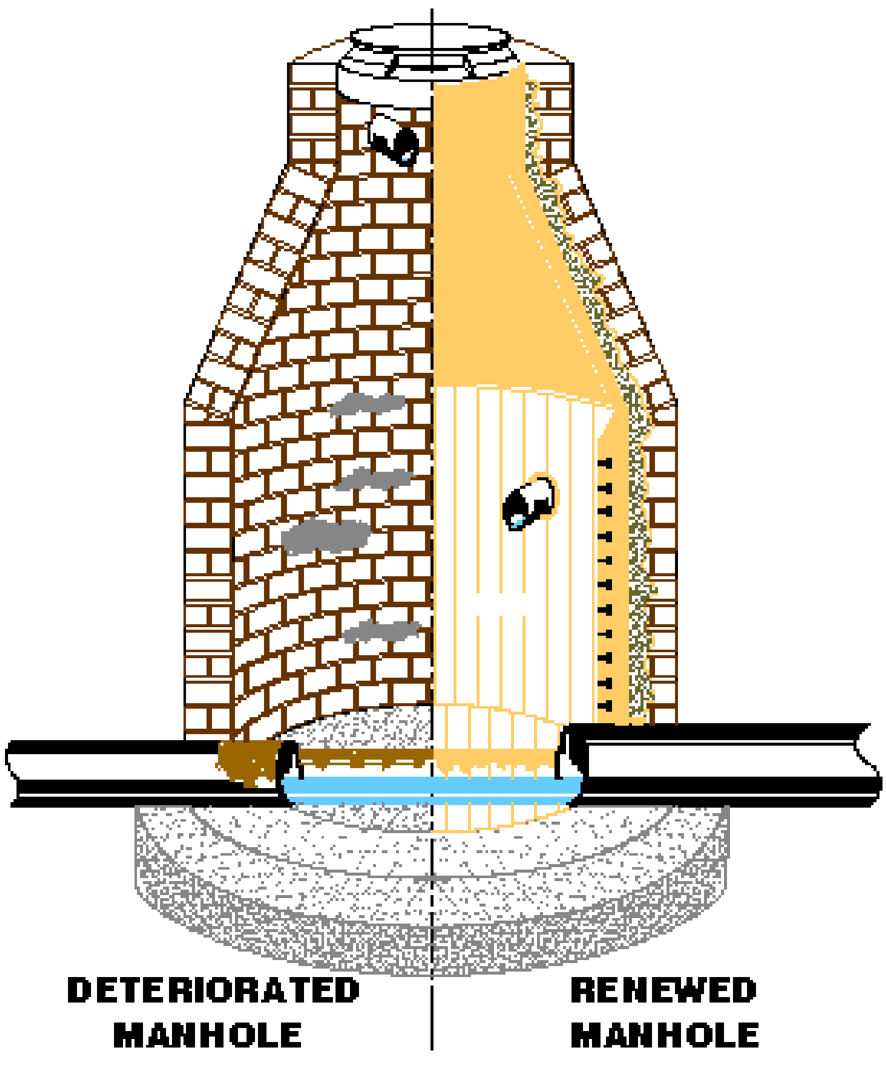
CONDENSED DESIGN GUIDE

for

TRENCHLESS MANHOLE RENEWAL

with

PERMACAST® / PERMAFORM® TECHNOLOGY



STRUCTURAL SHELL THICKNESS DESIGN GUIDE[1]

FOR CALCULATING THE APPROPRIATE THICKNESS TO REINFORCE, SEAL AND PROTECT EXISTING UNDERGROUND STRUCTURES

This method is selected when the existing manhole is structurally stable but degraded with actual or potential points of infiltration

1. MORTAR THICKNESS DESIGN

Factors to be considered for calculating the thickness of a cementitious liner placed against the existing interior wall of a cylindrical structure are:

- strength
- density
- elasticity of the mortar
- static and dynamic loading
- soil type
- ground water pressures
- existing structural conditions
- anticipated changes in conditions
- diameter and depth

The following minimum design parameters of the mortar material were used for these calculations:

- minimum 3,000 psi compressive strength in first 24 hours
- minimum 150,000 psi modulus of elasticity in first 24 hours
- extremely dense to prevent water migration (levels less than 1,000 coulombs)

Allowances can be made for materials of lesser physical properties by proportionately increasing the liner thickness.

