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Manhole Rehabilitation: Delivering on the Design with Proper Installation Practices and Related Quality Assurance Testing

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1. ABSTRACT

In a previous paper entitled "The Practical Design Approach to Coatings and Liners for the Rehabilitation of Cylindrical Shaped Manhole Structures" this author presented unique information on how the soil-structure interaction system impacts the horizontal lateral loading on a cylindrically-shaped vertical shaft, how it deviates from the vertical loading on horizontally oriented buried pipes, and what loads are likely to be borne by a coating or liner used in their renewal. In this paper the author will present how the engineer must ensure that the design assumptions are connected to the installation and quality assurance practices which are to be conveyed in the project specifications which deliver on the wall thickness design.

While all coatings rely on an adhesive bond with the wall surface of the manhole structure, liners can be either bonded or un-bonded to the wall surface of the structure. The above referenced paper on design demonstrated that the load coming onto these coatings and liners is for all practical purposes that of the external hydrostatic pressure generated by the groundwater surrounding the structure. In the design case of a bonded liner or coating, it is imperative that the level of adhesion accounted for in the engineer's design process be attained by the contractor's installation practices in the field. Further, given the challenges of working inside these structures it is incumbent upon the engineer to lay out a quality assurance testing methodology that confirms that a minimum level of adhesion was in fact achieved throughout the structure. A retrospective survey of the levels of adhesion in existing manholes subject to known external hydrostatic pressure is also presented and discussed.

2. INTRODUCTION

During the design process for manhole renewal work the Engineer starts with an engineering analysis to determine the current condition state of the existing manhole's wall structure; proceeding from there with a verification of the stability of the soil surrounding the manhole structure, and determining the environmental issues present which must be addressed in the design of the proposed coating or liner. In all but a few cases the engineer will find that a condition of stability, or equilibrium, exists which implies that the soil-structure interaction system is currently capable of carrying the external loads that are acting upon it. From this conclusion the coating or liner will then be designed to address the long-term environmental and structural performance requirements that the renewal work will need to address in order to produce the desired extension, or renewal, on the service life of the existing manhole. In those rare cases where the condition of stability cannot be assured for the desired service life extension by the application of the coating or liner, structural improvements must be employed to the existing soil-structure interaction system to rehabilitate it's components as required.

Selection of the appropriate renewal solution is based upon a two-step decision making process. The first step is using the long-term environmental and performance requirements to eliminate any solution that cannot meet those needs. The second step is the costing of the remaining viable alternatives using the design life and the estimated service life of the applicable solutions. Examples of the long-term environmental and performance requirements include corrosion resistance (i.e. creating a barrier to preserve the existing structural elements), infiltration/inflow reduction or elimination, and any structural enhancements (with due consideration of the whole soil-structure interaction system).

While it is currently common practice for the owner's project engineer to require that the wall thickness design used for the selected renewal solution alternatives be performed by an engineer specializing in the design of these systems, it is incumbent upon the project engineer putting the construction documents together to understand how the design will need to be performed. This understanding is necessary in order for him/her to convey the site specific conditions that are present at each structure that must be, in turn, taken into account by said specialist engineer; and later during the construction phase, to review and accept the wall thickness design submittal received. The time constraints of the relatively short period between the advertisement and the submittal of the contractor's bid necessitates that the contract documents be very thorough and complete in conveyance of the site specific conditions found by the project engineer during his/her design assessment. The industry standard design and/or service life expectations depend upon this information being given to the contractor so that a relatively accurate estimated wall thickness can be made in time for submitting of the bid proposal. Alternatively, the project engineer could perform the wall thickness design in-house; or at least provide an estimated wall thickness at bid time in order to establish a level playing field for the bidder's proposal. Any later required modifications to these estimated wall thicknesses would be addressed by the contractor.

As was presented in the earlier paper referenced above the wall thickness required for the overall majority of the manholes being renewed can be made without having to perform an actual wall thickness calculation for each and every manhole. This is because the practical minimum thicknesses for the various alternatives available typically exceed the actual calculated minimum thicknesses.

