Chapter 6
Plastic Pipe for Other Applications

6-1. General

a. Plastic pipes. Plastic pipes are available in both solid wall and profile wall thermoplastic acrylonitrile-butadiene-styrene (ABS), high-density polyethylene (HDPE), and polyvinyl chloride (PVC) pipes, as well as thermoset reinforced plastic mortar (RPM) pipes. They all possess the general attributes normally associated with plastics including light weight, long lengths, tight joints, and resistance to normal atmospheric corrosion. All these pipes are flexible, and in general the design considerations are similar to metal pipes. However, due to the visco-elastic nature of these materials, the time under load condition may require that long-term material properties be used in the design. Additionally, each specific grade of material, as well as the type of pipe (i.e., solid or profile) dictates the design properties.

b. Selection considerations. Plastic pipes vary significantly in strength, stiffness, and performance. Differences depend more on their design and intended use than on the specific pipe wall material. A thorough evaluation of the intended use and detailed material, jointing, and backfill specifications is necessary to ensure performance. Use of plastic pipes in drainage and subdrainage applications is increasing. However, their use in low cover with heavy wheel loads or high cover applications is limited (refer to paragraph 6-3). Plastic pipe will not be used through embankments of dams and levees without approval from HQUSACE. Plastic pipes will typically be used for drainage piping behind structures.

6-2. Materials

a. Plastic materials. The piping materials discussed in this chapter include ABS, HDPE, and PVC thermoplastic pipes and RPM thermosetting resin pipes. Thermoplastic pipes include both solid wall (smooth, solid pipe wall extrusions), as well as profile wall (corrugated, ribbed, etc.) pipes that provide the indicated level of pipe stiffness while providing a limited wall area to carry ring compression.

b. Profile wall pipe. These pipes are commonly more economical, especially in diameters exceeding 200 mm (8 in.). However, they provide 50 to 70 percent of the wall area when compared to equal stiffness solid wall pipes of the same material. This limits their load-carrying capability in high cover applications and also limits beam strength.

c. Reinforced plastic mortar. These pipes are strain sensitive. If the surface resin layer strain cracks, the reinforcing glass is exposed to corrosion. The manufacturer will supply strain limits which are typically in the 0.5 to 1.0 percent range. Control of deflection and localized deformation are very important in design and construction.

d. Plastic pipe systems. These systems are summarized in Table 6-1. Typical mechanical properties for plastic pipe design are shown in Table 6-2, and average values for the modulus of soil reaction are shown in Table 6-3.

e. Applications. Intended applications are provided in the American Society for Testing and Materials (ASTM) or American Association of State Highway and Transportation Officials (AASHTO) specification. The highest (most stringent) use is summarized above. Generally, piping systems can be downgraded in application and provide excellent performance, but they cannot be upgraded. Sanitary sewer pipes perform well in culvert, drainage, and subdrainage (if perforations are provided) applications. However, unperforated land drainage pipes do not perform well as culverts or sewers.

(1) Culverts. For culvert applications, the exposed ends of some types of plastic pipes need protection from exposure to ultraviolet, thermal cycling, etc. Concrete or metal end sections, headwalls, or other end protection is recommended.

(2) Pipe stiffness. Product specifications typically provide minimum pipe stiffness levels. Pipe stiffness and its relationship to AASHTO Flexibility Factor (FF) limits for adequate installation stiffness are provided in paragraph 6-5. In installations where poorly graded granular (SP, GP, etc.) or cohesive (CL or ML) backfill materials are to be used, specifying a stiffer pipe than required by the minimum design criteria is recommended (refer to paragraph 6-5).

