Pipeline Rehabilitation

A. Cured-in-place Pipe (CIPP)

1. **Description of Process and Materials:** One of the most widely used pipeline rehabilitation methods is the cured-in-place pipe (CIPP) lining method. The CIPP process begins by thoroughly cleaning the existing pipeline, removing any debris or protruding laterals, noting locations of existing lateral connections, and diverting sewer flows, if they are high, in preparation for the installation of the liner.

   a. **Liner:** The liner consists of an absorbent, flexible, industrial grade felt tube with an impermeable membrane on the inside surface. The size and length of the tube are custom made to fit each project. This makes CIPP an ideal method for odd sized or odd shaped pipes such as old brick sewers.

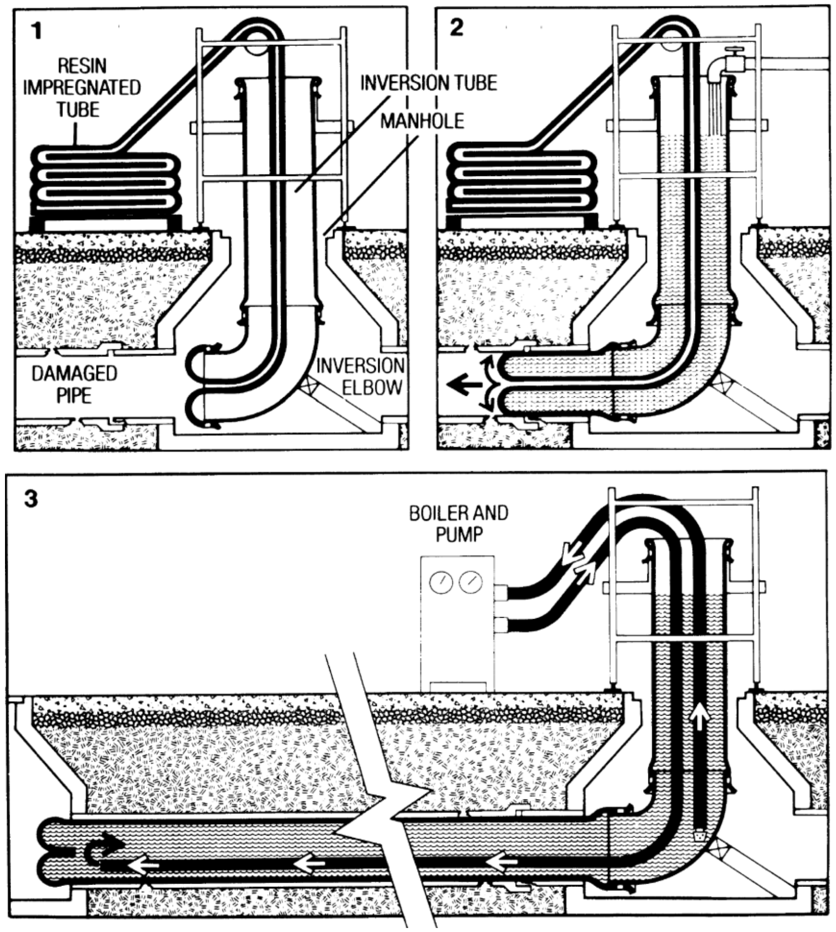
   b. **Resin:** As mentioned above, the resin is what hardens and ultimately gives the CIPP its strength. Various resins are available and each has different properties. The material property, of most interest to the designer in determining the thickness of the liner to be installed, is the strength or flexural modulus of elasticity. Resins with a flexural modulus of 250,000, 300,000, and 400,000 psi are common. Additional resin strengths may be available; it is recommended that a CIPP supplier be contacted to determine the currently available resins.

      Over time, the materials used for construction of CIPP will undergo deformation when exposed to a constant load. This deformation is defined as creep. This long term creep effectively reduces the strength of the liner over time. To account for this, a reduction factor (normally 50%) is applied to the initial flexural modulus of the resin material to provide a long term modulus of elasticity (E_L). This long term modulus is the value utilized in the liner designs discussed in the following sections on design.

   c. **Preparation for Lining:** Prior to beginning the lining process, the sewer should be thoroughly cleaned and televised. All service connection locations should be identified and carefully noted. Large pieces of debris such as bricks or chunks of concrete should be removed. Any obstructions that may interfere with the lining process, such as protruding services, severely offset joints, collapsed pipes, tree root penetration, etc., should be addressed by either remote repair or by open cut point repair.

   d. **CIPP Installation Process:** Just before delivery to the project site, the felt tube is thoroughly wetted with a thermosetting resin. As the resin is applied to the felt, the liner is turned inside-out, resulting in the impermeable membrane being on the outside, and the resin-impregnated felt on the inside of the tube. The liner is loaded on a truck and delivered to the project. Since the resin cures in the presence of heat, the liner may be shipped in a refrigerated truck or packed in ice if weather conditions dictate.

Figure 14C-2.01: Typical CIPP Inversion Process



Source: Iseley and Najafi, 1995, from Insituform

The sewer is lined by inverting the tube into the sewer line. In the inversion process, one end of the tube is cuffed back and attached to an inversion ring directly above the access point (typically a manhole). The inverted tube is filled with water. The resulting pressure head is used to force the liner through the sewer line and continue the inversion process. In addition to inverting the tube, the water head also acts to expand the tube inside the pipe, forcing the resin soaked felt (once again on the outside of the liner) against the inside walls of the existing sewer pipe. The pressure head applied by the water causes some of the resin in the felt to be squeezed out, filling leaky joints and cracks in the pipe. ASTM F 1216 addresses this potential loss of resin from the felt tube by requiring an additional 5 to 10% (by volume) of resin to be added to the tube beyond its saturation point.

