Chapter

5

Design Methodology

DESIGN METHODOLOGY

Overview of Structural Considerations

All pipe, whether flexible or rigid, relies on the backfill structure to transfer loads into the bedding. As a result, all pipe also must be installed as designed to perform as expected.

This chapter sets forth the design methodology for corrugated polyethylene pipe meeting the American Association of State Highway and Transportation Officials (AASHTO) M252 and M294 and MP7 used in non-pressure applications. Section properties for use in the design procedure are presented. Material properties, backfill criteria and load conditions play important roles in pipe performance. The design procedure evaluates deflection, buckling, bending stress, bending strain and wall stress. This procedure establishes limits for each condition.

"Height of Cover" tables showing minimum cover in trafficked installations and maximum cover heights under a variety of backfill conditions are shown in Tables 5-4 and 5-5 respectively. Sample calculations also are provided.

Corrugated polyethylene pipe performance has been extensively documented and researched through laboratory and field installations. This work reinforces the conservatism of this design procedure.

Introduction

This chapter was developed to assist those who utilize or specify corrugated polyethylene pipe, meeting the American Association of State Highway and Transportation Officials (AASHTO) M252 and M294 specifications, as well as CAN/CSA standards, in non-pressure applications to better understand its structural capabilities. Although it has been in use for nearly three decades in the United States and Canada, corrugated polyethylene pipe is still considered to be one of the newer products in the storm sewer and culvert markets. An extensive amount of laboratory testing, computer simulations and actual installations confirm the performance of these products.

Pipe behavior can be broadly classified as flexible or rigid, depending on how it performs when installed. Flexible pipe can move, or deflect, under loads without structural damage. Corrugated polyethylene pipe is an example. Rigid pipe is sometimes classified as pipe that cannot deflect significantly without structural distress, such as cracking. Reinforced and non-reinforced concrete pipe are examples.

Both flexible and rigid pipe depend on proper backfill. Backfill characteristics, and also trench configuration in the case of rigid pipe, enter into the design procedures. For flexible pipe, deflection allows loads to be transferred to and carried by the backfill. Rigid pipe transmits most of the load through the pipe wall into the bedding. Proper backfill is very important in determining how the load is transferred, for either flexible or rigid pipe. Refer to the appropriate chapters of this design manual for further information on proper installation techniques.

Numerous research projects have investigated the behavior of flexible pipe. Polyethylene pipe performance has been evaluated through the use of actual field installations, post-installation inspections, load cell tests and finite element computer analyses. As a result, nearly three decades after its introduction, the behavior of corrugated polyethylene pipe has probably been analyzed more than any other conventional drainage pipe.

The information in subsequent areas of this document provides a step-by-step guide for the structural design of gravity flow corrugated polyethylene pipe. The methodology represents the state-of-the-art design procedure, and has been proven through actual installations to be conservative.

Differences Between Flexible and Rigid Pipe

Nearly all pipe can be classified as either flexible or rigid, depending on how it performs when installed. Flexible pipe takes advantage of its ability to move, or deflect, under loads without structural damage. Common types of flexible pipe are manufactured from polyethylene, polyvinyl chloride (PVC), steel and aluminum. Rigid pipe is sometimes classified as pipe that cannot deflect more than 2% without significant structural distress, such as cracking. Reinforced and non-reinforced concrete pipe and clay pipe are examples. Figure 5-1 shows the difference between how flexible and rigid pipe respond to loads.

Figure 5-1

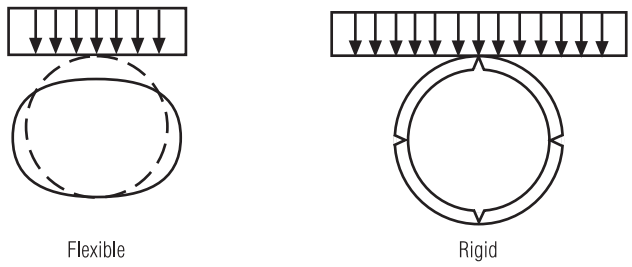

Figure 5-1: Pipe Response to Loading

Both flexible and rigid pipe require proper backfill, although the pipe/backfill interaction differs. When flexible pipe deflects against the backfill, the load is transferred to and carried by the backfill. When loads are applied to rigid pipe, on the other hand, the load is transferred through the pipe wall into the bedding. For both types of materials, proper backfill is very important in allowing this load transfer to occur. Figure 5-2 shows the pipe/backfill interaction and the corresponding load transfer.

Figure 5-2

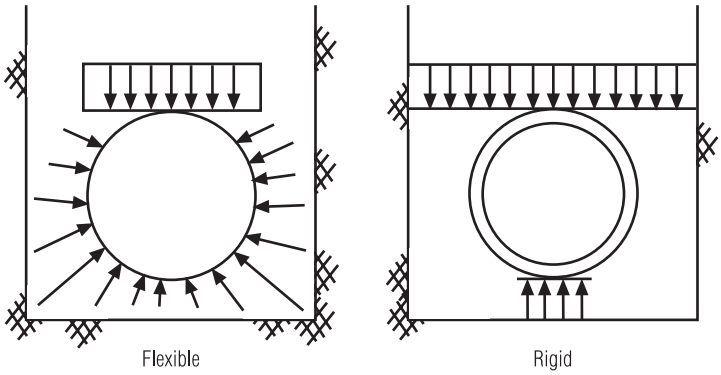

Figure 5-2: Pipe/Backfill Interaction

Flexible pipe offers significant structural benefits to the project designer. In many situations, a properly installed flexible pipe can be buried much deeper than a similarly installed rigid pipe because of the flexible pipe/backfill interaction. A rigid pipe is often stronger than the backfill material surrounding it, thus it must support earth loads well in excess of the prism load above the pipe. Conversely, a flexible pipe is not as strong as the surrounding backfill; this mobilizes the backfill envelope to carry the earth load. The flexible pipe/backfill interaction is so effective at maximizing the structural characteristics of the pipe that it allows the pipe to be installed in very deep installations, many times exceeding allowable cover for rigid pipe when identically installed.

The Viscoelastic Nature of Corrugated Polyethylene Pipe

Flexible pipe is manufactured from either plastics or metals. Plastics and metals are, however, very different types of materials. Metals exhibit elastic properties and plastics exhibit viscoelastic, or time-dependent, characteristics. It is *this* difference that is key to understanding corrugated polyethylene pipe and its installed performance as compared to other types of flexible pipe.

Making the assumption that the characteristics of viscoelastic materials can be analyzed using the same techniques used for elastic materials will undoubtedly yield misleading results. One of the most common misconceptions surrounding plastics, particularly polyethylene, is that they lose strength with time. This idea stems from applying elastic behavior criteria to a viscoelastic material. When a corrugated polyethylene pipe is deflected, or strained, in the laboratory, the stress versus strain curve that results has a high initial modulus that almost immediately begins to decrease. Figure 5-3 shows a diagram of what the stress/strain relationship could look like.

Figure 5-3

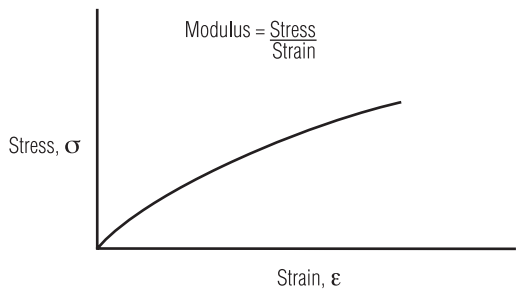

Figure 5-3: Typical Stress/Strain Relationship for Polyethylene

The elastic modulus, or flex modulus as it is commonly referred to for viscoelastic materials, is the ratio between the change in strain and the change in stress levels. The modulus is high initially, but then begins to decrease. The pipe appears to require less force over time to maintain the same strain level. If the material behaved according to elastic principles, it could be described as losing strength. However, polyethylene is viscoelastic and the conclusion that the material is losing strength would be erroneous.

