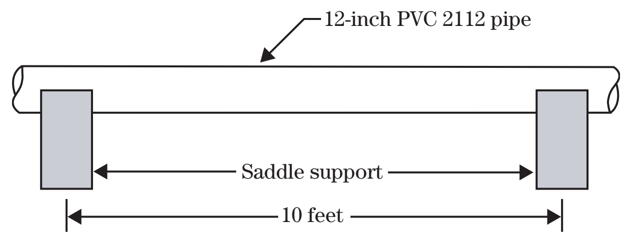
From appendix 52C, table 52C–5, the D_o = 8.625 inches

$$R_b = \frac{110,000 \times 8.625}{2 \times 400} = 1,185 \text{ in} = 98.8 \text{ ft}$$

Conclusion: The minimum longitudinal bending radius of the HDPE pipe made of PE3408 material with an SDR of 21 is 99 feet.

Design Example 7 — Aboveground Pipe

Problem: A 12-inch diameter PVC irrigation water supply pipe will be supported on concrete saddles. The pipe will have an internal pressure (including surge pressure) in the pipe of 60 pounds per square inch. It is desired to space a saddle support every 10 feet with the pipe restrained at both ends. The temperature of the water will vary by 30 degrees Fahrenheit.



Assumptions:
1. The pipe material will be PVC2112 with HDB of 2,500 lb/in^2.
2. Since this is pressure pipe, the joints are solvent cemented.
3. The pipe meets ASTM D 2241 and requires a SDR of 41 to provide a pressure rating of 60 lb/in^2 or greater.
4. The modulus of elasticity of the PVC is 400,000 lb/in^2, and long-term modulus of elasticity is 110,000 lb/in^2.
5. Conservatively assume density of PVC is equal to that of water.
6. The saddle angle will be 120 degrees.

Determine:
A. Maximum theoretical deflection and allowable deflection
B. Hoop stress caused by internal pressure
C. Bending stress because of unsupported length
D. Localized stress at the saddle
E. Stress caused by temperature change
F. Total stress at the saddle support
G. Allowable stress in the pipe wall

Solution:
A. Maximum theoretical deflection and allowable deflection
From table 52C–2, a 12-inch diameter, SDR 41 PVC pipe has a D_o = 12.240 inches and t = 0.299 inch.

From equation 52–64, the theoretical maximum deflection is

$$y = \frac{0.0130 \times w \times L_{span}^4}{E_{long} \times I}$$

w = weight of pipe filled with liquid

$$w = \frac{\pi D_o^{\ 2}}{4} \times \gamma_w = \frac{\pi \times 12.24^2}{4} \times \frac{62.4}{12^3} = 4.25 \text{ lb/in}$$

Design example 7—Aboveground pipe (continued)

$$I = \frac{\pi}{64}\left(D_o^{\,4} - D_i^{\,4}\right) = \frac{\pi}{64}\left[12.24^4 - \left(12.24 - 2\left(0.299\right)\right)^4\right] = 199 \text{ in}^4$$

$$y = \frac{0.0130 \times w \times L^4}{E_{long} \times I} = \frac{0.0130 \times 4.25 \times \left(10 \times 12\right)^4}{140,000 \times 199} = 0.41 \text{ in}$$

The maximum recommended deflection for PVC pipe is 0.50 percent of the span:

$$0.005 \times \left(10 \times 12\right) = 0.60 \text{ in} < 0.41 \text{ in}$$

B. Hoop stress from internal pressure
From equation 52–66, the hoop stress from internal pressure is

$$S_p = \frac{P \times D_i}{2 \times t} = \frac{60 \times \left(12.24 - 2\left(0.299\right)\right)}{2 \times 0.299} = 1,168 \text{ lb/in}^2$$

C. Bending stress caused by unsupported length
From equation 52–62, the bending stress caused by unsupported length is

$$S_b = \frac{0.0625 w L_{span}{}^2 D_o}{I} = \frac{0.0625 \times 4.25 \times \left[\left(10 \times 12\right)^2 \times 12.24\right]}{199} = 235 \text{ lb/in}^2$$

D. Localized stress at the saddle
From equation 52–67, the localized stress at the saddle is

$$S_l = k_{support} \frac{R_{support}}{t^2} \ln\left(\frac{R_o}{t}\right)$$

$$k_{support} = 0.02 - 0.00012\left(\beta - 90\right) = 0.02 - 0.00012\left(120 - 90\right) = 0.0164$$

$$R_{support} = \frac{wL_{span}}{2} = \frac{4.25 \times (10 \times 12)}{2} = 255 \text{ lb}$$

$$S_l = 0.0164 \frac{255}{0.299^2} \ln\left(\frac{\frac{12.24}{2}}{0.299}\right) = 141 \text{ lb/in}^2$$

E. Stress caused by temperature change
From section 636.5205 and table 52–5:

$$S_{EC} = E\alpha\Delta T = 400,000 \times .00003 \times 30 = 360 \text{ lb/in}^2$$

Design example 7—Aboveground pipe (continued)

F. Total stress at the saddle support from equation 52–69

$$S_T = vS_p + S_b + S_l + S_{EC} = 0.38 \times 1{,}168 + 235 + 141 + 360 = 1{,}179 \text{ lb/in}^2$$

G. Allowable stress in the pipe wall
From section 636.5206(e), allowable stress in the pipe wall is

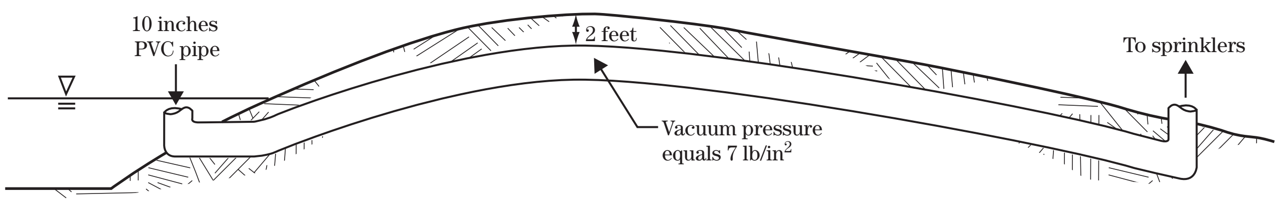
$$S_{all} = \frac{HDB \times T_f}{FS} = \frac{2{,}500 \times 1}{2} = 1{,}250 \text{ lb/in}^2$$

$$1{,}250 \text{ lb/in}^2 > 1{,}179 \text{ lb/in}^2 \qquad \text{O.K.}$$

Conclusion: A PVC pipe of PVC 2112 with SDR of 41 will span 10 feet with an acceptable allowable deflection and allowable stress in the pipe wall.

Design Example 8 — Plastic Pipe Siphon

Problem: A 10-inch diameter PVC plastic irrigation pipe (PIP) with SDR of 51 will be installed for an irrigation pipeline system. The pipe will be buried under 2 feet of soil. The line acts as a siphon with a vacuum pressure of 7 pounds per square inch. The excavation will be backfilled and slightly compacted to approximately 85 percent of the Standard Proctor with CL soils that have less than 25 percent coarse particles.



Assumptions:

1. The pipe has an outside diameter of 10.2 inches and thickness of 0.2 inch, from table 52C–2.
2. The PVC pipe will be PVC 1120.
3. PVC has a short-term modulus of elasticity of 400,000 pounds per square inch and a long-term modulus of elasticity of 140,000 pounds per square inch. The long-term value will be used for buckling since the loads and vacuum pressure are permanent.
4. Assume unit weight of soil = 100 pounds per cubic foot.
5. Slightly compacted CL soils, E'= 200 pounds per square inch.
6. Deflection lag factor for soil loads, D_L = 1.5.

Determine:

A. Soil pressure on the pipe
B. Percent deflection of the pipe caused by soil and vacuum pressure
C. Allowable buckling pressure
D. Reduced allowable buckling pressure

Solution:

A. Soil pressure on the pipe
From equation 52–17

$$P_S = \gamma_s \times h$$

$$100 \times 2 = 200 \text{ lb/ft}^2$$

$$P_v = 7 \text{ lb/in} = 7 \times 144 = 1,008 \text{ lb/ft}^2$$

Design example 8—Plastic pipe siphon (continued)

B. Percent deflection of the pipe from equation 52–29

$$\frac{\%\Delta X}{D} = \frac{\left(D_L P_s + P_L + P_v\right)\left(\frac{1}{144}\right)k\left(100\right)}{\left[\left(\frac{2E}{3\left(SDR-1\right)^3}\right)+0.061E'\right]}$$

$$\frac{\%\Delta X}{D} = \frac{\left(1.5\times 200+0+1{,}008\right)\left(\frac{1}{144}\right)\left(0.1\right)\left(100\right)}{\left[\left(\frac{2\left(400{,}000\right)}{3\left(51-1\right)^3}\right)+0.061\left(200\right)\right]}$$

$$\frac{\%\Delta X}{D} = 6.33\%$$

C. Allowable buckling pressure
From equation 52–33

$$q_a = \frac{1}{FS}\left(32R_w B'E'\frac{E_{Long}I_{pw}}{{D_o}^3}\right)^{\frac{1}{2}}$$

where:

$$\left(\frac{h}{\left(\frac{D_o}{12}\right)^2}\right) = \frac{2}{\frac{12}{10.2}} = 2.4 \geq 2 \text{ so F.S. } 2.5$$

$$R_w = 1.0$$

$$B' = \frac{4\left(h^2+\left(\frac{D_o}{12}\right)h\right)}{1.5\left(2h+\frac{D_o}{12}\right)^2} = \frac{4\left[2^2+\left(\frac{10.2}{12}\right)2\right]}{1.5\left(2^2+10.2\right)^2} = 0.640$$

$$I_{pw} = \frac{t^3}{12} = \frac{0.2^3}{12} = 0.00067 \text{ in}^4$$

$$q_a = \frac{1}{2.5}\left[32\left(1.0\right)\left(0.646\right)\left(200\right)\frac{\left(140{,}000\right)\left(0.00067\right)}{\left(10.20\right)^3}\right]^{\frac{1}{2}}$$

$$= 7.64 \text{ lb/in}^2$$

Design example 8—Plastic pipe siphon (continued)

D. Reduced allowable buckling pressure
From equation 52–34, the reduction factor for the allowable buckling pressure caused by deflection of the pipe is

$$C = \left[\frac{\left(1 - \frac{\%\Delta X}{D}\frac{1}{100}\right)}{\left(1 + \frac{\%\Delta X}{D}\frac{1}{100}\right)^2}\right]^3$$

$$= \left[\frac{\left(1 - 6.33\frac{1}{100}\right)}{\left(1 + 6.33\frac{1}{100}\right)^2}\right]^3$$

$$= 0.57$$

The reduced allowable buckling pressure caused by the deflected pipe is

$$q_aC = 7.64 \times 0.57$$

$$= 4.4 \text{ lb/in}^2 < P_s + P_v$$

$$P_s + P_v = 1.38 + 7$$

$$P_s + P_v = 8.38 \text{ lb/in}^2 > 4.4 \text{ lb/in}^2 \qquad \text{Not O.K.}$$

The PVC PIP with an SDR of 51 and backfilled as assumed does not provide adequate resistance to buckling. A higher quality backfill or pipe with a lower SDR (thicker wall) should be investigated. Try an SDR of 41 with t = 0.299 inch, from table 52C–2.

B1. Percent deflection of the SDR 41 pipe
From equation 52–29

$$\frac{\%\Delta X}{D} = \frac{(1.5 \times 200 + 0 + 1{,}008)\left(\frac{1}{144s}\right)(0.1)(100)}{\left[\left(\frac{2(400{,}000)}{3(41-1)^3}\right) + 0.061(200)\right]}$$

$$\frac{\%\Delta X}{D} = 5.54\%$$

Design example 8—Plastic pipe siphon (continued)

C1. Allowable buckling pressure of SDR 41 pipe

$$I_{pw} = \frac{t^3}{12}$$
$$= \frac{0.299^3}{12}$$
$$= 0.00223 \text{ in}^4$$

$$q_a = \frac{1}{2.5}\left[32(1.0)(0.646)(200)\frac{(140{,}000)(0.00223)}{(10.20)^3}\right]^{\frac{1}{2}}$$
$$= 13.9 \text{ lb/in}^2$$

D1. Reduced allowable buckling pressure of SDR 41 pipe
The reduction factor for the allowable buckling pressure from the deflection of the pipe is

$$C = \left[\frac{\left(1 - 5.54\frac{1}{100}\right)}{\left(1 + 5.54\frac{1}{100}\right)^2}\right]^3 = 0.61$$

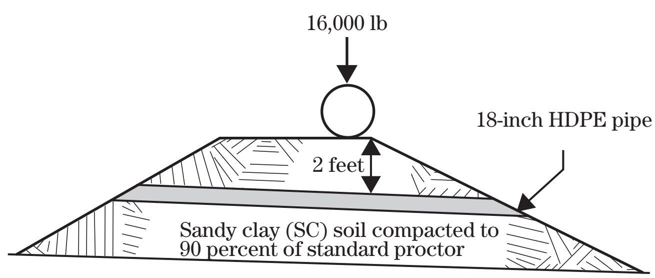
The reduced allowable buckling pressure caused by the deflected pipe is

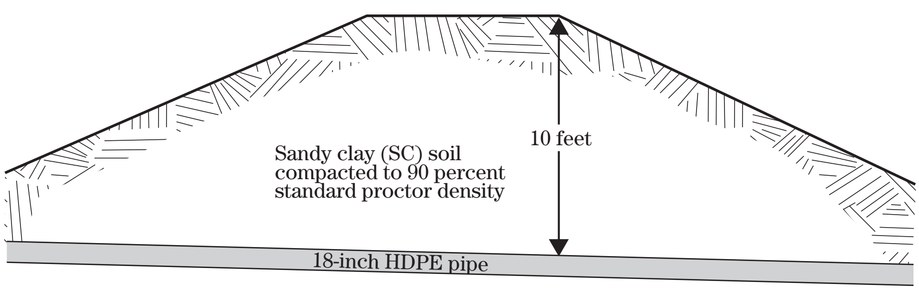
$$q_a C = 13.95 \times 0.61$$
$$= 8.5 \text{ lb/in}^2 > P_s + P_v$$
$$P_s + P_v = 1.38 + 7$$
$$= 8.38 \text{ lb/in}^2 < 8.5 \qquad \text{O.K.}$$

Conclusion: The PVC PIP with an SDR of 51 and backfilled as assumed does not provide adequate resistance to buckling. Using a lower SDR of 41 provides adequate resistance to buckling.

