



Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube¹²

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1. Scope

1.1 This practice describes the procedures for the reconstruction of pipelines and conduits (4 to 108-in. diameter) by the installation of a resin-impregnated, flexible tube which is inverted into the existing conduit by use of a hydrostatic head or air pressure. The resin is cured by circulating hot water or introducing controlled steam within the tube. When cured, the finished pipe will be continuous and tight-fitting. This reconstruction process can be used in a variety of gravity and pressure applications such as sanitary sewers, storm sewers, process piping, electrical conduits, and ventilation systems.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see 7.4.2.

2. Referenced Documents

2.1 ASTM Standards:

D 543 Test Method for Resistance of Plastics to Chemical Reagents³

D 638 Test Method for Tensile Properties of Plastics³

D 790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials³

¹ This practice is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.67 on Trenchless Plastic Pipeline Technology.

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² The following report has been published on one of the processes: Driver, F. T., and Olson, M. R., "Demonstration of Sewer Relining by the Insituform Process, Northbrook, Illinois," EPA-600/2-83-064, Environmental Protection Agency, 1983. Interested parties can obtain copies from the Environmental Protection Agency or from a local technical library.

³ *Annual Book of ASTM Standards*, Vol 08.01.

D 903 Test Method for Peel or Stripping Strength of Adhesive Bonds⁴

D 1600 Terminology for Abbreviated Terms Relating to Plastics³

D 3839 Practice for Underground Installation of Fiberglass (Glass-Fiber-Reinforced Thermosetting Resin) Pipe⁵

F 412 Terminology Relating to Plastic Piping Systems⁵

2.2 AWWA Standard:

Manual on Cleaning and Lining Water Mains, M 28⁶

2.3 NASSCO Standard:

Recommended Specifications for Sewer Collection System Rehabilitation⁷

NOTE 1—An ASTM specification for cured-in-place pipe materials appropriate for use in this standard is under preparation and will be referenced in this practice when published.

3. Terminology

3.1 Definitions are in accordance with Terminology F 412 and abbreviations are in accordance with Terminology D 1600, unless otherwise specified.

3.2 *Definitions of Terms Specific to This Standard:* Descriptions of Terms Specific to This Standard:

3.2.1 *cured-in-place pipe (CIPP)*—a hollow cylinder containing a nonwoven or a woven material, or a combination of nonwoven and woven material surrounded by a cured thermosetting resin. Plastic coatings may be included. This pipe is formed within an existing pipe. Therefore, it takes the shape of and fits tightly to the existing pipe.

3.2.2 *inversion*—the process of turning the resin-impregnated tube inside out by the use of water pressure or air pressure.

3.2.3 *lift*—a portion of the CIPP that has cured in a position such that it has pulled away from the existing pipe wall.

⁴ *Annual Book of ASTM Standards*, Vol 15.06.

⁵ *Annual Book of ASTM Standards*, Vol 08.04.

⁶ Available from the American Water Works Association, 6666 W. Quincey Ave, Denver, CO 80235.

⁷ Available from the National Association of Sewer Service Companies, 101 Wymore Rd., Suite 501, Altamonte, FL 32714.

4. Significance and Use

4.1 This practice is for use by designers and specifiers, regulatory agencies, owners, and inspection organizations who are involved in the rehabilitation of conduits through the use of a resin-impregnated tube inverted through the existing conduit. As for any practice, modifications may be required for specific job conditions.

5. Materials

5.1 *Tube*—The tube should consist of one or more layers of flexible needled felt or an equivalent nonwoven or woven material, or a combination of nonwoven and woven materials, capable of carrying resin, withstanding installation pressures and curing temperatures. The tube should be compatible with the resin system used. The material should be able to stretch to fit irregular pipe sections and negotiate bends. The outside layer of the tube should be plastic coated with a material that is compatible with the resin system used. The tube should be fabricated to a size that, when installed, will tightly fit the internal circumference and the length of the original conduit. Allowance should be made for circumferential stretching during inversion.

5.2 *Resin*—A general purpose, unsaturated, styrene-based, thermoset resin and catalyst system or an epoxy resin and hardener that is compatible with the inversion process should be used. The resin must be able to cure in the presence of water and the initiation temperature for cure should be less than 180°F (82.2°C). The CIPP system can be expected to have as a minimum the initial structural properties given in Table 1. These physical strength properties should be determined in accordance with Section 8.