When a measurable thickness of the original wall has been lost, the new structural liner should be replaced with a thickness equal to that cross sectional value that was lost. For example, a pre-cast concrete manhole with an original cross sectional thickness of 5 inches (130 mm) which has lost 1.5 inches (40 mm) of its original thickness would need to receive 1.5 inches (40 mm) of new liner material to restore it to its original diameter if it were of the same C495 Portland cement concrete as the original pre-cast manhole. If material meeting the minimum parameters described above were used, then the liner thickness would be as shown in Table 2.

Manholes are most adversely affected by traffic loads passing directly over or near the structure and hydrostatic loads from external ground water pressures. Since these conditions are the most critical factors for design calculations, design strengths which are able to overcome each of these factors, are sufficient to overcome all other factors. Vehicular loading moments affect the top 2 feet (600 mm) only and can be categorized as light or heavy. Ground water pressure increases with depth. The greater the depth and pressure, the thicker the liner must be. For equivalent strength levels in diameters larger than 48 inches (1200 mm), the thickness of the liner would increase proportionately. Larger diameter manholes require a greater thickness to provide a correspondingly acceptable structural reinforcement value (much like SDR thickness of pipe).

Therefore, shell thickness as a function of the moment load capacity can be computed. Results of these computations are summarized in Figure 1. These relationships included a bedding factor of 3.

An evaluation, comparing external symmetric pressures causing compressive hoop stresses and external pressures causing elastic instability, showed that buckling is the critical mode of failure when shell radius to thickness ratio is greater

[1] This information was determined from field observations and tests conducted at the Spangler Geotechnical Laboratory by the Civil & Construction Engineering Department of Iowa State University in Ames, Iowa under a research grant from the National Science Foundation.

than ten. Under such circumstances, buckling capacity can be estimated, as presented in Figure 2, with a method described in a report of in-situ manhole rehabilitation from Iowa State University.

The most common source of moment inducing loads on vertical structures is resulted from traffic passing near the structure. The obvious load is a vehicular wheel on the lid. Figure 3 shows the relationship of lateral pressure from wheel load against depth. A simple computation shows that a 10,000 lb. wheel load induces lateral stress along the axis of a one-half inch thick ring at about 270 psi compressive strength. The **PERMACAST®** mortars develop such strengths in a few minutes.

Table 1 shows the thickness required for (1) light traffic (less than 4,000 pound wheel load) and (2) heavy traffic, operating near a manhole. If vehicular traffic can be directed 3 feet (1 m) away from the newly lined manhole, traffic loads need only be considered in terms of full strength at 7 days. Table 2 shows thickness for hydrostatic loads alone. A monolithic liner is essential for leak proof integrity.

EXAMPLE: A manhole 20 feet (6 m) deep 48 inches (1200 mm) in diameter with a chimney 24 inches (600 mm) in diameter in a light traffic area without active leaks in a reasonably stable condition would require a thin shell structural wall of at least 1 inch (25 mm) in the top 2 feet (600 mm), at least ¾ inch (20 mm) in the upper 12 feet (3.5 m) and at least 1 inch (25 mm) in the lower portion down to the bench.[2] For consistency, the design engineer will likely specify 1 inch (25 mm) throughout.