Design Example 9–Plastic Pipe During Construction

Problem: An 18-inch diameter HDPE pipe will be installed as an outlet pipe in an earthen dam. Heavy construction equipment with wheel loads up to 16,000 pounds will be allowed to traverse the pipe once 2 feet of fill has been placed over the top of the pipe. The top of the pipe will be 10 feet below the top of the completed dam. The dam will be constructed of an SC material compacted to 90 percent of the standard Proctor density.





Assumptions:
1. The pipe is outside diameter controlled.
2. The HDPE pipe will be PE 3408 with a Hydrostatic Design Basis of 1,600 lb/in^2 (see app. 52C)
3. Assume unit weight of soil = 120 lb/ft^3
4. Since the pipe will be installed in an embankment dam of SC soil, E'= 400 lb/in^2.
5. The allowable deflection is 5 percent.

Determine:
- A. External soil and wheel load during construction
- B. Required wall area for external load during construction
- C. Deflection during construction
- D. Allowable buckling during construction
- E. Strain during construction
- F. External soil load upon completion of the dam
- G. Required wall area for completed external load
- H. Deflection upon completion of the dam
- I. Allowable buckling upon completion of the dam
- J. Strain upon completion of the dam

Design example 9—Plastic pipe during construction (continued)

Solution: A. External soil and wheel load during construction

From equation 52-17, the soil pressure due to 2 feet of soil is

$$P_s = \gamma_s \times h$$
$$= 120 \times 2$$
$$= 240 \text{ lb/ft}^2$$

Wheel loading: From table 52C-5 of appendix 52C, an 18-inch PE pipe with a SDR of 17 has a thickness, t = 1.059 in. From section 636.5203 (b) and equations 52-19 and 52-21:

Since
$$D_o - t < 2.67h \times 12$$
$$18\text{-}1.161 < 2.67\ (2) \times 12$$
$$16.84 < 64.1$$

$$W_L = \frac{0.48 P_L I_f \left(\frac{D_o - t}{12}\right)^2}{2.67h^3}\left[\frac{2.67h}{\left(\frac{D_o - t}{12}\right)} - 0.5\right]$$

Since the depth of cover is 2.0, the I_f is 1.2.

$$W_L = \frac{0.48(16{,}000)(1.2)\left(\frac{18 - 1.059}{12}\right)^2}{2.67(2)^3}\left[\frac{2.67(2)}{\left(\frac{18 - 1.059}{12}\right)} - 0.5\right]$$

W_L = 2,822 lbs./ft of pipe

$$P_W = \frac{W_L}{\left(\frac{D_o}{12}\right)}$$
$$= \frac{2{,}822}{\frac{18}{12}} = 1{,}881 \text{ lb/ft}^2$$

Design Pressure :

$$P = P_S + P_W + P_v$$
$$= 240 + 1{,}881 + 0 = 2{,}121 \text{ lb/ft}^2$$

Design example 9—Plastic pipe during construction (continued)

From equation 52-26:
Thrust:

$$T_{pw} = \frac{P \times \left(\frac{D_o}{12}\right)}{2}$$

$$T_{pw} = \frac{2{,}121 \times \frac{18}{12}}{2}$$

$$T_{pw} = 1{,}591 \text{ lb/ft of pipe}$$

B. Required wall area for external load during construction
From equation 52-27:

$$A_{pw} = \frac{\frac{T_{pw}}{12}}{\sigma}$$

$$A_{pw} = \frac{\frac{1{,}591}{12}}{800}, \ \sigma = 800 \text{ lb/in}^2 \text{ from appendix 52C, table 52C-1}$$

$$A_{pw} = 0.166 \text{ in}^2/\text{in}$$

Area of an 18-inch pipe with SDR of 17 using equation 52–28

$$A_{pw} = \frac{(D_o - D_i)}{2} \text{ or t}$$

$$A_{pw} = t$$

$$A_{pw} = 1.059 \text{ in}^2/\text{in} > 0.166 \text{ in}^2/\text{in} \quad \text{O.K.}$$

C. Deflection during construction:

From equation 52-29, the percent deflection for solid wall pipe is:

$$\frac{\%\Delta X}{D} = \frac{(D_L P_S + P_W + P_V)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{2E}{3(SDR-1)^3}\right) + 0.061E'\right]}$$

$$\frac{\%\Delta X}{D} = \frac{(1.5(240) + 1881 + 0)\left(\frac{1}{144}\right)(0.1)(100)}{\left[\left(\frac{2(110{,}000)}{3(17-1)^3}\right) + 0.061(400)\right]}$$

$$\frac{\%\Delta X}{D} = 3.67\% < \left(\frac{\%\Delta}{D}\right)_{allowable} = 5\% \quad \text{O.K.}$$

Design example 9—Plastic pipe during construction—(continued)

D. Allowable buckling pressure during construction:
From equation 52-33 using the short-term modulus of elasticity since the wheel loads are short and intermittent:

$$q_a = \frac{1}{FS}\left(32R_w B'E'\frac{EI}{D^3}\right)^{1/2}$$

where: $\dfrac{h}{\left(\dfrac{D_o}{12}\right)} = \dfrac{2}{\left(\dfrac{18}{12}\right)} = 1.3 < 2$

F.S.=3.0

Rw=1.0

$$B' = \frac{4\left(h^2 + \left(\dfrac{D_0}{12}\right)h\right)}{1.5\left(2h + \dfrac{D_o}{12}\right)^2} = \frac{4\left(2^2 + \left(\dfrac{18}{12}\right)2\right)}{1.5\left(2*2 + \dfrac{18}{12}\right)^2} = 0.617$$

$$I_{pw} = \frac{t^3}{12} = \frac{1.059^3}{12} = 0.099 \text{ in}^4/\text{in}$$

$$q_a = \frac{1}{3.0}\left(32(1.0)(0.617)(400)\frac{(110{,}000)(0.099)}{(18)^3}\right)^{\frac{1}{2}}$$

$$= 40.5 \text{ lb/in}^2 = 5.829 \text{ lb/ft}^2$$

From equation 52-34, the reduction factor for the allowable buckling pressure from the deflection of the pipe is:

$$C = \left[\frac{\left(1 - \dfrac{\%\Delta X}{D}\dfrac{1}{100}\right)}{\left(1 + \dfrac{\%\Delta X}{D}\dfrac{1}{100}\right)^2}\right]^3$$

$$C = \left[\frac{\left(1 - 3.67\dfrac{1}{100}\right)}{\left(1 + 3.67\dfrac{1}{100}\right)^2}\right]^3$$

$C = 0.72$

The reduced allowable buckling pressure is

$$q_a C = 5{,}829 \times 0.72 = 4{,}197 \text{ lb/ft}^2 > P = 2{,}121 \text{ lb/ft}^2 \qquad \text{O.K.}$$

Design example 9—Plastic pipe during construction (continued)

E. Strain during construction

From equation 52-36, the hoop strain due to external load is:

$$\varepsilon_h = \frac{\frac{P}{144} D_M}{2tE} = \frac{\frac{P}{144} \times (18 - 1.059)}{2 \times 1.059 \times 110,000} = 0.011 \text{ in/in}$$

From equation 52-37, the maximum strain due to ring bending is:

$$\varepsilon_f = \frac{1}{SDR} \left(\frac{\frac{3\Delta Y}{D_M}}{1 - 2\frac{\Delta Y}{D_M}} \right) = \frac{1}{17} \left(\frac{3 \times 0.0367}{1 - 2(0.0367)} \right) = 0.007 \text{ in/in}$$

From equation 52-37, the combined strain is:

$$\varepsilon = \varepsilon_f \pm \varepsilon_h$$

Since the hoop strain is due to external load it is subtracted.

$$\varepsilon = 0.007 - 0.0011 = 0.006$$

$$\varepsilon = 0.006 < \varepsilon_{all} = 5\% = 0.05 \qquad \text{O.K.}$$

F. External soil load upon completion of the dam

From equation 52-17, the soil pressure due to 10 feet of soil is

$$P_s = \gamma_s \times h$$
$$= 120 \times 10 = 1,200 \text{ lb/ft}^2$$

Design Pressure :

$$P = P_s + P_w + P_v$$
$$= 1,200 + 0 + 0 = 1,200 \text{ lb/ft}^2$$

From equation 52-26:

Thrust: $$T_{pw} = \frac{P \times \left(\frac{D_o}{12}\right)}{2}$$

$$T_{pw} = \frac{1,200 \times \frac{18}{12}}{2}$$

$$T_{pw} = 900 \text{ lb/ft of pipe}$$

Design example 9—Plastic pipe during construction (continued)

G. Required wall area for completed external load:
From equation 52-27:

$$A_{pw} = \frac{\frac{T_{pw}}{12}}{\sigma}$$

$$A_{pw} = \frac{\frac{900}{12}}{800}, \sigma = 800 \text{ lb/in}^2 \text{ frm appendix 52C, table 52C-1}$$

$$A_{pw} = 0.094 \text{ in}^2\text{/in}$$

Area of an 18-inch pipe with SDR of 17 using equation 52-28:

$$A_{pw} = \frac{(D_o - D_i)}{2}$$

$$A_{pw} = t$$

$$A_{pw} = 1.059 \text{ in}^2\text{/in} > 0.094 \text{ in}^2\text{/in} \quad \text{O.K.}$$

H. Deflection upon completion of the dam:

From equation 52-29, the percent deflection for solid wall pipe is:

$$\frac{\%\Delta X}{D} = \frac{(D_L P_S + P_W + P_V)\left(\frac{1}{144}\right)K(100)}{\left[\left(\frac{2E}{3(SDR-1)^3}\right) + 0.061E'\right]}$$

$$\frac{\%\Delta X}{D} = \frac{(1.5(1200)+0+0)\left(\frac{1}{144}\right)(0.1)(100)}{\left[\left(\frac{2(110,000)}{3(17-1)^3}\right) + 0.061(400)\right]}$$

$$\frac{\%\Delta X}{D} = 2.95\% < \left(\frac{\%\Delta X}{D}\right)_{allowable} = 5\% \quad \text{O.K.}$$

Design example 9—Plastic pipe during construction (continued)

I. Allowable buckling pressure upon completion of the dam:

From equation 52-33 using the long term modulus of elasticity since the soil load is a permanent load.

$$q_a = \frac{1}{FS}\left(32R_w B'E'\frac{EI}{D^3}\right)^{1/2}$$

where:

$$\frac{h}{\left(\frac{D_o}{12}\right)} = \frac{10}{\left(\frac{18}{12}\right)} = 6.66 \geq 2$$

F.S. = 2.5

Rw =1.0

$$B' = \frac{4\left(h^2 + \left(\frac{D_0}{12}\right)h\right)}{1.5\left(2h + \frac{D_o}{12}\right)^2} = \frac{4\left(10^2 + \left(\frac{18}{12}\right)10\right)}{1.5\left(2*10 + \frac{18}{12}\right)^2} = 0.663$$

$$I_{pw} = \frac{t^3}{12} = \frac{1.059^3}{12} = 0.099 \text{ in}^4/\text{in}$$

$$q_a = \frac{1}{2.5}\left(32(1.0)(0.663)(400)\frac{(22,000)(0.099)}{(18)^3}\right)^{1/2}$$

$$= 22.5 \text{ lb/in}^2 = 3,242 \text{ lb/ft}^2$$

From equation 52-34, the reduction factor for the allowable buckling pressure from the deflection of the pipe is:

$$C = \left[\frac{\left(1 - \frac{\%\Delta X}{D}\frac{1}{100}\right)}{\left(1 + \frac{\%\Delta X}{D}\frac{1}{100}\right)^2}\right]^3$$

$$C = \left[\frac{\left(1 - 2.95\frac{1}{100}\right)}{\left(1 + 2.95\frac{1}{100}\right)^2}\right]^3$$

$$C = 0.77$$

The reduced allowable buckling pressure is

$$q_a C = 3,242 \times 0.77 = 2,496 \text{ lb/ft}^2 > P = 1,200 \text{ lb/ft}^2 \quad \text{O.K.}$$

Design example 9—Plastic pipe during construction (continued)

J. Strain upon completion of the dam

From equation 52-36, the hoop strain due to external load is:

$$\varepsilon_h = \frac{\frac{P}{144} D_M}{2tE} = \frac{\frac{1,200}{144} \times (18 - 1.059)}{2 \times 1.059 \times 110,000} = 0.0006 \text{ in/in}$$

From equation 52-37, the maximum strain due to ring bending is:

$$\varepsilon_f = \frac{1}{SDR} \left(\frac{\frac{3\Delta Y}{D_M}}{1 - 2\frac{\Delta Y}{D_M}} \right) = \frac{1}{17} = 0.005 \text{ in/in}$$

From equation 52-37, the combined strain is:

$$\varepsilon = \varepsilon_f \pm \varepsilon_h$$

Since the hoop strain is due to external load it is subtracted.

$$\varepsilon = 0.005 - 0.0006 = 0.005$$
$$\varepsilon = 0.005 < \varepsilon_{all} = 5\% = 0.05 \qquad \text{O.K.}$$

Conclusion: An HDPE pipe of PE3408 with an SDR of 17 is acceptable for both the construction loads and final soil loads. NOTE: The construction loads are the most critical.

Appendix 52C Material Properties, Pressure Ratings, and Pipe Dimensions for Plastic Pipe

*(**Note:** The source of the information in this appendix is subject to periodic updating. The source documents should be referenced for any updated information.)*

Table 52C–1 Hydrostatic design basis, allowable long-term compressive stress, short-term hoop strength, and designation of plastic pipe

Plastic pipe material	Hydrostatic design basis (lb/in^2)	Allowable long-term compressive stress (lb/in^2)	Short-term hoop strength (lb/in^2)	Designation
PVC Type I, Grade 1 (12454-B)	4,000	2,000	6,400	PVC1120
PVC Type I, Grade 2 (12454-C)	4,000	2,000	6,400	PVC1220
PVC Type II, Grade 1 (14333-D)	4,000	2,000	6,400	PVC2120
PVC Type II, Grade 1 (14333-D)	3,200	1,600	5,000	PVC2116
PVC Type II, Grade 1 (14333-D)	2,500	1,250	5,000	PVC2112
PVC Type II, Grade 1 (14333-D)	2,000	1,000	5,000	PVC2110
ABS Type 1, Grade 2	1,600	800	3,300	ABS1208
ABS Type 1, Grade 2	2,000	1,000	5,240	ABS1210
ABS Type 2, Grade 1	2,700	1,350	6,600	ABS2112
ABS Type 1, Grade 3	3,200	1,600	6,000	ABS1316
PE Grade P 14	800	400	1,250	PE1404
PE Grade P 23	1,000	500	2,000	PE2305
PE Grade P 23	1,260	630	2,520	PE2306
PE Grade P 24	1,260	630	2,520	PE2406
PE Grade P 33	1,260	630	2,520	PE3306
PE Grade P 34	1,260	630	2,520	PE3406
PE Grade P 34	1,600	800	3,200	PE3408

Source: ASTM D 1527, D 1785, D 2104, D 2239, D 2241, D 2282, and D 3035.