6. Design Considerations

6.1 *General Guidelines*—The design thickness of the CIPP is largely a function of the condition of the existing pipe. Design equations and details are given in Appendix X1.

7. Installation

7.1 *Cleaning and Inspection:*

7.1.1 Prior to entering access areas such as manholes, and performing inspection or cleaning operations, an evaluation of the atmosphere to determine the presence of toxic or flammable vapors or lack of oxygen must be undertaken in accordance with local, state, or federal safety regulations.

7.1.2 *Cleaning of Pipeline*—All internal debris should be removed from the original pipeline. Gravity pipes should be cleaned with hydraulically powered equipment, high-velocity

jet cleaners, or mechanically powered equipment (see NASSCO Recommended Specifications for Sewer Collection System Rehabilitation). Pressure pipelines should be cleaned with cable-attached devices or fluid-propelled devices as shown in AWWA Manual on Cleaning and Lining Water Mains, M 28.

7.1.3 *Inspection of Pipelines*—Inspection of pipelines should be performed by experienced personnel trained in locating breaks, obstacles, and service connections by closed-circuit television or man entry. The interior of the pipeline should be carefully inspected to determine the location of any conditions that may prevent proper installation of the impregnated tube, such as protruding service taps, collapsed or crushed pipe, and reductions in the cross-sectional area of more than 40 %. These conditions should be noted so that they can be corrected.

7.1.4 *Line Obstructions*—The original pipeline should be clear of obstructions such as solids, dropped joints, protruding service connections, crushed or collapsed pipe, and reductions in the cross-sectional area of more than 40 % that will prevent the insertion of the resin-impregnated tube. If inspection reveals an obstruction that cannot be removed by conventional sewer cleaning equipment, then a point repair excavation should be made to uncover and remove or repair the obstruction.

7.2 *Resin Impregnation*—The tube should be vacuum-impregnated with resin (wet-out) under controlled conditions. The volume of resin used should be sufficient to fill all voids in the tube material at nominal thickness and diameter. The volume should be adjusted by adding 5 to 10 % excess resin for the change in resin volume due to polymerization and to allow for any migration of resin into the cracks and joints in the original pipe.

7.3 *Bypassing*—If bypassing of the flow is required around the sections of pipe designated for reconstruction, the bypass should be made by plugging the line at a point upstream of the pipe to be reconstructed and pumping the flow to a downstream point or adjacent system. The pump and bypass lines should be of adequate capacity and size to handle the flow. Services within this reach will be temporarily out of service.

7.3.1 Public advisory services will be required to notify all parties whose service laterals will be out of commission and to advise against water usage until the mainline is back in service.

7.4 *Inversion:*

7.4.1 *Using Hydrostatic Head*—The wet-out tube should be inserted through an existing manhole or other approved access by means of an inversion process and the application of a hydrostatic head sufficient to fully extend it to the next designated manhole or termination point. The tube should be inserted into the vertical inversion standpipe with the impermeable plastic membrane side out. At the lower end of the inversion standpipe, the tube should be turned inside out and attached to the standpipe so that a leakproof seal is created. The inversion head should be adjusted to be of sufficient height to cause the impregnated tube to invert from point of inversion to point of termination and hold the tube tight to the pipe wall, producing dimples at side connections. Care should be taken during the inversion so as not to over-stress the felt fiber.

TABLE 1 CIPP Initial Structural Properties^A

| Property | Test Method | Minimum Value | |
|--|-------------|---------------|---------|
| | | psi | (MPa) |
| Flexural strength | D 790 | 4 500 | (31) |
| Flexural modulus | D 790 | 250 000 | (1 724) |
| Tensile strength (for pressure pipes only) | D 638 | 3 000 | (21) |

^AThe values in Table 1 are for field inspection. The purchaser should consult the manufacturer for the long-term structural properties.

7.4.1.1 An alternative method of installation is a top inversion. In this case, the tube is attached to a top ring and is inverted to form a standpipe from the tube itself or another method accepted by the engineer.

NOTE 2—The tube manufacturer should provide information on the maximum allowable tensile stress for the tube.