Rather than inverting with water pressure as described above, CIPP liners can also be pulled into place by a winch and then expanded. When the pulled-in-place process is utilized, the membrane remains on the outside of the liner during the entire process. This membrane may remain impermeable or be perforated or slotted prior to installation (this should be specified in the plans). Even though the liner may be perforated or slotted during the installation process, the exterior liner can inhibit the migration of the resin from the liner into joints and cracks.

While the pulled-in-place installation method can be successfully utilized, the inversion method may be better suited for pipelines that have high levels of infiltration through the pipe joints or cracks. The pulled-in-place and inversion methods work equally well for lining pipes whose defects are more structural in nature.

e. **Curing and Hardening the CIPP Liner:** Regardless of the method of installation, the newly installed liner is then cured by applying heat. Typically, this is done by heating and circulating the water used to invert and expand the tube, or by applying pressurized steam to the line. The applied heat causes the thermosetting resin in the felt to cure or harden. This changes the resin from a liquid to a solid. After the resin has cured, the CIPP is cooled, resulting in a new pipe with a slightly smaller inside diameter, but of the same general shape as the original pipe.

f. **Completion:** The ends of the CIPP are trimmed off, and the service laterals are reopened. Reopening the service connections can be done by man-entry for larger diameters or robotically for smaller diameters. Normally, a small dimple is left in the liner directly over each service connection, allowing them to be easily located and reopened. However, the number and locations of the service connections should be noted during the pre-lining televising process to ensure that all connections are reopened and to aid in locating those that are difficult to identify.

The result of the CIPP process is that a new pipe is formed within the existing sewer pipe. This new pipe reduces infiltration and adds structural integrity to the existing line. The expected service life of a cured-in-place liner is generally accepted to be 50 years.

2. **CIPP Design:** Cured-in-place pipe liners should be designed in accordance with ASTM F 1216 – "Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube." This standard is recognized by virtually all CIPP suppliers and contractors. The standard for the CIPP is all inclusive, covering material requirements, construction methods, and design parameters. The equations and definitions utilized in this section are taken from ASTM F 1216.

The first step in designing a CIPP project is identifying the condition of the existing pipe. ASTM F 1216 divides existing pipe conditions into two classes: partially deteriorated condition and fully deteriorated condition. The condition of the pipe affects the method of design that is utilized. According to ASTM F 1216, these conditions are defined as follows:

"*Partially deteriorated pipe* - the original pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and up to 10% distortion of the diameter. If distortion of the diameter is greater than 10%, alternative design methods are required" (see fully deteriorated pipe).

"*Fully deteriorated pipe* - the original pipe is not structurally sound and cannot support soil and live loads nor is expected to reach this condition over the design life of the rehabilitated pipe. This condition is evident when sections of the original pipe are missing, the pipe has lost its original shape, or the pipe has corroded due to the effects of the fluid, atmosphere soil or applied loads."

a. Design for Partially Deteriorated Gravity Pipe Condition: Generally, the partially deteriorated condition is used when the existing pipe is in good condition, but has leaky joints. For this reason, the liner is only designed to resist the hydrostatic loads due to groundwater, since the soil and live loads are still being supported by the original pipe. The required thickness of the liner is determined utilizing the following equations:

$$t = \frac{D_o}{\left[\frac{2KE_L C}{P_W\left(1-\nu^2\right)N}\right]^{1/3}+1}$$

Equation 14C-2.01
(Note: this is a rearrangement of Equation X1.1 from ASTM F 1216)

where:

t	=	CIPP thickness, inches
D_o	=	Mean outside diameter of the CIPP, inches
K	=	enhancement factor of the soil and existing pipe, typically 7 (conservative), dimensionless
E_L	=	long term (time corrected) modulus of elasticity for CIPP, psi (see Section 3.2 A-1.b)
P_W	=	groundwater load (hydrostatic pressure), psi

$$P_W = \frac{H_W(\text{ft}) \times 62.4(\text{pcf})}{144\left(\text{in}^2/\text{ft}^2\right)} \text{ or } P_W = 0.433(H_W)$$

Equation 14C-2.02

H_W	=	Groundwater height above the top of the pipe, ft
ν	=	Poisson's ratio (0.3 average), dimensionless
N	=	factor of safety (normally 2.0), dimensionless
C	=	ovality reduction factor, dimensionless. See Table 3.2-1, or

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

Equation 14C-2.03

q	=	percent ovality of original pipe - estimate from the CCTV inspection the amount of ovality (deflection from original round shape). Normally, the ovality will vary along the length of the line (use the most oval condition). The more ovality, the thicker the liner will need to be.

Table 14C-2.01: Ovality Reduction Cactor (based upon Equation 14C-2.03)

Ovality, q, %	Factor, C	Ovality, q, %	Factor, C
0	1.00	12	0.35
2	0.84	14	0.29
4	0.70	15	0.27
5	0.64	16	0.24
6	0.59	18	0.20
8	0.49	20	0.17
10	0.41		

If the groundwater table is below the invert of the pipe, the hydrostatic pressure is zero, and Equation 1 cannot be used to calculate the liner thickness. If it is determined that the CIPP will not be underwater, ASTM F1216 recommends a CIPP with a maximum standard dimension ration (SDR) of 100. When there are no external hydrostatic forces on the pipe, the CIPP thickness is calculated with Equation 14C-2.04:

Equation 14C-2.04

$$t = \frac{D_o}{100}$$

where:

t	=	CIPP thickness, inches
D_o	=	Mean outside diameter of the CIPP, inches

When the existing host pipe is out of round or is deformed in a localized area, bending stresses may be the predominant force action on the CIPP when external hydrostatic pressure surrounds the pipe. When the host pipe is oval, the CIPP must be checked to ensure that bending stresses do not exceed the long term flexural strength of the CIPP. This value should be available from the liner supplier. The bending stresses that the pipe is expected to see over its life are given by Equation 14C-2.05 below.