Table 52C–2 PVC plastic irrigation pipe (PIP)

Nominal pipe size (in)	SDR/ pressure head	PVC pressure rating (lb/in²) Material 1120 1220	2116	2112	2110	Dimension and tolerance: Wall thickness minimum (in)	Wall thickness tolerance (in)	Outside diameter average (in)	± tolerance average OD (in)	± tolerance max & min (in)
4	50 ft	22				0.065	+0.020	4.134	0.009	0.050
	81	50	40	30	25	0.065	+0.020			
	51	80	63	50	40	0.081	+0.020			
	41	100	80	63	50	0.101	+0.020			
	32.5	125	100	80	63	0.127	+0.020			
	26	160	125	100	80	0.159	+0.020			
6	50 ft	22				0.070	+0.020	6.140	0.011	0.050
	100 ft	44				0.070	+0.020			
	81	50	40	30	25	0.076	+0.020			
	51	80	63	50	40	0.120	+0.020			
	41	100	80	63	50	0.150	+0.020			
	32.5	125	100	80	63	0.189	+0.023			
	26	160	125	100	80	0.236	+0.028			
8	50 ft.	22				0.080	+0.020	8.160	0.015	0.075
	100 ft	44				0.087	+0.020			
	81	50	40	30	25	0.101	+0.020			
	51	80	63	50	40	0.160	+0.020			
	41	100	80	63	50	0.199	+0.024			
	32.5	125	100	80	63	0.251	+0.031			
	26	160	125	100	80	0.314	+0.038			
10	50 ft	22				0.100	+0.020	10.200	0.015	0.075
	100 ft	44				0.109	+0.020			
	81	50	40	30	25	0.126	+0.020			
	51	80	63	50	40	0.200	+0.024			
	41	100	80	63	50	0.240	+0.030			
	32.5	125	100	80	63	0.314	+0.038			
	26	160	125	100	80	0.392	+0.047			
12	50 ft	22				0.120	+0.020	12.240	0.015	0.070
	100 ft	44				0.131	+0.020			
	81	50	40	30	25	0.151	+0.020			
	51	80	63	50	40	0.240	+0.029			
	41	100	80	63	50	0.299	+0.036			
	32.5	125	100	80	63	0.377	+0.045			
	26	160	125	100	80	0.471	+0.056			
14	51	80	63	50	40	0.280	+0.034	14.280	0.015	0.075
	41	100	80	63	50	0.348	+0.042			
	32.5	125	100	80	63	0.439	+0.053			
	26	160	125	100	80	0.549	+0.066			

Table 52C–2 PVC plastic irrigation pipe (PIP)—Continued

Nominal pipe size (in)	SDR/ pressure head	PVC pressure rating (lb/in^2) Material 1120 1220	2116	2112	2110	Dimension and tolerance — Wall thickness minimum (in)	Wall thickness tolerance (in)	Outside diameter average (in)	± tolerance average OD (in)	± tolerance max & min (in)
15	50 ft	22				0.150	+0.020	15.3	0.016	0.075
	100 ft	44				0.164	+0.020			
	81	50	40	30	25	0.189	+0.023			
	51	80	63	50	40	0.300	+0.042			
	41	100	80	63	50	0.373	+0.052			
	32.5	125	100	80	63	0.437	+0.052			
	32.5	125	100	80	63	0.471	+0.056			
	26	160	125	100	80	0.588	+0.070			
	21	200	160	125	100	0.728	+0.087			
18	100 ft	44				0.200	+0.024	18.701	0.020	0.075
	81	50	40	30	25	0.231	+0.028			
	51	80	63	50	40	0.366	+0.051			
	41	100	80	63	50	0.456	+0.064			
	32.5	125	100	80	63	0.534	+0.064			
	32.5	125	100	80	63	0.575	+0.069			
	26	160	125	100	80	0.719	+0.086			
21	100 ft	44				0.236	+0.028	22.047	0.025	0.075
	81	50	40	30	25	0.272	+0.033			
	51	80	63	50	40	0.432	+0.060			
	41	100	80	63	50	0.538	+0.075			
	32.5	125	100	80	63	0.630	+0.076			
	32.5	125	100	80	63	0.678	+0.081			
	26	160	125	100	80	0.848	+0.102			
24	100 ft	44				0.266	+0.032	24.803	0.032	0.075
	81	50	40	30	25	0.306	+0.037			
	51	80	63	50	40	0.486	+0.068			
	41	100	80	63	50	0.605	+0.085			
	32.5	100	80	63	50	0.709	+0.085			
	32.5	125	100	80	63	0.763	+0.092			
	26	160	125	100	80	0.954	0.115			
27	51	80	63	50	40	0.548	+0.077	27.953	0.038	0.075
	41	100	80	63	50	0.682	+0.095			
	32.5	125	100	80	63	0.799	+0.096			
	32.5	125	100	80	63	0.860	+0.103			
	26	160	125	100	80	1.075	+0.129			

Source: ASTM D 2241 and ASAE S376.2

Note: PIP pipe sizes in the source documents were developed from Soil Conservation Service Practice Standards 430DD and 430EE, whic have been rescinded.

Table 52C–3 PVC and ABS thermoplastic pipe (SDR-PR)-(IPS) (nonthreaded)

Nominal pipe size (in)	SDR	PVC pressure rating (lb/in²) Material 1120 1220 2120	2116	2112	2110	Dimension and tolerance: Wall thickness min. (in)	toler-ance (in)	Outside diameter average (in)	±tolerance avg OD (in)	±tolerance max & min (in)	ABS pressure rating (lb/in²) Material 1316	2112	1210	1208
1/8	13.5	315	250	200	160	0.060	+0.020	0.405	0.004	0.008	250	200	160	125
1/4	13.5	315	250	200	160	0.060	+0.020	0.540	0.004	0.008	250	200	160	125
3/8	13.5	315	250	200	160	0.060	+0.020	0.675	0.004	0.008	250	200	160	125
1/2	17	250	200	160	125	0.060	+0.020	0.840	0.004	0.008	200	160	125	100
	13.5	315	250	200	160	0.062	+0.020			0.008	250	200	160	125
3/4	21	200	160	125	100	0.060	+0.020	1.050	0.004	0.015	160	125	100	80
	17	250	200	160	125	0.062	+0.020			0.010	200	160	125	100
	13.5	315	250	200	160	0.078	+0.020			0.010	250	200	160	125
1	26	160	125	100	80	0.060	+0.020	1.315	0.005	0.015	125	100	80	
	21	200	160	125	100	0.063	+0.020			0.015	160	125	100	80
	17	250	200	160	125	0.077	+0.020			0.010	200	160	125	100
	13.5	315	250	200	160	0.097	+0.020			0.010	250	200	160	125
1 1/4	32.5	125	100	80	63	0.060	+0.020	1.660	0.005	0.015				
	26	160	125	100	80	0.064	+0.020			0.015	125	100	80	
	21	200	160	125	100	0.079	+0.020			0.015	160	125	100	80
	17	250	200	160	125	0.098	+0.020			0.012	200	160	125	100
	13.5	315	250	200	160	0.123	+0.020			0.012	250	200	160	125
1 1/2	32.5	125	100	80	63	0.060	+0.020	1.900	0.006	0.030				
	26	160	125	100	80	0.073	+0.020			0.030	125	100	80	
	21	200	160	125	100	0.090	+0.020			0.030	160	125	100	80
	17	250	200	160	125	0.112	+0.020			0.012	200	160	125	100
	13.5	315	250	200	160	0.141	+0.020			0.012	250	200	160	125
2	32.5	125	100	80	63	0.073	+0.020	2.375	0.006	0.030				
	26	160	125	100	80	0.091	+0.020			0.030	125	100	80	
	21	200	160	125	100	0.113	+0.020			0.030	160	125	100	80
	17	250	200	160	125	0.140	+0.020			0.012	200	160	125	100
	13.5	315	250	200	160	0.176	+0.020			0.012	250	200	160	125
2 1/2	32.5	125	100	80	63	0.088	+0.020	2.875	0.007	0.030				
	26	160	125	100	80	0.110	+0.020			0.030	125	100	80	
	21	200	160	125	100	0.137	+0.020			0.030	160	125	100	80
	17	250	200	160	125	0.169	+0.020			0.015	200	160	125	100
	13.5	315	250	200	160	0.213	+0.026			0.015	250	200	160	125
3	41	100	80	63	50	0.085	+0.020	3.500	0.008	0.030				
	32.5	125	100	80	63	0.108	+0.020			0.030				
	26	160	125	100	80	0.135	+0.020			0.030	125	100	80	
	21	200	160	125	100	0.167	+0.020			0.030	160	125	100	80
	17	250	200	160	125	0.206	+0.025			0.015	200	160	125	100
	13.5	315	250	200	160	0.259	+0.031			0.015	250	200	160	125

Table 52C–3 PVC and ABS thermoplastic pipe (SDR-PR)-(IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PVC pressure rating (lb/in^2) — Material 1120 1220 2120	2116	2112	2110	Dimension and tolerance — Wall thickness min. (in)	Wall thickness tolerance (in)	Outside diameter average (in)	±tolerance avg OD (in)	±tolerance max & min (in)	ABS pressure rating (lb/in^2) — Material 1316	2112	1210	1208
3 ½	41	100	80	63	50	0.098	+0.020	4.000	0.008	0.050				
	32.5	125	100	80	63	0.123	+0.020			0.050				
	26	160	125	100	80	0.154	+0.020			0.050	125	100	80	
	21	200	160	125	100	0.190	+0.023			0.050	160	125	100	80
	17	250	200	160	125	0.235	+0.028			0.015	200	160	125	100
	13.5	315	250	200	160	0.296	+0.036			0.015	250	200	160	125
4	64	63	50			0.070	+0.020	4.500	0.009	0.050				
	41	100	80	63	50	0.110	+0.020			0.050				
	32.5	125	100	80	63	0.138	+0.020			0.050				
	26	160	125	100	80	0.173	+0.020			0.050	125	100	80	
	21	200	160	125	100	0.214	+0.026			0.050	160	125	100	80
	17	250	200	160	125	0.265	+0.032			0.015	200	160	125	100
	13.5	315	250	200	160	0.333	+0.040			0.015	250	200	160	125
5	64	63	50			0.087	+0.020	5.563	0.010	0.050				
	41	100	80	63	50	0.136	+0.020			0.050				
	32.5	125	100	80	63	0.171	+0.021			0.050				
	26	160	125	100	80	0.214	+0.027			0.050	125	100	80	
	21	200	160	125	100	0.265	+0.032			0.050	160	125	100	80
	17	250	200	160	125	0.327	+0.039			0.030	200	160	125	100
	13.5	315	250	200	160	0.412	+0.049			0.030	250	200	160	125
6	64	63	50			0.104	+0.020	6.625	0.011	0.050				
	41	100	80	63	50	0.162	+0.020			0.050				
	32.5	125	100	80	63	0.204	+0.024			0.050				
	26	160	125	100	80	0.255	+0.031			0.050	125	100	80	
	21	200	160	125	100	0.316	+0.038			0.050	160	125	100	80
	17	250	200	160	125	0.390	+0.047			0.035	200	160	125	100
	13.5	315	250	200	160	0.491	+0.059			0.035	250	200	160	125
8	64	63	50			0.135	+0.020	8.625	0.015	0.075				
	41	100	80	63	50	0.210	+0.025			0.075				
	32.5	125	100	80	63	0.265	+0.032			0.075				
	26	160	125	100	80	0.332	+0.040			0.075	125	100	80	
	21	200	160	125	100	0.410	+0.049			0.045	160	125	100	80
	17	250	200	160	125	0.508	+0.061			0.045				
10	64	63	50			0.168	+0.020	10.750	0.015	0.075				
	41	100	80	63	50	0.262	+0.031			0.075				
	32.5	125	100	80	63	0.331	+0.040			0.075				
	26	160	125	100	80	0.413	+0.050			0.075	125	100	80	
	21	200	160	125	100	0.511	+0.061			0.050	160	125	100	80
	17	250	200	160	125	0.632	+0.076			0.050				

Table 52C–3 PVC and ABS thermoplastic pipe (SDR-PR)-(IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PVC pressure rating (lb/in^2) Material 1120 1220 2120	2116	2112	2110	Dimension and tolerance: Wall thickness min. (in)	Wall thickness tolerance (in)	Outside diameter average (in)	±tolerance avg OD (in)	±tolerance max & min (in)	ABS pressure rating (lb/in^2) Material 1316	2112	1210	1208
12	64	63	50			0.199	+0.024	12.750	0.015	0.075				
	41	100	80	63	50	0.311	+0.037			0.075				
	32.5	125	100	80	63	0.392	+0.047			0.075				
	26	160	125	100	80	0.490	+0.059			0.075	125	100	80	
	21	200	160	125	100	0.606	+0.073			0.075	160	125	100	80
	17	250	200	160	125	0.750	+0.090			0.060				
14	41	100	80	63	50	0.341	+0.048	14.000	0.015	0.100				
	32.5	125	100	80	63	0.430	+0.052			0.100				
	26	160	125	100	80	0.538	+0.064			0.100				
	21	200	160	125	100	0.666	+0.080			0.100				
	17	250	200	160	125	0.823	+0.099			0.075				
16	41	100	80	63	50	0.390	+0.055	16.000	0.019	0.160				
	32.5	125	100	80	63	0.492	+0.059			0.160				
	26	160	125	100	80	0.615	+0.074			0.160				
	21	200	160	125	100	0.762	+0.091			0.160				
	17	250	200	160	125	0.941	+0.113			0.080				
18	41	100	80	63	50	0.439	+0.061	18.000	0.019	0.180				
	32.5	125	100	80	63	0.554	+0.066			0.180				
	26	160	125	100	80	0.692	+0.083			0.180				
	21	200	160	125	100	0.857	+0.103			0.180				
	17	250	200	160	125	1.059	+0.127			0.090				
20	41	100	80	63	50	0.488	+0.068	20.000	0.023	0.200				
	32.5	125	100	80	63	0.615	+0.074			0.200				
	26	160	125	100	80	0.769	+0.092			0.200				
	21	200	160	125	100	0.952	+0.114			0.200				
	17	250	200	160	125	1.176	+0.141			0.100				
24	41	100	80	63	50	0.585	+0.082	24.000	0.031	0.240				
	32.5	125	100	80	63	0.738	+0.088			0.240				
	26	160	125	100	80	0.923	+0.111			0.240				
	21	200	160	125	100	1.143	+0.137			0.240				
	17	250	200	160	125	1.412	+0.169			0.120				
30	41	100	80	63	50	0.732	+0.123	30.000	0.041	0.300				
	32.5	125	100	80	63	1.108	+0.133			0.300				
	26	160	125	100	80	1.385	+0.166			0.300				
	21	200	160	125	100	1.714	+0.205			0.300				
	17	250	200	160	125	2.118	+0.254			0.150				

Table 52C–3 PVC and ABS thermoplastic pipe (SDR-PR)-(IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PVC pressure rating (lb/in²) — Material 1120 1220 2120	2116	2112	2110	Dimension and tolerance — Wall thickness min. (in)	toler- ance (in)	Outside diameter average (in)	±tolerance avg OD (in)	max & min (in)	ABS pressure rating (lb/in²) — Material 1316	2112	1210	1208
36	41	100	80	63	50	0.878	+0.123	36.000	0.050	0.360				
	32.5	125	100	80	63	1.108	+0.133			0.360				
	26	160	125	100	80	1.385	+0.166			0.360				
	21	200	160	125	100	1.714	+0.205			0.360				
	17	250	200	160	125	2.118	+0.254			0.180				

Source: ASTM D 2241 and D 2282.