7.4.2 *Using Air Pressure*—The wet-out tube should be inserted through an existing manhole or other approved access by means of an inversion process and the application of air pressure sufficient to fully extend it to the next designated manhole or termination point. The tube should be connected by an attachment at the upper end of the guide chute so that a leakproof seal is created and with the impermeable plastic membranes side out. As the tube enters the guide chute, the tube should be turned inside out. The inversion air pressure should be adjusted to be of sufficient pressure to cause the impregnated tube to invert from point of inversion to point of termination and hold the tube tight to the pipe wall, producing dimples at side connections. Care should be taken during the inversion so as not to overstress the woven and nonwoven materials.

NOTE 3—**Warning:** Suitable precautions should be taken to eliminate hazards to personnel in the proximity of the construction when pressurized air is being used.

7.4.3 *Required Pressures*—Before the inversion begins, the tube manufacturer shall provide the minimum pressure required to hold the tube tight against the existing conduit, and the maximum allowable pressure so as not to damage the tube. Once the inversion has started, the pressure shall be maintained between the minimum and maximum pressures until the inversion has been completed. Should the pressure deviate from within the range of the minimum and maximum pressures, the installed tube shall be removed from the existing conduit.

7.5 *Lubricant*—The use of a lubricant during inversion is recommended to reduce friction during inversion. This lubricant should be poured into the inversion water in the downtube or applied directly to the tube. The lubricant used should be a nontoxic, oil-based product that has no detrimental effects on the tube or boiler and pump system, will not support the growth of bacteria, and will not adversely affect the fluid to be transported.

7.6 *Curing:*

7.6.1 *Using Circulating Heated Water*—After inversion is completed, a suitable heat source and water recirculation equipment are required to circulate heated water throughout the pipe. The equipment should be capable of delivering hot water throughout the section to uniformly raise the water temperature above the temperature required to effect a cure of the resin. Water temperature in the line during the cure period should be as recommended by the resin manufacturer.

7.6.1.1 The heat source should be fitted with suitable monitors to gage the temperature of the incoming and outgoing water supply. Another such gage should be placed between the impregnated tube and the pipe invert at the termination to determine the temperatures during cure.

7.6.1.2 Initial cure will occur during temperature heat-up and is completed when exposed portions of the new pipe

appear to be hard and sound and the remote temperature sensor indicates that the temperature is of a magnitude to realize an exotherm or cure in the resin. After initial cure is reached, the temperature should be raised to the post-cure temperature recommended by the resin manufacturer. The post-cure temperature should be held for a period as recommended by the resin manufacturer, during which time the recirculation of the water and cycling of the boiler to maintain the temperature continues. The curing of the CIPP must take into account the existing pipe material, the resin system, and ground conditions (temperature, moisture level, and thermal conductivity of soil).

7.6.2 *Using Steam*—After inversion is completed, suitable steam-generating equipment is required to distribute steam throughout the pipe. The equipment should be capable of delivering steam throughout the section to uniformly raise the temperature within the pipe above the temperature required to effect a cure of the resin. The temperature in the line during the cure period should be as recommended by the resin manufacturer.

7.6.2.1 The steam-generating equipment should be fitted with a suitable monitor to gage the temperature of the outgoing steam. The temperature of the resin being cured should be monitored by placing gages between the impregnated tube and the existing pipe at both ends to determine the temperature during cure.

7.6.2.2 Initial cure will occur during temperature heat-up and is completed when exposed portions of the new pipe appear to be hard and sound and the remote temperature sensor indicates that the temperature is of a magnitude to realize an exotherm or cure in the resin. After initial cure is reached, the temperature should be raised to post-cure temperatures recommended by the resin manufacturer. The post-cure temperature should be held for a period as recommended by the resin manufacturer, during which time the distribution and control of steam to maintain the temperature continues. The curing of the CIPP must take into account the existing pipe material, the resin system, and ground conditions (temperature, moisture level, and thermal conductivity of soil).

7.6.3 *Required Pressures*—Before the curing begins, the pressure required to hold the flexible tube tight against the existing conduit shall be provided by the tube manufacturer. Once the cure has started and dimpling for laterals is completed, the required pressure shall be maintained until the cure has been completed. Should the pressure deviate more than 2.3 ft of water (1 psi) from the required pressure, the installed tube shall be removed from the existing conduit. If required by the owner, a continuous log of pressure during cure shall be maintained.