This concept is not an insignificant one for polyethylene. With typically referenced short-term (quick) and long-term modulus values of 110,000 psi (758 MPa) and 22,000 psi (152 MPa), respectively, design results would be very different. The question of which value to use in design certainly deserved more attention, and research projects were initiated to gain more understanding.

The University of Massachusetts designed a research project specifically to address the effect time has on the modulus of polyethylene. A corrugated polyethylene pipe was placed in a frame that allowed measurements of both stress and strain under repeated load intervals, and for a relatively long time. A load was applied to the pipe to create an initial level of deflection. The pipe reacted as predicted with an initial high

modulus which began to decrease almost immediately. With the pipe still deflected, the stress level was increased another increment. The pipe again responded with its initial modulus which then immediately began to decrease. Several more load increments were applied with the pipe responding the same each time. Graphical representations of the pipe response are shown in Figure 5-4.

Figure 5-4

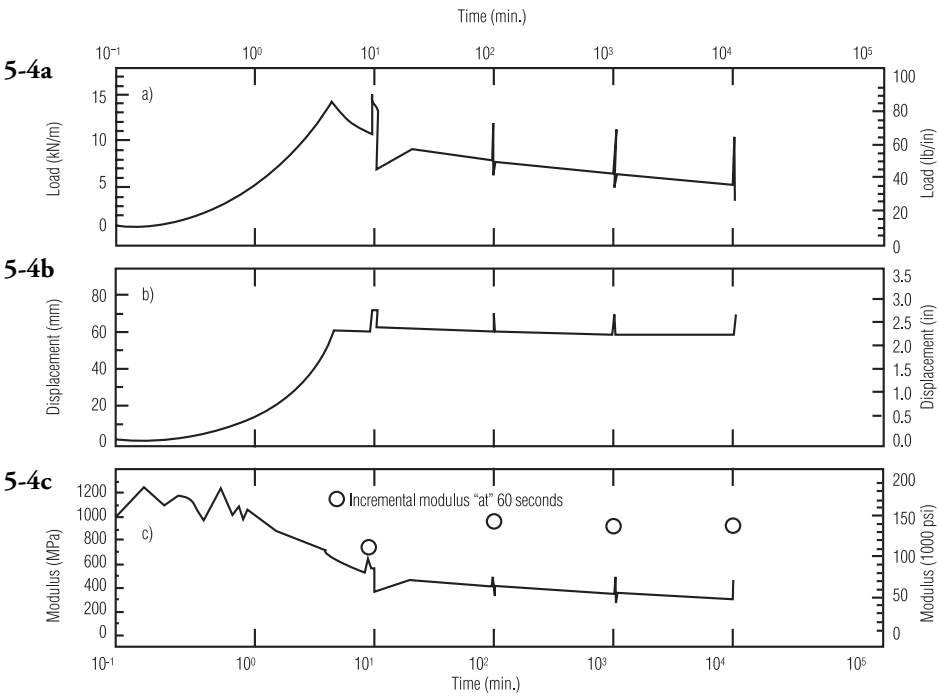

Figure 5-4: Effects of Repeated Loads on Corrugated Polyethylene Pipe

Part (c) of Figure 5-4 shows a modulus that seems to be decreasing over time. However, the modulus that occurs each and every time a new load is applied, regardless of when, remains approximately the same. This behavior is *not* indicative of a material that is losing strength.

Design Criteria

Design of non-pressure polyethylene pipe requires knowledge of material properties (Chapter 1), installation conditions (Chapter 6) and external loads (Chapter 4). All of these elements combine to define the behavior of the installed pipe. This section describes the criteria that enter into the design procedure found later in this chapter.

Pipe Section Properties

As in the design of other structural components, the geometry of the pipe wall influences how it will perform in the pipe/soil structure. Pipe properties include the moment of inertia of the wall profile (I), distance from the inside diameter to the neutral axis (c) and the cross-sectional area (A_S). Pipe stiffness (PS) per ASTM D 2412 is the value obtained by dividing the force per unit length of specimen by the resulting deflection in the same units at the prescribed percentage deflection. The 5% limit is arbitrary and, although substituted directly in the design equations, PS is a quality check and should not be interpreted to be a performance limit. The section properties in Table 5-1 represent a range of commercially available products, some of which include a smooth interior. Since pipe profiles vary, data for *specific* products should be obtained directly from the manufacturer.

Table 5-1

Inside Diameter, ID		Typical Outside Diameter, OD		Minimum Pipe Stiffness at 5% Deflection, PS		Section Area, A_s		Distance from Inside Diameter to Neutral Axis, c		Moment of Inertia, I	
in	mm	in	mm	pii	N/m/mm**	in^2/in	mm^2/mm	in	mm	in^4/in	mm^4/mm
4	100	4.7	119	35	241	0.0448	1.138	0.139	3.531	0.0	11.5
6	150	7	178	35	241	0.0568	1.443	0.192	4.876	0.0	54.1
8	200	9.9	251	35	241	0.0837	2.126	0.297	7.535	0.0	142.6
10	250	12	305	35	241	0.1044	2.652	0.393	9.97	0.0	303.2
12	300	14.7	373	50	345	0.125	3.175	0.35	8.89	0.0	393.3
15	375	17.7	457	42	290	0.159	4.043	0.45	11.43	0.1	868.5
18	450	21.5	546	40	275	0.195	4.953	0.5	12.70	0.1	1016.0
24	600	28.7	729	34	235	0.262	6.646	0.65	16.51	0.1	1900.9
30	750	36.4	925	28	195	0.327	8.297	0.75	19.05	0.2	2671.1
36	900	42.5	1080	22	150	0.375	9.525	0.9	22.86	0.22	3637.9
42	1050	48	1219	20	140	0.391	9.927	1.11	28.19	0.52	8898.2
48	1200	55	1397	18	125	0.429	10.901	1.15	29.21	0.52	8898.2
54	1350	61	1549	16	110	0.473	12.014	1.25	31.75	0.82	13552.1
60	1500	67.3	1709	14	97	0.538	13.665	1.37	34.798	1.0	16518.2

*Data represents a range of values encompassing most commercially made pipe meeting AASHTO M252, M294 or MP7. Contact the pipe manufacturer for information on specific products.
**Typical Canadian values for Canadian pipe stiffness are as per CAN/CSA B182.6

Table 5-1: Representative Section Properties* for Corrugated Polyethylene Pipe Meeting AASHTO M252, M294 and MP7

An important soil property used in design, the shape factor (D_f), is a function of pipe stiffness, type of backfill material, and the compaction level. This factor is used in the bending stress and bending strain equations. Table 5-2 lists shape factors for a variety of typical installation conditions.

Table 5-2

	Gravel GW, GP, GW-GC, GW-GM, GP-GC and GP-GM		Sand SW, SP, SM, SC, GM, GC or Mixtures	
Pipe Stiffness, PS pii (kPa)	Dumped to Slight (<85% SPD)	Moderate to High (≥85% SPD)	Dumped to Slight (<85% SPD)	Moderate to High (≥85% SPD)
14 (97)	4.9	6.2	5.4	7.2
16 (110)	4.7	5.8	5.2	6.8
17 (117)	4.6	5.7	5.1	6.7
20 (138)	4.4	5.4	4.9	6.4
22 (152)	4.3	5.3	4.8	6.3
28 (193)	4.1	4.9	4.4	5.9
30 (210)	4.0	4.8	4.3	5.8
34 (234)	3.9	4.6	4.1	5.6
35 (241)	3.8	4.6	4.1	5.6
38 (262)	3.8	4.5	4.0	5.4
40 (276)	3.7	4.4	3.9	5.4
42 (290)	3.7	4.4	3.9	5.3
46 (320)	3.7	4.4	3.9	5.2
50 (345)	3.6	4.2	3.8	5.1

Notes:
1) Interpolate for intermediate pipe stiffness values.
2) For Class IA and IB backfill materials, use the appropriate "Gravel" column.
3) Information has been modified from ANSI/AWWA C950-88, p. 28, for pipe stiffnesses appropriate for corrugated polyethylene pipe.