(3) Gravity flow. The listed materials, except as noted, are gravity flow piping systems limited to applications where internal hydrostatic heads will not exceed 7.6 m (25 ft) of water.

f. Joints. The types of joints available for each system are shown in Table 6-4. When watertight joints

Table 6-1
Plastic Pipe Systems

Standard	Primary Use	Diameters	Joints
AASHTO M 294 Corrugated HDPE Pipe (Profile Wall)	Storm sewer when the smooth interior wall (M 294-S) is specified, land drainage when it is not (M 294-C)	305 to 900 mm (12 to 36 in.)	Various - must be specified for degree of performance.
ASTM D 2680 ABS Composite Pipe (Profile Wall)	Sanitary sewer	200 to 380 mm (8 to 15 in.)	Solvent weld (watertight)
ASTM D 2680 PVC Composite Pipe (Profile Wall)	Sanitary sewer	200 to 380 mm (8 to 15 in.)	Gasketed or solvent weld (watertight)
ASTM D 3034 PVC Pipe (Solid Wall)	Sanitary sewer	100 to 380 mm (4 to 15 in.)	Gasketed or solvent weld (watertight)
ASTM D 3262 RPM Pipe (Solid Wall)	Sanitary sewer	76 to 1,240 mm (3 to 49 in.)	Gasketed
ASTM F 667 Corrugated HDPE Pipe (Profile Wall)	Land drainage	200 to 610 mm (8 to 24 in.)	Various - must be specified for degree of performance
ASTM F 714 HDPE Pipe (Solid Wall)	Sanitary sewer or pressure	76 to 1,200 mm (3 to 48 in.)	Fusion welded
ASTM F 794 PVC Pipe (Profile Wall)	Sanitary sewer	200 to 1,200 mm (8 to 48 in.)	Gasketed (watertight)
ASTM F 894 Profile Wall HDPE Pipe	Sanitary sewer	460 to 2,450 mm (18 to 96 in.)	Gasketed or fusion welded (watertight)
ASTM F 949 Profile Wall PVC Pipe	Sanitary sewer	200 to 1,200 mm (8 to 48 in.)	Gasketed (watertight)
AASHTO M 304	Nonpressure storm drains, culverts, underdrains, and other subsurface drainage systems	100 to 1,200 mm (4 to 48 in.)	Soiltight or watertight: bells, external sleeves, internal sleeves, and band couplers

are required, gasketed joints meeting ASTM D 3212, solvent welded, or fusion welded joints may be used. Solvent welded and fusion welded joints are as strong as the pipe and provide excellent pull-apart strength for slope drain and other applications. However, PVC solvent welded joints should not be specified for installation in wet conditions or when temperatures are cold. Fusion welding requires special equipment and skill, and it can be time-consuming and, in remote areas or with large pipes, costly.

g. Granular backfill. Culvert and drainage applications with granular backfills require soil-tight joints to prevent the migration of fine backfill materials into the pipe. Gasketed, solvent welded, or fusion welded joints are recommended unless each joint is wrapped with a geotextile.

6-3. Installation

The strength of all plastic pipe systems depends on the quality and placement of the bedding and backfill material. Unless flowable concrete or controlled low-strength materials (CL, SM) are used, ASTM D 2321 will be followed for all installations except for perforated pipes in subdrainage applications.

a. Backfill materials. Using ASTM Class IVA materials (CL, ML, etc.) is not recommended. Clayey and silty materials may provide acceptable performance only in low live load and low cover less than 3 m (10 ft) applications where they can be placed and compacted in dry conditions at optimum moisture levels. They do not apply where they may become saturated or inundated