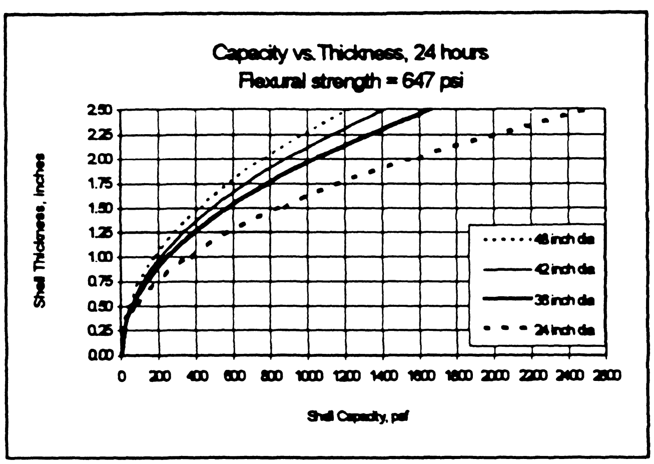


Figure 1. Moment load capacity of shells, 24 hour test

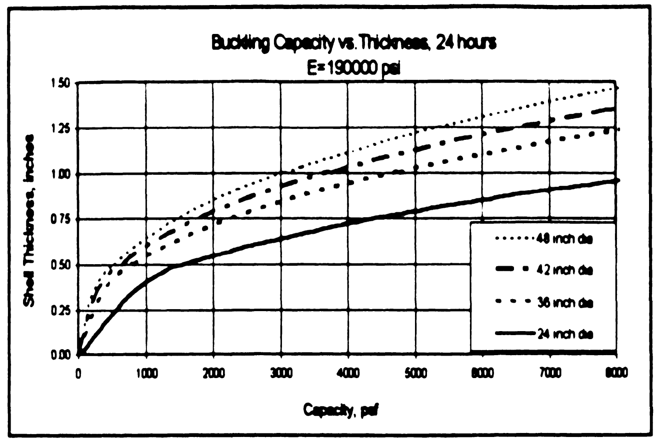


Figure 2. Buckling capacity, 24 hour test

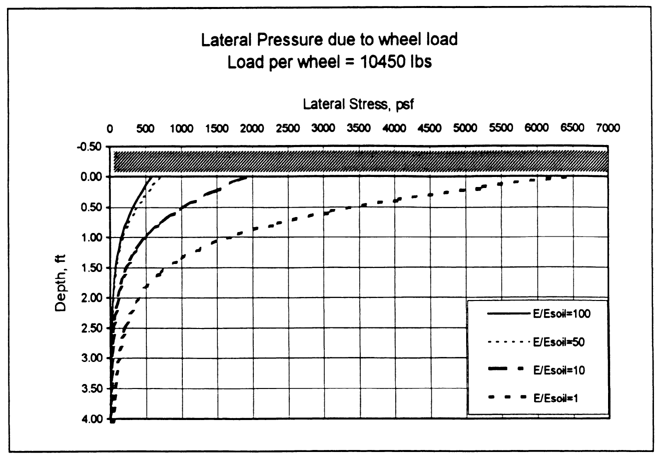


Figure 3. Lateral stresses due to wheel load

LIST OF ASTM STANDARDS

C 109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars
C 293 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
C 469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C 882 Standard Test Method for Bond Strength of Epoxy-Systems Used with Concrete by Slant Shear
C 157 Modified Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete (AASHTO T 277 Equivalent)
C1202 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

[2] Liner material of lesser physical properties than MS-10,000 may be used by proportionately increasing the minimum thickness.

2. MATERIALS FOR PERMACAST® TECHNOLOGY

This specification establishes the minimum standard for material and method of application for restoring and sealing leaking and deteriorated manholes by centrifugally casting a special mortar, onto its interior in one application at a specified thickness. The type of material, which may be selected, depends upon the source and concentration levels of the corrosive environment. See Table 3 for relative comparisons.

2.1 PERMACAST® MS-10,000

The material, **PERMACAST® MS-10,000**, is an ultra high strength, high build, corrosion resistant mortar, based on Portland cement fortified with micro silica. When mixed with the appropriate amount of water, a paste-like material will develop which may be sprayed, cast, pumped or gravity-flowed into any area ¼ inch and larger. This mortar will harden quickly without any need for special curing.

The hardened binder is dense and highly impermeable. The above performance is achieved by a complex formulation of mineral, organic and densifying agents and sophisticated chemical admixtures. Graded quartz sands are used to enhance particle packing and further improve the fluidity and hardened density. The composition also possesses excellent thin-section toughness, high modulus of elasticity and self-bonding. Fibers are added as an aid to casting, for increased cohesion and to enhance flexural strength.

The water content may be adjusted to achieve consistencies ranging from thin motor oil to modeling clay. Despite its high fluidity, the mortar has good wet adhesion and does not sag or run after placement. The mortar may be cast against soil, metals (including aluminum and lead), wood, plastic, cardboard or other normal construction material.