Table 5-2: Shape Factors (D_f)

Loads

Loads are considered to be either a live (moving) load or a dead (static) load. Live loads change in position or magnitude; whereas dead loads remain static throughout the design life of the drainage system. The most commonly considered live loads in pipe applications are vehicular loads, usually from trucks, trains or aircraft. The soil load is often the sole dead load consideration, however foundation loads and groundwater conditions should be factored in the design when appropriate.

Live Loads (L_W)

Vehicular loads are typically based on the AASHTO H-25 configuration. Figure 5-5 represents a 25 ton (22.7 metric ton) semi-truck with a 40,000 lb (18,140 kg) axle load. Similarly in railroad applications, the load is represented by the Cooper E-80 configuration at 80,000 lb/ft (119,300 kg/m) of track.

Figure 5-5

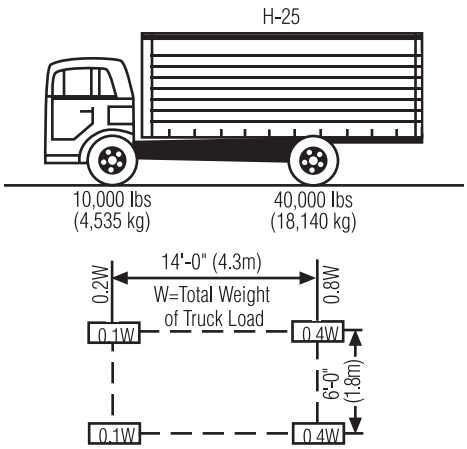

Figure 5-5: AASHTO H-25 Highway Load
Source: AASHTO Standard Specifications for Highway Bridges

In applications where the pipe is buried relatively shallow, it can experience an additional force from the rolling motion of the vehicle. To account for this additional force, the stationary vehicular load is multiplied by an "impact factor". For highway loads, AASHTO establishes a range of impact factors from 1.3 at about 1 ft. (0.3 m) of cover to 1.1 at depths just under 3 ft. (1 m). Impact has negligible influence at depths over 3 ft. (1 m). Table 5-3 provides information about the resultant H-25, HS-25 and E-80 vehicular forces at various cover heights with impact included in the shallow cover situations.

Table 5-3

Cover, ft. (m)	AASHTO H-25 or HS-25[1]		Cooper E-80[1]	Cover, ft. (m)	AASHTO H-25 or HS-25[1]		Cooper E-80[1]
	Live Load Transferred to Pipe, P_L, psi (N/mm²)	Live Load Distribution Width, L_W in (mm)	Live Load Transferred to Pipe, P_L, psi (N/mm²)		Live Load Transferred to Pipe, P_L, psi (N/mm²)	Live Load Distribution Width, L_W in (mm)	Live Load Transferred to Pipe, P_L, psi (N/mm²)
1 (0.3)	15.63 (0.108)	31 (787)	N/R	14 (4.3)	negligible	N/A	4.17 (0.0288)
2 (0.6)	6.95 (0.048)	52 (1321)	26.39 (0.1824)	16 (4.9)	negligible	N/A	3.47 (0.0240)
3 (0.9)	5.21 (0.036)	73 (1854)	23.61 (0.1632)	18 (5.5)	negligible	N/A	2.78 (0.0192)
4 (1.2)	3.48 (0.024)	94 (2388)	18.40 (0.1272)	20 (6.1)	negligible	N/A	2.08 (0.0144)
5 (1.5)	2.18 (0.015)	115 (2921)	16.67 (0.1152)	22 (6.7)	negligible	N/A	1.91 (0.0132)
6 (1.8)	1.74 (0.012)	136 (3454)	15.63 (0.1080)	24 (7.3)	negligible	N/A	1.74 (0.0120)
7 (2.1)	1.53 (0.011)	157 (3988)	12.15 (0.0840)	26 (7.9)	negligible	N/A	1.39 (0.0096)
8 (2.4)	0.86 (0.006)	178 (4521)	11.11 (0.0768)	28 (8.5)	negligible	N/A	1.04 (0.0072)
10 (3.0)	negligible	N/A	7.64 (0.0528)	30 (9.1)	negligible	N/A	0.69 (0.0048)
12 (3.7)	negligible	N/A	5.56 (0.0384)	35 (10.7)	negligible	N/A	negligible

Notes:
1) Includes impact where required.
2) N/R indicates that the cover height is not recommended.
3) N/A indicates that the information is not applicable.
4) Information has been modified from Buried Pipe Design, Moser, McGraw-Hill, 1990, p. 34.

Table 5-3: Live Load Data for AASHTO H-25 or HS-25 and Cooper E-80 (P_L, L_W)

Loads from aircraft vary widely in magnitude and distribution. The FAA pavement design manual should be referenced for more specific information. This information is available on the FAA Web site.

Some construction vehicles may pose a temporary, although severe, live load consideration. The magnitude and distribution of the load should be evaluated. Mounding and compacting additional cover over the pipe when necessary, then grading following construction, may be warranted in situations where the pipe has little cover. In general, for equipment between 30 and 60 tons (27.3 and 54.5 metric tons) with weight distributions similar to the HS-25 configuration, a minimum of 2 ft. (0.6 m) of cover is needed over the pipe. Higher loads will require a minimum of 3 ft. (1 m) of cover.

Dead Loads

The soil load is calculated in this design procedure using two different techniques, the soil column load (W_C) and the soil arch load (W_A). It is important to understand the differences between these two methods, as well as when to use the results from each of them.

Soil Column Load (W_C)

The soil column load is defined as the weight of the soil directly above the outside diameter of the pipe at the height of the pipe crown and must be used to determine deflection. The deflection equation was developed from empirical relationships based on the soil column load. In reality, the actual soil load is less than the calculated column load because the column is suspended, in part, by adjacent soil columns.

The soil column load is calculated as follows:

$$W_C = \frac{H\,\gamma_S\,OD}{144} \qquad \textbf{Equation 5-1}$$

Where:

W_C = soil column load, lb/linear inch of pipe
H = burial depth to top of pipe, ft.
γ_S = soil density, pcf
OD = outside diameter of pipe, in. (Table 5-1)

Or, in metric units:

$$W_C = 9.81\text{x}10^{-6}\,(H)(\gamma_S)(OD) \qquad \textbf{Equation 5-1(a)}$$

Where:

W_C = soil column load, N/linear mm of pipe
H = burial depth to top of pipe, m
γ_S = soil density, kg/m^3
OD = outside diameter of pipe, mm (Table 5-1)

Soil Arch Load (W_A)

The soil arch load (W_A) more closely represents the actual soil load experienced by a pipe. The arch load calculation uses a vertical arching factor (VAF) to reduce the earth load in order to account for the support provided by adjacent soil columns. The soil arch load must be used to determine wall thrust.