Table 6-2
Mechanical Properties for Plastic Pipe Design

Type of Pipe	Initial Minimum Tensile Strength MPa (psi)	Initial Minimum Modulus of Elasticity MPa (psi)	Standard Cell Class	50-Year Minimum Tensile Strength MPa (psi)	50-Year Minimum Modulus of Elasticity MPa (psi)	Strain Limit Percent (%)	Pipe Stiffness kPa (psi)
Smooth Wall, PE	20.7 (3,000)	758 (110,000)	ASTM D 3350, 335434C ASTM F 714	9.93 (1,440)	152 (22,000)	5	Varies
Corrugated PE	20.7 (3,000)	758 (110,000)	ASTM D 3350, 335412C AASHTO M 294	6.21 (900)	152 (22,000)	5	Varies
Ribbed, PE	20.7 (3,000)	758 (110,000)	ASTM D 3350, 335434C AASHTO M 278 ASTM F 679	9.93 (1,440)	152 (22,000)	5	320 (46)
Ribbed, PE	20.7 (3,000)	758 (110,000)	ASTM D 3350, 335434C AASHTO M 278 ASTM F 679	9.93 (1,440)	152 (22,000)	5	320 (46)
Smooth Wall, PVC	48.3 (7,000)	2,758 (400,000)	ASTM D 1754, 12454C AASHTO M 278 ASTM F 679	25.51 (3,700)	965 (140,400)	5	320 (46)
Smooth Wall, PVC	41.4 (6,000)	3,034 (440,000)	ASTM D 1784, 12364C ASTM F 679	17.93 (2,600)	1,092 (158,400)	3.5	320 (46)
Ribbed, PVC	41.4 (6,000)	3,034 (440,000)	ASTM D 1784, 12454C ASTM F 794	17.93 (2,600)	1,092 (158,400)	3.5	70 (10) 320 (46)
Ribbed, PVC	48.3 (7,000)	2,758 (400,000)	ASTM D 1784, 12454C ASTM F 794 & ASTM F 949	25.51 (3,700)	965 (140,000)	5	348 (50)
PVC Composite	48.3 (7,000)	2,758 (400,000)	ASTM D 1784, 12454C ASTM D 2680	25.51 (3,700)	965 (140,000)	5	1,380 (200)

during service. When used, these materials must be approved by the geotechnical engineer.

b. Pipe envelope. The pipe envelope and bedding and backfill terms are illustrated in Figure 6-1.

c. Seepage control. When seepage along the pipeline is a consideration, a drainage fill detail is required as discussed in paragraph 1-6.e. If flowable concrete, CLSM, or other such materials are used, note that these materials do not adhere to plastics and will not control seepage unless a sufficient number of rubber water stops (gaskets) are used. Piping systems intended for sanitary sewer applications offer water stop gaskets that seal to the outer pipe wall and bond to concrete.

d. Subdrainage applications. For this application, open grade, nonplastic granular backfill materials compacted to 90 percent relative density in accordance with ASTM D 4254 and D 4253 will be used to fill the pipe zone above the invert. Granular backfill should be wrapped in a suitable geotextile to prevent the migration of soil fines into the granular material.

e. Foundation. Foundation is the in situ material struck to grade or the trench bottom below the pipe and its bedding layer. The foundation supports the pipe and maintains its grade. Plastic pipes, due to their viscoelastic properties, do not provide the necessary long-term beam strength to bridge soft spots or settlement of the foundation. The foundation must carry the fill loads with

Table 6-3
Average Values of Modulus of Soil Reaction E' (For Initial Flexible Pipe Deflection)

Soil Type Pipe Bedding Material (Unified Classification System[a])	E' for Degree of Compaction of Bedding, in MPa (psi)			
	Dumped	Slight <85% Proctor, 40% Relative Density	Moderate, 85%- 95% Proctor, 40%-70% Relative Density	High >95% Proctor, >70% Relative Density
Fine-grained soils (LL > 50)[b] Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; otherwise use E' = 0			
Fine-grained soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse-grained particles	0.34 (50)	1.38 (200)	2.76 (400)	6.89 (1,000)
Fine-grained soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with more than 25% coarse-grained particles Coarse-grained soils with fines GM, GC, SM, SC contains more than 12% fines	0.69 (100)	2.76 (400)	6.89 (1,000)	13.79 (2,000)
Coarse-grained soils Little or no fines GW, GP, SW, SP[c] contains less than 12% fines	1.38 (200)	6.89 (1,000)	13.79 (2,000)	20.68 (3,000)
Crushed rock	6.89 (1,000)	20.68 (3,000)	20.68 (3,000)	20.68 (3,000)

Note: Standard proctors in accordance with ASTM D 698 are used with this table.
Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only, appropriate Deflection Lag Factor must be applied for long-term deflections.
[a]ASTM Designation D 2487, USBR Designation E-3.
[b]LL = Liquid limit.
[c]Or any borderline soil beginning with one of these symbols (i.e. GM-GC, GC-SC).