Table 52C–4 Polyethylene plastic pipe (SIDR-PR)–I.D. controlled (nonthreaded)

Nominal pipe size (in)	SIDR	PE pressure rating (lb/in²) Material 3408	3306 3406 2306 2406	2305	1404	Dimension and tolerance: Wall thickness min. (in)	Wall thickness tolerance (in)	Inside diameter average (in)	±tolerance + (in)	±tolerance − (in)
1/2	19	80				0.060	+0.020	0.622	0.010	0.010
	15	100	80			0.060	+0.020			
	11.5	125	100	80		0.060	+0.020			
	9	160	125	100	80	0.069	+0.020			
	7	200	160	125	100	0.089	+0.020			
	5.3	250	200	160	125	0.117	+0.020			
3/4	19	80				0.060	+0.020	0.824	0.010	0.015
	15	100	80			0.060	+0.020			
	11.5	125	100	80		0.072	+0.020			
	9	160	125	100	80	0.092	+0.020			
	7	200	160	125	100	0.118	+0.020			
	5.3	250	200	160	125	0.155	+0.020			
1	19	80				0.060	+0.020	1.049	0.010	0.020
	15	100	80			0.070	+0.020			
	11.5	125	100	80		0.091	+0.020			
	9	160	125	100	80	0.117	+0.020			
	7	200	160	125	100	0.150	+0.020			
	5.3	250	200	160	125	0.198	+0.024			
1 1/4	19	80				0.073	+0.020	1.380	0.010	0.020
	15	100	80			0.092	+0.020			
	11.5	125	100	80		0.120	+0.020			
	9	160	125	100	80	0.153	+0.020			
	7	200	160	125	100	0.197	+0.024			
	5.3	250	200	160	125	0.260	+0.031			
1 1/2	19	80				0.085	+0.020	0.230	0.015	0.020
	15	100	80			0.107	+0.020			
	11.5	125	100	80		0.140	+0.020			
	9	160	125	100	80	0.179	+0.020			
	7	200	160	125	100	0.230	+0.028			
	5.3	250	200	160	125	0.304	+0.036			
2	19	80				0.109	+0.020	2.067	0.015	0.020
	15	100	80			0.138	+0.020			
	11.5	125	100	80		0.180	+0.022			
	9	160	125	100	80	0.230	+0.028			
	7	200	160	125	100	0.295	+0.035			
	5.3	250	200	160	125	0.390	+0.047			
2 ½	19	80				0.130	+0.020	2.469	0.015	0.025
	15	100	80			0.165	+0.020			
	11.5	125	100	80		0.215	+0.025			

Table 52C–4 Polyethylene plastic pipe (SIDR-PR)–I.D. controlled (nonthreaded)—Continued

Nominal pipe size (in)	SIDR	PE pressure rating (lb/in^2) — Material: 3408	3306 3406 2306 2406	2305	1404	Dimension and tolerance — Wall thickness: min. (in)	tolerance (in)	Inside diameter: average (in)	±tolerance + (in)	±tolerance − (in)
3	19	80				0.161	+0.020	3.068	0.015	0.030
	15	100	80			0.205	+0.020			
	11.5	125	100	80		0.267	+0.032			
4	19	80				0.212	+0.025	4.026	0.015	0.035
	15	100	80			0.268	+0.032			
	11.5	125	100	80		0.350	+0.042			
6	19	80				0.319	+0.038	6.065	0.020	0.035
	15	100	80			0.404	+0.048			
	11.5	125	100	80		0.527	+0.063			

Source: ASTM D 2239

Table 52C–5 Polyethylene plastic pipe (SDR-PR)–O.D. controlled (IPS) (nonthreaded)

Nominal pipe size (in)	SDR	PE pressure rating (lb/in^2) — Material 3408	3306 3406 2306 2406	2305	1404	Wall thickness min. (in)	Wall thickness toler-ance (in)	Outside diameter average (in)	±tolerance + (in)	±tolerance − (in)
1/2	32.5	51	40	32	25	0.062	0.020	0.840	0.004	0.004
	26	64	50	40	32	0.062	0.020			
	21	80	63	50	40	0.062	0.020			
	17	100	79	63	50	0.062	0.020			
	15.5	110	87	69	55	0.062	0.020			
	13.5	128	100	80	64	0.062	0.020			
	11	160	126	100	80	0.076	0.020			
	9.3	193	152	120	96	0.090	0.020			
	9	200	158	125	100	0.093	0.020			
	7	267	210	167	133	0.120	0.020			
3/4	32.5	51	40	32	25	0.062	0.020	1.050	0.004	0.004
	26	64	50	40	32	0.062	0.020			
	21	80	63	50	40	0.062	0.020			
	17	100	79	63	50	0.062	0.020			
	15.5	110	87	69	55	0.068	0.020			
	13.5	128	100	80	64	0.078	0.020			
	11	160	126	100	80	0.095	0.020			
	9.3	193	152	120	96	0.113	0.020			
	9	200	158	125	100	0.117	0.020			
	7	267	210	167	133	0.150	0.020			
1	32.5	51	40	32	25	0.062	0.020	1.315	0.005	0.005
	26	64	50	40	32	0.062	0.020			
	21	80	63	50	40	0.063	0.020			
	17	100	79	63	50	0.077	0.020			
	15.5	110	87	69	55	0.084	0.020			
	13.5	128	100	80	64	0.097	0.020			
	11	160	126	100	80	0.120	0.020			
	9.3	193	152	120	96	0.141	0.020			
	9	200	158	125	100	0.146	0.020			
	7	267	210	167	133	0.188	0.023			
1 1/4	32.5	51	40	32	25	0.062	0.020	1.660	0.005	0.005
	26	64	50	40	32	0.064	0.020			
	21	80	63	50	40	0.079	0.020			
	17	100	79	63	50	0.098	0.020			
	15.5	110	87	69	55	0.107	0.020			
	13.5	128	100	80	64	0.123	0.020			
	11	160	126	100	80	0.151	0.020			
	9.3	193	152	120	96	0.178	0.021			
	9	200	158	125	100	0.184	0.022			
	7	267	210	167	133	0.237	0.028			

Table 52C–5 Polyethylene plastic pipe (SDR-PR)–O.D. controlled (IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PE pressure rating (lb/in^2) Material 3408	3306 3406 2306 2406	2305	1404	Wall thickness min. (in)	Wall thickness toler-ance (in)	Outside diameter average (in)	±tolerance + (in)	±tolerance – (in)
1 1/2	32.5	51	40	32	25	0.062	0.020	1.900	0.006	0.006
	26	64	50	40	32	0.073	0.020			
	21	80	63	50	40	0.090	0.020			
	17	100	79	63	50	0.112	0.020			
	15.5	110	87	69	55	0.123	0.020			
	13.5	128	100	80	64	0.141	0.020			
	11	160	126	100	80	0.173	0.021			
	9.3	193	152	120	96	0.204	0.024			
	9	200	158	125	100	0.211	0.025			
	7	267	210	167	133	0.271	0.033			
2	32.5	51	40	32	25	0.073	0.020	2.375	0.006	0.006
	26	64	50	40	32	0.091	0.020			
	21	80	63	50	40	0.113	0.020			
	17	100	79	63	50	0.140	0.020			
	15.5	110	87	69	55	0.153	0.020			
	13.5	128	100	80	64	0.176	0.021			
	11	160	126	100	80	0.216	0.026			
	9.3	193	152	120	96	0.255	0.031			
	9	200	158	125	100	0.264	0.032			
	7	267	210	167	133	0.339	0.041			
3	32.5	51	40	32	25	0.108	0.020	3.500	0.008	0.008
	26	64	50	40	32	0.135	0.020			
	21	80	63	50	40	0.167	0.020			
	17	100	79	63	50	0.206	0.025			
	15.5	110	87	69	55	0.226	0.027			
	13.5	128	100	80	64	0.259	0.031			
	11	160	126	100	80	0.318	0.038			
	9.3	193	152	120	96	0.376	0.045			
	9	200	158	125	100	0.389	0.047			
	7	267	210	167	133	0.500	0.060			
4	32.5	51	40	32	25	0.138	0.020	4.500	0.009	0.009
	26	64	50	40	32	0.173	0.021			
	21	80	63	50	40	0.214	0.026			
	17	100	79	63	50	0.265	0.032			
	15.5	110	87	69	55	0.290	0.035			
	13.5	128	100	80	64	0.333	0.040			
	11	160	126	100	80	0.409	0.049			
	9.3	193	152	120	96	0.484	0.058			
	9	200	158	125	100	0.500	0.060			
	7	267	210	167	133	0.643	0.077			

Table 52C–5 Polyethylene plastic pipe (SDR-PR)–O.D. controlled (IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PE pressure rating (lb/in^2) Material 3408	3306 3406 2306 2406	2305	1404	Dimension and tolerance: Wall thickness min. (in)	Wall thickness tolerance (in)	Outside diameter average (in)	±tolerance + (in)	±tolerance – (in)
5	32.5	51	40	32	25	0.171	0.021			
	26	64	50	40	32	0.214	0.026			
	21	80	63	50	40	0.265	0.032			
	17	100	79	63	50	0.327	0.039			
	15.5	110	87	69	55	0.359	0.043			
	13.5	128	100	80	64	0.412	0.049			
	11	160	126	100	80	0.506	0.061			
	9.3	193	152	120	96	0.598	0.072			
	9	200	158	125	100	0.618	0.074			
	7	267	210	167	133	0.795	0.095			
6	32.5	51	40	32	25	0.204	0.024	6.625	0.011	0.011
	26	64	50	40	32	0.255	0.031			
	21	80	63	50	40	0.315	0.038			
	17	100	79	63	50	0.390	0.047			
	15.5	110	87	69	55	0.427	0.051			
	13.5	128	100	80	64	0.491	0.059			
	11	160	126	100	80	0.602	0.072			
	9.3	193	152	120	96	0.712	0.085			
	9	200	158	125	100	0.736	0.088			
	7	267	210	167	133	0.946	0.114			
8	32.5	51	40	32	25	0.265	0.032	8.625	0.013	0.013
	26	64	50	40	32	0.332	0.040			
	21	80	63	50	40	0.411	0.049			
	17	100	79	63	50	0.507	0.061			
	15.5	110	87	69	55	0.556	0.067			
	13.5	128	100	80	64	0.639	0.077			
	11	160	126	100	80	0.784	0.094			
	9.3	193	152	120	96	0.927	0.111			
	9	200	158	125	100	0.958	0.115			
	7	267	210	167	133	1.232	0.147			
10	32.5	51	40	32	25	0.331	0.040	10.750	0.015	0.015
	26	64	50	40	32	0.413	0.050			
	21	80	63	50	40	0.512	0.061			
	17	100	79	63	50	0.632	0.076			
	15.5	110	87	69	55	0.694	0.083			
	13.5	128	100	80	64	0.796	0.096			
	11	160	126	100	80	0.977	0.117			
	9.3	193	152	120	96	1.156	0.139			
	9	200	158	125	100	1.194	0.143			
	7	267	210	167	133	1.536	0.184			

Table 52C–5 Polyethylene plastic pipe (SDR-PR)–O.D. controlled (IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PE pressure rating (lb/in^2) — Material 3408	3306 3406 2306 2406	2305	1404	Dimension and tolerance — Wall thickness min. (in)	Wall thickness toler-ance (in)	Outside diameter average (in)	±tolerance + (in)	±tolerance − (in)
12	32.5	51	40	32	25	0.392	0.047	12.750	0.017	0.017
	26	64	50	40	32	0.490	0.059			
	21	80	63	50	40	0.607	0.073			
	17	100	79	63	50	0.750	0.090			
	15.5	110	87	69	55	0.823	0.099			
	13.5	128	100	80	64	0.944	0.113			
	11	160	126	100	80	1.159	0.139			
	9.3	193	152	120	96	1.371	0.165			
	9	200	158	125	100	1.417	0.170			
	7	267	210	167	133	1.821	0.219			
14	32.5	51	40	32	25	0.431	0.052	14.000	0.063	0.063
	26	64	50	40	32	0.538	0.065			
	21	80	63	50	40	0.667	0.080			
	17	100	79	63	50	0.824	0.099			
	15.5	110	87	69	55	0.903	0.108			
	13.5	128	100	80	64	1.037	0.124			
	11	160	126	100	80	1.273	0.153			
	9.3	193	152	120	96	1.505	0.181			
	9	200	158	125	100	1.556	0.187			
	7	267	210	167	133	2.000	0.240			
16	32.5	51	40	32	25	0.492	0.059	16.000	0.072	0.072
	26	64	50	40	32	0.615	0.074			
	21	80	63	50	40	0.762	0.091			
	17	100	79	63	50	0.941	0.113			
	15.5	110	87	69	55	1.032	0.124			
	13.5	128	100	80	64	1.185	0.142			
	11	160	126	100	80	1.455	0.175			
	9.3	193	152	120	96	1.720	0.206			
	9	200	158	125	100	1.778	0.213			
	7	267	210	167	133	2.286	0.274			
18	32.5	51	40	32	25	0.554	0.066	18.000	0.081	0.081
	26	64	50	40	32	0.692	0.083			
	21	80	63	50	40	0.857	0.103			
	17	100	79	63	50	1.059	0.127			
	15.5	110	87	69	55	1.161	0.139			
	13.5	128	100	80	64	1.333	0.160			
	11	160	126	100	80	1.636	0.196			
	9.3	193	152	120	96	1.935	0.232			
	9	200	158	125	100	2.000	0.240			
	7	267	210	167	133	2.571	0.309			