The arch load is determined using the procedure described below. First, the geostatic load is calculated by determining the weight of soil directly above the outside diameter of the pipe plus a small triangular load extending just beyond the outside diameter. The equation for the geostatic load, P_{sp}, is shown in Equation 5-2 and 5-2(a).

$$P_{sp} = \frac{(\gamma_S)(H + 0.11\ \frac{OD}{12})}{144}$$ **Equation 5-2**

Where:

P_{sp} = geostatic load, psi
H = burial depth to top of pipe, ft.
γ_S = soil density, pcf
OD = outside diameter of pipe, in. (Table 5-1)

Or, in metric units:

$$P_{sp} = (9.81)(\gamma_S)[H + 1.1 \times 10^{-4}(OD)]$$ **Equation 5-2(a)**

Where:

P_{sp} = geostatic load, N/m^2
H = burial depth to top of pipe, m
γ_S = soil density, kg/m^3
OD = outside diameter of pipe, mm (Table 5-1)

Next, the vertical arching factor (VAF) must be determined. This factor accounts for the support provided by adjacent soil columns by reducing the geostatic load. The vertical arching factor is computed as shown in Equation 5-3 or 5-3(a).

$$VAF = 0.76 - 0.71\left(\frac{S_h - 1.17}{S_h + 2.92}\right)$$ **Equation 5-3**

Where:

VAF = vertical arching factor, dimensionless
S_h = hoop stiffness factor;
= $\phi_S\ M_S\ R/(EA_S)$
ϕ_S = capacity modification factor for soil, 0.9
M_S = secant constrained soil modulus, psi (Table 6-3)
R = effective radius of pipe, in.
= ID/2+c
ID = inside diameter of pipe, in. (Table 5-1)
c = distance from inside diameter to neutral axis, in. (Table 5-1)
E = modulus of elasticity of polyethylene
= 110,000 psi for short term conditions
= 22,000 psi for long term conditions
A_S = section area, in^2/in (Table 5-1)

Or, in metric units:

$$VAF = 0.76 - 0.71\left(\frac{S_h - 1.17}{S_h + 2.92}\right) \qquad \textbf{Equation 5-3(a)}$$

Where:

VAF = vertical arching factor, dimensionless
S_h = hoop stiffness factor;
= $\phi_S M_S R/(EA_S)$
ϕ_S = capacity modification factor for soil, 0.9
M_S = secant constrained soil modulus, kPa (Table 6-3)
R = effective radius of pipe, mm
= ID/2+c
ID = inside diameter of pipe, mm (Table 5-1)
c = distance from inside diameter to neutral axis, mm (Table 5-1)
E = modulus of elasticity of polyethylene
= 758,500 kPa for short term conditions
= 151,700 kPa for long term conditions
A_S = section area, mm^2/mm mm (Table 5-1)

After the geostatic load, P_{sp}, and the VAF have been determined, the soil arch load can be found as shown in Equation 5-4 or 5-4(a).

$$W_A = (P_{sp})(VAF) \qquad \textbf{Equation 5-4}$$

Where:

W_A = soil arch load, psi
P_{sp} = geostatic load, psi
VAF = vertical arching factor, dimensionless

Or, in metric units:

$$W_A = (P_{sp})(VAF) \qquad \textbf{Equation 5-4(a)}$$

Where:

W_A = soil arch load, N/m^2
P_{sp} = geostatic load, N/m^2
VAF = vertical arching factor, dimensionless

Hydrostatic Loads

The pressure of groundwater must also be accounted for only if present at or above the pipe springline. Equations 5-5 and 5-5(a) provide the method to calculate hydrostatic pressure.

$$P_W = \frac{\gamma_W (H_g)}{144} \qquad \textbf{Equation 5-5}$$

Where:

P_W = hydrostatic pressure at springline of pipe, psi
γ_W = unit weight of water, 62.4 pcf
H_g = height of groundwater above springline of pipe, ft.

Or, in metric units:

$$P_W = (9.81)(\gamma_W)(H_g) \qquad \textbf{Equation 5-5(a)}$$

Where:

P_W = hydrostatic pressure at springline of pipe, N/m^2
γ_W = unit weight of water, 1000 kg/m^3
H_g = height of groundwater above springline of pipe, m

Design of corrugated polyethylene pipe in nonpressure applications involves calculating wall thrust, deflection, buckling, bending stress and bending strain. Criteria for pipe, installation conditions and loads from the design criteria section are required for this procedure; references are made to areas where the required information can be found. Maximum and minimum cover height tables calculated using the following procedure have already been prepared and can be found in this chapter (Tables 5-4 and 5-5). A sample problem using this procedure is shown at the end of this chapter.

Wall Thrust

In the soil structure interaction, the load reduction (i.e. pipe relaxation) with time is faster than the apparent tensile strength reduction (i.e. creep). These calculations are in conformance with AASHTO.

Thrust, or stress, in the pipe wall is determined by the total load on the pipe including soil loads, vehicular loads and hydrostatic forces. The pipe must be able to withstand these forces in order for it to remain structurally stable. The critical wall thrust, determined in Equations 5-6 or 5-6(a), must be equal to or greater than the wall thrust calculated in Equations 5-7 or 5-7(a).

For installations that involve only dead loads, the wall thrust analysis uses the long-term material properties throughout the procedure. For installations where both dead loads and live loads are present [typically any trafficked installation with 8 ft. (2.4 m) or less of cover], two wall stress analysis are required. The first analysis accounts for both the dead loads and live loads and employs the short term material properties throughout the procedure. The second analysis accounts for only the dead load and employs the long term material properties throughout. The more limiting of the two analysis governs.

$$T_{cr} = (F_y)(A_s)(\phi_p) \qquad \textbf{Equation 5-6}$$

Where:

T_{cr} = critical wall thrust, lb/linear inch of pipe
F_y = minimum tensile strength of polyethylene, psi
= 3000 psi for short term conditions
= 900 psi for long term conditions
A_S = section area, in^2/inch of pipe (Table 5-1)
ϕ_p = capacity modification factor for pipe, 1.0

Or, in metric units:

$$T_{cr} = (F_y)(A_s)(\phi_p) \qquad \textbf{Equation 5-6(a)}$$

Where:

T_{cr} = critical wall thrust, N/linear m of pipe
F_y = minimum tensile strength of polyethylene, kPa
= 20,700 kPa for short term conditions
= 6,200 kPa for long term conditions
A_S = section area, mm^2/mm of pipe (Table 5-1)
ϕ_p = capacity modification factor for pipe, 1.0

$$T = 1.3(1.5W_A+1.67P_LC_L+P_W)(\frac{OD}{2}) \qquad \textbf{Equation 5-7}$$

Where:

T = calculated wall thrust, lb/in
W_A = soil arch load, psi (Equation 5-4)
P_L = live load transferred to pipe, psi (Table 5-3)
C_L = live load distribution coefficient
= the lesser of (L_W/ OD) or 1.0
L_W = live load distribution width at the crown in. (Table 5-3)
OD = outside diameter, in. (Table 5-1)
P_W = hydrostatic pressure at springline of pipe, psi (Equation 5-5)

Or, in metric units:

$$T = 1.3(1.5W_A+1.67P_LC_L+P_W)(\frac{OD}{2000})$$ **Equation 5-7(a)**

Where:

T = calculated wall thrust, N/m
W_A = soil arch load, N/m² [Equation 5-4(a)]
P_L = live load, N/m²
= $(1x10^6)$(live load transferred to pipe from Table 5-3)
C_L = live load distribution coefficient
= the lesser of (L_W/ OD) or 1.0
L_W = live load distribution width at the crown, mm (Table 5-3)
OD = outside diameter, mm
P_W = hydrostatic pressure at springline of pipe, N/m² [Equation 5-5(a)]

Foundation Loads

Some pipe installations are beneath or near foundations. This load contribution must be added to the prism load before proceeding with the design process. Soil mechanics' textbooks include procedures to determine the effect of foundation loads a specified distance away from the point of application.

Design Procedure

Deflection

Deflection is the change in inside diameter that results when a load is applied to a flexible pipe. When deflections are small, as in most pipe installations, the reduction in vertical diameter is approximately the same as the increase in horizontal diameter. In pipe design, it is the vertical dimension that is usually of more concern. Vertical deflection is usually limited to 7.5% of the base inside diameter; the base inside diameter is the nominal diameter less manufacturing and out-of-roundness tolerances inherent to the manufacturing process. This level of deflection is highly conservative and still provides a safety factor of approximately 3 against reverse curvature. This limit also is used in the design of other thermoplastic pipe and has been incorporated into several product specifications.