2.2 PERMACAST® CR-9,000

The material, **PERMACAST® CR-9,000**, shall be high strength, high build, corrosion resistant, resin impregnated synthetic mortar based on calcium aluminate cement and non-reactive quartz sand. When mixed with the appropriate amount of water, a paste-like material will develop which may be, sprayed, cast, pumped or gravity-flowed into any area 1/4 inch and larger.

This mortar will harden quickly without any need for special curing and can be considered mature after 24 hours. The hardened mortar has been purposely developed to be resistant to very aggressive soil conditions, such as low pH and high sulfates, seawater and dilute sulfuric acid resulting from bacteriological oxidation of hydrogen sulfide common to sanitary sewers. The raw materials are carefully selected and contain no calcium sulfates, no tri-calcium aluminates and no agents aggressive to reinforcing steel. The mortar is designed to resist biogenic corrosion in atmospheres in which Portland cements may reach levels as low as pH2. Like all calcium aluminate cements, it will experience the effects of corrosion at pH levels less than 2 but at much slower rates than Portland cement mortars.

The hardened binder is dense and relatively impermeable and does not contain any free lime hydrates. The above performance is achieved by a complex formulation of mineral, organic and densifying elements and sophisticated chemical admixtures. Finely ground silica quartz sands are used to enhance particle packing and further improve the fluidity and hardened density. The composition also possesses excellent thin-section toughness and bonding power. Non-metallic alkali resistant fibers control cracking and enhance its flexural resistance.

The mortar can be used as the sole protection against aggressive elements common to most sanitary sewer systems. The water content may be reduced to achieve any consistency ranging from thin motor oil to that of modeling clay. Despite its high fluidity, the mortar has good wet adhesion and does not sag or run after placement. The mortar may be cast against soil, metals (including aluminum and lead), wood, plastic, cardboard or any other normal construction material.

2.3 COR+GARD® COMPOSITE

COR+GARD® is a two-component 100% solids epoxy especially formulated for use in sewer systems. It is white in color for enhanced visibility. It is usually applied robotically from the PERMACAST® patented applicator for uniform distribution over the entire interior surface of manholes, pipe, and similar structures without requiring entry. It will cure quickly, even when immersed in fresh or salt waters. It rapidly forms a tenacious bond to freshly applied **PERMACAST®** mortars, which are formulated to prevent delaminating calcium powders during hydration. **COR+GARD®** composite produces a smooth, glossy and homogenous protective layer that is impervious to biological corrosion, water, oils and most chemicals.

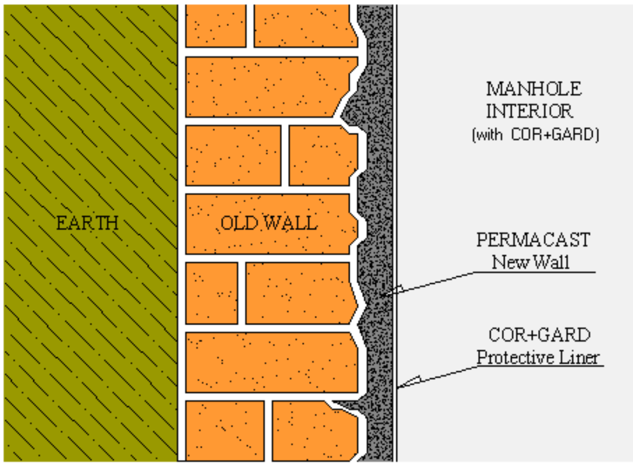
Once the cementitious underlayment has been applied to seal, reinforce and smooth the existing interior surface, the **COR+GARD®** epoxy shall be applied to a minimum thickness of .065 inches to provide a complete and uniform vapor barrier against attack by sewer gases and corrosion causing bacteria. The surface shall be free of entrapped air bubbles or holidays.

2.4 CON^{MIC}SHIELD®

Con^{MIC}Shield® is a liquid admixture for concrete and mortars for the prevention of hydrogen sulfide generated bacterial corrosion (MIC) common to concrete pipe, manholes and similar structures in municipal sewer environments. As an additive, it permeates the concrete or repair mortar during the mixing phase and molecularly bonds to the cement particles to become an integral component of the hardened product and to create an environment incompatible with harmful bacterial growth.

