

Chapter 11

Pipeline Rehabilitation by Sliplining with PE Pipe

Introduction

An integral part of the infrastructure is the vast network of pipelines, conduits, and culverts in North America. These are among the assets we take for granted, since most are buried and we never see them. We do not see them deteriorate either, but we know that they do. Television inspection of the interiors of these systems often reveals misaligned pipe segments, leaking joints, or other failing pipe integrity.

The effects of continued deterioration of a pipeline could be quite drastic and costly. A dilapidated gravity sewer system permits substantial infiltration of groundwater, which increases the volume of flow and reduces the available hydraulic capacity of the existing line. So the old pipeline often increases treatment and transportation costs for the intended flow stream⁽²⁴⁾. Continued infiltration may also erode the soil envelope surrounding the pipe structure and cause eventual subsidence of the soil.

The case for positive-pressure pipelines is somewhat different, but the results are equally unacceptable. In this situation, continued leakage through the existing pipeline allows exfiltration of the contents of the flow stream that eventually leads to extensive property damage or water resource pollution. Also, in many cases, the contents of the flow stream are valuable enough that their loss through exfiltration becomes another economic factor. PE pipe provides an excellent solution to the problem of leaky joints, whether it is due to infiltration or to exfiltration. This is because the standard method of joining PE pipe uses a heat fusion process that results in a monolithic pipe system, that is, the joints are as strong as, and as leak free, as the pipe itself.

When the harmful results of pipeline deterioration become apparent, we must either find the most economical method that

will restore the original function or abandon the failed system. Excavation and replacement of the deteriorating structure can prove prohibitively expensive and will also disrupt the service for which the original line is intended⁽¹⁸⁾. An alternate method for restoration is “sliplining” or “insertion renewal” with polyethylene pipe. More than 30 years of field experience shows that this is a proven cost-effective means that provides a new pipe structure with minimum disruption of service, surface traffic, or property damage that would be caused by extensive excavation.

The sliplining method involves accessing the deteriorated line at strategic points within the system and subsequently inserting polyethylene pipe lengths, joined into a continuous tube, throughout the existing pipe structure. This technique has been used to rehabilitate gravity sewers^(11, 24), sanitary force mains, water mains, outfall lines, gas mains^(2, 13), highway and drainage culverts⁽¹⁸⁾, and other piping structures with extremely satisfactory results. It is equally appropriate for rehabilitating a drain culvert 40-feet long under a road or straight sewer line with manhole access as far as $\frac{1}{2}$ mile apart. The technique has been used to restore pipe as small as 1-inch, and there are no apparent maximum pipe diameters.

Mechanical connections are used to connect PE pipe systems to each other and to connect PE pipe systems to other pipe materials and systems. The reader can refer to the Handbook chapter that is titled ‘Polyethylene Joining Procedures’ for additional information on Mechanical Connections and Mechanical Joint (MJ) Adapters.

Design Considerations

The engineering design procedure required for a sliplining project consists of five straightforward steps:

1. Select a pipe liner diameter.
2. Determine a liner wall thickness.
3. Determine the flow capacity.
4. Design necessary accesses such as terminal manholes, headwall service and transition connections.
5. Develop the contract documents.

Select a Pipe Liner Diameter

To attain a maximum flow capacity, select the largest feasible diameter for the pipe liner. This is limited by the size and condition of the original pipe through which it will be inserted. Sufficient clearance will be required during the sliplining process to insure trouble-free insertion, considering the grade and direction, the severity of any offset joints, and the structural integrity of the existing pipe system.

The selection of a polyethylene liner that has an outside diameter 10% less than the inside diameter of the pipe to be rehabilitated will generally serve two purposes. First, this size differential usually provides adequate clearance to accommodate the insertion process. Second, 75% to 100% or more of the original flow capacity may be maintained. A differential of less than 10% may provide adequate clearance in larger diameter piping structures. It is quite common to select a 5% to 10% differential for piping systems with greater than 24-inch diameters, assuming that the conditions of the existing pipe structure will permit insertion of the liner.

Determine a Liner Wall Thickness

Non-Pressure Pipe

In the majority of gravity pipeline liner projects, the principal load that will act on the polyethylene pipe is the hydrostatic load that is created when the water table rises above the crown (top) of the liner.