Table 52C–5 Polyethylene plastic pipe (SDR-PR)–O.D. controlled (IPS) (nonthreaded)—Continued

Nominal pipe size (in)	SDR	PE pressure rating (lb/in^2) Material 3408	3306 3406 2306 2406	2305	1404	Dimension and tolerance Wall thickness min. (in)	toler-ance (in)	Outside diameter average (in)	±tolerance + (in)	− (in)
20	32.5	51	40	32	25	0.615	0.074	20.000	0.090	0.090
	26	64	50	40	32	0.769	0.092			
	21	80	63	50	40	0.952	0.114			
	17	100	79	63	50	1.176	0.141			
	15.5	110	87	69	55	1.290	0.155			
	13.5	128	100	80	64	1.481	0.178			
	11	160	126	100	80	1.818	0.218			
	9.3	193	152	120	96	2.151	0.258			
	9	200	158	125	100	2.222	0.267			
	7	267	210	167	133	2.857	0.343			
22	32.5	51	40	32	25	0.677	0.089	22.000	0.099	0.099
	26	64	50	40	32	0.846	0.102			
	21	80	63	50	40	1.048	0.126			
	17	100	79	63	50	1.294	0.155			
	15.5	110	87	69	55	1.419	0.170			
	13.5	128	100	80	64	1.630	0.196			
	11	160	126	100	80	2.000	0.240			
	9.3	193	152	120	96	2.366	0.284			
	9	200	158	125	100	2.444	0.293			
	7	267	210	167	133	3.143	0.377			
24	32.5	51	40	32	25	0.738	0.089	24.000	0.108	0.108
	26	64	50	40	32	0.923	0.111			
	21	80	63	50	40	1.143	0.137			
	17	100	79	63	50	1.412	0.169			
	15.5	110	87	69	55	1.548	0.186			
	13.5	128	100	80	64	1.778	0.213			
	11	160	126	100	80	2.182	0.262			
	9.3	193	152	120	96	2.581	0.310			
	9	200	158	125	100	2.667	0.320			
	7	267	210	167	133	3.429	0.411			

Source: ASTM D 3035

Table 52C–6a PVC schedule 40, 80, and 120 and ABS schedule 40, and 80 plastic pipe (unthreaded)

Nominal pipe size (in)	Sch.	PVC pressure rating (lb/in^2) - Material				Dimension and tolerance					ABS pressure rating (lb/in^2) - Material			
						Wall thickness		Outside diameter						
		1120 1220 2120	2116	2112	2110	min. (in)	tolerance (in)	average (in)	±tolerance avg OD (in)	±tolerance max & min (in)	1316	2112	1210	1208
1/8	40	810	650	500	400	0.068	+0.020	0.405	0.004	0.008	650	500	400	320
	80	1230	980	770	610	0.095	+0.020				980			
1/4	40	780	620	490	390	0.088	+0.020	0.540	0.004	0.008	620	490	390	310
	80	1130	900	710	570	0.119	+0.020				900			
3/8	40	620	500	390	310	0.091	+0.020	0.675	0.004	0.008	500	390	310	250
	80	920	730	570	460	0.126	+0.020				730			
1/2	40	600	480	370	300	0.109	+0.020	0.840	0.004	0.008	480	370	300	240
	80	850	680	530	420	0.147	+0.020				680	530	420	340
	120	1010	810	630	510	0.170	+0.020							
3/4	40	480	390	300	240	0.113	+0.020	1.050	0.004	0.010	390	300	240	190
	80	690	550	430	340	0.154	+0.020				550	430	340	280
	120	770	620	480	390	0.170	+0.020							
1	40	450	360	280	220	0.133	+0.020	1.315	0.005	0.010	360	280	220	180
	80	630	500	390	320	0.179	+0.021				500	390	320	250
	120	720	570	450	360	0.200	+0.024							
1 1/4	40	370	290	230	180	0.140	+0.020	1.660	0.005	0.012	290	230	180	150
	80	520	420	320	260	0.191	+0.023				420	330	260	210
	120	600	480	370	300	0.215	+0.026							
1 1/2	40	330	260	210	170	0.145	+0.020	1.900	0.006	0.012	260	210	170	130
	80	470	380	290	240	0.200	+0.024				380	290	240	190
	120	540	430	340	270	0.225	+0.027							
2	40	280	220	170	140	0.154	+0.020	2.375	0.006	0.012	220	170	140	110
	80	400	320	250	200	0.218	+0.026				320	250	200	160
	120	470	380	290	240	0.250	+0.030							
2 1/2	40	300	240	190	150	0.203	+0.024	2.875	0.007	0.015	240	190	150	120
	80	420	340	260	210	0.276	+0.033				340	270	210	170
	120	470	370	290	230	0.300	+0.036							
3	40	260	210	160	130	0.216	+0.026	3.500	0.008	0.015	210	160	130	100
	80	370	300	230	190	0.300	+0.036				300	230	190	150
	120	440	360	280	220	0.350	+0.042							
3 1/2	40	240	190	150	120	0.226	+0.027	4.000	0.008	0.050	190	150	120	90
	80	350	280	220	170	0.318	+0.038			0.015	280	220	170	140
	120	380	310	240	190	0.350	+0.042			0.015				
4	40	220	180	140	110	0.237	+0.028	4.500	0.009	0.050	180	140	110	90
	80	320	260	200	160	0.337	+0.040			0.015	260	200	160	130
	120	430	340	270	220	0.437	+0.052			0.015				

Table 52C–6a PVC schedule 40, 80, and 120 and ABS schedule 40, and 80 plastic pipe (unthreaded)—Continued

Nominal pipe size (in)	Sch.	PVC pressure rating (lb/in²) Material 1120 1220 2120	2116	2112	2110	Dimension and tolerance: Wall thickness min. (in)	Wall thickness toler-ance (in)	Outside diameter average (in)	±tolerance avg OD (in)	±tolerance max & min (in)	ABS pressure rating (lb/in²) Material 1316	2112	1210	1208
5	40	190	160	120	100	0.258	+0.031	5.563	0.010	0.050	160	120	100	80
	80	290	230	180	140	0.375	+0.045			0.030	230	180	140	120
	120	400	320	250	200	0.500	+0.060			0.030				
6	40	180	140	110	90	0.280	+0.034	6.625	0.011	0.050	140	110	90	70
	80	280	220	170	140	0.432	+0.052			0.035	220	170	140	110
	120	370	300	230	190	0.562	+0.067			0.035				
8	40	160	120	100	80	0.322	+0.039	8.625	0.015	0.075	120	100	80	60
	80	250	200	150	120	0.500	+0.060			0.075	200	150	120	100
	120	380	290	230	180	0.718	+0.086			0.045				
10	40	140	110	90	70	0.365	+0.044	10.750	0.015	0.075	110	90	70	60
	80	230	190	150	120	0.593	+0.071			0.075	190	150	120	90
	120	370	290	230	180	0.843	+0.101			0.050				
12	40	130	110	80	70	0.406	+0.049	12.750	0.015	0.075	110	80	70	50
	80	230	180	140	110	0.687	+0.082			0.075	180	140	110	90
	120	340	270	210	170	1.000	+0.120			0.060				
14	40	130	100	80	60	0.437	+0.053	14.000	0.015	0.100				
	80	220	180	140	110	0.750	+0.090							
16	40	130	100	80	60	0.500	+0.060	16.000	0.019	0.160				
	80	220	180	140	110	0.843	+0.101							
18	40	130	100	80	60	0.562	+0.067	18.000	0.019	0.180				
	80	220	180	140	110	0.937	+0.112							
20	40	120	100	80	60	0.593	+0.071	20.000	0.023	0.200				
	80	220	170	140	110	1.031	+0.124							
24	40	120	90	70	60	0.687	+0.082	24.000	0.031	0.240				
	80	210	170	130	110	1.218	+0.146							

Source: ASTM D 1785 for PVC and D 1527 for ABS.

Table 52C–6b PE schedule 40 and 80 plastic pipe (unthreaded)

Nominal pipe size (in)	Sch.	PE pressure rating (lb/in²) Material 2306 2406 3306 3406	PE pressure rating (lb/in²) Material 2305	PE pressure rating (lb/in²) Material 1404	Dimension and tolerance D2104 Inside diameter average (in)	Inside diameter ±tolerance + (in)	Inside diameter ±tolerance − (in)	Wall thickness min. (in)	Wall thickness tolerance (in)	D2447 Outside diameter average (in)	Outside diameter ±tolerance + (in)	Outside diameter ±tolerance − (in)	PE pressure rating (lb/in²) Material 2306 2406 3306 3406	PE pressure rating (lb/in²) Material 2305	PE pressure rating (lb/in²) Material 1404
1/2	40	190	150	120	0.622	0.010	0.010	0.109	+0.020	0.840	0.004	0.004	188	149	119
	80							0.147	+0.020				267	212	170
3/4	40	150	120	100	0.824	0.010	0.015	0.113	+0.020	1.050	0.004	0.004	152	120	96
	80							0.154	+0.020				217	172	137
1	40	140	110	90	1.049	0.010	0.020	0.133	+0.020	1.315	0.005	0.005	142	113	90
	80							0.179	+0.021				199	158	126
1 1/4	40	120	90	70	1.380	0.010	0.020	0.140	+0.020	1.660	0.005	0.005	116	92	74
	80							0.191	+0.023				164	130	104
1 1/2	40	100	80	70	1.610	0.015	0.020	0.145	+0.020	1.900	0.006	0.006	104	83	66
	80							0.200	+0.024				148	118	94
2	40	90	70	60	2.067	0.015	0.020	0.154	+0.020	2.375	0.006	0.006	87	69	55
	80							0.218	+0.026				127	101	81
2 1/2	40	100	80	60	2.469	0.015	0.025	0.203	+0.024	2.875	0.007	0.007	96	76	61
	80							0.276	+0.033				134	106	85
3	40	80	70	50	3.068	0.015	0.030	0.216	+0.026	3.500	0.008	0.008	83	66	53
	80							0.300	+0.036				118	94	75
3 1/2	40							0.226	+0.027	4.000	0.008	0.008	75	60	50
	80							0.318	+0.038				109	86	69
4	40	70	60	NPR	4.026	0.015	0.035	0.237	+0.028	4.500	0.009	0.009	70	55	NPR
	80							0.337	+0.040				102	81	65
5	40							0.258	+0.031	5.563	0.010	0.010	61	50	NPR
	80							0.375	+0.045				91	72	58
6	40	60	NPR	NPR	6.065	0.020	0.035	0.280	+0.034	6.625	0.011	0.011	55	NPR	NPR
	80							0.432	+0.052				88	70	56
8	40							0.322	+0.039	8.625	0.015	0.015	50	NPR	NPR
10	40							0.365	+0.044	10.750	0.015	0.015	NPR	NPR	NPR
12	40							0.406	+0.049	12.750	0.015	0.015	NPR	NPR	NPR

Source: ASTM D 2104 for inside diameter controlled and D 2447 for outside diameter controlled. NPR: Not Pressure Rated

Table 52C–7 Polyethylene plastic tubing

Nominal pipe size (in)	SDR	Pressure rating (lb/in^2) Material 3408	3306 3406 2306 2406	2305	Dimension and tolerance: Wall thickness min. (in)	toler-ance (in)	Outside diameter average (in)	±tolerance avg. OD (in)	max. & min. (in)
1/2	7.3			160	0.086	+0.010	0.625	0.004	0.015
	9	200	160		0.069	+0.010			
	11	160			0.062	+0.010			
5/8	7.3			160	0.103	+0.010	0.750	0.004	0.015
	9	200	160		0.083	+0.010			
	11	160			0.068	+0.010			
3/4	7.3			160	0.120	+0.012	0.875	0.004	0.015
	9	200	160		0.097	+0.010			
	11	160			0.080	+0.010			
1	7.3			160	0.154	+0.015	1.125	0.005	0.015
	9	200	160		0.125	+0.012			
	11	160			0.102	+0.010			
1 1/4	7.3			160	0.188	+0.019	1.375	0.005	0.015
	9	200	160		0.153	+0.015			
	11	160			0.125	+0.012			
1 1/2	7.3			160	0.233	+0.022	1.625	0.006	0.015
	9	200	160		0.181	+0.018			
	11	160			0.148	+0.015			
2	7.3			160	0.291	+0.029	2.125	0.006	0.015
	9	200	160		0.236	+0.024			
	11	160			0.193	+0.019			

Source: ASTM D 2737

Table 52C–8 PVC plastic pipe dimensions, pressure classes, SDR, and tolerances for iron pipe sizes

Nominal pipe size (in)	Pressure class (lb/in^2)	SDR	Outside diameter (in) average	Outside diameter (in) tolerance	Minimum wall thickness (in) minimum	Minimum wall thickness (in) tolerance
4	100	25	4.80	0.009	0.192	0.023
	150	18			0.267	0.032
	200	14			0.343	0.041
6	100	25	6.90	0.011	0.276	0.033
	150	18			0.383	0.046
	200	14			0.493	0.059
8	100	25	9.05	0.015	0.362	0.043
	150	18			0.503	0.060
	200	14			0.646	0.078
10	100	25	11.10	0.015	0.444	0.053
	150	18			0.617	0.074
	200	14			0.793	0.095
12	100	25	13.20	0.015	0.528	0.063
	150	18			0.733	0.088
	200	14			0.943	0.113

Source: AWWA C900

Hydrostatic Design Stress (HDS) = 1,600 lb/in^2

Table 52C–9 Polyethylene pipe, inside diameter based

Nominal pipe size (in)	SIDR	Pressure class Material 2406 3406	Pressure class Material 3408	Inside diameter minimum (in)	Inside diameter tolerance – (in)	Inside diameter tolerance + (in)	Wall thickness minimum	Wall thickness tolerance
0.5	9	125	160	0.622	0.010	0.010	0.069	+0.020
	7	160	200				0.089	+0.020
	5.3	200					0.117	+0.020
0.75	11.5		125	0.824	0.015	0.010	0.072	+0.020
	9	125	160				0.092	+0.020
	7	160	200				0.118	+0.020
	5.3	200					0.155	+0.020
1	11.5		125	1.049	0.020	0.010	0.091	+0.020
	9	125	160				0.117	+0.020
	7	160	200				0.150	+0.020
	5.3	200					0.198	+0.024