Con^{MIC}Shield® becomes an integrated component of the hardened binder. It cannot wash off, delaminate or lose its effectiveness from wear. Scraping or erosion of the concrete surface only serves to expose additional material to the environment that would otherwise foster bacterial growth. As bacterial growth is neutralized, hydrogen sulfide gases released from the raw sewerage cannot be metabolized and converted into sulfuric acid in concentrations sufficient to damage the impregnated concrete and mortar.

This material is ideally suited for concrete used to manufacture precast pipe and manholes for use in municipal sewer environments or wherever Thiobacillus bacteria may cause microbiologically induced corrosion (MIC). Repair mortars with **Con^{MIC}Shield®** subjected to concentrations of Thiobacillus bacteria in the laboratory have shown complete neutralization in just 24 hours.



Typical cross section of PERMACAST® shell

3. ENGINEERING ADVANTAGES OF HIGH SPEED RADIAL IMPINGEMENT

Centrifugal casting of the mortars and epoxies ensures the highest level of quality assurance possible for “in field” manufactured manhole liners. Centrifugal application procedures are therefore far superior to hand spraying. With a given volume of material pumped to the spinner head, the thickness is easily controlled by the number of passes repeated through the center axis of the manhole. The repeated up and down passes are controlled by a powered winch to guarantee uniformity. Thorough coverage is easily controlled and the thickness is verified by use of a wet gage measurement at any point since the same amount of material is cast evenly around the interior.

Hand applied materials depend upon the skill of the “in hole” applicator doing physically strenuous work in an uncomfortable and hazardous environment. The risk of applying too little material at any given interior location is extremely high. It is known that stresses concentrate at the thinnest portion of the liner. If a thin portion is less than the minimum engineered thickness, the liner is likely to fail under strain at that very point by cracking or spalling.

Uniform application is even more critical when applying protective coatings. **COR+GARD®** is spun on through the **PERMACAST®** spinner head in the same way that the mortars are applied. Multiple passes through the center axis ensure thorough and complete coverage. Hand spraying accurately and consistently from inside any manhole is very difficult at best. The risk of being too thin or missing a single point is very high. Any coverage less than 100% can allow an entry point for harmful bacteria or chemicals to attack the underlying substrate.

- uniform placement at pre-selected thickness
- one application; monolithic; <u>not layered</u>
- thorough coverage
- easily verified at any point
- easily inspected
- dense compaction without troweling
- even application of **COR+GARD®** epoxy
- minimizes hazardous confined space entry

Spinner Head in Operation

DETERIORATED BRICK MANHOLE

BEFORE

MANHOLE SPUN WITH PERMACAST® MATERIAL

AFTER

PRECAST MANHOLE WITH HIGH H_2S CORROSION

BEFORE

COR+GARD® COMPOSITE APPLIED ONTO PERMACAST® MATERIAL FOR CORROSION PROTECTION

AFTER

CHARTS OF PERMACAST® DESIGN GUIDE

Diameter (in.)	Depth (ft.)	Light Traffic			Heavy Traffic		
		12 hours	24 hours	7 days	12 hours	24 hours	7 days
		Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)
24	**1**	1	1	0.75	1.75	1.25	1.25
"	**> 2**	0.5	0.5	0.5	0.5	0.5	0.5
36	**1**	1.25	1	1	2	1.75	1.5
"	**> 2**	0.5	0.5	0.5	0.5	0.5	0.5
48	**1**	1.5	1.25	1	2.25	1.75	1.75
"	**> 2**	0.5	0.5	0.5	0.5	0.5	0.5

Table 1. Traffic Load

Depth (ft.)	Diameter 24 in.			Diameter 36 in.			Diameter 48 in.		
	12 hours	24 hours	7 days	12 hours	24 hours	7 days	12 hours	24 hours	7 days
	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)	Thickness (in.)
4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
8	0.5	0.5	0.5	0.75	0.5	0.5	0.75	0.75	0.5
12	0.5	0.5	0.5	0.75	0.75	0.5	0.75	0.75	0.5
16	0.75	0.5	0.5	0.75	0.75	0.75	1	1	0.75
20	0.75	0.75	0.5	1	0.75	0.75	1	1	0.75
30	0.75	0.75	0.75	1	1	0.75	1.25	1	1
40	1	0.75	0.75	1	1	1	1.25	1.25	1