Equation 14C-2.05

$$\left[\frac{1.5q}{100}\left(1+\frac{q}{100}\right)\left(\frac{D_o}{t}\right)^2 - 0.5\left(1+\frac{q}{100}\right)\left(\frac{D_o}{t}\right)\right]P_W N = \sigma_L$$

where,

σ_L	=	long term flexural strength of the CIPP, psi
q	=	percentage of ovality of the original pipe, %
D_o	=	mean outside diameter of the CIPP, inches
t	=	CIPP thickness, inches
P_W	=	external water pressure, psi (see Equation 14C-2.02)
N	=	factor of safety (normally 2.0), dimensionless

b. Design for Fully Deteriorated Gravity Pipe Condition: Generally, the fully deteriorated condition is chosen when the existing pipe is showing signs of significant deterioration. The liner pipe is expected to carry all of the hydraulic, soil, and live loads by itself, as if the host pipe were not present. The fully deteriorated liner design is begun by determining the anticipated external loading on the liner:

Hydrostatic pressure:

P_W - See Equation 14C-2.02 in the preceding section.

Soil pressure:

Soil pressure is estimated by determining the prism load, P_s, acting on the pipe. This load is determined as follows:

$$P_s = \frac{\omega H_S R_W}{144}$$ **Equation 14C-2.06**

where,

P_s = Soil prism loading pressure, psi
ω = Soil density, lb./ft^3
H_S = Height of soil above <u>top</u> of pipe, feet
R_W = Water buoyancy factor, dimensionless

$$R_W = 1 - 0.33\left(\frac{H_W}{H_S}\right) \text{(minimum value = 0.67)}$$ **Equation 14C-2.07**

H_W = water height above the top of the pipe, feet
H_S = soil height above the top of the pipe, feet

Live load:

Live load exerted by traffic, railroads, aircraft, or from other sources should be calculated. Typical values are shown in Table 14C-2.02.

Table 14C-2.02: Live Load Pressures at Various Depths

Height of fill (feet)	**Highway HS-20 (psi)**	**Railroad Cooper E-80 (psi)**	**Airport[1] (psi)**	
			Rigid Pavement	***Flexible Pavement***
1	16	19	10	59
2	7	18	9	30
3	3	16	8	23
4	2	14	8	16
5	2	12	7	12
6		10	6	10
8		8	5	7
10		6	4	5
15		4		
20		2		

[1] 180,000 Pound Dual-Tandem Gear Assembly, 190 psi tire pressure, 26 inch c/c spacing between dual tires, 66 inch c/c spacing between fore and aft tandem tires.
Table values developed from American Concrete Pipe Association, Concrete Pipe Design Manual, 2000

Total external pipe load:

$$P_t = P_W + P_S + P_L$$ **Equation 14C-2.08**

where,

P_t = Total external pipe load, psi
P_W = Hydrostatic pressure, psi
P_S = Soil pressure, psi
P_L = Live load, psi

Once the total external load that the liner pipe must support has been determined, the liner thickness can be determined with Equation 14C-2.09.

Equation 14C-2.09
(Note: this is a rearrangement of Equation X1.3 from ASTM F 1216)

$$t = \left[\frac{0.375\left(P_t \frac{N}{C}\right)^2 D_o^3}{E_L R_W B' E'_S} \right]^{1/3}$$

where:

t = CIPP thickness, inches
P_t = Total pressure due to water, soil, and live load acting on CIPP, psi
N = factor of safety (normally 2.0), dimensionless
C = ovality reduction factor, dimensionless. See Table 1, or Equation 3
D_o = Mean outside diameter of the CIPP, inches
E_L = long term (time corrected) modulus of elasticity for CIPP, psi (see Section 14C-2, A, 1, b)
R_W = Water buoyancy factor, dimensionless (see Equation 7)
B' = Empirical coefficient of elastic support, dimensionless

$$B' = \frac{1}{1 + 4\boldsymbol{e}^{-0.065 H_S}}$$ **Equation 14C-2.10**

$\boldsymbol{e}$ = base of natural log = 2.718
H_S = soil height above top of pipe, feet
E'_S = Modulus of soil reaction, psi (see note below)

While most of the terms utilized in Equation 14C-2.09 should be known or could be calculated, the Modulus of Soil Reaction is a relatively subjective term. This is a variable that is used to reflect the amount of support being given to the new liner pipe from the surrounding soil. Since the surrounding soil is actually the host pipe, this value can be hard to determine. Use judgment after viewing the CCTV video of the sewer. Badly cracked pipe, missing bricks, and missing pipe are reasons to thicken the liner. Values to be used are between 500 psi (bad pipe, thick liner) and 2,000 psi (fair pipe, thinner liner).

For shallow pipes with little or no groundwater to contribute to the load, a minimum thickness check should be completed. This is a similar design condition as previously described for partially deteriorated pipe having no groundwater. For this special case, there is a provision in ASTM F 1216 that requires the CIPP to have a minimum pipe stiffness that is 1/2 that of the value specified in AWWA C950. Based upon this requirement, the minimum pipe thickness is checked by the following equation:

Equation 14C-2.11

$$t \geq (D_o)\left(\sqrt[3]{\frac{1.116}{E}}\right)$$

where:

- t = CIPP thickness, inches
- D_o = Outside diameter of CIPP
- E = initial modulus of elasticity for CIPP

One final check of the design needs to be completed. As described for partially deteriorated pipe in the preceding section, the bending stresses need to be checked for pipes which are out of round. The bending stresses that a fully deteriorated pipe is expected to see over its life are calculated in the same manner as for a partially deteriorated pipe and are given by Equation 14C-2.05.

3. Project Considerations:

a. Contractor Review: Prior to bidding any CIPP project, it is always a good idea to review the project with an experienced CIPP contractor. There are construction and performance related limitations to the use of CIPP for pipeline rehabilitation. These limitations relate to the condition of the existing pipeline, the maximum practical thickness of the liner, and the point where CIPP lining is no longer a cost effective option. The contractor may be able to recommend alternatives to reduce the cost or improve the performance of a CIPP liner.

