PERMACAST® SHELL DESIGN METHODOLOGY
FOR UNDERGROUND PIPE CULVERTS

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ABSTRACT

Permacast® pipe/culvert renewal methodology has been independently reviewed by R&D Engineering. The following procedure provides the appropriate design calculations needed to determine the required liner thickness. This procedure includes the needed components for lining storm culverts and sanitary sewer pipe having various levels and types of duress. This paper presents an overview of the lining process, the materials utilized, and the design thickness required for the composite materials. This process expands the present day technological envelope.

It is the intent of this process to provide for the waterproofing, sealing, structural reinforcement and corrosion protection of existing underground storm and sewer pipe/culverts by the safe, quick and economical application of a uniform cementitious layer of special mortar, which cures in place to form an interior hardened shell. The testing of these materials is based on pertinent ASTM Standards utilized for this lining technology.

INTRODUCTION AND BACKGROUND

AP/M Permaform of Des Moines, Iowa developed the Permacast® lining process in 1994. The process utilizes a special centrifugal apparatus placed in the center of the culvert/pipe and applies a liner design depending upon the level and type of duress. The basic substrate mortar has the desired properties of rapid hydration (cure), low permeability, high flexural strength, adhesion and high modulus of elasticity.

MATERIAL SELECTION

The Permacast mortar liner is designed to seal, reinforce and protect existing culverts/pipes which have experienced various levels of deterioration and/or leaks. This information establishes the minimum standard for material and method of application for restoring and sealing leaking and deteriorated sewer pipe, culvert pipe and manholes by centrifugally casting PERMACAST® PL-8,000, onto its interior in one or more passes at a specified thickness. In some instances, it may be necessary to hand spray the liner material.

The normal repair is for culverts/pipes that are still structurally stable i.e. no full collapses.

Culverts/pipes in this condition can benefit significantly from:

- **lining to strengthen and extend its useful life;**
- **lining to improve flow;**
- **sealing to eliminate extraneous groundwater penetration;**
- **sealing to protect against contamination from ex-filtration; and**
- **protection against corrosion**

The unique Permacast system may be the only process that permits engineering flexibility so that the material and thickness can be custom designed to meet any specific degree of degradation mitigation. The material is selected according to the level of corrosiveness of the sewerage and its by-products, whether they are chemically or biologically developed. The thickness is selected in a cost-effective manner to renew the structural condition. The thickness of the liner is in addition or on top of any filling of voids or cracks beyond the normal interior diameter.

The principal material for wall buildup is Permacast PL-8000, which is composed of micro silica (MS), Portland cement (PC), and a wide array of admixtures, and other proprietary ingredients. This material provides density, sealing, structural reinforcement, and basic corrosion protection to existing manholes, pipe, wet wells and culverts/pipes of various materials. The application is a safe, quick and economically uniform layer of special high density fiber reinforced mortar that cures in place to form a hardened structural shell. The centrifugal application provides the desired density without troweling.

The PL-8000 material is mixed with the appropriate amount of water, forming a paste-like mixture which many be sprayed, cast, pumped or gravity-flowed onto any area. The spin casting method provides a mechanical interlocking in concrete, clay, metal and/or brick culverts. This mortar will harden quickly without the need for special curing.

When the existing structure (i.e. culvert, etc.) has and/or is experiencing high levels of corrosion, it is recommended to use the PL-8000 cementitious liner with ConShield added to the liner mortar. This proven material is ideally suited for use in municipal sewer systems and storm water systems or wherever thiobacillus bacteria may cause microbiologically induced corrosion (MIC). PL-8000 treated with ConShield has been subjected to massive concentrations of thiobacillus bacteria in the laboratory and has been shown to be 100% effective in killing the thiobacillus bacteria. ConShield is a unique biocide that is registered with the United States Environmental Protection Agency (EPA). ConShield has been successfully used in storm and sewer culverts/pipes for over twelve years.

It is always recommended that engineered construction materials and testing follow ASTM Standards and practices that are appropriate for their application. This includes pertinent concrete testing standards for cements and/or cements with polymers in order to determine modulus, tensile and compression values to be utilized for design purposes. It is also important to use plastic materials testing for the various plastics or polymers for the same reasons. Concrete and plastics also perform as composite when utilized in the structure. It is important to understand how each performs separately and together. The material selections utilized in the Permacast® lining systems have been tested individually and as a composite for structural strengths and corrosion resistant features.