Table 2. Hydrostatic Load

	Portland Cement	Portland Cement + Mirco Silica (PCMS)	High Alumina Cement	PCMS with Con^MIC^Shield®	Epoxy/PCMS Composite
Strength Gain	Low	High	Medium	High	Very high
Elasticity	Low	High	Medium	High	High
Corrosion Resistance	Poor	Medium	Good	Excellent against MIC	Excellent against MIC & most chemicals
Permeability	Moderate	Very low	Moderate	Very low	Excellent
Initial Cost	Low	Low	Moderate	Moderate	High

Table 3. Material Comparison

RECONSTRUCTION DESIGN GUIDE

INSITU-STRUCTURAL REPLACEMENT WITHOUT EXCAVATING OR DISRUPTING SEWER FLOWS

This method is selected when the existing manhole is unstable or structurally failed.

1. THICKNESS DESIGN EVALUATION

PERMAFORM® is the renewal technology for structural replacement of severely degraded brick, block and pre-cast manholes. This procedure places a 3-inch thick wall of Portland cement concrete within the existing structure *without digging* and *without interrupting flows.* Permaform is an internal forming system for pouring a new, seamless and structurally independent *manhole within a manhole* conforming generally to the existing inside dimensions and shape. This method is not limited by diameter, depth, piping configuration or shape. Work is performed without removing the cone.

The new 3-inch wall is designed to completely fill voids in the existing structure and provide sufficient strength to withstand vertical and axisymmetric loading. The most common source of moment inducing vertical loads on buried structures is dynamic traffic loading on or near the structures. Solid pavement can reduce this problem by transferring vertical stress onto the supporting soil. The greater significance to these structures, therefore, are the horizontal stresses transmitted through the soil. Spangler's solution for lateral surcharge stresses on a vertical wall can be applied. This theory[3] suggests that traffic loads play a significant role only to a depth of 2-3 feet beneath the base of the pavement. Axisymmetric loads, on the other hand, can result from soil or water or a combination of both. Soil around aged structures has developed cohesion over time and is fully compacted, which can easily eliminate lateral pressure. However, since most aged underground structures leak, failure often results from vertical collapse when voids are formed by soil piping or lost ground support. Thus, water leaking into the structure is the main failure mechanism, Figure 4 shows pressures acting onto the structure, and the renewed manhole must therefore concentrate on making the structure completely impermeable and fully capable of withstanding external hydraulic pressure.

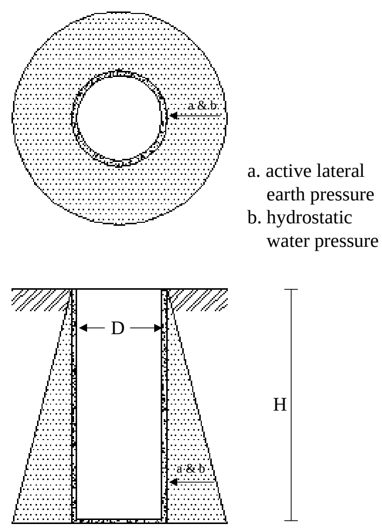


Figure 4. Triangular distribution of lateral loads acting on manhole

Evaluation of 3-inch thickness wall by B. Jay Schrock, P.E., JSC International Engineering, Inc.:

Buckling of Shell:

$P_c = 24 \, E \, I / D^3$

$I = t^3 / 12$

P_c = Buckling collapse resistance

E = Elastic modulus

D = Renewed manhole diameter

t = thickness of concrete liner

[3] Spangler, M.G., *Soil Engineering*, 2nd Ed., International Textbook, Scranton, PA, 1960.

With a conservative safety factor (S.F.) of 10, the allowable buckling (P_a) resistance of the 3-inch wall at any depth of manhole is calculated and summarized in the Table below.