Pipe stiffness (PS), dead (W_C) and live (W_L) loads, and backfill conditions (E') are needed to predict deflection. Use the modified Iowa equation [Equations 5-8 or 5-8(a)] to calculate deflection.

$$\Delta y = \frac{K(D_LW_C+W_L)}{0.149PS+0.061E'}$$ **Equation 5-8**

Where:

Δy = deflection, in
K = bedding constant, dimensionless (commonly assumed to be 0.1)
D_L = deflection lag factor, dimensionless; 1.0 when the soil column load is used
W_C = soil column load on pipe, lb/linear inch of pipe (Equation 5-1)
W_L = live load, lb/linear inch of pipe
= $OD*P_L$(from Table 5-3)
OD = outside diameter of pipe, in
PS = pipe stiffness, pii (Table 5-1)
E' = modulus of soil reaction, psi (Table 6-3)

Or, in metric units:

$$\Delta y = \frac{1000K(D_L W_C + W_L)}{0.149PS + 0.061E'}$$ **Equation 5-8(a)**

Where:

Δy = deflection, mm
K = bedding constant, dimensionless(commonly assumed to be 0.1)
D_L = deflection lag factor, dimensionless; 1.0 when the prism load is used
W_C = soil column load on pipe, N/linear mm of pipe [Equation 5-1(a)]
W_L = live load, N/linear mm of pipe
= $OD*P_L$(from Table 5-3)
OD = outside diameter of pipe, mm
PS = pipe stiffness, kPa (Table 5-1)
E' = modulus of soil reaction, kPa (Table 6-3)

Buckling

The potential for wall buckling is determined by the burial conditions (E') and the pipe stiffness (PS). The critical buckling pressure found from Equation 5-9 or 5-9(a) must be greater than the actual pressure found by Equation 5-10 or 5-10(a).

Critical buckling pressure:

$$P_{CR} = \frac{0.772}{SF}\left[\frac{E'\ PS}{1-\nu^2}\right]^{1/2}$$ **Equation 5-9**

Where:

P_{CR} = critical buckling pressure, psi
E' = modulus of soil reaction, psi (Table 6-3)
PS = pipe stiffness, pii (Table 5-1)
ν = poisson ratio, dimensionless; 0.4 for polyethylene
SF = safety factor, 2.0

Or, in metric units:

$$P_{CR} = \frac{0.772}{SF}\left[\frac{E'\ PS}{1-\nu^2}\right]^{1/2}$$ **Equation 5-9(a)**

Where:

P_{CR} = critical buckling pressure, kPa
E' = modulus of soil reaction, kPa (Table 6-3)
PS = pipe stiffness, kPa (Table 5-1)
ν = poisson ratio, dimensionless; 0.4 for polyethylene
SF = safety factor, 2.0

Actual buckling pressure:

$$P_V = \frac{R_W\ H\ \gamma_S}{144} + \frac{\gamma_W\ H_W}{144} + \frac{W_L}{OD}$$ **Equation 5-10**

Where:

P_V = actual buckling pressure, psi
R_W = water buoyancy factor, dimensionless
= $1 - 0.33\ (H_W/H)$
H = burial depth to top of pipe, ft
γ_S = soil density, pcf
γ_W = unit weight of water, 62.4 pcf
H_W = height of groundwater above top of pipe, ft
W_L = live load, lb/linear inch of pipe
= $OD_* P_L$ (from Table 5-3)
OD = outside diameter of pipe, in (Table 5-1)

Or, in metric units:

$$P_V = 0.00981[(R_W\ H\ \gamma_S) + (\gamma_W\ H_W)] + \frac{1000W_L}{OD}$$ **Equation 5-10(a)**

Where:

P_V = actual buckling pressure, kPa
R_W = water buoyancy factor, dimensionless
= $1 - 0.33\ (H_W/H)$
H = burial depth to top of pipe, m
γ_S = soil density, kg/m^3
γ_W = unit weight of water, 1000 kg/m^3
H_W = height of groundwater above top of pipe, m
W_L = live load, N/linear mm of pipe
= $OD_* P_L$ (from Table 5-3)
OD = outside diameter of pipe, mm (Table 5-1)

Bending

A check on the bending stress and strain will ensure that they are within material capability. Bending stress should not exceed the long term tensile strength of polyethylene, 900 psi (6,200 kPa) and bending strain should not exceed 5%. Bending stress and strain can be found with Equations 5-11 or 5-11(a) and 5-12 or 5-12(a), respectively.

Stress, $\sigma_b = \dfrac{(2)(D_f)(E)(\Delta y)(y_O)(SF)}{D_M^2}$ **Equation 5-11**

Where:

σ_b = bending stress, psi
D_f = shape factor, dimensionless (Table 5-2)
E = long term modulus of elasticity of polyethylene, 22,000 psi
Δy = deflection, in (Equation 5-8)
y_O = distance from centroid of pipe wall to the furthest surface of the pipe, in
= the greater of $\dfrac{OD - D_M}{2}$ or $\dfrac{D_M - ID}{2}$
OD = outside diameter of pipe, in (Table 5-1)
ID = inside diameter of pipe, in (Table 5-1)
SF = safety factor, 1.5
D_M = mean pipe diameter, in
= ID + 2c
c = distance from inside diameter to neutral axis, in (Table 5-1)

Or, in metric units:

Stress, $\sigma_b = \dfrac{(2)(D_f)(E)(\Delta y)(y_O)(SF)}{D_M^2}$ **Equation 5-11(a)**

Where:

σ_b = bending stress, kPa
D_f = shape factor, dimensionless (Table 5-2)
E = long term modulus of elasticity of polyethylene, 151,700 kPa
Δy = deflection, mm [Equation 5-8(a)]
y_O = distance from centroid of pipe wall to the furthest surface of the pipe, mm
= the greater of $\dfrac{OD - D_M}{2}$ or $\dfrac{D_M - ID}{2}$
OD = outside diameter of pipe, mm (Table 5-1)
ID = inside diameter of pipe, mm (Table 5-1)
SF = safety factor, 1.5
D_M = mean pipe diameter, mm
= ID + 2c
c = distance from inside diameter to neutral axis, mm (Table 5-1)

Bending strain:

$$\varepsilon_B = \frac{2D_f \, \Delta y \, y_O \, SF}{D_M^2} \qquad \textbf{Equation 5-12}$$

Where:

ε_B = bending strain, in/in

D_f = shape factor, dimensionless (Table 5-2)

Δy = deflection, in (Equation 5-8)

y_O = distance from centroid of pipe wall to the furthest surface of the pipe, in

= the greater of $\frac{OD - D_M}{2}$ or $\frac{D_M - ID}{2}$

OD = outside diameter of pipe, in (Table 5-1)

ID = inside diameter of pipe, in (Table 5-1)

SF = safety factor, 1.5

D_M = mean pipe diameter, in

= ID + 2c

c = distance from inside diameter to neutral axis, in (Table 5-1)

Or, in metric units:

$$\varepsilon_B = \frac{2D_f \, \Delta y \, y_O \, SF}{D_M^2} \qquad \textbf{Equation 5-12(a)}$$

Where:

ε_B = bending strain, mm/mm

D_f = shape factor, dimensionless (Table 5-2)

Δy = deflection, mm [Equation 5-8(a)]

y_O = distance from centroid of pipe wall to the furthest surface of the pipe, mm

= the greater of $\frac{OD - D_M}{2}$ or $\frac{D_M - ID}{2}$

OD = outside diameter of pipe, mm (Table 5-1)

ID = inside diameter of pipe, mm (Table 5-1)

SF = safety factor, 1.5

D_M = mean pipe diameter, mm

= ID + 2c

c = distance from inside diameter to neutral axis, mm (Table 5-1)

Minimum & Maximum Cover Limitations

The design procedure described in the prior section can be time-consuming and may provide an unnecessarily high level of detail for many installations. The information in this section is designed to provide answers to common cover height questions much more quickly. The two typical cover height concerns are minimum cover in trafficked areas and maximum burial depths. Both can be considered “worst case” situations from a load perspective.