The generic Love's equation (Eq. 1) shows that the ability of a free-standing pipe to withstand external hydrostatic loading is essentially a function of the pipe wall moment of inertia and the apparent modulus of elasticity of the pipe material. The critical buckling pressure, P_c , for a specific pipe construction can be determined by using equation Eq. 1.

(1) Love's Equation

$$P_c = \frac{24EI}{(1 - \nu^2) \times D_m^3} \times f_0$$

WHERE

P_c = Critical buckling pressure, psi

E = Apparent modulus of elasticity (Refer to Appendix, Chapter 3, for the appropriate value for the Material Designation Code of the PE pipe being used and the applicable service conditions.)

I = Pipe wall moment of inertia, in⁴/in

= $t^3/12$ for solid wall PE, where t = minimum wall thickness of the pipe, in

ν = Poisson's Ratio, 0.45 for all PE pipe materials

D_m = Mean diameter, inches (outside diameter minus one wall thickness)

f_0 = Ovality compensation factor, dimensionless (see Figure 1)

D = Pipe average outside diameter, in

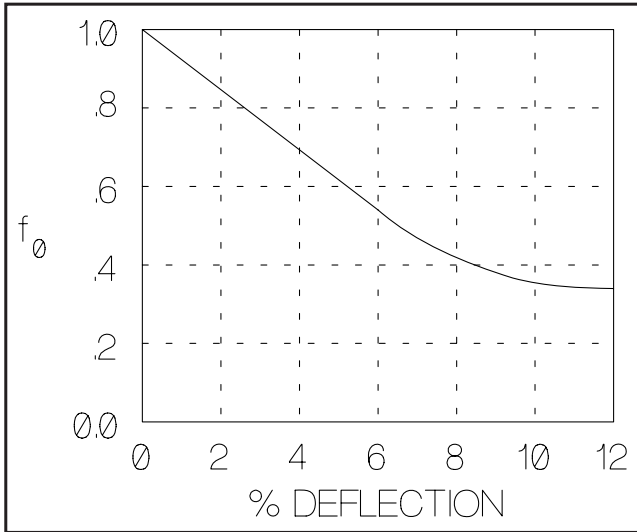


Figure 1 % Deflection vs. Ovality Correction Factor, f_o

$$\text{where \% Deflection} = \frac{D - D_{\min}}{D} \times 100$$

$D_{\min}$ = Pipe minimum diameter, in

To compute the buckling pressure of a dimension ratio (DR) series polyethylene pipe (i.e., a grouping of solid wall pipes of different diameters but with the same ratio of specified outside diameter to minimum wall thickness), the following variation of Love's equation⁽²²⁾, Eq. 2, is used.

(2) Love's Equation for DR Solid Wall Pipe

$$P_c = E \times \left(\frac{2}{1 - \nu^2} \right) \times \left(\frac{1}{DR - 1} \right)^3 \times f_o$$

WHERE

DR = Dimension ratio, dimensionless (OD/t)

OD = Actual outside diameter, inches

t = Minimum wall thickness, inches

The process of calculating the buckling resistance of a free-standing pipe is iterative in that, once the critical buckling resistance of a trial choice has been determined, it can be compared to the anticipated hydrostatic load. If the pipe's calculated buckling resistance is significantly larger than the anticipated hydrostatic loading, the procedure can be used to evaluate a lesser wall thickness (with the advantages of lighter weight materials and lower costs). The prudent practice is to select a design

buckling resistance that provides an adequate safety factor (SF) over the maximum anticipated hydrostatic load.

(3) Safety Factor, SF

$$SF = \frac{P_c}{\text{Anticipated Hydrostatic Load}}$$

For an example of the calculations that can be made with Equations 2 and 3, consider a 22-inch DR 26 solid-wall polyethylene liner placed within a 24-inch clay tile pipe and subjected to a maximum excess hydrostatic load of 3 feet of water table.