Table 52C–9 Polyethylene pipe, inside diameter based—Continued

Nominal pipe size (in)	SIDR	Pressure class - - - Material - - - 2406 3406	3408	Dimension and tolerance - - - Inside diameter - - - minimum (in)	- - - tolerance - - - – (in)	+ (in)	- - - Wall thickness - - - minimum	tolerance
1.25	11.5		125	1.380	0.020	0.010	0.120	+0.020
	9	125	160				0.153	+0.020
	7	160	200				0.197	+0.024
	5.3	200					0.260	+0.031
1.5	11.5		125				0.140	+0.020
	9	125	160				0.179	+0.020
	7	160	200				0.230	+0.028
	5.3	200					0.304	+0.036
2	19		80	2.067	0.020	0.015	0.109	+0.020
	15	80	100				0.138	+0.020
	11.5	100	125				0.180	+0.022
	9	125	160				0.230	+0.028
	7	160	200				0.295	+0.035
	5.3	200					0.390	+0.047
2.5	19		80	2.469	0.025	0.015	0.130	+0.020
	15	80	100				0.165	+0.020
	11.5	100	125				0.215	+0.025
	9	125	160				0.272	+0.033
	7	160	200				0.353	+0.042
	5.3	200					0.466	+0.056
3	19		80	3.068	0.030	0.015	0.161	+0.020
	15	80	100				0.205	+0.020
	11.5	100	125				0.267	+0.032
	9	125	160				0.341	+0.041
	7	160	200				0.438	+0.053
	5.3	200					0.579	+0.069

Source: AWWA C 901

Table 52C–10 Polyethylene pipe, outside diameter based

Nominal pipe size (in)	SDR	Pressure class Material 2406 3406	Pressure class Material 3408	Outside diameter minimum (in)	Outside diameter tolerance – (in)	Outside diameter tolerance + (in)	Wall thickness minimum	Wall thickness tolerance
0.5	11	125	160	0.840	0.004	0.004	0.076	+0.020
	9	160	200				0.093	+0.020
0.75	13.5		125	1.050	0.004	0.004	0.078	+0.020
	11	125	160				0.095	+0.020
	9	160	200				0.117	+0.020
1	13.5		125	1.315	0.005	0.005	0.097	+0.020
	11	125	160				0.119	+0.020
	9	160	200				0.146	+0.020
1.25	13.5		125	1.660	0.005	0.005	0.123	+0.020
	11	125	160				0.151	+0.020
	9	160	200				0.184	+0.022
1.5	13.5		125	1.900	0.006	0.006	0.141	+0.020
	11	125	160				0.173	+0.021
	9	160	200				0.211	+0.025
2	21		80	2.375	0.006	0.006	0.113	+0.020
	17	80	100				0.140	+0.020
	13.5	100	125				0.176	+0.021
	11	125	160				0.216	+0.026
	9	160	200				0.264	+0.032
3	21		80	3.500	0.008	0.008	0.167	+0.020
	17	80	100				0.206	+0.025
	13.5	100	125				0.259	+0.031
	11	125	160				0.318	+0.038
	9	160	200				0.389	+0.047

Source: AWWA C 901

Table 52C–11 PVC plastic pipe, iron pipe size (IPS) outside diameter

Nominal pipe size (in)	SDR	Pressure rating (lb/in^2)	Dimension and tolerance: Outside diameter (in) average	Outside diameter (in) tolerance (–/+)	Wall thickness (in) minimum	Wall thickness (in) tolerance
14	41	100	14.000	0.015	0.341	+0.048
	32.5	125			0.430	+0.052
	26	160			0.538	+0.064
	21	200			0.666	+0.080
16	41	100	16.000	0.019	0.390	+0.055
	32.5	125			0.492	+0.059
	26	160			0.615	+0.074
	21	200			0.762	+0.091
18	41	100	18.000	0.019	0.439	+0.061
	32.5	125			0.554	+0.066
	26	160			0.692	+0.083
	21	200			0.857	+0.103
20	41	100	20.000	0.023	0.488	+0.068
	32.5	125			0.615	+0.074
	26	160			0.769	+0.092
	21	200			0.952	+0.114
24	41	100	24.000	0.031	0.585	+0.082
	32.5	125			0.738	+0.088
	26	160			0.923	+0.111
	21	200			1.143	+0.137
30	41	100	30.000	0.041	0.732	+0.102
	32.5	125			0.923	+0.111
	26	160			1.154	+0.138
	21	200			1.428	+0.171
36	41	100	36.000	0.050	0.878	+0.123
	32.5	125			1.108	+0.133
	26	160			1.385	+0.166
	21	200			1.714	+0.205

Source: AWWA C 905
PVC material cell class 12454-B as defined by ASTM D 1784 with hydrostatic design basis of 4,000 pounds per square inch.

Table 52C–12 PVC plastic pipe, ductile iron pipe size (IPS) outside diameter

Nominal pipe size (in)	SDR	Pressure rating (lb/in²)	Dimension and tolerance: Outside diameter (in) average	Outside diameter tolerance (–/+)	Wall thickness (in) minimum	Wall thickness tolerance
14	41	100	15.300	0.015	0.373	+0.052
	32.5	125			0.471	+0.056
	25	165			0.612	+0.073
	21	200			0.729	+0.088
	18	235			0.850	+0.102
	14	305			1.093	+0.131
16	41	100	17.400	0.020	0.424	+0.059
	32.5	125			0.535	+0.064
	25	165			0.696	+0.084
	21	200			0.829	+0.100
	18	235			0.967	+0.116
	14	305			1.243	+0.149
18	51	80	19.500	0.020	0.382	+0.053
	41	100			0.476	+0.067
	32.5	125			0.600	+0.072
	25	165			0.780	+0.094
	21	200			0.929	+0.111
	18	235			1.083	+0.130
	14	305			1.393	+0.167
20	51	80	21.600	0.025	0.424	+0.059
	41	100			0.527	+0.074
	32.5	125			0.665	+0.080
	25	165			0.864	+0.104
	21	200			1.029	+0.123
	18	235			1.200	+0.144
24	51	80	25.800	0.030	0.506	+0.071
	41	100			0.629	+0.088
	32.5	125			0.794	+0.095
	25	165			1.032	+0.124
	21	200			1.229	+0.147
	18	235			1.433	+0.172
30	51	80	32.000	0.040	0.627	+0.088
	41	100			0.780	+0.109
	32.5	125			0.985	+0.118
	25	165			1.280	+0.154
	21	200			1.524	+0.183
	18	235			1.778	+0.213

Table 52C–12 PVC plastic pipe, ductile iron pipe size (IPS) outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure rating (lb/in^2)	Dimension and tolerance: Outside diameter (in) average	Outside diameter (in) tolerance (–/+)	Wall thickness (in) minimum	Wall thickness (in) tolerance
36	51	80	38.300	0.050	0.751	+0.105
	41	100			0.934	+0.131
	32.5	125			1.178	+0.141
	25	165			1.532	+0.184
	21	200			1.824	+0.219
42	51	80	44.500	0.060	0.872	+0.122
	41	100			1.085	+0.152
	32.5	125			1.369	+0.164
	25	165			1.780	+0.214
48	51		50.800	0.075	0.996	+0.139
	41				1.239	+0.173
	32.5				1.563	+0.188
	25				2.032	+0.244

Source: AWWA C 905
PVC material Cell class 12454-B as defined by ASTM D 1784 with hydrostatic design basis of 4,000 pounds per square inch.

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter

Nominal pipe size (in)	SDR	Pressure class - - - - Material - - - - 2406 3406	3408	Dimension and tolerance - - Outside diameter - - minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
4	32.5	40	51	4.5	0.020	0.138
	26	50	64			0.173
	21	63	80			0.214
	17	78	100			0.265
	15.5	86	110			0.290
	13.5	100	128			0.333
	11	125	160			0.409
	9.3	151	193			0.482
	9	156	200			0.500
	7.3	198	254			0.616
5	32.5	40	51	5.563	0.025	0.171
	26	50	64			0.214
	21	63	80			0.265
	17	78	100			0.327
	15.5	86	110			0.359
	13.5	100	128			0.412
	11	125	160			0.506
	9.3	151	193			0.598
	9	156	200			0.618
	7.3	198	254			0.762
6	32.5	40	51	6.625	0.030	0.204
	26	50	64			0.255
	21	63	80			0.316
	17	78	100			0.390
	15.5	86	110			0.427
	13.5	100	128			0.491
	11	125	160			0.602
	9.3	151	193			0.710
	9	156	200			0.736
	7.3	198	254			0.908
7	32.5	40	51	7.125	0.034	0.220
	26	50	64			0.274
	21	63	80			0.340
	17	78	100			0.420
	15.5	86	110			0.460
	13.5	100	128			0.528
	11	125	160			0.648
	9.3	151	193			0.766
	9	156	200			0.792
	7.3	198	254			0.976

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class ---- Material ---- 2406 3406	3408	Dimension and tolerance -- Outside diameter -- minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
8	32.5	40	51	8.625	0.039	0.265
	26	50	64			0.332
	21	63	80			0.411
	17	78	100			0.507
	15.5	86	110			0.556
	13.5	100	128			0.639
	11	125	160			0.784
	9.3	151	193			0.927
	9	156	200			0.958
	7.3	198	254			1.182
10	32.5	40	51	10.75	0.048	0.331
	26	50	64			0.413
	21	63	80			0.512
	17	78	100			0.632
	15.5	86	110			0.694
	13.5	100	128			0.796
	11	125	160			0.977
	9.3	151	193			1.156
	9	156	200			1.194
	7.3	198	254			1.473
12	32.5	40	51	12.75	0.057	0.392
	26	50	64			0.490
	21	63	80			0.607
	17	78	100			0.750
	15.5	86	110			0.823
	13.5	100	128			0.944
	11	125	160			1.159
	9.3	151	193			1.371
	9	156	200			1.417
	7.3	198	254			1.747
13	32.5	40	51	13.375	0.060	0.412
	26	50	64			0.515
	21	63	80			0.638
	17	78	100			0.788
	15.5	86	110			0.863
	13.5	100	128			0.991
	11	125	160			1.216
	9.3	151	193			1.438
	9	156	200			1.486
	7.3	198	254			1.832

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class Material 2406 3406	Pressure class Material 3408	Outside diameter minimum (in)	Outside diameter tolerance (–/+)	Wall thickness minimum (in)
14	32.5	40	51	14.000	0.063	0.431
	26	50	64			0.538
	21	63	80			0.667
	17	78	100			0.824
	15.5	86	110			0.903
	13.5	100	128			1.037
	11	125	160			1.273
	9.3	151	193			1.505
	9	156	200			1.556
	7.3	198	254			1.918
16	32.5	40	51	16.000	0.072	0.492
	26	50	64			0.615
	21	63	80			0.762
	17	78	100			0.941
	15.5	86	110			1.032
	13.5	100	128			1.185
	11	125	160			1.455
	9.3	151	193			1.720
	9	156	200			1.778
	7.3	198	254			2.192
18	32.5	40	51	18.000	0.081	0.554
	26	50	64			0.692
	21	63	80			0.857
	17	78	100			1.059
	15.5	86	110			1.161
	13.5	100	128			1.333
	11	125	160			1.636
	9.3	151	193			1.935
	9	156	200			2.000
	7.3	198	254			2.466
20	32.5	40	51	20.000	0.090	0.615
	26	50	64			0.769
	21	63	80			0.952
	17	78	100			1.176
	15.5	86	110			1.290
	13.5	100	128			1.481
	11	125	160			1.818
	9.3	151	193			2.151
	9	156	200			2.222
	7.3	198	254			2.740

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class ---- Material ---- 2406 3406	3408	Dimension and tolerance -- Outside diameter -- minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
21.5	32.5	40	51	21.500	0.097	0.662
	26	50	64			0.827
	21	63	80			1.024
	17	78	100			1.265
	15.5	86	110			1.387
	13.5	100	128			1.593
	11	125	160			1.955
	9.3	151	193			2.312
	9	156	200			2.389
	7.3	198	254			2.945
22	32.5	40	51	22.000	0.099	0.677
	26	50	64			0.846
	21	63	80			1.048
	17	78	100			1.294
	15.5	86	110			1.419
	13.5	100	128			1.630
	11	125	160			2.000
	9.3	151	193			2.366
	9	156	200			2.444
	7.3	198	254			3.014
24	32.5	40	51	24.000	0.108	0.738
	26	50	64			0.923
	21	63	80			1.143
	17	78	100			1.412
	15.5	86	110			1.548
	13.5	100	128			1.778
	11	125	160			2.182
	9.3	151	193			2.581
	9	156	200			2.667
	7.3	198	254			3.288
26	32.5	40	51	26.000	0.117	0.800
	26	50	64			1.000
	21	63	80			1.238
	17	78	100			1.529
	15.5	86	110			1.677
	13.5	100	128			1.926
	11	125	160			2.364
	9.3	151	193			2.796
	9	156	200			2.889
	7.3	198	254			3.562

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class - - - - Material - - - - 2406 3406	3408	Dimension and tolerance - - Outside diameter - - minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
28	32.5	40	51	28.000	0.126	0.862
	26	50	64			1.077
	21	63	80			1.333
	17	78	100			1.647
	15.5	86	110			1.806
	13.5	100	128			2.074
	11	125	160			2.545
	9.3	151	193			3.011
	9	156	200			3.111
	7.3	198	254			3.836
32	32.5	40	51	32.000	0.144	0.985
	26	50	64			1.231
	21	63	80			1.524
	17	78	100			1.882
	15.5	86	110			2.065
	13.5	100	128			2.370
	11	125	160			2.909
	9.3	151	193			3.441
	9	156	200			3.566
	7.3	198	254			4.384
34	32.5	40	51	34.000	0.153	1.046
	26	50	64			1.308
	21	63	80			1.619
	17	78	100			2.000
	15.5	86	110			2.194
	13.5	100	128			2.519
	11	125	160			3.091
	9.3	151	193			3.656
	9	156	200			3.778
	7.3	198	254			4.658
36	32.5	40	51	36.000	0.162	1.108
	26	50	64			1.385
	21	63	80			1.714
	17	78	100			2.118
	15.5	86	110			2.323
	13.5	100	128			2.667
	11	125	160			3.273
	9.3	151	193			3.871
	9	156	200			4.000
	7.3	198	254			4.932