7.7 *Cool-Down:*

7.7.1 *Using Cool Water After Heated Water Cure*—The new pipe should be cooled to a temperature below 100°F (38°C) before relieving the static head in the inversion standpipe. Cool-down may be accomplished by the introduction of cool water into the inversion standpipe to replace water being drained from a small hole made in the downstream end. Care should be taken in the release of the static head so that a vacuum will not be developed that could damage the newly installed pipe.

7.7.2 *Using Cool Water After Steam Cure*—The new pipe should be cooled to a temperature below 113°F (45°C) before relieving the internal pressure within the section. Cool-down may be accomplished by the introduction of cool water into the section to replace the mixture of air and steam being drained from a small hole made in the downstream end. Care should be taken in the release of the air pressure so that a vacuum will not be developed that could damage the newly installed pipe.

7.8 *Workmanship*—The finished pipe should be continuous over the entire length of an inversion run and be free of dry spots, lifts, and delaminations. If these conditions are present, remove and replace the CIPP in these areas.

7.8.1 If the CIPP does not fit tightly against the original pipe at its termination point(s), the space between the pipes should be sealed by filling with a resin mixture compatible with the CIPP.

7.9 *Service Connections*—After the new pipe has been cured in place, the existing active service connections should be reconnected. This should generally be done without excavation, and in the case of non-man entry pipes, from the interior of the pipeline by means of a television camera and a remote-control cutting device.

8. Inspection Practices

8.1 For each inversion length designated by the owner in the contract documents or purchase order, the preparation of two CIPP samples is required, one from each of the following two methods:

8.1.1 The sample should be cut from a section of cured CIPP at an intermediate manhole or at the termination point that has been inverted through a like diameter pipe which has been held in place by a suitable heat sink, such as sandbags.

8.1.2 The sample should be fabricated from material taken from the tube and the resin/catalyst system used and cured in a clamped mold placed in the downtube when circulating heated water is used and in the silencer when steam is used.

8.1.3 The samples for each of these cases should be large enough to provide a minimum of three specimens and a recommended five specimens for flexural testing and also for tensile testing, if applicable. The following test procedures should be followed after the sample is cured and removed.

8.1.3.1 *Short-Term Flexural (Bending) Properties*—The initial tangent flexural modulus of elasticity and flexural stress should be measured for gravity and pressure pipe applications in accordance with Test Methods D 790 and should meet the requirements of Table 1.

8.1.3.2 *Tensile Properties*—The tensile strength should be measured for pressure pipe applications in accordance with Test Method D 638 and must meet the requirements of Table 1.

8.2 *Gravity Pipe Leakage Testing*—If required by the owner in the contract documents or purchase order, gravity pipes should be tested using an exfiltration test method where the CIPP is plugged at both ends and filled with water. This test should take place after the CIPP has cooled down to ambient temperature. This test is limited to pipe lengths with no service laterals and diameters of 36 in. or less. The allowable water exfiltration for any length of pipe between termination points should not exceed 50 U.S. gallons per inch of internal pipe

diameter per mile per day, providing that all air has been bled from the line. During exfiltration testing, the maximum internal pipe pressure at the lowest end should not exceed 10 ft (3.0 m) of water or 4.3 psi (29.7 kPa) and the water level inside of the inversion standpipe should be 2 ft (0.6 m) higher than the top of the pipe or 2 ft higher than the groundwater level, whichever is greater. The leakage quantity should be gaged by the water level in a temporary standpipe placed in the upstream plug. The test should be conducted for a minimum of one hour.

NOTE 4—It is impractical to test pipes above 36-in. diameter for leakage due to the technology available in the pipe rehabilitation industry. Post inspection of larger pipes will detect major leaks or blockages.

8.3 *Pressure Pipe Testing*—If required by the owner in the contract documents or purchase order, pressure pipes should be subjected to a hydrostatic pressure test. A recommended pressure and leakage test would be at twice the known working pressure or at the working pressure plus 50 psi, whichever is less. Hold this pressure for a period of two to three hours to allow for stabilization of the CIPP. After this period, the pressure test will begin for a minimum of one hour. The allowable leakage during the pressure test should be 20 U.S. gallons per inch of internal pipe diameter per mile per day, providing that all air has been evacuated from the line prior to testing and the CIPP has cooled down to ambient temperature.