The summary of the material selection and use is provided below:

PL - 8000 – waterproofing, sealing, structural reinforcement & corrosion resistant

PL - 8000 Physical Properties

Color	Gray
Unit Weight	125 pcf
Shelf Life	one year
Water Demand	7-8 Pints/50lb. bag
Working Time	30 minutes
Fibers	Polypropylene or Equiv.
Set Time @ 70˚F ASTM C-403	
Initial Set	150 minutes
Final Set	240 minutes

Modulus of Elasticity ASTM C-469	
28 days	3,560,000 psi
Flexural Strength ASTM C-293	
24 hours	min. 600 psi
28 days	>1,080 psi
Compressive Strength ASTM C-109	
24 hours	3,000 psi
28 days	8,000 psi
Tensile Strength	682 psi
Shrinkage	none

ConShield – Anti-bacterial, anti-corrosion liquid additive

ConShield Physical Properties

Color	Pale yellow
Specific Gravity	1.0 gm/ml
Shelf Life	One year
Flammability	Non-flammable

LINER THICKNESS SELECTION

The thickness is determined based upon the existing structure condition and this design guide along with calculations. Since liners depend on the underlying integrity of the existing structure, surface preparation and application methodology are just as critical to effective renewal as the interfacing material to be utilized. The surface preparation requires a thorough hydraulic cleaning of all loose and/or corroded material. In significantly corroded areas, culvert wall build up will be required to restore its original inside dimensions in addition to the design thickness.

Material for effective renewal should:

- **Reach 3,000 psi minimum compressive strength in the first 24 hours;**
- **Reach 8,000 psi minimum compressive strength in 28 days;**
- **Be quick setting for rapid sealing;**
- **Have high flexural modulus for resistance to buckling;**
- **Tested and certified by an Independent laboratory; and**
- **Be applied by factory trained applicators**

DESIGN THICKNESS

Detailed research sponsored by the National Science Foundation has been conducted on the Permacast [1] Lining System at Iowa State University. The following calculated values were provided by the detailed research along with other information for the designers benefit.

SOIL PRESSURE

MARSTON THEORY

Marston developed methods for determining the vertical load on buried conduits caused by soil forces in all of the most commonly encountered construction conditions. In general, the theory states that the load on a buried pipe is equal to the weight of the prism of soil directly over it. The theory makes the following assumptions:

1. The calculated load is the load which will develop when ultimate settlement has taken place.
2. The magnitude of the lateral pressures which induce the shearing forces between the interior and the adjacent soil prisms is computed in accordance with Rankine's theory.
3. Cohesion is negligible except for tunnel conditions.

The general form of Marston's equation is:

$$W = CwB^2$$

In which W = vertical load per unit length acting on the pipe.

W = unit weight of soil.

B = trench width or sewer pipe width.

C = dimensionless coefficient that measures the effect of the following variables:

- The ratio of the height of fill to width of the trench or pipe;
- The shearing forces between interior and adjacent soil prisms;
- The direction and amount of relative settlement between interior and adjacent soil prisms for embankment conditions.

Marston's formula for loads on rigid pipes in trench conditions is:

$$W_c = C_d w B_d^2$$

In which W_c = load on the pipe (lbs/ft^2)

W = density of the backfill soil (lbs/ft^3)

B_d = width of the trench at the top of the pipe

C_d = dimensionless load coefficient which is a function of the ratio of height of fill to width of trench and of the friction coefficient between the backfill and the sides of the trench.