Minimum Cover in Trafficked Applications

Pipe in traffic areas (AASHTO loads) should have at least 1 ft. (0.3 m) of cover over the pipe crown for 4" - 48" (0.1 m - 1.2 m) diameter pipe and 1.5 ft. (0.5 m) of cover for 54" and 60" (1.55 m - 1.5 m) diameter pipe. In theory, the pipe can be buried with slightly less cover, but application variables are such that 1 ft. (0.3 m) is the conservative limit. The backfill envelope should provide a minimum E' value of 1,000 psi (6,900 kPa). In Table 5-4, this condition is represented by a Class III material compacted to 90% Standard Proctor Density, although other material can provide similar strength at slightly lower levels of compaction. Structural backfill material should extend 6 in. (0.15 m) over the crown of the pipe; the remaining cover should be appropriate for the installation. If settlement or rutting is a concern, it may be appropriate to extend the structural backfill to grade. Where pavement is involved, subbase material can be used.

The pavement layer can sometimes be included as part of the minimum cover. For flexible pavement, the paving equipment load and the amount of the cover over the pipe must be considered to determine if the resultant load can be supported by the pipe/backfill system.

Minimum cover calculated for flexible pavement is measured from the top of the pipe to the bottom of the pavement section.

Minimum cover calculated for rigid pavement is measured from the top of the pipe to the top of the pavement section.

Table 5-4

Note: Minimum covers presented here were calculated based on a minimum of 6 in. (0.15 m) of structural backfill material over the pipe crown with an additional layer of compacted native soil for a total cover as shown. In shallow trafficked installations, especially where pavement is involved, it may be best to use a good quality compacted material to grade, to prevent surface settlement and rutting.

Inside Diameter, ID in (mm)	Minimum Cover, H ft (m)
3 (75)	1 (0.3)
4 (100)	1 (0.3)
6 (150)	1 (0.3)
8 (200)	1 (0.3)
10 (250)	1 (0.3)
12 (300)	1 (0.3)
15 (375)	1 (0.3)

Inside Diameter, ID in (mm)	Minimum Cover, H ft (m)
18 (450)	1 (0.3)
21 (525)	1 (0.3)
24 (600)	1 (0.3)
30 (750)	1 (0.3)
36 (900)	1 (0.3)
42 (1050)	1 (0.3)
48 (1200)	1 (0.3)
54 (1350)	1.5 (0.5)
60 (1500)	1.5 (0.5)

Table 5-4: Minimum Cover Requirements for Corrugated Polyethylene Pipe

Based on Class III Backfill Compacted to 90% Standard Proctor Density and AASHTO HS-25 Load

Maximum Cover

The prism load was assumed in the design procedure, which results in very conservative maximum cover limits. Highway loads have negligible effect in deep burials, as shown in Table 5-3. Maximum cover limits for corrugated polyethylene pipe are shown in Table 5-5 for a variety of backfill conditions. This table was developed based on pipe properties from Table 5-1.

Table 5-5

	Class I		Class II				Class III		
Pipe Dia.	uncompacted	compacted	85%	90%	95%	100%	85%	90%	95%
4	17(ft)*	59(ft)	17(ft)	24(ft)	37(ft)	59(ft)	15(ft)	18(ft)	24(ft)
6	16	57	16	24	36	57	15	17	24
8	14	51	14	21	32	51	13	15	22
10	13	50	13	20	31	50	12	14	21
12	13	49	13	20	31	49	12	14	21
15	13	49	13	20	31	49	12	14	21
18	13	49	13	20	31	49	12	14	21
24	13	51	13	21	32	51	12	14	21
30	13	51	13	21	32	51	12	14	21
36	13	50	13	20	31	50	12	14	21
42	11	47	11	19	29	47	10	13	19
48	11	46	11	18	29	46	10	12	19
54	11	44	11	18	28	44	10	12	18
60	11	45	11	18	28	45	10	12	19

Note: Alternate backfill materials and compaction levels not shown in the table may also be acceptable. This is a general guideline based on Table 5-1. Contact the manufacturer for further detail. *All cover heights measured in feet.

Table 5-5: Maximum Cover Heights based on Table 5-1 Section Properties

Bibliography

Corrugated polyethylene pipe has been extensively researched in the laboratory and through actual installations. This section summarizes the findings of some of those projects; additional information about these and other reports can be obtained from various manufacturers.

Pipe Deflections – A Redeemable Asset. Written by Dr. Lester Gabriel and Michael Katona, and published in Structural Performance of Flexible Pipes, edited by Sargand, Mitchell and Hurd, October 1990, pp. 1-6.

This paper provides an easy-to-read description of the role of deflection in properly performing flexible pipe. Deflection is not a liability, but a behavior that forces the backfill material to take on the majority of load. Deflection allows flexible pipe to be installed in applications with surprisingly deep burials.

Analysis of the Performance of a Buried High Density Polyethylene Pipe. Written by Naila Hashash and Ernest Selig, University of Massachusetts, and published in *Structural Performance of Flexible Pipes, edited by Sargand, Mitchell and Hurd, October 1990, pp. 95-103.*

In 1988, the Pennsylvania Department of Transportation began a study to evaluate the behavior of corrugated polyethylene pipe backfilled with crushed stone under a 100 ft. (30.5 m) burial depth. This document, which is a status report of the pipe condition 722 days after installation, summarizes one of the most heavily instrumented pipe installations to date. Measured vertical deflection was 4.6% and horizontal deflection was 0.6%. Much of this was due to a slight (1.6%) circumferential shortening. This is well within the 7.5% generally accepted limit. Soil arching reduced the load on the pipe by 77%, which shows that the prism load is a very conservative method to estimate this load component.

Field Performance of Corrugated Polyethylene Pipe. Written by John Hurd, Ohio Department of Transportation, and published in Public Works magazine in October 1987.

This article summarizes the results of a field study conducted in 1985 on 172 culvert installations. These installations represented real-world applications where backfill procedures may or may not have been conducted in accordance with standard ODOT recommendations. Regardless, the primary findings regarding structural integrity were that shallow cover, even with heavy truck traffic, did not appear to cause significant amounts of deflection; the deflection that did occur seemed to be due to installation.

Short-Term Versus Long-Term Pipe Ring Stiffness in the Design of Buried Plastic Sewer Pipes. Written by Lars-Eric Janson and published in Pipeline Design and Installation, proceedings from the International Conference sponsored by the Pipeline Planning Committee of the Pipeline Division of the American Society of Civil Engineers, March 1990, pp. 160-167.

This report describes the viscoelastic behavior of polyethylene. The author endorses use of short-term properties when the pipe is backfilled in a stable environment, such as firm silty/clayey soils.

Design Method for Flexible Pipe. Written by Dr. Timothy McGrath

Stiffness of HDPE Pipe in Ring Bending. Written by Timothy McGrath, Ernest Selig and Leonard DiFrancesco, and published in Buried Plastic Pipe Technology – 2nd Volume, 1994, pp. 195-205.

This project was conducted to determine how or if the modulus of elasticity changes over time. The pipe was deflected and held in position to generate a stress/strain curve. Although the results gave the appearance that the material was losing strength over time, repeated incremental loads caused the pipe to respond with its short-term modulus which did not decrease at any time.