NOTE 5—The allowable leakage for gravity and pressure pipe testing is a function of water loss at the end seals and trapped air in the pipe.

8.4 *Delamination Test*—If required by the owner in the contract documents or purchase order, a delamination test should be performed on each inversion length specified. The CIPP samples should be prepared in accordance with 8.1.2, except that a portion of the tube material in the sample should be dry and isolated from the resin in order to separate tube layers for testing. (Consult the tube manufacturer for further information.) Delamination testing shall be in accordance with Test Method D 903, with the following exceptions:

8.4.1 The rate of travel of the power-actuated grip shall be 1 in. (25 mm)/min.

8.4.2 Five test specimens shall be tested for each inversion specified.

8.4.3 The thickness of the test specimen shall be minimized, but should be sufficient to adequately test delamination of nonhomogeneous CIPP layers.

8.5 The peel or stripping strength between any nonhomogeneous layers of the CIPP laminate should be a minimum of 10 lb/in. (178.60 g/mm) of width for typical CIPP applications.

NOTE 6—The purchaser may designate the dissimilar layers between which the delamination test will be conducted.

NOTE 7—For additional details on conducting the delamination test, contact the CIPP contractor.

8.6 *Inspection and Acceptance*—The installation may be inspected visually if appropriate, or by closed-circuit television if visual inspection cannot be accomplished. Variations from true line and grade may be inherent because of the conditions of the original piping. No infiltration of groundwater should be observed. All service entrances should be accounted for and be unobstructed.

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CONSIDERATIONS

X1.1 Terminology:

X1.1.1 *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 10.0% distortion of the diameter. If the distortion of the diameter is greater than 10.0%, alternative design methods are required (see Note 2).

X1.1.2 *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.

X1.2 Gravity Pipe:

X1.2.1 *Partially Deteriorated Gravity Pipe Condition*—The CIPP is designed to support the hydraulic loads due to groundwater, since the soil and surcharge loads can be supported by the original pipe. The groundwater level should be determined by the purchaser and the thickness of the CIPP should be sufficient to withstand this hydrostatic pressure without collapsing. The following equation may be used to determine the thickness required:

$$P = \frac{2KE_L}{(1 - \nu^2)} \cdot \frac{1}{(SDR - 1)^3} \cdot \frac{C}{N} \tag{X1.1}$$

where:

- P = groundwater load, psi (MPa),
- K = enhancement factor of the soil and existing pipe adjacent to the new pipe (a minimum value of 7.0 is recommended where there is full support of the existing pipe),
- E_L = long-term (time corrected) modulus of elasticity for CIPP, psi (MPa) (see Note X1.1),
- ν = Poisson's ratio (0.3 average),
- SDR = standard dimension ratio of CIPP,
- C = ovality reduction factor =

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

q = percentage ovality of original pipe =

$$100 \times \frac{(\text{Mean Inside Diameter} - \text{Minimum Inside Diameter})}{\text{Mean Inside Diameter}}$$

or

$$100 \times \frac{(\text{Maximum Inside Diameter} - \text{Mean Inside Diameter})}{\text{Mean Inside Diameter}}$$

and

N = factor of safety.

NOTE X1.1—The choice of value (from manufacturer's literature) of E_L will depend on the estimated duration of the application of the load, P , in relation to the design life of the structure. For example, if the total duration of the load, P , is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value for E_L will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

NOTE X1.2—If there is no groundwater above the pipe invert, the CIPP should typically have a maximum SDR of 100, dependent upon design conditions.

X1.2.1.1 If the original pipe is oval, the CIPP design from Eq X1.1 shall have a minimum thickness as calculated by the following formula:

$$1.5 \frac{q}{100} \left(1 + \frac{q}{100} \right) SDR^2 - 0.5 \left(1 + \frac{q}{100} \right) SDR = \frac{\sigma_L}{PN} \tag{X1.2}$$

where:

σ_L = long-term (time corrected) flexural strength for CIPP, psi (MPa) (see Note X1.5).

X1.2.1.2 See Table X1.1 for typical design calculations.