1. Calculate the equivalent hydrostatic load in psi.
Water load = 3 ft x 62.4 lb/ft³ x 1 ft²/144 in² = 1.3 psi
2. Calculate the critical buckling pressure, P_c , using Eq. 2 assuming the following variable values: $E = 28,200$ psi, $\nu = 0.45$ and $f_o = 0.79$
3. Calculate the Safety Factor, SF, from Eq. 3 for this load assumption.
 $SF = 3.6/1.3 = 2.8$

A safety factor of 2.0 or greater is often used for frequent or long-term exposure to such loads. If a larger safety factor is preferred, repeat the procedure for a heavier wall configuration or consider the enhancement of the pipe's buckling strength by the effects of external restraint.

Love's equation assumes that the liner being subjected to the indicated hydrostatic load is free-standing and is not restrained by any external forces. Actually, the existing pipe structure serves to cradle the flexible liner, enhancing its collapse resistance. Maximum external reinforcement can be provided, where required, by placing a stable load-bearing material such as cement, fly ash, polyurethane foam, or low-density grout in the annular space between the liner and the existing pipe. Studies show that filling the annular cavity will enhance the collapse resistance of a polyethylene pipe by at least a four-fold factor and often considerably more, depending on the load-bearing capabilities of the particular fill material. Contact the pipe suppliers for additional information.

For solid wall PE pipe, the significant variable that determines adequate wall stiffness is the pipe DR. It is a simple matter to specify the DR once the amount of the loading on the pipe is determined. A typical manufacturer's recommendation for safe long-term (50-year) external pressure loading might follow the guidelines in Table 1, which were derived according to the procedure shown in ASTM F585, Practice for Insertion of Flexible Polyethylene Pipe into Existing Sewers.

TABLE 1

Allowable Height⁽¹⁾ of Water Above DR Dimensioned Pipe at the Maximum Operating Temperature of 73°F (23°C)⁽²⁾ and Under a Continuous Duration of Loading of 50-years⁽³⁾. Not Grouted vs. Grouted Pipe

Pipe Dimension Ratio (DR)	Height of water (feet) above pipe made from materials designated as PE 4XXX ⁽⁴⁾		Height of water (feet) above pipe made from materials designated as PE 3XXX ⁽⁴⁾	
	Not Grouted	Grouted	Not Grouted	Grouted
32.5	2.0	10.0	1.9	9.5
26	4.0	20.0	3.9	19.5
21	7.9	39.5	7.6	38.0
17	15.4	77.0	14.8	74.0
13.5	32.2	161.0	31.1	155.0
11	62.9	314.5	60.8	304.0

Notes:

- (1) The values of allowable height were computed by means of equation (2) and under the following assumptions:
 - The apparent modulus E is 28,000 psi for PE3XXX and 29,000 psi for PE4XXX materials at 73°F and for a 50-year load duration; refer to Appendix, Chapter 3 of this Handbook.
 - The value of Poisson's ratio (μ) is 0.45
 - The value of f_o , the pipe ovality correction factor, is 0.75, which corresponds to a pipe deflection of 3%
 - A safety factor of 2.0 was used. See preceding discussion on selecting an appropriate safety factor
 - For grouted applications, the height of water above pipe was computed by multiplying by 5 the height obtained for the corresponding non-grouted applications.
- (2) Table B.1.2 of the Appendix of Chapter 3 lists temperature adjusting factors which may be used to convert the above results to other maximum operating temperatures
- (3) Values for apparent modulus for other periods of continuous loading are listed in Table B.1.1 in the Appendix to Chapter 3
- (4) The first numeral after PE is the standard classification for the PE's density. The X's designate any recognized value for the other coded properties. See the section on Structural Properties of Chapter 3 for a detailed description of the PE piping material designation code.

The figures in this table represent a Safety Factor, SF, of 2.0 and a diametrical ovality of 3%. Grouted strength of the pipe was derived by applying a multiplier of 5 to the non-grouted value⁽³²⁾. If the existing sewer will not provide structural integrity to earth and live loads, a more conservative Safety Factor should be used.

For profile wall pipe the variable that determines adequate wall stiffness is a function of the pipe wall moment of inertia and pipe inside mean diameter. The following equation can be used to estimate maximum allowable long-term (50-year) height of water above the pipe with no grout:

$$(4) \quad H = \frac{0.9 \times RSC}{D_m}$$

WHERE

H = Height of water, feet

RSC = Measured Ring Stiffness Constant

D_m = Mean diameter, inches

This equation contains a Safety Factor (SF) of 2.0 based on pipe with a maximum 3% deflection.