Stress Relaxation Characteristics of the HDPE Pipe-Soil System. Written by Larry Petroff and published in Pipeline Design and Installation, proceedings from the International Conference sponsored by the Pipeline Planning Committee of the Pipeline Division of the American Society of Civil Engineers, March 1990, pp. 280-293.

This is an excellent report on the viscoelastic nature of polyethylene which discusses both creep and stress relaxation behaviors. One of the major points made is how deflection decreases with time; over 80% of the total deflection that a pipe will experience throughout its life will occur within the first 30 days. Petroff also indicates that the highest stresses for polyethylene pipe buried in a compacted granular material occur soon after installation, but relax soon thereafter.

Laboratory Test of Buried Pipe in Hoop Compression. Written by Ernest Selig, Leonard DiFrancesco and Timothy McGrath, and published in Buried Plastic Pipe Technology – 2nd Volume, 1994, pp. 119-132.

This project involved developing a fixture so as to subject the pipe to purely compressive forces. A pressure of 55 psi (380 kPa) was reached wherein equipment problems developed. The authors indicated this pressure was the equivalent of 100 ft. (30.5 m) of cover in other tests they had performed. At this pressure, the pipe also experienced a 3% circumferential shortening that resulted in a significant beneficial soil arching.

Structural Performance of Three Foot Corrugated Polyethylene Pipe Buried Under High Soil Cover. Written by Reynold K. Watkins and published in Structural Performance of Flexible Pipes, edited by Sargand, Mitchell and Hurd, October 1990, pp. 105-107.

A 3 ft. (900 mm) diameter corrugated polyethylene pipe was tested in a load cell to determine if it performed as well as the smaller sizes. The author supports the use of the short-term modulus of elasticity for design and recognizes stress relaxation. The report concludes that, "There is no reason why corrugated polyethylene pipes of 3 ft. (900 mm) diameter cannot perform structurally under high soil cover provided that a good granular pipe zone backfill is carefully placed and compacted." This is consistent with the backfill and material recommendations set forth in previous sections.

Sample Calculations

Example 1 (Standard Units)

A 15-inch corrugated polyethylene pipe is proposed as a culvert. AASHTO HS-25 loads are anticipated and minimum cover will be 1 ft. (0.3 m). Groundwater is below the pipe invert. Backfill material will be the native soil which, in this situation, is categorized as a Class III (SM) material. Density of this material is 120 pcf. Minimum compaction will be 90% Standard Proctor Density.

Determine whether this will be a successful installation based on wall stress, deflection, buckling, bending stress and bending strain.

Wall Thrust

Because this installation involves both live (vehicular) and dead (soil) loads, two wall thrust analyses must be made. The first analysis accounts for both the dead loads and live loads and employs the short term material properties throughout the procedure. The second analysis accounts for only the dead load and employs the long term material properties throughout. *The more limiting of the two analyses governs.*

Analysis 1 (This analysis accounts for both dead loads and live loads and employs the short term material properties throughout the procedure.)

$$T_{cr} = (F_y)(A_s)(\phi_p) \qquad \textbf{Equation 5-6}$$

Where:

T_{cr} = critical wall thrust, lbs/linear inch of pipe
F_y = tensile strength, 3000 psi for short term conditions
A_S = section area, 0.159 in^2/inch of pipe (Table 5-1)
ϕ_p = capacity modification factor for pipe, corrugated HDPE 1.0

Substituting:

$$T_{cr} = (3000)(0.159)(1.0)$$
$$= 478 \text{ lb/in}$$

To check whether the calculated wall thrust is in excess of this value, use Equation 5-7.

$$T = 1.3[1.5W_A+1.67P_LC_L+P_W]\ (OD/2)$$ **Equation 5-7**

Where:

T = calculated wall thrust, lb/in

W_A = soil arch load, psi (Equation 5-4)

= $(P_{sp})(VAF)$

$$P_{sp} = \frac{(\gamma_S)\ [H + 0.11(OD/12)]}{144}$$

P_{sp} = geostatic load, psi

γ_S = soil density, 120 pcf

H = burial depth, 1.0 ft

OD = outside diameter, 17.7 in (Table 5-1)

$$P_{sp} = \frac{(120)\ [1.0 + 0.11(17.7/12)]}{144}$$

= 1 psi

$$VAF = 0.76 - 0.71\left(\frac{S_h - 1.17}{S_h + 2.92}\right)$$

Where:

VAF = vertical arching factor

S_h = hoop stiffness factor

$$S_h = \frac{(\phi_S)(M_S)(R)}{EA_S}$$

ϕ_S = capacity modification factor for soil, 0.9

M_S = secant constrained soil modulus, 1000 psi (Table 6-3)

R = effective radius of pipe, in

= ID/2+c

= 8.375 in

ID = inside diameter of pipe, 15 in (Table 5-1)

c = distance from inside diameter to neutral axis, 0.45 in (Table 5-1)

E = short term modulus of elasticity of polyethylene, 110,000 psi

$$S_h = \frac{(0.9)(1{,}000)(8.375)}{(110{,}000)(0.1592)}$$

= 0.43

$$VAF = 0.76 - 0.71\left(\frac{S_h - 1.17}{S_h + 2.92}\right)$$

= 0.92

W_A = $(P_{sp})(VAF)$

= (1.0)(0.92)

= 0.92 psi

P_L = live load transferred to pipe, 12.5 psi (Table 5-3)
C_L = live load distribution coefficient
= the lesser of L_W/OD or 1.0
L_W = live load distribution width at the crown, 31 in (Table 5-3)
P_W = hydrostatic water pressure at the springline of pipe, 0 psi, (Equation 5-5); provided groundwater is at the pipe springline or lower, it can be ignored

Substituting:

$$T = 1.3[1.5(0.92)+1.67(12.50)(1.0)+0]\left(\frac{17.7}{2}\right)$$

= 256 lb/in ($T<T_{cr}$; wall stress is well within limit)

Analysis 2 (This analysis accounts for only dead load and employs the long term material properties throughout.)

$$T_{cr} = (F_y)(A_s)(\phi_p) \qquad \textbf{Equation 5-8}$$

Where:
T_{cr} = critical wall thrust, lbs/linear inch of pipe
F_y = tensile strength, 900 psi for long term conditions
A_s = section area, 0.1592 in^2/inch of pipe (Table 5-1)
ϕ_p = capacity modification factor for pipe corrugated HDPE 1.0

Substituting:

$$T_{cr} = (900)(0.1592)(1.0)$$

= 143 lb/in

To check whether the calculated wall thrust is in excess of this value, use Equation 5-9, recalling that live load is not included.

$$T = 1.3[1.5W_A+1.67P_L\,C_L + P_W]\left(\frac{OD}{2}\right) \qquad \textbf{Equation 5-9}$$

Where:
T = calculated wall thrust, lb/in
W_A = soil arch load, psi (Equation 5-4)
= $(P_{sp})(VAF)$

$$P_{sp} = (\gamma_S)\,\frac{[H + 0.11(OD/12)]}{144}$$

P_{sp} = geostatic load, psi
γ_S = soil density, 120 pcf
H = burial depth to top of pipe, 1.0 ft
OD = outside diameter, 17.7 in (Table 5-1)

$$P_{sp} = \frac{(120)\ [1.0 + 0.11(17.7/12)]}{144}$$

$$= 1 \text{ psi}$$

$$VAF = 0.76 - 0.71\left(\frac{S_h - 1.17}{S_h + 2.92}\right)$$

Where:

VAF = vertical arching factor

S_h = hoop stiffness factor

$$S_h = \frac{(\phi_S)(M_S)(R)}{EA}$$

ϕ_S = capacity modification factor for soil, 0.9

M_S = secant constrained soil modulus, 1,000 psi (Table 6-3)

R = effective radius of pipe, in

= ID/2+c

= 8.375 in

ID = inside diameter of pipe, 15 in (Table 5-1)

c = distance from inside diameter to neutral axis, 0.875 in (Table 5-1)

E = long term modulus of elasticity of polyethylene, 22,000 psi

$$S_h = \frac{(0.9)(1{,}000)(8.375)}{(22{,}000)(0.1592)}$$

$$= 2.15$$

$$VAF = 0.76 - 0.71\left(\frac{2.15 - 1.17}{2.15 + 2.92}\right)$$

$$= 0.62$$

$$W_A = (P_{sp})(VAF)$$

$$= (1.0)(0.62)$$

$$= 0.62 \text{ psi}$$

P_W = hydrostatic water pressure at the springline of pipe, 0 psi, (Equation 5-5): In this example, provided groundwater is at the pipe springline or lower, it can be ignored.

