DESIGN CONSIDERATIONS

1. Terminology

1.1. Partially deteriorated pipe

1.1.1. The original pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe.

1.1.2. The soil adjacent to the existing pipe must provide adequate side support.

1.1.3. 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.

1.2. Fully deteriorated pipe

1.2.1. 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.

1.2.2. 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.

2. Gravity Pipe

2.1. Partially Deteriorated Gravity Pipe Condition

2.1.1. 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:

$$P = \frac{2KE_L}{(1-v^2)} \times \frac{1}{(SDR-1)^3} \times \frac{C}{N} \qquad \text{(eq\#1)}$$

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 #1)
- v = Poisson's ratio (0.3 average)
- SDR = standard dimension ratio of CIPP

- C = Ovality Reduction Factor = $\left\{ \frac{(1-q/100)}{(1+q/100)^2} \right\}^3$ (eq #2)
- Q = Percentage ovality of original pipe
  = $100 \times \frac{\text{(Mean Inside Diameter - Minimum Inside Diameter)}}{\text{Mean Inside Diameter}}$
  or
  = $100 \times \frac{\text{(Maximum Inside Diameter - Mean Inside Diameter)}}{\text{Mean Inside Diameter}}$
- N = factor of safety

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

2.1.2. If the original pipe is oval, the CIPP design from equation #1 shall have a minimum thickness as calculated by the following formula:

$$1.5\, q/100(1+q/100)SDR^2-0.5(1+q/100)SDR = \sigma_L/PN \qquad \text{(eq \#3)}$$

where:

σ_L = long-term (time corrected) flexural strength for CIPP, psi (MPa) (see note #5)

2.1.3. See Table A for typical design calculations

2.2. Fully Deteriorated Gravity Pipe Conditions

2.2.1. The CIPP is designed to supoort hydraulic, soil, and live loads. The ground water 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:

$$q_t = C/N[32R_wB^1E^1{}_s(E_LI/D^3)]^{1/2} \qquad \text{(eq \#4)}$$

where:

q_t = total external pressure on pipe, psi (MPa)
R_w = water buoyancy factor (0.67 min) = 1-0.33 (H_w/H)
H_w = height of water above top of pipe, ft(m)
H = height of soil above tope of pipe, ft(in)
B^1 = 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. (mm^1/mm) - $t^3/12$
t = thickness of CIPP, in.(mm)
C = ovality reduction factor (see 2.1.1.)
N = factor of safety
$E^1{}_s$ = modulus of soil reduction, psi (MPa) (see Note #4)
E_L = long-term modulus of elasticity for CIPP, psi (MPa)
D = mean inside diamter of original pipe, in.(mm)

2.2.1.1. The CIPP design from equation #4 should have a minimum thickness as calculated by the following formula:

$$EI/D^3 = E/12(SDR)^3 \geq 0.093 \text{ (inch-pound units)} \qquad \text{(eq \#5)}$$

or

$$E/12(SDR)^3 \geq 0.00064 \text{ (SI units)} \qquad \text{(eq \#6)}$$

where:

E = initial modulus of elasticity, psi (MPa)

note #3 Finite element analysis is an alternative design method for non-circular pipes.
note #4 For definition of modulus of soil reaction, see Practice D 3839.

2.2.2. The minimum CIPP design thickness for a fully deteriorated condition should also meet the requirements of eq #1 and eq #3.

3. Pressure Pipe

3.1. Partially Deteriorated Pressure Condition

3.1.1. 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 #1 are compared to those from eq #8 or eq #9, as directed by eq #7, 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 #7, eq #8, and eq #9 as applicable.

3.1.1.1. If the ratio of the hole in the original pipe wall to the pipe diamter does not exceed the quantity shown in eq #7, 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 #8 is used for design. For holes larger than the d/D value in eq #7, the liner cannot be considered in flat plate loading, but rather in ring tension or hoop stress, and eq #9 is used.

$$d/D \leq 1.83\ (t/D)^{1/2} \qquad \text{(eq \#7)}$$

where:

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

$$P=5.33/(sdr-1)^2\ (D/d)^2\ \sigma_L/N \qquad \text{(eq \#8)}$$

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 #5)
N = factor of safety

note #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.

3.2. Fully Deteriorated Pressure Pipe Condition

3.2.1. 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 #1, #4, #5, and #9, and the largest thickness is selected. If the pipe is above ground, the CIPP is designed to withstand internal pressure only by using eq #9.

$$P=2\sigma_{TL}/(SDR-2)N \qquad \text{(eq \#9)}$$

where:

P	=	internal pressure, psi (MPa)
σ_{TL}	=	long-term (time corrected) tensile strength for CIPP, psi (MPa) (see note #6)
SDR	=	standard dimension ratio of CIPP
N	=	factor of safety

note #6 The choice of value (from manufacturer's literature) of σ_{TL} will depend on the estimated duration of the applicaiton of the load, P, in relation to the design life of the structure. For example, if the total duraion 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.

3.3. Negative Pressure

3.3.1. 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.

3.4. Table A

3.4.1. 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.

TABLE A
Maximum Groundwater Loads for Partially Deteriorated Gravity Pipe Condition

Diameter (Inside Dia. of Original Pipe)	Nominal CIPP Thickness	CIPP Thickness	Maximum Allowable Groundwater Load[A] (above invert)	
in.	mm	t, in.	ft.	m
8	6	0.236	40.00	12.2
10	6	0.236	20.10	6.1
12	6	0.236	11.50	3.5
15	9	0.354	20.10	6.1
18	9	0.354	11.50	3.5
18	12	0.472	27.80	8.5
24	12	0.472	11.50	3.5
24	15	0.591	22.80	6.9
30	15	0.591	11.50	3.5
30	18	0.709	20.10	6.1

[A]Assumes K = 7.0, E = 125,000 psi (862 MPa)(50-year strength), $_{v}$ = 0.30, C = 0.64 (5% ovality), and N = 2.0

4. CHEMICAL RESISTANCE TESTS

4.1. Scope

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

4.2. Procedure for Chemical-Resistance Testing

4.2.1. 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 (230C). During this period, the CIPP test specimens should lose no more that 20% of their initial flexural strength and flexural modulus when tested in accordance with Tests Methods D 790.

4.3. Table B

4.3.1. Table B 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.

TABLE B
Minimum Chemical Resistance Requirements for Domestic Sanitary Sewer Applications

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

4.3.2. 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.