For grout with a minimum compressive strength of 500 psi at 24 hours (1,800 psi at 28 days), the allowable long-term (50-year) height of water above the pipe may be determined from the following equation:

$$^{(5)} H = 5 \times \frac{(0.9 \times \text{RSC})}{D_m}$$

This equation contains a Safety Factor (SF) of 2.0.

Pressure Pipe

A liner, which will be exposed to a constant internal pressure or to a combination of internal and external stresses must be analyzed in a more detailed manner. The guidelines for a detailed loading analysis such as this are available from a variety of resources that discuss in detail the design principles concerned with underground installation of flexible piping materials.^(3,15,16,19,26,29) The reader is also advised to refer to Chapters 3 and 6 of this Handbook for additional information on design principles and the properties applicable to the particular Material Designation Code of the PE pipe being used.

In those installations where the liner will be subjected to direct earth loading, the pipe/soil system must be capable of withstanding all anticipated loads. These include earth loading, hydrostatic loading, and superimposed loads. The structural stability of a polyethylene liner under these conditions is determined largely by the quality of the external support. For these situations, refer to any of the above referenced information sources that concern direct burial of thermoplastic pipe. A polyethylene liner that has been selected to resist hydrostatic loading will generally accommodate typical external loading conditions if it is installed properly.

Other Loading Considerations

Filling of the entire annular space is rarely required. If it is properly positioned and sealed off at the termination points, a polyethylene liner will eliminate the sluice path that could contribute to the continued deterioration of most existing pipe structures. With a liner, a gradual accumulation of silt or sediment occurs within the annular space, and this acts to eliminate the potential sluice path.

On occasion, deterioration of the original pipe may continue to occur even after the liner has been installed.⁽¹⁸⁾ This situation may be the result of excessive ground-water movement combined with a soil quality that precludes sedimentation within the annular space. Soil pH and resistivity can also help deteriorate the host culvert or pipe. As a result, uneven or concentrated point loading upon the pipe liner or even subsidence of the soil above the pipe system may occur. This can be avoided by filling the annular space with a cement-sand mixture, a low-density grout material⁽¹⁰⁾, or fly ash.

Determine the Flow Capacity

The third step in the sliplining process is to assess the impact of sliplining on the hydraulic capacity of the existing pipe system. This is accomplished by using commonly-accepted flow equations to compare the flow capacity of the original line against that of the smaller, newly-installed polyethylene liner. Two equations widely used for this calculation are the Manning Equation (Eq. 6) and the Hazen-Williams Approximation for other than gravity flow systems (Eq. 7).^(2,5) The reader is referred to Chapter 6 of this Handbook, where the subject of fluid flow is covered extensively.

(6) Manning Equation for Gravity Flow

$$Q = \frac{1.486 \times A \times R^{0.667} \times S^{0.5}}{n}$$

WHERE

Q = Flow, ft³/sec

A = Flow area, ft² (3.14 x ID²/4)

R = Hydraulic radius, feet (ID/4 for full flow)

S = Slope, ft/ft

n = Manning flow factor for piping material, 0.009 for smooth wall PE

ID = Inside diameter, feet

For circular pipe flowing full, the formula may be simplified to

$$Q = \frac{0.463 \times ID^{2.667} \times S^{0.5}}{n}$$

(7) Hazen-Williams Approximation for Other Than Gravity Flow

$$H = \frac{1044 \times G^{1.85}}{C_H^{1.85} \times ID^{4.865}}$$

WHERE

H = Friction loss in ft of H₂O/100 ft

G = Volumetric flow rate, gpm

$$= 2.449 \times V \times ID^2$$

V = Flow velocity, ft/sec

ID = Inside diameter, inches

C_H = Hazen Williams flow coefficient, dimensionless

$$= 150 \text{ for smooth wall polyethylene}$$

The insertion of a smaller pipe within the existing system may appear to reduce the original flow capacity. However, in the majority of sliplining applications, this is not the case. The polyethylene liner is extremely smooth in comparison to most piping materials. The improved flow characteristic for clear water is evidenced by