Before designing a project with unusual conditions (odd-shaped pipe, deep pipe, severely deteriorated pipe, difficult access, etc.), it may also be wise to meet with a local CIPP installation contractor, visit the site, and review the sewer tapes with the contractor.

b. Preparing Contract Documents for a CIPP Project: One of the most important things to consider when designing a CIPP liner and preparing the contract documents for the project is that there are a variety of different strength resins available. These different resins can be used in conjunction with different thicknesses of felt to produce multiple liner designs, which meet the requirements of a particular project. The point is to find the combination of resin strength and liner thickness that meets the requirements of the project and has the lowest cost.

For this reason, a single resin strength / liner thickness should not normally be specified on a particular project. Rather, multiple resin strengths / liner thicknesses should be allowed. The combination of resin and liner that is the most economical for one contractor may be different than that of another contractor.

There are two different ways to allow each contractor the flexibility of selecting their own resin/liner combination while assuring that the product being bid meets the requirements of the job. The first method is to allow the contractor to design the liner thickness themselves. If this is done, the engineer should state on the plans that the liner shall be designed in accordance with ASTM F 1216 (or F 1743 if pulled-in-place installation is allowed). In addition, the engineer should require that each potential bidder submit their calculations prior to the letting for review. During this review, the engineer should verify that all bidders are using the same design criteria, and that this criterion matches the site conditions. The alternative method for specifying a liner is to give various combinations of resin and liner thicknesses, allowing the contractor to select the one that is most economical. This method requires the engineer to calculate several liner thicknesses for different resins, but eliminates the possibility that a contractor may use an incorrect value or make an error in their calculations. Typical information provided in the plans is shown in Table 14C-2.03.

Table 14C-2.03: Typical Plan Information for a CIPP Project (Partially deteriorated condition)

Between Manholes	Length, (ft)	Pipe Dia., in	Water above Pipe H_W, ft	Ovality Factor, C	Safety Factor, N	Min. liner thickness, in		
						E_L(psi) = 125,000	E_L(psi) = 150,000	E_L(psi) = 200,000
41 to 47	1100	12	12	.64	2.0	.240	.226	.205

Table 14C-2.04: Typical Plan Information for a CIPP Project (Fully deteriorated condition)

Between Manholes	Length, (ft)	Pipe Dia., in	Live Load P_L, psi	Total Load P_T psi	Water Buoyancy Factor R_W	Water above Pipe H_W, ft	Soil above pipe H, ft	Coeff. Of Elastic Support, B'	Ovality Factor, C	Safety Factor, N	Modulus of Soil, E'_S, (psi)	Min. liner thickness, in		
												E_L(psi) = 125,000	E_L(psi) = 150,000	E_L(psi) = 200,000
41 to 47	1,100	12	2.0	6.5	.87	2	5	.257	.64	2.0	1,000	.211	.199	.181
47 to 173	1,600	12	7.6	14.8	.88	3	8	.296	.84	2.0	500	.366	.345	.313

The CCTV video of the sewer to be lined should be made available to any potential bidders for review prior to the bid. The contract documents can state that a video is available for viewing and who to contact to arrange a time to view the video, or copies of the video can be distributed to each potential bidder along with the contract documents.

Any time restrictions or additional requirements of the work should be clearly spelled out in the contract documents. These include bypass pumping requirements, time restrictions such as night or weekend work, coordination with other projects, etc. In addition, the contract documents should indicate what testing of the liner will be required.

c. **Testing:** ASTM F 1216 and F 1743 both address the testing requirements for CIPP linings. When specified by the owner, these specifications require the contractor to prepare samples in one (or both when specified) of two ways. The first is to cut a section of the cured CIPP from the liner where it passes through an intermediate manhole or from the terminating end of the CIPP liner. Alternatively, a section of the uncured liner, which is made of the same felt and resin as the liner, can be bolted into a frame and placed inside the pipe during the curing process.

The samples provided may be tested for short-term flexural (bending) properties and delamination. In addition, exfiltration testing for sewer lines 36 inches and smaller, which do not have any service laterals, may also be required.

d. Costs: The main concern with CIPP is normally the cost. Depending on the situation, the cost for a CIPP liner may approach or exceed than that for open cut removal and replacement. However, one must consider the main reason for considering a trenchless technique in the first place (reduced disruption to the public). The disruption caused by CIPP lining is minimal (the process can often be completed with no excavation of any kind required).

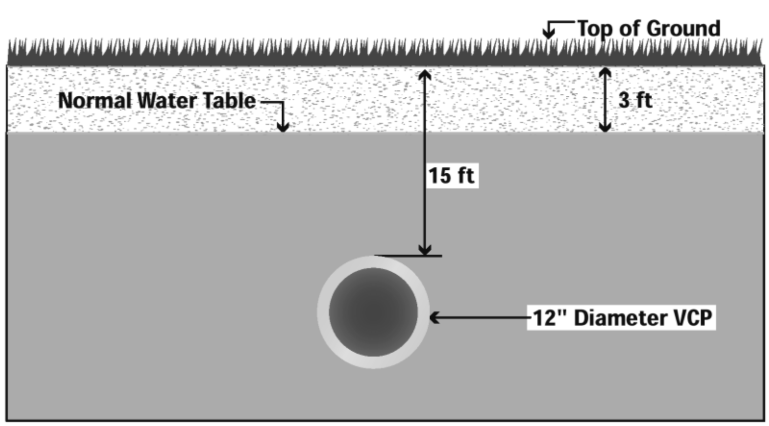
There are several recommendations for reducing the costs associated with a CIPP lining project. The first is to avoid lining small quantities of pipe. Lining large quantities (1,000 feet or greater) under a single project significantly reduces the unit cost of CIPP lining. One of the most significant costs involved with the lining process is mobilization of people and equipment. If two or three separate lines are being considered for lining, it is much more cost effective to do them all as a single project than to do them each separately. Check with surrounding communities to see if they are planning any lining projects that could be combined and let together. This allows the contractor to install two projects with only one mobilization cost.