Table 6-4
Requirements for Joints

Type of Joint	Standards	Requirements
Gravity-flow gasketed	ASTM D 3212	Internal Pressure: Certified test reports are required for each diameter of pipe used. External Pressure: 7620 mm (25 ft) water head for 10 minutes when subjected to 560 mm (22 in.) of mercury, 7620 mm (25 ft) of water vacuum for 10 minutes.
Pressure-rated gasketed	ASTM D 3919, ASTM C 900, & AWWA C 950	Internal Pressure: ASTM D 3919, Requires pressure testing, ASTM C 900, same requirements of D 3919, American Water Works Association (AWWA) C 950, same requirements as ASTM D 4161. External Pressure: ASTM D 3919, Vacuum tested to only 7620 mm (25 ft) of water at any pressure rating, ASTM C 900, same requirements as D 3919, AWWA C 950, same requirement as ASTM D 4161.
Pressure-rated and nonpressure gasketed	ASTM D 4161	Internal Pressure: Tested to twice the rated pressure for pressure pipe or 200 kPa (29 psi) for non-pressure pipe. External Pressure: Requires an external rating of 8230 mm (27 ft) of water head for 10 minutes.
Solvent joints	---	Solvent cemented joints for PVC (not recommended in wet conditions) and ABS pipes typically have tightness requirements. These joints are not recommended for ABS or PVC pipe as there are no standards for joint integrity.
Butt-fused	---	For HDPE solid-wall. No standards for joint integrity.
Extrusion-welded	---	For HDPE. No standards for joint integrity.

