Development of Design Calculation Application for Sprayed-in-place Pipe (SIPP) Trenchless Technology

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INTRODUCTION

Trenchless technologies for underground infrastructure systems have continuously evolved since the 1970s. Over several million miles of buried pressure and non-pressure pipes supply and collect throughout the United States. SIPP is a new innovated trenchless technology that emerged in the market.

This design calculator development is based on the ASTM F1216-16 Standard for both horizontal and vertical structure structural rehabilitation.

This project is a showcase of academic collaboration with the industry to provide a useful design calculation tool to promote the SIPP technology application.

The proposed application is able to calculate the SIPP lining thickness under various design and site conditions for both partially deteriorated condition and fully deteriorated condition of the existing underground infrastructure systems.

TEST AND APPLICATION PROCEDURES

Polyurea is a primary polymer material selected for the SIPP technology application and mechanical properties of the Polyurea is presented in Table 1. Flexural strength, Flexural modulus, and Tensile strength are required to calculate the maximum allowable load to the applied liner.
Other polymer materials such as Epoxy and Polyurethane can be used for the SIPP application.

Table 1. Mechanical Test Result

RESULTS:

Specimen #	Width (in.)	Thickness (in.)	Maximum Flexural Strength (psi)	Flexural Modulus (psi)	Strain @ Maximum Flexural Strength (in.)
1	0.708	0.304	10537.0	452976.8	0.535
2	0.712	0.308	10244.0	399224.5	0.562
3	0.713	0.305	11285.3	434959.9	0.535
4	0.688	0.303	10510.3	444223.4	0.516
5	0.715	0.305	10452.9	420486.3	0.586
Average	0.707	0.305	10605.9	430374.2	0.547

The SIPP field application requires the following procedures:

- System analysis including mapping, inspection, and structural assessment to identify and diagnose
- Preparation of the pipe interior cleaning to meet the specified cleaning requirements
- Repair of any existing structural defects
- Polymer (polyurea) lining and service connection
- Final inspection

Figure 1. SIPP Field Application Procedures

DESIGN METHODS FOR GRAVITY PIPE

The following equations are used to calculate the thickness of the SIPP applications for partially deteriorated and fully deteriorated non-pressure pipe.

Partially Deteriorated Circular Shape Non-pressurized Pipe

$$t = \frac{D}{\left[\frac{2KE_LC}{PN(1-\nu^2)}\right]^{1/3} + 1}$$

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

where:

P = groundwater load, psi (MPa), measured from the invert of the pipe
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),
DR = dimension ratio of CIPP,
C = ovality reduction factor =

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

Δ = percentage ovality of original pipe equals

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

or

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

and

N = factor of safety.

Fully Deteriorated Circular Shape Non-pressurized Pipe

$$t = 0.721D\left[\frac{(Nq_t/C)^2}{E_LR_wB'E'_s}\right]^{1/3}$$

$$q_t = \frac{1}{N}\left[32\,R_w\,B'\,E'_s \cdot C\,(E_LI/D^3)\right]^{1/2} \qquad \text{(X1.3)}$$

where:

q_t = total external pressure on pipe, psi (MPa),
= $0.433H_w + wHR_w/144 + W_s$, (English Units),
$0.00981H_w + wHR_w/1000 + W_s$, (Metric Units)
R_w = water buoyancy factor (0.67 min) = $1 - 0.33\,(H_w/H)$,
w = soil density, lb.ft^3 (KN/m^3),
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. (mm^4/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:

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

or

$$\frac{E}{12(DR)^3} \geq 0.00064\ (\textit{SI units})$$

where:

E = initial modulus of elasticity, psi (MPa)