Table 52C–13 Polyethylene pipe, iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class — Material 2406 3406	Pressure class — Material 3408	Dimension and tolerance — Outside diameter minimum (in)	Outside diameter tolerance (–/+)	Wall thickness minimum (in)
42	32.5	40	51	42.000	0.189	1.292
	26	50	64			1.615
	21	63	80			2.000
	17	78	100			2.471
	15.5	86	110			2.710
	13.5	100	128			3.111
	11	125	160			3.818
	9.3	151	193			4.516
	9	156	200			4.667
	7.3	198	254			5.753
48	32.5	40	51	48.000	0.216	1.477
	26	50	64			1.846
	21	63	80			2.286
	17	78	100			2.824
	15.5	86	110			3.097
	13.5	100	128			3.556
	11	125	160			4.364
	9.3	151	193			5.161
	9	156	200			5.333
	7.3	198	254			6.575
54	32.5	40	51	54.000	0.243	1.662
	26	50	64			2.077
	21	63	80			2.571
	17	78	100			3.177
	15.5	86	110			3.484
	13.5	100	128			4.000
	11	125	160			4.909
	9.3	151	193			5.807
	9	156	200			6.000
	7.3	198	254			7.397
63	32.5	40	51	63.000	0.284	1.938
	26	50	64			2.423
	21	63	80			3.000
	17	78	100			3.706
	15.5	86	110			4.065
	13.5	100	128			4.667
	11	125	160			5.727
	9.3	151	193			6.774
	9	156	200			7.000
	7.3	198	254			8.630

Source: AWWA C 906

Table 52C–14 Polyethylene pipe, ductile iron pipe size outside diameter

Nominal pipe size (in)	SDR	Pressure class ---- Material ---- 2406 3406	3408	Dimension and tolerance -- Outside diameter -- minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
4	32.5	40	51	4.800	0.022	0.148
	26	50	64			0.185
	21	63	80			0.229
	17	78	100			0.282
	15.5	86	110			0.310
	13.5	100	128			0.356
	11	125	160			0.436
	9.3	151	193			0.516
	9	156	200			0.533
	7.3	198	254			0.658
6	32.5	40	51	6.900	0.031	0.212
	26	50	64			0.265
	21	63	80			0.329
	17	78	100			0.406
	15.5	86	110			0.445
	13.5	100	128			0.511
	11	125	160			0.627
	9.3	151	193			0.742
	9	156	200			0.787
	7.3	198	254			0.945
8	32.5	40	51	9.050	0.041	0.278
	26	50	64			0.348
	21	63	80			0.431
	17	78	100			0.532
	15.5	86	110			0.584
	13.5	100	128			0.670
	11	125	160			0.823
	9.3	151	193			0.973
	9	156	200			1.006
	7.3	198	254			1.240
10	32.5	40	51	11.100	0.050	0.342
	26	50	64			0.427
	21	63	80			0.529
	17	78	100			0.653
	15.5	86	110			0.716
	13.5	100	128			0.822
	11	125	160			1.009
	9.3	151	193			1.194
	9	156	200			1.233
	7.3	198	254			1.521

Table 52C–14 Polyethylene pipe, ductile iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class ---- Material ---- 2406 3406	3408	Dimension and tolerance -- Outside diameter -- minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
12	32.5	40	51	13.200	0.059	0.406
	26	50	64			0.508
	21	63	80			0.629
	17	78	100			0.776
	15.5	86	110			0.852
	13.5	100	128			0.978
	11	125	160			1.200
	9.3	151	193			1.419
	9	156	200			1.467
	7.3	198	254			1.808
14	32.5	40	51	15.300	0.069	0.471
	26	50	64			0.588
	21	63	80			0.729
	17	78	100			0.900
	15.5	86	110			0.987
	13.5	100	128			1.133
	11	125	160			1.391
	9.3	151	193			1.645
	9	156	200			1.700
	7.3	198	254			2.096
16	32.5	40	51	17.400	0.078	0.535
	26	50	64			0.669
	21	63	80			0.829
	17	78	100			1.024
	15.5	86	110			1.123
	13.5	100	128			1.289
	11	125	160			1.582
	9.3	151	193			1.871
	9	156	200			1.933
	7.3	198	254			2.384
18	32.5	40	51	19.500	0.088	0.600
	26	50	64			0.750
	21	63	80			0.929
	17	78	100			1.147
	15.5	86	110			1.258
	13.5	100	128			1.444
	11	125	160			1.773
	9.3	151	193			2.097
	9	156	200			2.167
	7.3	198	254			2.671

Table 52C–14 Polyethylene pipe, ductile iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class - - - - Material - - - - 2406 3406	3408	Dimension and tolerance - - Outside diameter - - minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
20	32.5	40	51	21.600	0.097	0.665
	26	50	64			0.831
	21	63	80			1.029
	17	78	100			1.271
	15.5	86	110			1.394
	13.5	100	128			1.600
	11	125	160			1.964
	9.3	151	193			2.323
	9	156	200			2.400
	7.3	198	254			2.959
24	32.5	40	51	25.800	0.116	0.794
	26	50	64			0.992
	21	63	80			1.229
	17	78	100			1.518
	15.5	86	110			1.665
	13.5	100	128			1.911
	11	125	160			2.345
	9.3	151	193			2.774
	9	156	200			2.867
	7.3	198	254			3.534
30	32.5	40	51	32.000	0.144	0.985
	26	50	64			1.231
	21	63	80			1.524
	17	78	100			1.882
	15.5	86	110			2.065
	13.5	100	128			2.370
	11	125	160			2.909
	9.3	151	193			3.441
	9	156	200			3.556
	7.3	198	254			4.384
36	32.5	40	51	38.300	0.172	1.178
	26	50	64			1.473
	21	63	80			1.824
	17	78	100			2.253
	15.5	86	110			2.471
	13.5	100	128			2.837
	11	125	160			3.482
	9.3	151	193			4.118
	9	156	200			4.256
	7.3	198	254			5.247

Table 52C–14 Polyethylene pipe, ductile iron pipe size outside diameter—Continued

Nominal pipe size (in)	SDR	Pressure class ---- Material ---- 2406 3406	3408	Dimension and tolerance -- Outside diameter -- minimum (in)	tolerance (–/+)	Wall thickness minimum (in)
42	32.5	40	51	44.500	0.200	1.369
	26	50	64			1.712
	21	63	80			2.119
	17	78	100			2.618
	15.5	86	110			2.871
	13.5	100	128			3.296
	11	125	160			4.046
	9.3	151	193			4.785
	9	156	200			4.944
	7.3	198	254			6.096
48	32.5	40	51	50.800	0.229	1.563
	26	50	64			1.954
	21	63	80			2.419
	17	78	100			2.988
	15.5	86	110			3.277
	13.5	100	128			3.763
	11	125	160			4.618
	9.3	151	193			5.462
	9	156	200			5.644
	7.3	198	254			6.959
54	32.5	40	51	57.100	0.257	1.757
	26	50	64			2.196
	21	63	80			2.719
	17	78	100			3.359
	15.5	86	110			3.684
	13.5	100	128			4.230
	11	125	160			5.191
	9.3	151	193			6.140
	9	156	200			6.344
	7.3	198	254			7.822

Source: AWWA C 906.

Table 52C–15 Type PSM PVC pipe

Nominal pipe size (in)	Outside diameter (in) average	Outside diameter (in) tolerance	Minimum wall thickness (in) SDR 41	SDR 35	SDR 26	SDR 23.5
4	4.215	0.009		0.120	0.162	0.178
6	6.275	0.011	0.153	0.180	0.241	0.265
8	8.400	0.012	0.205	0.240	0.323	
9	9.440	0.014	0.230			
10	10.500	0.015	0.256	0.300	0.404	
12	12.500	0.018	0.305	0.360	0.481	
15	15.300	0.023	0.375	0.437	0.588	

Source: ASTM D 3034
Note: PSM is not an abbreviation, but rather an arbitrary designation for a product having certain dimensions.

Table 52C–16 PVC large-diameter plastic pipe

Nominal pipe size (in)	Outside diameter (in) average	Outside diameter (in) tolerance	Minimum wall thickness (in) cell class 12454	Minimum wall thickness (in) cell class 12364	Minimum pipe stiffness (lb/in^2)
18	18.701	0.028	0.536	0.499	46
21	22.047	0.033	0.632	0.588	46
24	24.803	0.037	0.711	0.661	46
27	27.953	0.042	0.801	0.745	46
30	31.946	0.047	0.903	0.840	46
30*	32.000	0.040	0.917	0.853	46
33	35.433	0.053	1.016	0.945	46
36	39.370	0.059	1.129	1.050	46
36*	38.300	0.050	1.098	1.021	46
42	44.500	0.060	1.276	1.187	46
48	50.800	0.075	1.456	1.355	46

Source: ASTM F 679
* Cast iron pipe size

Table 52C–17 Smooth wall PVC plastic underdrain pipe

Nominal pipe size (in)	Outside diameter (in)		Minimum wall thickness (in)	
	average	tolerance	PS28	PS46
4	4.215	0.009	0.103	0.120
6	6.275	0.011	0.153	0.180
8	8.400	0.012	0.205	0.240

Source: ASTM F 758

Note: PS = pipe stiffness

Table 52C–18 Type PS46 and PS115 PVC plastic pipe

Nominal pipe size (in)	Pipe stiffness (lb/in^2)	Outside diameter (in)		Wall thickness (in)					
				T–1		T–2		T–3	
		average	tolerance	est. avg.	minimum	est. avg.	minimum	est. avg.	minimum
4	46.000	4.215	0.009	0.114	0.107	0.111	0.104	0.108	0.102
	115.000			0.152	0.143	0.148	0.139	0.144	0.135
6	46.000	6.275	0.011	0.170	0.160	0.165	0.155	0.161	0.151
	115.000			0.226	0.214	0.220	0.207	0.215	0.202
8	46.000	8.400	0.012	0.227	0.213	0.221	0.208	0.216	0.203
	115.000			0.302	0.284	0.294	0.276	0.287	0.270
10	46.000	10.500	0.015	0.284	0.267	0.276	0.259	0.270	0.254
	115.000			0.378	0.355	0.363	0.341	0.359	0.337
12	46.000	12.500	0.018	0.338	0.318	0.329	0.309	0.321	0.302
	115.000			0.450	0.423	0.438	0.414	0.428	0.402
15	46.000	15.300	0.023	0.414	0.389	0.403	0.379	0.393	0.369
	115.000			0.548	0.515	0.536	0.504	0.523	0.492
18	46.000	18.700	0.028	0.507	0.477	0.494	0.464	0.482	0.452
	115.000			0.673	0.633	0.655	0.616	0.640	0.602

Source: ASTM F 789

T-1: Made with material that has modulus of 440,000 to 480,000 lb/in^2.

T-2: Made with material that has modulus of 480,000 to 520,000 lb/in^2.

T-3: Made with material that has modulus of 520,000 to 560,000 lb/in^2.

Table 52C–19 Open and dual wall PVC profile plastic pipe dimensions and tolerances

Nominal pipe size (in)	Inside diameter (in) minimum	Inside diameter (in) tolerance	Minimum wall thickness in waterway (in) open profile PS 10	open profile PS 46	dual wall PS 10	dual wall PS 46
4	3.939	0.034		0.030		0.022
6	5.875	0.049		0.045		0.025
8	7.863	0.053		0.060		0.035
10	9.825	0.067		0.070		0.045
12	11.687	0.085		0.085		0.058
15	14.303	0.116		0.105		0.077
18	17.510	0.195	0.040	0.130	0.070	0.084
21	20.656	0.200	0.085	0.160	0.070	0.095
24	23.412	0.204	0.105	0.180	0.070	0.110
27	26.371	0.209	0.115	0.205	0.070	0.120
30	29.388	0.220	0.130	0.235	0.085	0.130
33	32.405	0.227	0.150	0.260	0.095	0.150
36	35.370	0.235	0.165	0.290	0.105	0.155
39	38.380	0.245	0.195	0.315	0.120	0.200
42	41.370	0.255	0.215	0.345	0.130	0.200
45	44.365	0.265	0.225	0.370	0.145	0.200
48	47.355	0.285	0.230	0.400	0.160	0.200

Source: ASTM F 794

Table 52C–20 PVC corrugated pipe with smooth interior dimensions and tolerances

Nominal pipe size (in)	Pipe stiffness (lb/in^2)	Outside diameter (in)		Inside diameter (in)		Minimum wall thickness (in)		
		average	tolerance	average	tolerance	inner wall	outer wall	at valley
4	46	4.300	0.009	3.950	0.011	0.022	0.018	0.028
6	46	6.420	0.011	5.909	0.015	0.025	0.022	0.032
8	46	8.600	0.012	7.881	0.018	0.035	0.030	0.045
	115					0.037	0.050	0.048
10	46	10.786	0.015	9.846	0.021	0.045	0.036	0.055
	115					0.046	0.052	0.065
12	46	12.795	0.018	11.715	0.028	0.058	0.049	0.072
	115					0.070	0.068	0.091
15	46	15.658	0.023	14.338	0.035	0.077	0.055	0.092
	115					0.092	0.088	0.118
18	46	19.152	0.028	17.552	0.042	0.084	0.067	0.103
21	46	22.630	0.033	20.705	0.049	0.095	0.073	0.110
24	46	25.580	0.039	23.469	0.057	0.110	0.085	0.123
27	46	28.860	0.049	26.440	0.069	0.120	0.091	0.137
30	46	32.150	0.059	29.469	0.081	0.130	0.105	0.147
36	46	38.740	0.079	35.475	0.105	0.150	0.125	0.171

Source: ASTM F 949

Table 52C–21 Open profile polyethylene pipe dimensions and tolerances

Nominal pipe size (in)	Inside diameter (in) average	Inside diameter (in) tolerance	Minimum wall thickness in pipe waterway (in) RSC 40	RSC 63	RSC 100	RSC 160	Min. bell thickness (in)
18	18.00	0.38	0.18	0.18	0.18	0.22	0.7
21	21.00	0.38	0.18	0.18	0.18	0.24	0.7
24	24.00	0.38	0.18	0.18	0.22	0.24	0.7
27	27.00	0.38	0.18	0.18	0.24	0.24	0.7
30	30.00	0.38	0.18	0.22	0.24	0.26	0.7
33	33.00	0.38	0.18	0.24	0.24	0.30	0.95
36	36.00	0.38	0.18	0.24	0.26	0.30	1.05
42	42.00	0.42	0.24	0.24	0.30	0.38	1.15
48	48.00	0.48	0.24	0.26	0.30	0.38	1.25
54	54.00	0.54	0.24	0.30	0.38	0.42	1.25
60	60.00	0.60	0.26	0.30	0.38	0.52	1.3
66	66.00	0.66	0.30	0.38	0.42	0.67	1.3
72	72.00	0.72	0.30	0.38	0.42	0.90	1.3
78	78.00	0.78	0.30	0.38	0.52	0.90	1.35
84	84.00	0.84	0.38	0.42	0.67	0.90	1.35
90	90.00	0.90	0.38	0.42	0.90	0.95	1.35
96	96.00	0.96	0.38	0.52	0.90	0.95	1.35
108	108.00	1.08	0.42	0.67	0.90	0.95	1.35
120	120.00	1.20	0.52	0.67	0.90	0.95	1.35