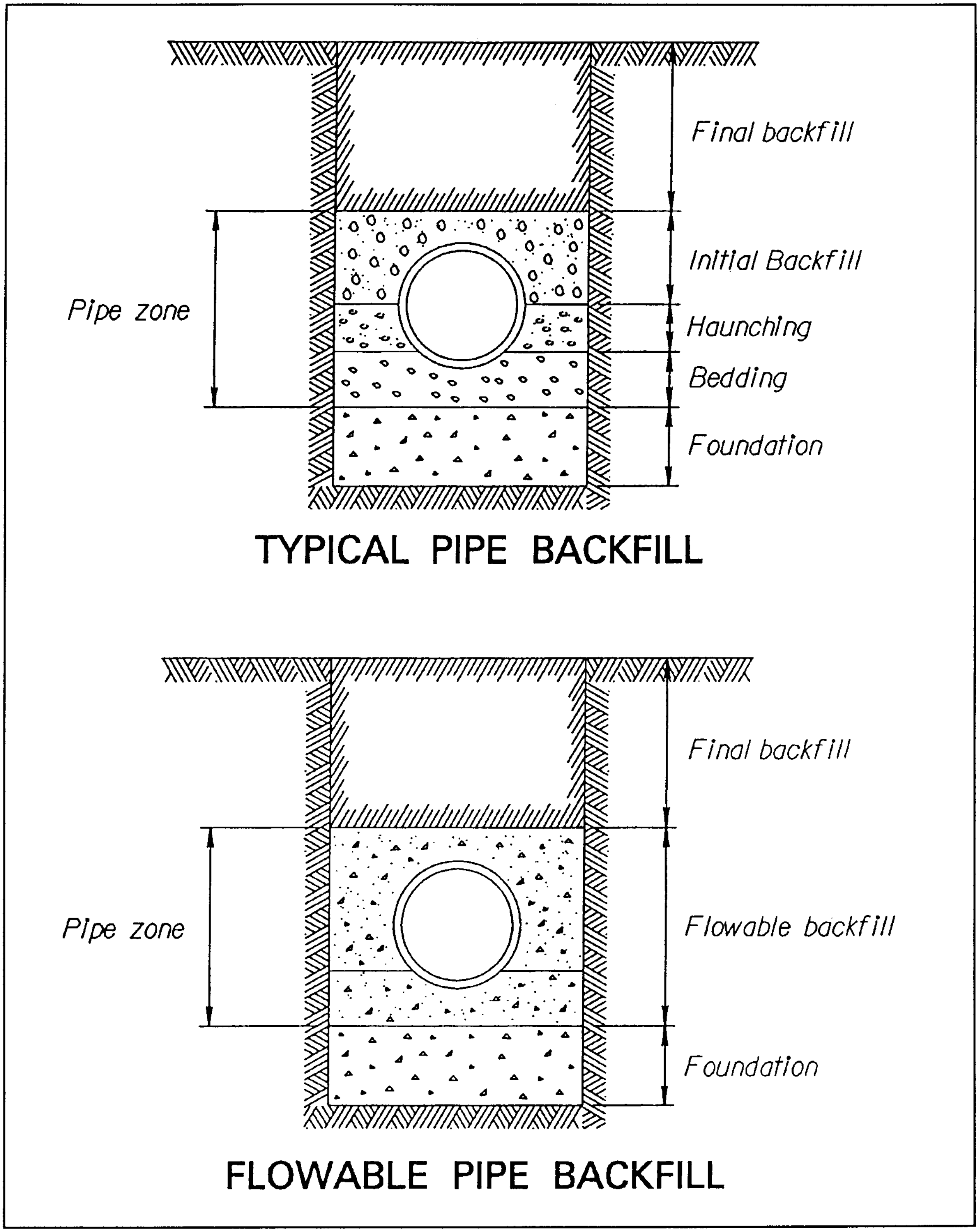

Figure 6-1. Flexible pipe backfill

a suitable limit on settlements which will be directly exhibited as grade changes that occur over the pipe as sags develop in the pipe. Where the foundation is inadequate, it may be improved by overexcavation and replacement with compacted ASTM D 2321 backfill materials, surcharged to induce the settlement beforehand. Concrete cradles and other pipe supports should not be used.

f. Bedding. Bedding is used to support the pipe directly over the foundation material. For plastic pipe, the bedding material is typically granular. The proper selection of bedding material ensures the proper soil-pipe interaction and the development of pipe strength. The strength of the plastic pipe is built in the trench. Concrete cradles should not be used under plastic pipe, because these pipes are subject to wall crushing at the springline or local buckling at the contact point between the pipe and the cradle.

g. Haunching. Haunching the volume of backfill supports the pipe from the top of the bedding to the springline of the pipe. Compaction of the pipe haunch areas is critical to the successful installation of plastic pipes and prevents pipe sagging in the haunch area. Special construction procedures are necessary when installing plastic pipe in a trench box, as the haunching material can slough away from the pipe wall when the trench box is advanced. The designer should review the contractor's construction procedures when using a trench box.

h. Initial backfill. Initial backfill is the material placed above the springline and 305 mm (12 in.) over the pipe. Completion of this zone with well-compacted granular material ensures that the pipe strength is developed.

i. Final backfill. Final backfill is the material that completes the pipe installation and brings the trench to final grade. Proper compaction is required in the trench to limit surface settlements. A minimum depth of final backfill over plastic pipe of 610 mm (2 ft) is recommended when installing plastic pipe under paved surfaces. Since these soils do not completely rebound, the surface pavement will crack and settle with time if less than minimum cover is used. Therefore, a well-compacted backfill is required for the pipe to function properly.

j. Flowable backfill. Flowable backfill is used to replace the pipe zone materials described above. Flowable backfill places a CLSM around the pipe to ensure good support for the pipe, yet uses a material that can be easily removed if the pipe needs to be replaced in the future.

6-4. Loadings

Vertical trench loads for plastic pipe are calculated as indicated in Chapter 2. The horizontal pressures are controlled by the granular backfill requirements. These loads are calculated as shown in Chapter 2. Concentrated live loads for plastic pipe are designed for highway or railroad loadings as required by standards of the affected authority. Normally, these pipes will require a casing pipe when crossing under highways and railroads, or the pipe may be encased in CLSM.

6-5. Methods of Analysis

Plastic pipe analysis requires the designer to check values that include pipe stiffness, pipe deflection, ring buckling strength, hydrostatic wall buckling, wall crushing strength, and wall strain cracking.

a. Pipe stiffness. When plastic pipe is installed in granular backfills, the stiffness of the plastic pipe selected will affect the end performance. Stiffness for plastic pipes is most widely discussed in terms of pipe stiffness ($F/\Delta Y$) which must be measured by the ASTM D 2412 test. Most plastic pipe standards have specific minimum required pipe stiffness levels. While pipe stiffness is used to estimate deflections due to service loads, stiffness is also the primary factor in controlling installation deflections. AASHTO controls installation deflection with a flexibility factor (FF) limit indicated in Equations 6-1 and 6-2.

$$FF = \frac{D^2}{EI} * 1000 \leq C_{FF} \tag{6-1}$$

$$PS = \frac{EI}{0.149R^3} \geq \frac{C_{PS}}{D} \tag{6-2}$$

where

D = mean pipe diameter, m (in.)