Substituting:

$$T = 1.3[1.5(0.62)+0]\left(\frac{17.7}{2}\right)$$

$$= 10.7 \text{ psi } (T<T_{cr}\text{; wall stress is well within limit})$$

Of the two analyses, neither violates their respective critical wall stress value; the wall thrust is within acceptable limits.

Deflection:

$$\Delta y = \frac{K[(D_L)(W_C)+W_L]}{(0.149)(PS)+(0.061)(E')}$$ **Equation 5-10**

Where:

Δy = deflection, in

K = bedding constant, dimensionless; assume 0.1

D_L = deflection lag factor, dimensionless; typically 1.0

W_C = soil column load on pipe, lb/linear inch of pipe (Equation 5-1)

$$W_C = \frac{(H)(\gamma_S)(OD)}{144}$$

$$W_C = \frac{(1.0)\ (120)\ (17.7)}{144}$$

= 15 lb/linear inch of pipe

W_L = live load, lb/linear inch of pipe

= (OD)(live load transferred to pipe from Table 5-3)

= (17.7 in)(15.6 psi)

= 276 lb/linear inch of pipe

PS = pipe stiffness (Table 5-1)

= 42 psi

E' = modulus of soil reaction, psi (Table 6-3)

= 1,000 psi based on a Class III material compacted to 90% SPD

Substituting:

$$\Delta y = \frac{0.11[(1.0)(15)+276]}{[(0.149)(42)+(0.061)(1000)]}$$

= 0.48 in

= 3.2% (design OK; deflection is well within 7.5% limit)

Buckling:

$$P_{CR} = \frac{0.772}{SF}\left[\frac{E'\ PS}{1-\nu^2}\right]^{1/2}$$ **Equation 5-11**

Where:

P_{CR} = critical buckling pressure, psi

ν = poisson ratio, dimensionless; 0.4 for polyethylene

SF = safety factor, 2.0

Substituting:

$$P_{CR} = \frac{0.772}{2}\left[\frac{(1{,}000)\ (42)}{1-0.4^2}\right]^{1/2}$$

= 86 psi

To check whether the actual buckling pressure is in excess of this value, use Equation 5-12:

$$P_V = \frac{(R_W)(H)(\gamma_S)}{144} + \frac{(\gamma_W)(H_W)}{144} + \frac{(W_L)}{OD}$$ **Equation 5-12**

Where:

P_V = actual buckling pressure, psi
R_W = water buoyancy factor, dimensionless
= $1 - 0.33\ (H_W/H)$
γ_W = unit weight of water, 62.4 pcf
H_W = height of groundwater above top of pipe, ft
= zero in this situation

Substituting:

$$P_V = \frac{(1.0)(1.0)(120)}{144} + \frac{(62.4)(0)}{144} + \frac{221}{17.7}$$

= 13 psi (design OK; actual buckling pressure is less than allowable)

Bending Stress:

Bending stress should be less than the long term tensile stress, 900 psi (F_y).

$$\sigma_b = \frac{(2)(D_f)(E)(\Delta y)(y_O)(SF)}{D_M^2}$$ **Equation 5-13**

Where:

σ_b = bending stress, psi
D_f = shape factor, dimensionless (Table 5-2)
= 5.3 for SM material compacted to 90% SPD and PS of 42 psi
E = modulus of elasticity of polyethylene, 22,000 psi
y_O = distance from centroid of pipe wall to the furthest surface of pipe, in
= the greater of $\frac{OD - D_M}{2}$ or $\frac{D_M - ID}{2}$
= 0.875 in
SF = safety factor, 1.5
D_M = mean pipe diameter, in
= ID + 2c
= 16.750 in
c = distance from inside diameter to neutral axis, in (Table 5-1)
= 0.875 in

Substituting:

$$\sigma_b = \frac{2(5.3)(22{,}000)(0.48)(0.875)(1.5)}{16.750^2}$$

$$= 524 \text{ psi (design OK; actual stress is less than allowable 900 psi)}$$

Bending Strain:

$$\varepsilon_B = \frac{(2)(D_f)(\Delta y)(y_O)(SF)}{D_M^2} \qquad \textbf{Equation 5-14}$$

Where:

ε_B = bending strain, in/in

Substituting:

$$\varepsilon_B = \frac{(2)(5.3)(0.48)(0.875)(1.5)}{16.750^2}$$

$$= 0.024 \text{ in/in}$$

$$= 2.42\% \text{ (criteria OK; actual strain is less than allowable 5\%)}$$

Conclusion:
This is a suitable application for 15" corrugated polyethylene pipe.
All criteria are well within allowable values.

Appendix – Variable Definitions

A_S = section area, in^2/in (mm^2/mm)
c = distance from the inside surface to the neutral axis, in (mm)
C_L = live load distribution coefficient, dimensionless
D_f = shape factor, dimensionless
D_L = deflection lag factor, dimensionless
D_M = mean pipe diameter, in (mm)
E = modulus of elasticity, psi (kPa)
E' = modulus of soil reaction, psi (kPa)
F_y = tensile strength, psi (kPa)
H = burial depth to top of pipe, ft (m)
H_g = height of groundwater above springline of pipe, ft (m)
H_W = height of groundwater above top of pipe, ft (m)
I = moment of inertia of the wall profile, in^4/in (mm^4/mm)
ID = inside diameter of pipe, in (mm)
K = bedding constant, dimensionless
L_W = live load distribution width at the crown, in (mm)
M_S = secant constrained soils modulus, psi (KPa)

OD = outside diameter of pipe, in (mm)
P_{CR} = critical buckling pressure, psi (kPa)
P_L = live load transferred to pipe, psi (N/m^2)
PS = pipe stiffness measured at 5% deflection, pii (kPa)
P_{sp} = geostatic load, psi (N/m^2)
P_V = actual buckling pressure, psi (kPa)
P_W = hydrostatic pressure of springline, psi (N/m^2)
R = effective radius of pipe, in (mm)
R_W = water buoyancy factor, dimensionless
SF = safety factor
S_h = hoop stiffness factor, dimensionless
T = wall thrust of pipe, lb/in (N/m)
T_{cr} = critical wall thrust of pipe, 16/linear inch of pipe (N/m)
VAF = virtual arching factor, dimensionless
W_A = soil arch load, psi (N/m^2)
W_C = soil column load, lb/linear inch of pipe (N/linear mm of pipe)
W_L = live load, lb/linear inch of pipe (N/linear mm of pipe)
y_O = distance from centroid of pipe wall to the furthest surface of the pipe, in (mm)
Δy = deflection, in (mm)
γ_S = soil density, pcf (kg/m^3)
γ_W = unit weight of water, pcf (kg/m^3)
ε_B = bending strain, in/in (mm/mm)
ν = poisson ratio, dimensionless
σ_b = bending stress, psi (kPa)
ϕ_p = capacity modification factor for pipe, dimensionless
ϕ_S = capacity modification factor, dimensionless

Notes