Source: ASTM F 894

Table 52C–22 Closed profile polyethylene pipe dimensions and tolerances

Nominal pipe size (in)	Inside diameter (in) average	Inside diameter (in) tolerance	Min. wall thickness in pipe waterway (in)	Min. bell thickness (in)
10	10.00	0.38	0.18	0.5
12	12.00	0.38	0.18	0.5
15	15.00	0.38	0.18	0.5
18	18.00	0.38	0.18	0.5
21	21.00	0.38	0.18	0.5
24	24.00	0.38	0.18	0.5
27	27.00	0.38	0.18	0.5
30	30.00	0.38	0.18	0.5
33	33.00	0.38	0.18	0.5
36	36.00	0.38	0.18	0.5
40	40.00	0.38	0.18	0.5
42	42.00	0.42	0.18	0.5
48	48.00	0.48	0.18	0.5
54	54.00	0.54	0.18	0.5
60	60.00	0.60	0.18	0.6
66	66.00	0.66	0.18	0.6
72	72.00	0.72	0.18	0.6
78	78.00	0.78	0.18	0.6
84	84.00	0.84	0.18	0.7
90	90.00	0.90	0.18	0.7
96	96.00	0.96	0.18	0.7
108	108.00	1.08	0.18	0.7
120	120.00	1.20	0.18	0.8

Source: ASTM F 894

Appendix 52D Selection Properties of Corrugated and Spiral Rib Metal Pipe

Table 52D–1 Section properties of corrugated steel pipe

Gage	Specified thickness (galvanized) (in)	1-1/2" x 1/4" Corrugation: Area of section, A_s (in^2/ft)	1-1/2" x 1/4" Corrugation: Moment of I, inertia (in^4/in)	1-1/2" x 1/4" Corrugation: Radius of gyration, r (in)	2-2/3" x 1/2" Corrugation: Area of section, A_s (in^2/ft)	2-2/3" x 1/2" Corrugation: Moment of I, inertia (in^4/in)	2-2/3" x 1/2" Corrugation: Radius of gyration, r (in)
20	0.040	0.456	0.000253	0.0816	0.465	.001122	0.1702
18	0.052	0.608	0.000343	0.0824	0.619	.001500	0.1707
16	0.064	0.761	0.000439	0.0832	0.775	.001892	0.1712
14	0.079	0.950	0.000566	0.0846	0.968	.002392	0.1721
12	0.109	1.333	0.000857	0.0879	1.356	.003425	0.1741
10	0.138	1.712	0.001205	0.0919	1.744	.004533	0.1766
8	0.168	2.098	0.001635	0.0967	2.133	.005725	0.1795

Gage	Specified thickness (galvanized) (in)	3" x 1" Corrugation: Area of section, A_s (in^2/ft)	3" x 1" Corrugation: Moment of I, inertia ($Ix10^{-3}in^4/in$)	3" x 1" Corrugation: Radius of gyration, r (in)	5" x 1" Corrugation: Area of section, A_s (in^2/ft)	5" x 1" Corrugation: Moment of I, inertia ($I \times 10^{-3} in^4/in$)	5" x 1" Corrugation: Radius of gyration, r (in)
18	0.052	0.711	0.006892	0.3410			
16	0.064	0.890	0.008658	0.3417	0.794	.008850	0.3657
14	0.079	1.113	0.010883	0.3427	0.992	.011092	0.3663
12	0.109	1.560	0.015458	0.3448	1.390	.015550	0.3677
10	0.138	2.008	0.020175	0.3472	1.788	.020317	0.3693
8	0.168	2.458	0.025083	0.3499	2.186	.025092	0.3711

Source: ASTM A 796
AASHTO Standard Specifications for Highway Bridges

Table 52D–2 Ultimate longitudinal seam strength of riveted or spot welded corrugated steel pipe

Gage	Specified thickness (galvanized) (in)	Seam strength (lb/ft of seam): 5/16" rivets, 2 2/3" x 1/2", single	5/16" rivets, 2 2/3" x 1/2", double	3/8" rivets, 2 2/3" x 1/2", single	3/8" rivets, 2 2/3" x 1/2", double	3/8" rivets, 3 x 1" and 5 x 1", double	7/16" rivets, 3 x 1" and 5 x 1", double
16	.064	16,700	21,600			28,700	
14	0.079	18,200	29,800			35,700	
12	0.109			23,400	46,800		53,000
10	0.138			24,500	49,000		63,700
8	0.168			25,600	51,300		70,700

Source: ASTM A 796.

Table 52D–3 Section properties of corrugated aluminum pipe

Gage	Specified thickness (in)	1-1/2" x 1/4" Corrugation: Area of section, A_s (in^2/ft)	1-1/2" x 1/4" Corrugation: Moment of I, inertia (in^4/in)	1-1/2" x 1/4" Corrugation: Radius of gyration, r (in)	2-2/3" x 1/2" Corrugation: Area of section, A_s (in^2/ft)	2-2/3" x 1/2" Corrugation: Moment of I, inertia (in^4/in)	2-2/3" x 1/2" Corrugation: Radius of gyration, r (in)
18	0.048	0.608	0.000344	0.0824			
16	0.060	0.761	0.000349	0.0832	0.775	0.001892	0.1712
14	0.075	—	—	—	0.968	0.002392	0.1721
12	0.105	—	—	—	1.356	0.003425	0.1741
10	0.135	—	—	—	1.745	0.004533	0.1766
8	0.164	—	—	—	2.130	0.005725	0.1795

Gage	Specified thickness (in)	3" x 1" Corrugation: Area of section, A_s (in^2/ft)	3" x 1" Corrugation: Moment of I, inertia (in^4/in)	3" x 1" Corrugation: Radius of gyration, r (in)	6" x 1" Corrugation: Area of section, A_s (in^2/ft)	6" x 1" Corrugation: Effective area (in^2/ft)	6" x 1" Corrugation: Moment of I, inertia (in^4/in)	6" x 1" Corrugation: Radius of gyration, r (in)
16	0.060	0.890	0.008659	0.3417	0.775	0.387	0.008505	0.3629
14	0.075	1.118	0.010883	0.3427	0.968	0.484	0.010631	0.3630
12	0.105	1.560	0.015459	0.3448	1.356	0.678	0.014340	0.3636
10	0.135	2.008	0.020183	0.3472	1.744	0.872	0.019319	0.3646
8	0.164	2.458	0.025091	0.3499	2.133	1.066	0.02376	0.3656

Source: ASTM B 790
AASHTO Standard Specification for Highway Bridges

Table 52D–4 Ultimate longitudinal seam strength of riveted corrugated aluminum pipe

Gage	Specified thickness (in)	Seam strength (lb/ft of seam): 5/16 in rivets, 2 2/3 x 1/2 in, single	5/16 in rivets, 2 2/3 x 1/2 in, double	3/8 in rivets, 2 2/3 x 1/2 in, single	3/8 in rivets, 2 2/3 x 1/2 in, double	3/8 in rivets, 3 x 1 in and 5 x 1 in, double	1/2 in rivets, 3 x 1 in and 5 x 1in, double
16	0.064	9,000	14,000			16,500	
14	0.075	9,000	18,000			20,500	
12	0.105			15,600	31,500		28,000
10	0.135			16,200	33,000		42,000
8	0.164			16,800	34,000		54,500

Source: ASTM B 790

Table 52D–5 Section properties of spiral rib steel pipe

Gage	Specified thickness (galvanized) (in)	3/4" x 3/4" x 7-1/2" Area of section, A_s (in^2/ft)	Moment of I, inertia (in^4/in)	Radius of gyration, r (in)	3/4" x 1" x 11-1/2" Area of section, A_s (in^2/ft)	Moment of I, inertia (in^4/in)	Radius of gyration, r (in)	3/4" x 1" x 8-1/2" Area of section, A_s (in^2/ft)	Moment of I, inertia (in^4/in)	Radius of gyration, r (in)
16	0.064	0.509	0.002821	0.258	0.374	0.00458	0.383	0.499	0.005979	0.379
14	0.079	0.712	0.003701	0.25	0.524	0.00608	0.373	0.694	0.007913	0.37
12	0.109	1.184	0.005537	0.237	0.883	0.00926	0.355	1.149	0.011983	0.354
10	0.138	1.717	0.007433	0.228						

Source: ASTM A 796

Table 52D–6 Section properites of spiral rib aluminum pipe

Gage	Specified thickness (in)	3/4" x 3/4" x 7-1/2" Area of section, A_s (in^2/ft)	Moment of I, inertia (in^4/in)	Radius of gyration, r (in)	3/4" x 1" x 11-1/2" Area of section, A_s (in^2/ft)	Moment of I, inertia (in^4/in)	Radius of gyration, r (in)
16	0.06	0.415	0.002558	0.272	0.312	0.00408	0.396
14	0.075	0.569	0.003372	0.267	0.427	0.00545	0.391
12	0.105	0.914	0.005073	0.258	0.697	0.00839	0.38
10	0.135	1.29	0.006826	0.252	1.009	0.01148	0.369

Source: ASTM B 790

Appendix 52E Allowable Flexibility Factors of Corrugated and Spiral Rib Metal Pipe

Table 52E–1 Flexibility factor for corrugated metal pipe

Depth of corruga-tion (in)	Material thickness (in)	Flexibility factor (in/lbf)			
		In trench		Embankment	
		steel	aluminum	steel	aluminum
1/4	0.060	0.043	0.031	0.043	0.031
	0.075	0.043	0.061	0.043	0.061
	others	0.043	0.092	0.043	0.092
1/2	0.060	0.060	0.031	0.043	0.031
	0.075	0.060	0.061	0.043	0.061
	others	0.060	0.092	0.043	0.092
1	all	0.060	0.060	0.033	0.060
2	all	0.020	—	0.020	—
2 1/2	all	—	0.025	—	0.025
5 1/2	all	0.020	—	0.020	—

Source: ASTM A 796 and B 790

Table 52E–2 Flexibility factor for spiral rib metal pipe

Profile (in)	Flexibility factor (in/lbf)					
	In trench w/compacted soil envelope		In trench w/o compacted soil envelope		Embankment	
	steel	aluminum	steel	aluminum	steel	aluminum
3/4 x 3/4 x 7-1/2	$0.367\ I^{1/3}$	$0.600\ I^{1/3}$	$0.263\ I^{1/3}$	$0.420\ I^{1/3}$	$0.217\ I^{1/3}$	$0.340\ I^{1/3}$
3/4 x 1 x 8-1/2	$0.262\ I^{1/3}$		$0.163\ I^{1/3}$		$0.140\ I^{1/3}$	
3/4 x 1 x 11-1/2	$0.220\ I^{1/3}$	$0.310\ I^{1/3}$	$0.163\ I^{1/3}$	$0.215\ I^{1/3}$	$0.140\ I^{1/3}$	$0.175\ I^{1/3}$

Source: ASTM A 796 and B 790

Appendix 52F Nominal Thickness for Standard Pressure Classes of Ductile Iron Pipe

Table 52F–1 Nominal thickness for standard pressure classes of ductile iron pipe and allowances for casting tolerance

Size, in	Outside diameter, in (mm)	Nominal thickness, in (mm) — Pressure class 150	200	250	300	350	Casting tolerance, in (mm)
3	3.96 (100.6)	—	—	—	—	0.25 (6.4)	0.05 (1.3)
4	4.80 (121.9)	—	—	—	—	0.25 (6.4)	0.05 (1.3)
6	6.90 (175.3)	—	—	—	—	0.25 (6.4)	0.05 (1.3)
8	9.05 (229.9)	—	—	—	—	0.25 (6.4)	0.05 (1.3)
10	11.10 (281.9)	—	—	—	—	0.26 (6.6)	0.06 (1.5)
12	13.20 (335.3)	—	—	—	—	0.28 (7.1)	0.06 (1.5)
14	15.30 (388.6)	—	—	0.28 (7.1)	0.30 (7.6)	0.31 (7.9)	0.07 (1.8)
16	17.40 (442.0)	—	—	0.30 (7.6)	0.32 (8.1)	0.34 (8.6)	0.07 (1.8)
18	19.50 (495.3)	—	—	0.31 (7.9)	0.34 (8.6)	0.36 (9.1)	0.07 (1.8)
20	21.60 (548.6)	—	—	0.33 (8.4)	0.36 (9.1)	0.38 (9.7)	0.07 (1.8)
24	25.80 (655.3)	—	0.33 (8.4)	0.37 (9.4)	0.40 (10.2)	0.43 (10.9)	0.07 (1.8)
30	32.00 (812.8)	0.34 (8.6)	0.38 (9.7)	0.42 (10.7)	0.45 (11.4)	0.49 (12.4)	0.07 (1.8)
36	38.30 (972.8)	0.38 (9.7)	0.42 (10.7)	0.47 (11.9)	0.51 (12.9)	0.56 (14.2)	0.07 (1.8)
42	44.50 (1,130.3)	0.41 (10.4)	0.47 (11.9)	0.52 (13.2)	0.57 (14.5)	0.63 (16.0)	0.07 (1.8)
48	50.80 (1,290.3)	0.46 (11.7)	0.52 (13.2)	0.58 (14.7)	0.64 (16.3)	0.70 (17.8)	0.08 (2.0)
54	57.56 (1,450.3)	0.51 (12.9)	0.58 (14.7)	0.65 (16.5)	0.72 (18.3)	0.79 (20.1)	0.09 (2.3)
60	61.61 (1,564.9)	0.54 (13.7)	0.61 (15.5)	0.68 (17.3)	0.76 (19.3)	0.83 (21.1)	0.09 (2.3)
64	65.67 (1,668.0)	0.56 (14.2)	0.64 (16.3)	0.72 (18.3)	0.80 (20.3)	0.87 (22.1)	0.09 (2.3)

Source: ASTM A 746