DESIGN OF SIPP THICKNESS CALCULATION FOR VERTICAL STRUCTURE

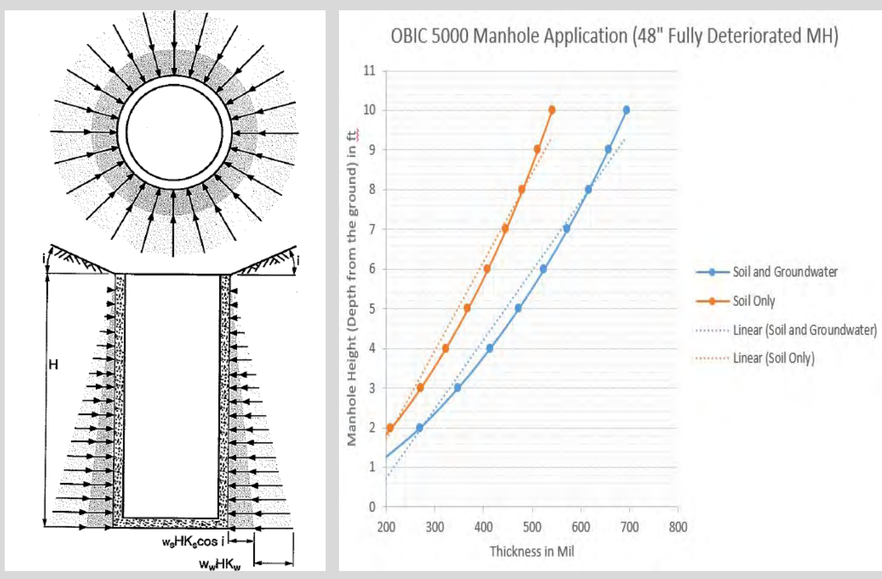

Figure 2. Vertical Structure Stress Distribution and Calculation Results

Calculation Example:

- The plotted red line represents thickness of the given polyurea application to meet the design criteria and structural requirements of the existing manhole.
- Manhole height (y axis) is the height of soil (and groundwater) from the ground to the depth from the ground.
- The thickness increases as the depth of soil (and groundwater) increases.

DESIGN OF SIPP THICKNESS CALCULATION FOR HORIZONTAL STRUCTURE

The design application calculates the input parameters, as shown in Figure 3. The interactive graphic diagram shows the horizontal and vertical layout of the existing underground structure. A summary of the design calculation is provided on the right panel for the engineer's review. The thickness of the SIPP application is presented in the output box under the diagram. The calculation result will support the industry in performing a preliminary design prior to the field application.

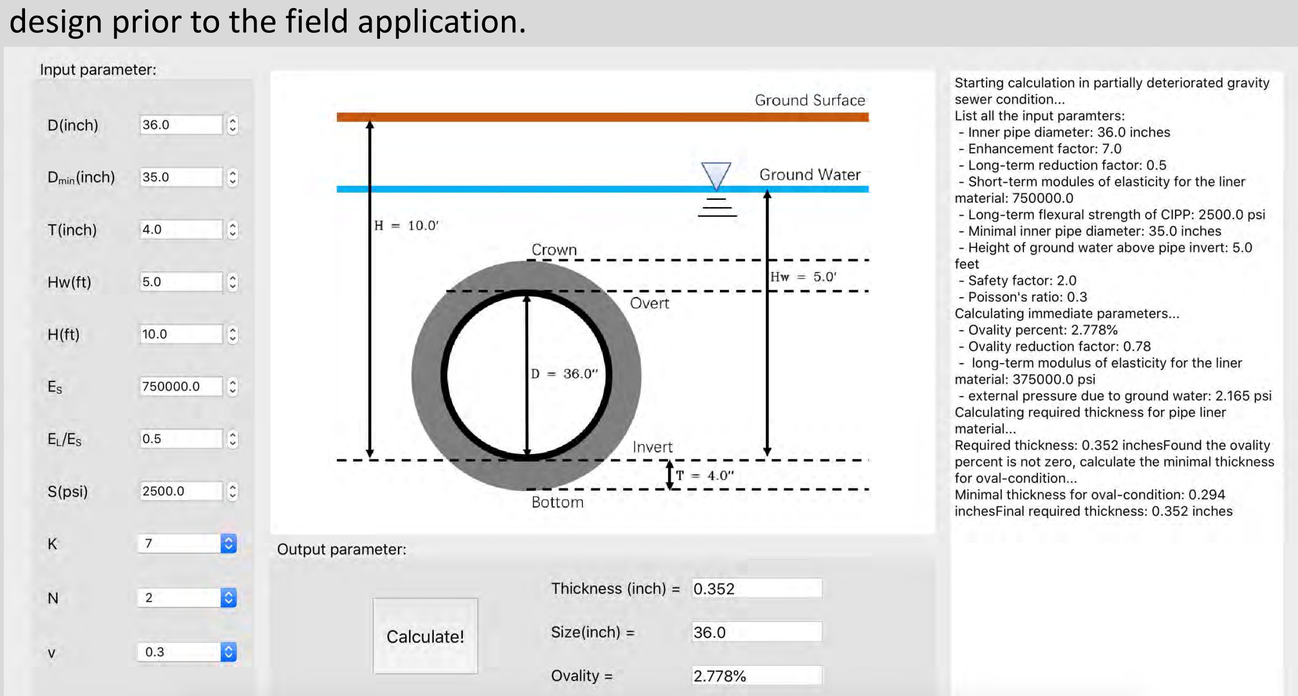

Figure 3. Horizontal Structure Calculation Results

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