X1.2.2 *Fully Deteriorated Gravity Pipe Condition*—The CIPP is designed to support hydraulic, soil, and live loads. The groundwater level, soil type and depth, and live load should be determined by the purchaser, and the following equation should be used to calculate the CIPP thickness required to withstand these loads without collapsing:

TABLE X1.1 Maximum Groundwater Loads for Partially Deteriorated Gravity Pipe Condition

| Diameter, in. (Inside Diameter of Original Pipe) | Nominal CIPP Thickness, mm | CIPP Thickness, t , in. | Maximum Allowable Groundwater Load ^A (above invert) | |
|--|----------------------------|---------------------------|--|------|
| | | | ft | m |
| 8 | 6 | 0.236 | 40.0 | 12.2 |
| 10 | 6 | 0.236 | 20.1 | 6.1 |
| 12 | 6 | 0.236 | 11.5 | 3.5 |
| 15 | 9 | 0.354 | 20.1 | 6.1 |
| 18 | 9 | 0.354 | 11.5 | 3.5 |
| 18 | 12 | 0.472 | 27.8 | 8.5 |
| 24 | 12 | 0.472 | 11.5 | 3.5 |
| 24 | 15 | 0.591 | 22.8 | 6.9 |
| 30 | 15 | 0.591 | 11.5 | 3.5 |
| 30 | 18 | 0.709 | 20.1 | 6.1 |

^AAssumes $K = 7.0$, $E = 125\,000$ psi (862 MPa) (50-year strength), $\nu = 0.30$, $C = 0.64$ (5% ovality), and $N = 2.0$

$$q_t = \frac{C}{N} [32R_w B' E'_s (E_L/D^3)]^{1/2} \quad (X1.3)$$

where:

- q_t = total external pressure on pipe, psi (MPa),
= $04.33H_w + wHR_w/144 + W_s$, (English Units),
= $0.00981H_w + wHR_w/1000 + W_s$, (Metric Units)
- R_w = water buoyancy factor (0.67 min) = $1 - 0.33 \left(\frac{H_w}{H} \right)$,
- w = soil density, lb.ft³(KN/m³),
- W_s = live load, psi (Mpa),
- H_w = height of water above top of pipe, ft (m)
- H = height of soil above top of pipe, ft (m),
- B' = coefficient of elastic support = $1/(1 + 4e^{-0.065H})$
inch-pound units, $(1/(1 + 4e^{-0.213H}))$ SI units
- I = moment of inertia of CIPP, in.⁴/in. (mm⁴/mm) = $t^3/12$,
- t = thickness of CIPP, in. (mm),
- C = ovality reduction factor (see X1.2.1),
- N = factor of safety,
- E'_s = modulus of soil reaction, psi (MPa) (see Note X1.4),
- E_L = long-term modulus of elasticity for CIPP, psi (MPa),
and
- D = mean inside diameter of original pipe, in. (mm)

X1.2.2.1 The CIPP design from Eq X1.3 should have a minimum thickness as calculated by the following formula:

$$\frac{EI}{D^3} = \frac{E}{12(SDR)^3} \geq 0.093 \text{ (inch-pound units)}, \quad (X1.4)$$

or

$$\frac{E}{12(SDR)^3} \geq 0.00064 \text{ (SI units)}$$

where:

E = initial modulus of elasticity, psi (MPa)

NOTE X1.3—Finite element analysis is an alternative design method for noncircular pipes.

NOTE X1.4—For definition of modulus of soil reaction, see Practice D 3839.

X1.2.2.2 The minimum CIPP design thickness for a fully deteriorated condition should also meet the requirements of Eq X1.1 and X1.2.

X1.3 Pressure Pipe:

X1.3.1 *Partially Deteriorated Pressure Condition*—A CIPP installed in an existing underground pipe is designed to support external hydrostatic loads due to groundwater as well as withstand the internal pressure in spanning across any holes in the original pipe wall. The results of Eq X1.1 are compared to those from Eq X1.6 or Eq X1.7, as directed by Eq X1.5, and the largest of the thicknesses is selected. In an above-ground design condition, the CIPP is designed to withstand the internal pressure only by using Eq X1.5-X1.7 as applicable.