E = the initial modulus (Young's modulus) of the pipe wall material, N/m^2 (psi)

I = pipe wall moment of inertia, m^4/m (in.^{4}/in.)

C_{FF} = Constant: 0.542 metric (95 english)

PS = pipe stiffness, N/m/m (lbs/in./in.)

R = mean pipe radius, m (in.)

C_{PS} = Constant: 98946 metric (565 english)

b. Deflection.

(1) Excessive pipe deflections should not occur if the proper pipe is selected and it is properly installed and backfilled with granular materials. However, when pipes are installed in cohesive soils, the deflection can be excessive. Deflections occur from installation loadings (the placement and compaction of backfill) and service loads due to soil cover and live loads.

(2) In installations, where heavy compaction equipment is often used, or when difficult to compact backfill materials (GP, SP, CL, ML, etc.) are used, specifying a minimum pipe stiffness of 317 kPa (46 psi) or twice that required by Equation 6-2, whichever is less, is desirable to facilitate backfill compaction and control installation deflections.

(3) Deflections under service loads depend mostly on the quality and compaction level of the backfill material in the pipe envelope. Service load deflections are generally evaluated by using Spangler's Iowa Formula. However, it significantly overpredicts deflections for stiffer pipes (pipe stiffnesses greater than 4,790 N/m/m (100 lb/in./in.) and underpredicts deflections for less stiff pipes (pipe stiffnesses less than 960 N/m/m (20 lb/in./in.). In both cases, the error is roughly a factor of 2.0. The form of the Iowa Formula easiest to use is shown in Equation 6-3.

$$\frac{\Delta Y}{D} = \left(\frac{D_L \; K \; P}{0.149\,(PS) \; + \; 0.061\,(E')} \right) 100 \qquad (6\text{-}3)$$

where

$\Delta Y/D$ = pipe deflection, percent

D_L = deflection lag factor
= 1.0 minimum value for use only with granular backfill and if the full soil prism load is assumed to act on the pipe
= 1.5 minimum value for use with granular backfill and assumed trench loadings
= 2.5 minimum value for use with CL, ML backfills, for conditions where the backfill can become saturated, etc.

K = bedding constant (typically 0.11)

P = service load pressure on the crown of the pipe, N/m^2 (psi)

PS = pipe stiffness, N/m/m (lb/in./in.)

E' = modulus of soil reaction as determined by the geotechnical engineer, N/m^2 (psi)

Note: Table 6-3 provides generally accepted values that may apply to specific site conditions and backfill materials if they do not become saturated or inundated.

b. Wall stress (crushing). Wall stress is evaluated on the basis of conventional ring compression formulas. Because of the time-dependent strength levels of plastic materials, long-term loads such as soil and other dead loads must be evaluated against the material's long-term (50-year) strength. Very short term loads, such as rolling vehicle loads, may be evaluated using initial properties. Use Equations 6-4 through 6-6 to evaluate wall stress.

$$T_{ST} = \frac{DP_{ST}}{2} \qquad (6\text{-}4)$$

$$T_{LT} = \frac{DP_{LT}}{2} \qquad (6\text{-}5)$$

$$A \geq 2 \left(\frac{T_{ST}}{f_i} + \frac{T_{LT}}{f_{50}} \right) * 10^6 \qquad (6\text{-}6)$$

where

T_{ST} = thrust due to short-term loads

D = pipe diameter or span, m (ft)

P_{ST} = short-term loading pressure at the top of the pipe, N/m^2 (psf)

T_{LT} = thrust due to long-term loads

P_{LT} = long-term loading pressure at the top of the pipe, N/m^2 (psf)

A = required wall area using a minimum factor of safety of 2.0 (A/10^6 in.^{2}/ft)

f_i = initial tensile strength level, N/m^2 (psi) (Table 6-2)

f_{50} = 50-year tensile strength level, N/m^2 (psi) (Table 6-2)

c. Ring buckling. The backfilled pipe may buckle whether the groundwater table is above the bottom of the pipe or not. The critical buckling stress may be evaluated by the AASHTO formula shown in Equation 6-7.

$$f_{cr} = 0.77 \frac{R}{A} \sqrt{\frac{BM_s EI}{0.149R^3}} \qquad (6\text{-}7)$$

where

f_{cr} = maximum, critical stress in the pipe wall, N/m^2 (psi), using a factor of safety of 2.0

R = mean pipe radius, m (in.)