The second recommendation is to allow a large time frame for a lining project. Most CIPP contractor's territories cover large portions of the country. Providing a flexible time frame allows the contractor to schedule and complete several projects in a particular area at the same time. Again, this reduces mobilization costs.

Also consider other rehabilitation methods which may be less expensive. For larger pipe (>42 inches), sliplining may be more economical if the line has sufficient capacity to account for the reduced cross section created by the sliplining process.

4. CIPP Design Examples:

Figure 14C-2.02: Partially Deteriorated Design Example



Source: Inliner Technologies

Given: A partially deteriorated 12 inch diameter sanitary sewer pipe with some cracking and offset joints is leaking and in need of renewal (see Figure 14C-2.02). Through CCTV inspection, it appears that in at least one area, the pipe is no longer round and has deflected approximately 5 percent. The water table, through investigation, is found to normally be at 3 feet below the surface. The pipe is buried at a depth of 15 feet to the top of the pipe. Assume a modulus of elasticity for the resin of 300,000 psi (long term modulus, $E_L = 0.5(300,000) = 150,000$ psi) and a long term flexural strength of 2,500 psi.

Required: Determine the wall thickness required for a CIPP liner.

Solution:

Step 1: Determine the hydrostatic pressure acting on the CIPP
H_W = 15' (pipe depth) - 3' (depth of water table) = 12'

$$P_W = \frac{12(ft)*62.4(pcf)}{144\left(in^2/ft^2\right)} = 5.2psi$$ From Equation 14C-2.02

Step 2: Pipe ovality

From Table 14C-2.01 or Equation 14C-2.03, C = 0.64

Step 3: Determine the CIPP design thickness from Equation 14C-2.01

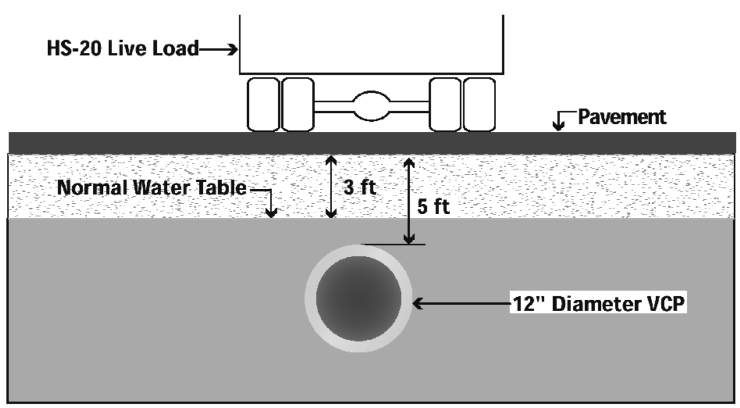
$$t = \frac{D_o}{\left[\frac{2KE_LC}{P_W(1-\nu^2)N}\right]^{1/3}+1} = \frac{12}{\left[\frac{2(7)(150,000)(0.64)}{(5.2)(1-0.3^2)(2)}\right]^{1/3}+1} = 0.226 \text{ Inches}$$

Step 4: Because the pipe has some out-of-roundness, bending stresses must be calculated to ensure they do not exceed the long-term flexural strength of the CIPP. From Equation 14C-2.05:

$$\sigma_L = \left[\frac{1.5(5)}{100}\left(1+\frac{5}{100}\right)\left(\frac{12}{.226}\right)^2 - 0.5\left(1+\frac{5}{100}\right)\left(\frac{12}{.226}\right)\right]5.2(2) = 2020 \text{psi}$$

Since the long term bending stress of 2,020 psi is less than the long term flexural strength of the product, the initial design is OK. However, if the bending stresses had exceeded the long term flexural strength, then the bending stresses would control the thickness design and Equation 14C-2.05 would need to be solved for thickness.

Figure 14C-2.03: Fully Deteriorated Design Example



Source: Inliner Technologies

Given: The 12 inch VCP sanitary sewer pipe shown in Figure 14C-2.03 is cracked and leaking. The severity of the cracking has progressed to the point that some pieces of the pipe wall have fallen into the pipeline and voids have begun to form around the pipe. The pipe is shallow and located under a busy city street subject to HS-20 loading. Assume that the pipe is buried under a clay soil with a unit weight of 120 pcf. As in the previous example, the pipe is no longer round and has deflected approximately 5%. The water table is normally located 3 feet below the surface. Assume a modulus of elasticity for the resin of 300,000 psi (long term modulus, E_L = 0.5(300,000) = 150,000 psi), a long term flexural strength of 2,500 psi, and a soil modulus of 1,000 psi.

Required: Determine the wall thickness required for a CIPP liner.

Solution:

Step 1: Determine the total load, P_t, acting on the pipe above.

Hydrostatic Pressure: $P_W = \frac{2(\text{ft}) * 62.4(\text{pcf})}{144\left(\text{in}^2/\text{ft}^2\right)} = 0.87\ \text{psi}$ From Equation 14C-2.02

Soil Load: $R_W = 1 - 0.33\left(\frac{2}{5}\right) = 0.87$ (min. = 0.67) From Equation 14C-2.07

$P_s = \frac{(120)(5)(0.87)}{144} = 3.63\ \text{psi}$ From Equation 14C-2.06

Live Load: From Table 14C-2.02, the live load at 5 feet for HS-20 loading = 2 psi

Total Load:

$P_t = 0.87 + 3.63 + 2 = 6.5\ \text{psi}$ From Equation 14C-2.08

Step 2: Determine the coefficient of elastic support

$B' = \frac{1}{1 + 4e^{-0.065(5)}} = 0.26$ From Equation 14C-2.10

Step 3: Pipe ovality and ovality reduction factor

From Table 14C-2.01 or Equation 14C-2.03, C = 0.64

Step 4: Determine the CIPP thickness from Equation 14C-2.09

$$t = \left[\frac{0.375\left(P_t \frac{N}{C}\right)^2 D_o^3}{E_L R_W B' E'_S}\right]^{1/3} = \left[\frac{0.375\left(6.5\frac{2}{0.64}\right)^2 12^3}{(150{,}000)(0.87)(0.26)(1{,}000)}\right]^{1/3} = 0.199\ \text{inches}$$

Step 5: Minimum thickness check from Equation 14C-2.11

$$t \geq (D_o)\left(\sqrt[3]{\frac{1.116}{E}}\right) = 12\left(\sqrt[3]{\frac{1.116}{300{,}000}}\right) = 0.186 \text{ Inches}$$

Since the design thickness calculated in Step 4 is greater than the minimum thickness given in Step 5, the calculated design thickness is OK.