X1.3.1.1 If the ratio of the hole in the original pipe wall to the pipe diameter does not exceed the quantity shown in Eq X1.5, then the CIPP is assumed to be a circular flat plate fixed at the edge and subjected to transverse pressure only. In this case, Eq X1.6 is used for design. For holes larger than the d/D

value in Eq X1.5, the liner cannot be considered in flat plate loading, but rather in ring tension or hoop stress, and Eq X1.7 is used.

$$\frac{d}{D} \leq 1.83 \left(\frac{t}{D} \right)^{1/2} \quad (X1.5)$$

where:

- d = diameter of hole or opening in original pipe wall, in. (mm),
- D = mean inside diameter of original pipe, in. (mm), and
- t = thickness of CIPP, in. (mm).

$$P = \frac{5.33}{(SDR - 1)^2} \left(\frac{D}{d} \right)^2 \frac{\sigma_L}{N} \quad (X1.6)$$

where:

- SDR = standard dimension ratio of CIPP,
- D = mean inside diameter of original pipe, in. (mm),
- d = diameter of hole or opening in original pipe wall, in. (mm),
- σ_L = long-term (time corrected) flexural strength for CIPP, psi (MPa) (see Note X1.5), and
- N = factor of safety.

NOTE X1.5—The choice of value (from manufacturer's literature) of σ_L will depend on the estimated duration of the application of the load, P , in relation to the design life of the structure. For example, if the total duration of the load, P , is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value of σ_L will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

X1.3.2 *Fully Deteriorated Pressure Pipe Condition*—A CIPP to be installed in an underground condition is designed to withstand all external loads and the full internal pressure. The design thicknesses are calculated from Eq X1.1, Eq X1.3, Eq X1.4, and Eq X1.7, and the largest thickness is selected. If the pipe is above ground, the CIPP is designed to withstand internal pressure only by using Eq X1.7.

$$P = \frac{2\sigma_{TL}}{(SDR - 2)N} \quad (X1.7)$$

where:

- P = internal pressure, psi (MPa),
- σ_{TL} = long-term (time corrected) tensile strength for CIPP, psi (MPa) (see Note 12),
- SDR = standard dimension ratio of CIPP, and
- N = factor of safety.

NOTE X1.6—The choice of value (from manufacturer's literature) of σ_{TL} will depend on the estimated duration of the application of the load, P , in relation to the design life of the structure. For example, if the total duration of the load, P , is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value of σ_{TL} will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

X1.4 — *Negative Pressure*—Where the pipe is subject to a vacuum, the CIPP should be designed as a gravity pipe with the external hydrostatic pressure increased by an amount equal to the negative pressure.

NOTE X1.7—Table X1.1 presents maximum groundwater loads for partially deteriorated pipes for selected typical nominal pipe sizes. CIPP is custom made to fit the original pipe and can be fabricated to a variety of sizes from 4 to 96-in. diameter which would be impractical to list here.

X2. CHEMICAL-RESISTANCE TESTS

X2.1 Scope:

X2.1.1 This appendix covers the test procedures for chemical-resistance properties of CIPP. Minimum standards are presented for standard domestic sewer applications.

X2.2 Procedure for Chemical-Resistance Testing:

X2.2.1 Chemical resistance tests should be completed in accordance with Test Method D 543. Exposure should be for a minimum of one month at 73.4°F (23°C). During this period, the CIPP test specimens should lose no more than 20 % of their

initial flexural strength and flexural modulus when tested in accordance with Section 8 of this practice.

X2.2.2 Table X2.1 presents a list of chemical solutions that serve as a recommended minimum requirement for the chemical-resistant properties of CIPP in standard domestic sanitary sewer applications.

X2.2.3 For applications other than standard domestic sewage, it is recommended that chemical-resistance tests be conducted with actual samples of the fluid flowing in the pipe. These tests can also be accomplished by depositing CIPP test specimens in the active pipe.

TABLE X2.1 Minimum Chemical Resistance Requirements for Domestic Sanitary Sewer Applications

| Chemical Solution | Concentration, % |
|--------------------|------------------|
| Tap water (pH 6–9) | 100 |
| Nitric acid | 5 |
| Phosphoric acid | 10 |
| Sulfuric acid | 10 |
| Gasoline | 100 |
| Vegetable oil | 100 |
| Detergent | 0.1 |
| Soap | 0.1 |

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