Allowable buckling resistance

Manhole Diameter	P_c (psi)	P_a (psi)
36-in.	3005	300.5
42-in.	1821	182.1
48-in.	1185	118.5
54-in.	814	81.4

2. MATERIALS FOR PERMAFORM® TECHNOLOGY

2.1 PORTLAND CEMENT CONCRETE

The concrete shall be Portland cement concrete with 5/8" minus or smaller coarse aggregate producing compressive strengths of 4,000 psi at full cure. Admixtures such as super plasticizers enhance placement and consolidation. Polypropylene fibers increase flexural strength and cohesion. A high-strength, quick-setting cement grout is used at the base for positioning and sealing the form to allow flows at the channel to remain active. Internal by passing is available for pipe penetrations at elevations above the bench, which must remain active.

2.2 PLASTIC LINER PROTECTION

In corrosive environments, a plastic liner with integral locking extensions is embedded into the concrete wall as an impermeable barrier for corrosion protection. The plastic liner used in municipal sewer environments is most commonly a white, high-polymer, plasticized, vinyl chloride. In industrial environments, the plastic liner is usually made of polyethylene, which is available in a variety of colors. Both plastic corrosion barriers are capable of being cast into the concrete and made an integral part of the structure. The plastic protective liner shall have a minimum thickness of .065 inch, and shall be capable of resisting strong acid, alkaline, salt solutions and acid formed by bacterial metabolization. This thickness has been proven by more than 40 years of continuous service to prevent vapor transmissions. Industrial applications may specify thicker liners for abrasion and chemical contact safety considerations.

As the liner is fitted closely around the internal forming system prior to placement of the concrete, the plastic liner extension ribs or studs, which extend outward, are embedded fully into the new 3 inch wall when the concrete is consolidated behind the forms. Once locked in place, the plastic liner becomes an integral part of the new seamless wall of concrete. Since there are no joints in the new 3 inch wall, there are no entry points for ground water to affect the plastic liner from the exterior. The pull out strength of the embedded plastic liner exceeds 100 pounds per linear inch. In this procedure, the plastic liner is not mechanically fastened or glued onto an existing interior wall and it does not have to span connecting joints as in large diameter pipes or pre-cast manholes. The concrete wall remains free of deterioration because harmful bacteria and chemical agents cannot directly contact it. (See Los Angeles County Green Book, Section 500-2.2)

3. QUALITY ASSURANCE

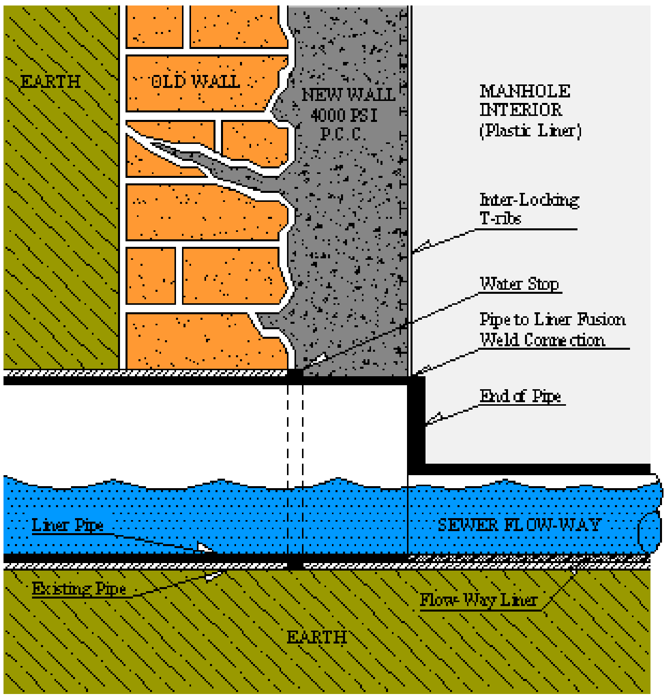
Once the concrete hardens and the interior mold forms are removed, joints in the plastic liner are sealed by heat fusion or extrusion welding with an overlapping joint strip of the same material. Each seam in the plastic liner is spark tested with a holiday detector at the voltage prescribed for its thickness. In this manner, the entire interior is guaranteed to be free of pinholes and voids which might otherwise permit corrosive liquids or gases to contact the new concrete wall. Unlike field applied coatings, the plastic liner is factory manufactured under controlled conditions to precision tolerances and tested for integrity before shipment. In this manner, consistently high quality is more easily controlled and verified.