Step 6: Bending stress check from Equation 14C-2.10

$$\sigma_L = \left[\frac{1.5(5)}{100}\left(1+\frac{5}{100}\right)\left(\frac{12}{0.20}\right)^2 - 0.5\left(1+\frac{5}{100}\right)\left(\frac{12}{0.20}\right)\right](0.4)(2) = 204 \text{ psi}$$

The calculated bending stress (204 psi) is less than the allowable long-term flexural strength of the product (2,500 psi). If the bending stresses had exceeded the long term flexural strength, then the bending stresses would control and Equation 5 would need to be solved for thickness.

B. Fold-and-formed Pipe (FFP) and Deformed Reformed Pipe (DRP) Lining

The fold-and-formed pipe (FFP) and deformed-reformed pipe (DRP) techniques are pipeline rehabilitation methods that were once common, but are seeing decreased usage today. FFP and DRP are both names for a process which consist of folding or deforming a circular polyethylene (PE) or Poly Vinyl Chloride (PVC) pipe into a "U" shape during the time of manufacture, to reduce the cross sectional area of the pipe. The deformed pipe is then coiled on a spool for transport.

At the project site, the coiled pipe is pulled into the existing pipe. The reduced cross section of the folded pipe allows it to fit inside of the host pipe. At this point, steam or hot water is circulated through the pipe to heat it until it becomes pliable. The pipe is then rounded utilizing steam or water pressure, or by pulling a rounding device through the pipe. The pipe is then allowed to cool and harden in place. Service laterals are then reopened robotically or by digging them up and re-establishing them.

As mentioned above, use of the FFP/DRP method is declining, especially in the northern climates. This is due, at least in part, to problems encountered with the pipe developing a "memory" during the deformation process. Over time, the rounded pipe starts to return to its original deformed shape. The action appears to be accelerated by the cold weather conditions experienced in the northern states. This can cause the liner to pull away from the host pipe, reducing support and separating from service laterals.

Given the declining usage of the FFP/DRP process, the design and construction process is not discussed in detail herein. Should the designer wish to pursue a FFP/DRP project, the following ASTM references are provided:

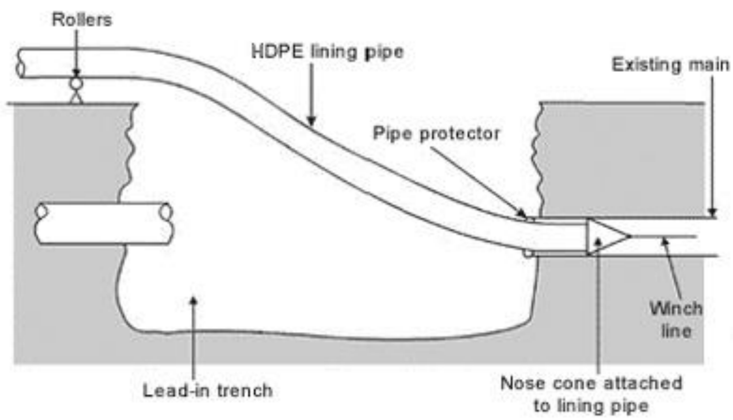
- F 1504 Standard Specification for Folded Poly Vinyl Chloride (PVC) Pipe for Existing Sewer and Conduit Rehabilitation
- F 1947 Standard Practice for Installation of Folded Poly Vinyl Chloride (PVC) Pipe into Existing Sewers and Conduits
- F 1871 Standard Specification for Folded/Formed Poly Vinyl Chloride Pipe Type A for Existing Sewer and Conduit Rehabilitation

F 1867 Standard Practice for Installation of Folded/Formed Poly Vinyl Chloride (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation
F 1533 Standard Specification for Deformed Polyethylene (PE) Liner
F 1606 Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner

C. Sliplining

1. **Description of Process and Materials:** The concept of sliplining is one of the simplest techniques for rehabilitating an existing sewer line. Sliplining basically involves pushing or pulling a new pipe into the old one, reconnecting the services, and possibly grouting the space between the pipes.

Figure 14C-2.04: Typical Sliplining Installation



Source: PROFUNDIS Presse

a. **Polyethylene Pipe:** The most common material used for sliplining is polyethylene (PE) pipe. Its ability to be fusion welded into long jointless sections, which can be quickly pulled into place, make it a popular choice for sliplining.

The process of sliplining with PE pipe begins by excavating a starter trench at one end of the line. This trench allows the pipe to be pulled from the ground surface into the pipe without requiring sharp bends. Prior to installation, individual sections of PE pipe are fusion welded together to form a single continuous section of pipe that matches the length of the pipe to be lined. This pipe is laid out in a long line on the ground surface. At this point, sewer flows must be diverted. A cable is fed through the host pipe and attached to a towing head. This towing head is attached to the end of the new liner pipe and the liner is pulled into place with a winch. After the pipe has been pulled into place, the annular space between the host pipe and the lining pipe is normally filled with grout. Grouting this space helps to restrain the liner pipe and increases its stiffness. This can be the most difficult part of a sliplining project. Finally, any service lines must be reconnected. These lines cannot normally be reconnected from inside the pipe like CIPP lining. The connections must be excavated and a new wye installed on the lining pipe.