A = pipe wall area, mm^2/m ($in.^2/in.$)

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

h_w = height of water surface above the top of the pipe, m (ft)

h = height of cover above the top of the pipe, m (ft)

M_s = Soil modulus (of the backfill material, N/m^2 (psi)), as determined by a geotechnical engineer

E = 50-year modulus of elasticity of the pipe wall material, N/m^2 (psi) (Table 6-2)

I = pipe wall moment of inertia, mm^4/m ($in.^4/in.$)

d. Hydrostatic buckling.

(1) When pipes are submerged but not adequately backfilled, such as service lines laid on the bottom of a lake, the critical hydrostatic pressure to cause buckling can be evaluated by the Timoshenko buckling formula provided in Equation 6-8. The variable C is used to account for decrease in buckling stress due to pipe out of roundness P_{cr}.

$$P_{cr} = C \left(\frac{K\ EI}{(1 - \nu^2)\ R^3} \right) \qquad (6\text{-}8)$$

where

P_{cr} = critical buckling pressure, N/m^2 (psf)

C = ovality factor at: 0 % deflection, C = 1.0; 1%, 0.91; 2%, 0.84; 3%, 0.76; 4%, 0.70, and 5%, 0.64

K = constant $1.5\ (10)^{-12}$ metric, 216 non-SI

ν = Poisson's ratio for the pipe wall material (typically 0.33 to 0.45) other factors same as Equation 6-7

(2) A factor of safety of 2.0 is typically applied for round pipe. However, note that 5 percent pipe deflection reduces P_{cr} to 64 percent of its calculated value.

(3) Equation 6-8 can be conservatively applied to hydrostatic uplift forces acting on the invert of round pipes.

e. Wall strain cracking. Wall strain cracking is a common mode of failure in plastic pipe, especially RPM and reinforced thermosetting resin (RTR) pipes, the two common forms of fiberglass pipe. Refer to ASTM D 3839 for the standard practice to install these pipes and to ASTM D 3262 for the minimum allowable strain limits for these pipes. The manufacturer of the pipe material must provide the maximum allowable wall strain limit based upon ASTM D 3262. Also, AASHTO provides information on the allowable long-term strain limits for many plastics. Excessive wall strain in fiberglass pipe will lead to an accelerated premature failure of the pipe. The typical long-term strain value for HDPE and PVC is 5 percent at a modulus of 2,760 MPa (400,000 psi), or 3.5 percent for PVC with a modulus of 3,030 MPa (440,000 psi). Refer to Equation 6-9.

$$\varepsilon_b = \frac{t_{\max}}{D} \left(\frac{0.03 \frac{\Delta Y}{D}}{1 - 0.02 \frac{\Delta Y}{D}} \right) \le \frac{\varepsilon_{limit}}{FS} \qquad (6\text{-}9)$$

where

ε_b = bending strain due to deflection, percent

t_{max} = pipe wall thickness, m (in.)

D = mean pipe diameter, m (in.)

$\Delta Y/D$ = pipe deflection, percent

ε_{limit} = maximum long-term strain limit of pipe wall, percent

FS = factor of safety (2.0 recommended)

f. Flowable backfill. This material has a compressive strength less than 3.4 MPa (500 psi). Flexural strength is not a concern since cracking of the backfill material does not control the design of the pipe. A cracked backfill material would still form an arch over the pipe and provide adequate support.

6-6. Joints

Requirements for joints are provided in Table 6-4.

6-7. Camber

Where considerable foundation settlement is likely to occur, camber should be used to ensure positive drainage and to accommodate the extension of the pipe due to settlement.