The Marston formula is graphically shown as the following figure 1:

Figure 1

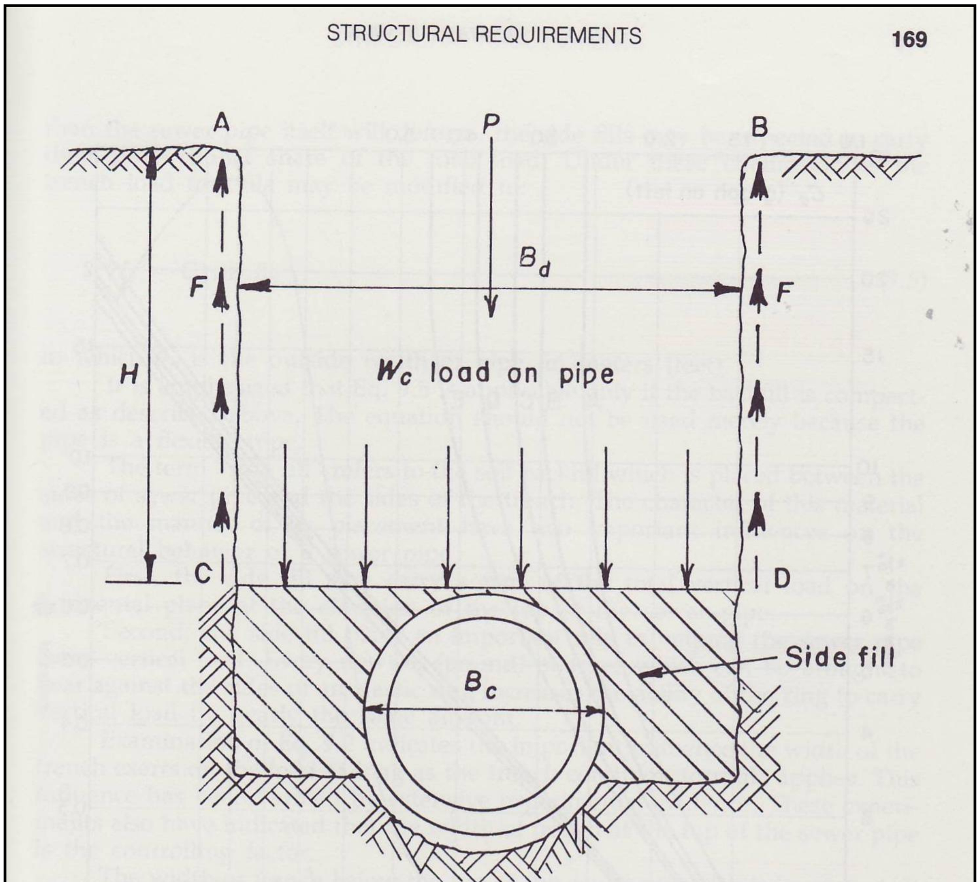


Fig. 9-2. Load-producing forces: P = weight of backfill ABCD; F = upward shearing forces on AC and BD; and, $W_c = P\text{-}2F$.

The load coefficient, C_d is computed as follows:

$$C_d = 1 - e\,\frac{^{-2ku'H/Bd}}{2ku'}$$

in which e is the base of natural logarithms and *k* is Rankine's ratio of lateral pressure to vertical pressure.

The value of C_d for various ratios of H/Bd and various types of soil backfill may be obtained from the following figure 2:

Figure 2

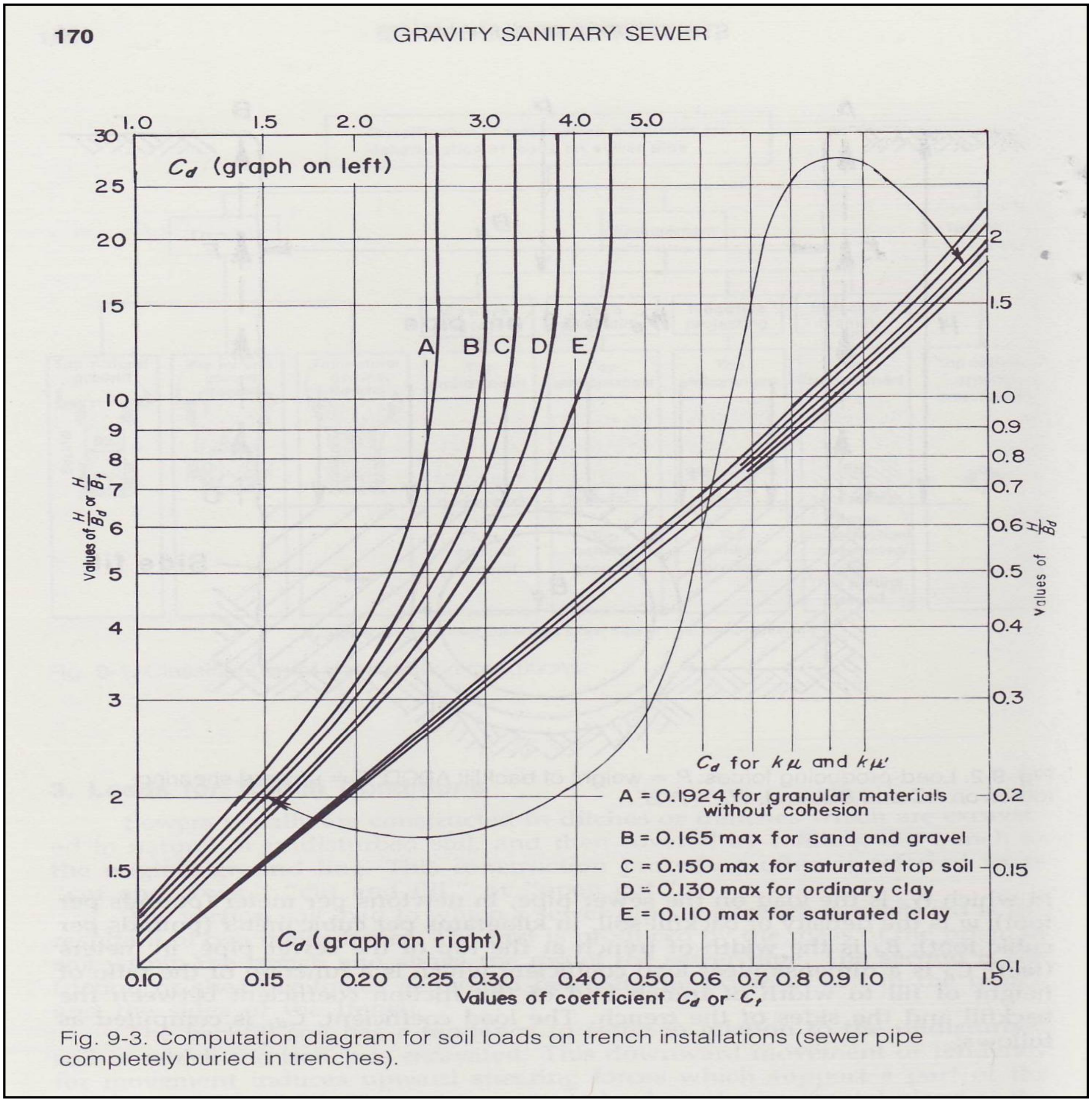


Fig. 9-3. Computation diagram for soil loads on trench installations (sewer pipe completely buried in trenches).

WATER PRESSURE

Determining the hydrostatic pressure is much easier; however, various assumptions must still be made.

For the case of a liquid at rest, it is convenient to measure distances vertically downward from the free liquid surface. If h is the distance below the free liquid surface and if the pressure of air and vapor on the surface is arbitrarily taken to be zero then the calculation is:

$$\rho = \gamma h$$

where: ρ – pressure (lbs/ft^2) γ – specific weight (lbs/ft^3) h – distance to liquid surface

DESIGN SUMMARY

All lining renewal products/materials require a certain minimum thickness that provide structural, corrosion resistance, shrink resistance, pinhole (void) free acceptable performance. The designer should calculate a design thickness using the product strengths rather than arbitrarily setting a minimum thickness, regardless of the qualities of the material. The design procedure is included in Appendix A.

REFERENCES

(1) Pitt, John M., PhD, "Centrifugal Cast Mortar For In situ Manhole Rehabilitation", No-Dig '95, NASTT, Toronto, Canada.

(2) Joint Task Force, American Society of Civil Engineers, "Gravity Sanitary Sewer Design and Construction", ASCE-Manuals and Reports on Engineering Practice – No. 60, WPCF-Manual of Practice – No. FD-5.

(3) Young, Warren C., "Roark's Formulas for Stress & Strain", 6th Edition, Copyright 1989.

(4) B. Jay Schrock, P.E., "PERMACAST® SHELL DESIGN METHODOLOGY" Report.