There are several disadvantages to sliplining with PE pipe. The first is that the pipe stretches under the high tensile forces developed during the installation process. After the pipe is in place and the tensile forces are relieved, the pipe slowly shrinks back to its original shape. This can cause problems if service lines are re-established before the liner pipe has had a chance to relax. If a service connection is re-opened in the liner pipe too soon, the liner pipe will shrink, and the opening in the liner will move past the connection, creating a blockage. It is generally recommended that the liner pipe be allowed at least 24 hours to relax prior to reestablishing service connections. This may require the establishment of temporary services.

Since most polyethylene pipe used for sliplining is black in color (to protect it from ultraviolet degradation) it is a common practice to specify that the pipe be lined with a light colored material to facilitate future CCTV inspection.

b. Other Materials: As indicated above, sliplining pipe is most commonly polyethylene; however, it may be any common sewer material that can be inserted into the host pipe. The main criteria is that, in order to minimize the reduction in cross sectional area of the pipe, joints or socket protrusions beyond the barrel of the pipe should be minimized or eliminated. Fortunately, there are a wide variety of pipe products that meet this criterion. Most are intended for pipe jacking, microtunneling, or directional boring; however, their bell-less or low profile bell configurations also make them well suited for sliplining.

Rigid products such as vitrified clay, concrete, ductile iron, and centrifugally-cast glass-fiber reinforced polymer mortar (CCFRPM) pipe can all be pushed into the pipe from a relatively small access pit. These products are pushed into the pipe utilizing jacking equipment similar to that for microtunneling or pipe jacking. Flow bypassing is not normally required since the line remains open during the insertion process. In addition, due to the inherent structural integrity of these rigid pipe products, grouting the annular space is not as critical as for flexible pipe; however, it is still normally done in order to lock the pipe in place.

Additional pipes products with restrained joints, such as PVC or ductile iron, can also be pulled into the line in a manner similar to that for PE pipe. These materials are usually installed a section at a time, rather than being completely assembled prior to installation like polyethylene. Again, flow bypassing is not normally required. Grouting of the annular space is not required for ductile iron and is optional for PVC depending on the condition of the original pipe.

2. Additional Considerations:

a. Limitations: Probably the biggest issue to contend with when considering a sliplining project is the reduction in pipe diameter that will result. Since the sliplining pipe must fit inside of the host pipe, the outside diameter of the lining pipe should be slightly smaller than the inside diameter of the host pipe at its narrowest point. The capacity of the smaller diameter liner pipe must be checked to verify that it can carry future anticipated flows. If sliplining the pipe causes too much of a reduction pipe capacity, alternative rehabilitation methods such as pipe bursting or CIPP may be considered.

For large diameter pipes (42 inches and greater), it may be possible to reestablish services by man-entry in the pipe; however, in most cases, the service connections must be excavated and re-established.

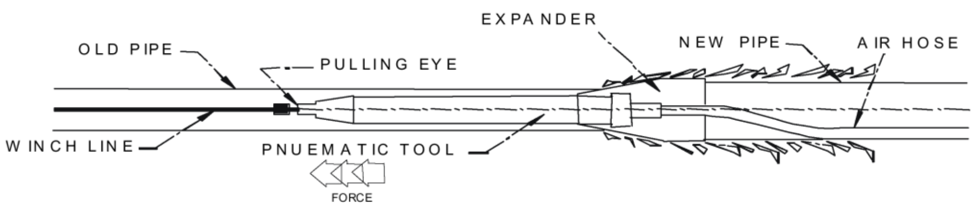
b. Cost: Sliplining is a relatively cost effective method of rehabilitation, especially for larger diameters. Many times, it may be the least costly method of pipeline rehabilitation. This is due in part to the relatively minimal equipment investment required and the commonly available materials utilized.

D. Pipe Bursting

1. **Description of Process and Materials:** Pipe bursting is a trenchless technique for replacing worn out and undersized pipes with a new pipe of the same or larger diameter. The pipe bursting process involves the insertion of a conical shaped bursting head into the old pipe. This head fractures the existing pipe and displaces the pipe fragments outward into the surrounding soil. At the same time, a new pipe is pulled in behind the bursting head. There are several different classes of pipe bursting systems. It should be noted that most of these systems are patented processes. Most contractors pay a licensing fee to be allowed to use the technique.

    a. **Pneumatic Bursting:** Pneumatic pipe bursting is the most commonly used system for pipe bursting. This method utilizes a percussion head (similar to an impact mole) to fracture and break the pipe. In addition to the percussion force, cable is attached to the front of the mole and a winch provides tension to keep the bursting head pressed against the pipe wall and to aid in pulling the new pipe in behind the mole.

Figure 14C-2.05: Typical Pneumatic Bursting System



Source: Simicevic and Sterling

    b. **Hydraulic Expansion:** The hydraulic expansion system utilizes a bursting head, which can be expanded outward to break the existing pipe. In this process, the contracted head is pulled into the pipe. Hydraulic pressure is used to expand the head radially outward, breaking a section of the pipe, and pushing the fractured pieces into the surrounding soil. The head is then contracted and pulled forward with a winch, pulling in the new pipe behind it. This process is repeated in steps until the entire pipeline has been replaced.

    c. **Static Pull:** With the static pull method, the force for breaking and displacing the pipe comes only from pulling the bursting head forward. The cone shaped bursting head converts the horizontal tensile forces into radial forces that fracture the pipe. The tensile forces required to burst the existing pipe and pull in the new pipe are significant. For this reason, a pulling rod assemble may be used in lieu of a winch and cable system.

    d. **Implosion (Pipe Crushing):** The implosion system incorporates a crushing head, which fits around the outside diameter of the existing pipe. As the head is pulled forward, the crushing head breaks the existing pipe and forces the fragments inwards (into the pipe void). A steel cone follows the crushing head and pushes the pipe fragments outward, making room for the new pipe, which is pulled in behind the steel cone.

    e. **Pipe Splitting:** Pipe splitting is a method used for pipes that are not brittle, such as steel, ductile iron, and plastic. Rather than bursting the pipe, it is split open and expanded. This is accomplished with a three step process. Rotary slitter wheels make an initial longitudinal cut along the bottom of the pipe. Next, a hardened sail blade splits the pipe along the bottom. Finally, the pipe is “unwrapped,” or expanded, creating a hole immediately behind the splitter for the new pipe. The old pipe is displaced to a position immediately above the new pipe.

f. Rigid Pipe Replacement Methods: All of the methods previously described require the new pipe to be pulled in behind the bursting head. As a result, the new pipe must be flexible (typically polyethylene). There are methods available which allow the installation of rigid pipes (clay, ductile iron, concrete, GPMP, etc.) instead of polyethylene.