4. ENGINEERING ADVANTAGES

- replacement without digging prevents disturbance of surrounding soil; no settlement; no pavement cracks;
- the new wall is thickest exactly where the old wall is weakest; voids and pockets in the old wall are completely filled with new concrete;
- flows can be kept active throughout the procedure; avoids costly over pumping and site congestion;
- no joints to allow future leaks, new wall is seamless; primary failure mechanism is eliminated;
- structurally independent; stand alone design;
- avoids social disruption; saves time;
- verifiable seal at all pipe penetrations regardless of the piping material;
- mechanically anchored protective plastic barrier

5. POSITIVE PIPE SEAL

A primary concern in municipal sewerage systems is ground water infiltrating through the manhole walls and around its pipe. Industry has a far greater concern for exfiltration of contaminated sewerage wastes through these same defects. Points of infiltration and exfiltration must be addressed in any renewal design but particularly in industries which transport harmful chemical wastes. **PERMAFORM®**, with an embedded plastic liner, is uniquely able to provide a positive seal between the plastic liner on the manhole wall and the penetrating pipe regardless of the type of pipe or pipe lining product, e.g. iron, vitrified clay, PVC, PE, CIPP, etc. See Diagram below.



Typical cross section of PERMAFORM® manhole

6. VERSATILITY IN DESIGN

Confronted with the problem of needing a positive seal as discussed earlier, a combination of both **PERMACAST®** and **PERMAFORM®** procedures may be utilized. In this example, **PERMAFORM®** is used only in the bottom portion of the manhole to seal the pipe penetrations while **PERMACAST®** is used to seal and reinforce the remaining upper portion. While the degree of reinforcement and sealing required for the upper portion is usually the determining factor for the choice of method, the need to optimize space may warrant the use of the **PERMACAST®** liner.

Manholes with diameters smaller than the pipe on which they set are another versatile application of this system. Manholes with diameters of 48 inches sometimes are positioned on pipe with diameters of 72 to 108 inches and larger. With **PERMAFORM®** technology, work can be performed without entering the heavy and turbulent flows in the large diameter pipe yet still allow the seal to be made between the crown of the pipe and the manhole wall. Failure to make such a vapor proof seal would permit an entry point for sewer gases and bacteria that would eventually destroy both the pipe and the manhole.

SERIOUSLY DETERIORATED MANHOLE

BEFORE

RENEWED MANHOLE WITH PLASTIC LINER

AFTER

MANHOLE RENEWAL DECISION MATRIX

Leaks / Spot Defects Structurally Sound	Heavy Leaks Structurally Impaired	Structurally Damaged
	Condition of Ratings 1&2 + any of the following:	***Condition of Ratings 1 thru 6 + any of the following:***
(1) Isolated leaks (2) Evidence of inflow (a) Through cover (b) Under frame (3) Inflow problems (4) Missaligned / broken casting (5) No evidence of corrosion (6) Unsafe steps (7) Minor damage to bench and/or leaking channel (8) Low ground water table	(1) More than 15% of area leaking or leaks of 5 GMP or greater during a rain event (2) Some missing bricks (3) Repairable small voids (4) More than 40 years old (5) Evidence of corrosion (6) Damaged bench (7) Cracked channel (8) High ground water table	(1) Portions of wall missing (2) More than 1" of precast wall corroded (3) Exposed rebar (4) Subjected to heavy traffic loading (5) Manhole located in a critical area with the sewer system that requires a long term cost effective renewal solution with low risk
	DEFECT RATING	
1 – 2	**3 –4 –5 – 6 – 7**	**8 – 9 –10**
	CORRECTIVE ACTION REQUIRED	
(1) Plug leaks (2) Install rain bowl (3) Install frame / chimney seal (4) Repair bench / channel	(1) Plug leaks (2) Fill voids (3) Reinforce and seal with structural cementitious liner (4) Evidence of bacterial corrosion: Use corrosion resistant mortar liner (5) Evidence of chemical corrosion: Use protective coating over restored manhole	(1) Replace (a) Excavate, remove, set a new manhole, backfill, pave (b) Insitu replacement (2) If corrosion is present or likely to occur because of system improvements, specify plastic lining on replacement manhole or corrosion resistant concrete