APPENDIX A
DESIGN FORMULA AND EXAMPLES

Determine load produced by the soil:

Given: Figure 1
Pipe culvert = 108 inches = 9 feet
Depth of pipe culvert (H) = 20 feet (Top of Pipe)
Soil = saturated clay due to ground water
Groundwater table = 10 feet below surface, pipe submerged = 14.5 ft.
w = density of the backfill soil saturated – 130 lbs/ft^3
C_d = Figure 2, Use E = 0.110 for saturated clay
B_d = 108 inches + 6 inch sides for trench = 120 inches = 10 feet

H/B_d = (20 ft. X 12) / 120 in. = 2.0 therefore C_d = 1.65

$W_c = C_d w B_d^2$ for Rigid Pipe = 1.65 (130 lbs/ft3) 10^2 ft. = 21,450 lb/ft.

q'_s = unit soil load on pipe = 21,450 lb/ft X 1/ 9 feet (pipe width) = 2383 lb/ft^2
= 16.55 lb/in^2 (psi)

Determine load produced by groundwater:

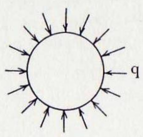
Given: h = 14.5 feet
γ = 62.4 lbs/ft^3

$\rho = \gamma h$ = 62.4 lbs/ft^3 X 14.5 feet = 904.8 lbs/ft^2 (psf) = 6.28 lbs/in^2 (psi)

$\rho = q'_w$ unit water load on pipe = 6.28 lbs/in^2 (psi)

The buckling capacity on the liner is provided for a circular shell using the following equation figure 3, (reference – 19, Roark and Young, 1975).

Figure 3

19. Thin tube under uniform lateral external pressure (radius of tube = r)  $\frac{r}{t} > 10$	19a. Very long tube with free ends; length l	$q' = \frac{1}{4}\frac{E}{1-\nu^2}\frac{t^3}{r^3}$ Applicable when $l > 4.90r\sqrt{\frac{r}{t}}$ (Ref. 19)
	19b. Short tube, of length l, ends held circular, but not otherwise constrained, or long tube held circular at intervals l	$q' = 0.807\frac{Et^2}{lr}\sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3\frac{t^2}{r^2}}$ approximate formula (Ref. 19)

$$q' = 0.807\,\frac{Et^2}{lr}\left[\left(\frac{1}{1-\mu^2}\right)^3\frac{t^2}{r^2}\right]^{0.25}$$

where:

q' = External Pressure at which buckling occurs, psf

$= q'_s + q'_w$

E = Young's Modulus, psf
r = Average radius of the shell, ft.
t = Thickness of the shell, ft.
l = Effective length of the shell, ft.
μ = Poisson's ratio of the liner material

Given: 108-inch diameter pipe
r = 54-inches
E = 3,560,000 psi (28 day Modulus)
l = 1 foot (12 inches) per foot of pipe
Use SF = 2.0
μ = 0.26 for cementitious material

1) To solve for lining thickness when depth of the pipe culvert is known and solving for t, use Figure 3, 19b equation, as follows:

$$t^{2.5} = \frac{qlr^{1.5}(1-\mu^2)^{0.75}\,SF}{0.807E}$$

1) Given: q' = 16.55 + 6.28 = 22.83 lbs/in^2 (psi)

$$t^{2.5} = \frac{22.83\ (12)\ 54^{1.5}\ (0.9324)^{0.75}\ 2.0}{0.807\ (3{,}560{,}000)}$$

$$t^{2.5} = \frac{547.92\ (396.82)\ 0.949}{2{,}872{,}920} = 0.0718$$

$$t = 0.349 \text{ inches} \quad \text{Use 1.0 inches minimum}$$

Note 1: reducing seven (7) day flexural modulus values necessitates thicker walls.

Note 2: modulus of elasticity values are needed to determine design wall thickness.

SUMMARY

This report has proven that a 1 inch liner utilizing the Permaform PL-8000 will perform satisfactorily to support soil and hydrostatic pressure based on the depth, type and diameter of the pipe, soil type and level of the ground water as given above.

I have produced this report in such a way as to the user may determine the required thickness for their unique situation (i.e. pipe diameter/type, depth, soil type, ground water table, etc.) by using the formulas provided in this report.

03/25/2009