One method, based in part upon microtunneling techniques, utilizes jacks to push new sections of pipe in behind the breaking head. Another method utilizes a cable that is thread through the host pipe from the receiving pit to the launch pit and through the next section of pipe to be installed. The cable is attached to a pull plate on the end of the pipe furthest from the receiving pit. This causes the rigid pipe system to act as if it were being pushed instead of pulled.

g. Pipe Removal Techniques: Several other techniques, which result in removal of the existing pipe, are also available.

1) **Pipe Eating:** Pipe eating is a modified microtunneling system in which the existing pipe is crushed by the microtunneling head and, along with any excess soil, removed through the new pipeline by a slurry system. The new pipe is jacked in immediately behind the microtunneling machine. This system also allows line and grade adjustments to be made.
2) **Pipe Reaming:** Pipe reaming is a modified version of the back reaming method used for directional drilling. A drill string is fed through the existing pipe and attached to a specially designed reaming head. The head is pulled back through the pipe as the reamer crushes and pulverizes the existing pipe. The pipe fragments and any excess soil required for upsizing are removed via a slurry system.
3) **Pipe Ejection:** Pipe ejection uses modified pipe jacking techniques to remove the old pipe. The replacement pipe is placed against the old pipe and, as the new pipe section is jacked, the old pipe is pushed out into the reception pit. This method requires that the structural condition of the existing pipe be in sufficient condition to withstand the jacking forces produced.

2. Design Considerations:

a. Range of Applications: As previously mentioned, the types of pipe suitable for bursting are typically brittle materials such as vitrified clay, cast iron, asbestos cement, and plain concrete. Lightly reinforced or heavily deteriorated reinforced concrete pipe may also be able to be replaced by pipe bursting. Ductile iron, steel, and plastic are not suitable for pipe bursting, but can be replaced by pipe splitting.

The normal bursting length is between 300 and 400 feet, the typical distance between manholes. The size of the pipes currently being replaced by pipe bursting ranges from 2 to 36 inches and is increasing as bursting equipment and techniques are improved. The most common pipe replacement is size-for-size; however, the pipe can be upsized up to 3 pipe diameters or greater.

b. Pipe Materials and Design: Replacement pipes should be designed to withstand earth loads and live loads in the same manner as they would be for an open cut situation (see Chapter 9, Part 9B). For most installations, standard sewer or water main pipe materials with special restrained or bell-less joints are suitable. Installation forces are not normally a concern. Flexible pipes with restrained joints, intended for directional drilling and other trenchless construction, are designed to withstand high tensile forces, and are therefore suitable for the moderate tensile forces typically experienced during the pipe bursting process. Likewise, rigid bell-less pipes intended for pipe jacking and microtunneling are designed to withstand very high compressive forces and are, therefore, also suitable for pipe bursting.

While standard sewer and water materials may be used for pipe bursting, the most common pipe material utilized is polyethylene. The main benefits of polyethylene are its flexibility and ability to be fused into long sections. The wall thickness for PE pipe should be designed to withstand earth and live loads. Since polyethylene is softer than other pipe materials, it is more susceptible to damage by the broken fragment of existing pipe. For this reason, the design thickness is commonly increased by 10% to account for scarring of the outer surface. When polyethylene pipe it used, it is a common practice to specify that the pipe be made of or lined with a light colored material to facilitate future CCTV inspection.

c. **Effect of Pipe Bursting on the Surrounding Environment:** All pipe bursting operations result in the displacement of soil. Even when the replacement is size for size, soil is displaced since the bursting head has a diameter greater than that of the replacement pipe. The soil expands in the direction of least resistance and can cause heaving at the surface. The amount of displacement depends on the degree of upsizing, the existing soil properties, and the depth of the bursting.

   Heaving of the existing ground surface is most likely when the existing pipe is shallow or already large diameter pipes are upsized. The potential for heaving must be carefully considered, especially when bursting under existing pavements or structures.

   In addition to heaving, adjacent utilities can also be affected by pipe bursting. In general, if there are deteriorated utilities within 2-3 pipe diameters of the bursting operation, there is potential for damage. Damage to adjacent services or structures can be minimized by creating a temporary excavation along the service or structure to protect it from the effects of the surrounding ground displacements.

d. **Service Connections:** Prior to bursting, all service connections should be excavated and disconnected. The purpose of this is to provide a temporary service connection and to prevent the service line from being damaged by the bursting operation. If the replacement pipe is polyethylene, it is likely that the new pipe has been stretched during the installation process. Prior to reestablishing the service connections, the new pipe should be allowed to relax and return to its original shape for at least 24 hours.

3. **Cost and Comparison to Other Techniques:** Open cut replacement is normally preferred and more cost efficient than pipe bursting when the pipe is shallow and the excavation does not create a major inconvenience. When the depth of the existing pipe, and the resulting excavation required becomes a significant factor in the cost of replacement, pipe bursting may have a significant economic advantage over open cut replacement. Compared to other rehabilitation techniques, such as CIPP and sliplining, the main advantage of pipe bursting is that it does not result in a loss of capacity due to reduced pipe diameter and can significantly increase capacity by upsizing the line.