3. ADHESIVE BONDING

As stated above, while all coatings rely on an adhesive bond with the wall surface of the manhole structure, liners can be either bonded or un-bonded to the wall surface of the structure. For bonded applications to be successful, the level of the bonding that must be achieved in the ground must be consistent with what the proposed material is capable of achieving with each specific host wall structure when applied in the environmental conditions that exist in these candidate structures such as; temperature, level of dampness, ability to properly clean and prep the wall surface to remove any contaminants (i.e. grease, mold), and to produce the required surface texture. Special efforts such as heating the manhole to produce the manufacturer's recommended environmental conditions are to be used with caution and only by truly certified installers as the consequences of this technique can complicate the installation process and, in turn, may raise the risk of the installation not achieving its intended long-term design performance. The certification process must include classroom and hands-on field training of the installer, successful passing of a written exam, and routine recertification of the installer. In the absence of a truly certified installer, it would be better to consider the material being applied as an un-bonded liner; provided it can be installed as such in the environmental conditions present.

The engineer is further advised that the level of adhesion used in the design process is more than just the coating or liner's lab tested bond with the wall surface material itself. It also must account for the level of adhesive (tensile) strength present in the matrix of the existing wall structure as well. Therefore, as previously recommended above, it is the responsibility of the owner's project engineer to conduct enough tensile tests on the manholes to be renewed to establish an estimate of what the contractor's design engineer can rely upon in the wall thickness design at the time of bidding. To this end, it is recommended that a table be incorporated into the contract documents that will convey this and other salient information obtained by the project engineer during the course of his/her work in preparing the project's performance requirements.

Table 1. Sample table of design information to be considered.

Manhole	Height (ft.)	Depth to Water Table (ft.)	Wall's pH	Adhesive Strength (psi)	Surcharge Height (ft.)
AA-00-10	12.0	8.0	3.0	605	0.0
BB-02-11	8.0	5.0	2.8	400	0.0
CC-02-23	7.5	10.0	2.0	380	1.5
DD-01-10	22.0	10.0	3.5	485	0.0

For the reader's better understanding of information being supplied in Table 1, the following definitions are given:

- Height (of manhole) – refers to the measurement taken from the top of the ring above the outlet pipe to the flowline out. Where the manhole projects above the top of the ground, a separate value for the depth of bury should be included.
- Depth to Water Table – refers to the distance between the top of the ground and the project engineer's verified location of the phreatic surface (level in the groundwater where the pressure is equal to the atmospheric pressure). Arbitrarily assigned values are not recommended because of the typically stated design life expectation of 50 years or more. As this is the dominant and most likely load to come onto the coating or liner after installation, it should not be taken so lightly by the owner's project engineer.
- Wall's pH – refers to the pH taken on the surface of the manhole wall *before any cleaning*. Cleaning of the wall before taking the pH measurements alters the true environmental condition present for which the coating or liner must work in.
- Adhesive Strength – refers to the average of three or more tests made during the survey of the manhole's existing condition. These tests should be done following ASTM D7234 using a 20mm or larger diameter dolly.
- Surcharge Height – refers to the routine depth of the fluid flow above the bench in the manhole or the springline of the pipe, whichever is greater.

In the event that the condition of the existing manhole wall is such that a reasonable minimum value for the tensile strength is not to be found, the design approach must assume that the coating alternatives are eliminated from consideration and that the liner thickness must be based upon an un-bonded cylindrical liner structure. This will be evident to the engineer skilled in the design of liners for structural renewal upon his/her review of the values in the recommended table discussed above; but it should be communicated in the written specification. Materials that can successfully operate within the environmental conditions present and be applied to the necessary thickness to perform as standalone un-bonded cylindrical shells will then comprise the list of alternatives.

As the level of adhesion achieved in the application of these type coatings and liners can be vital to their long-term performance, it is quite important to assure all parties involved in the project (owner, project engineer, materials provider, and contractor) that the necessary minimum level of adhesion and finished thickness was indeed achieved for the coating or liner. As stated earlier, adhesion testing should be carried out following the methodology outlined in ASTM D7234; Pull-off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers.

4. INSTALLATION PRACTICES

The use of spray-applied coatings and liners requires adhering to the system manufacturers' stated requirements with respect to amount of material that can be applied per pass and the maximum time that can elapse between subsequent passes; typically referred to as the recoat window. This is a key requirement for producing a uniform coating or liner that will be able to perform as a monolithic membrane or structure. Given the large number of polymeric and cementitious material formulations commercially available today it is impractical to touch on each of these systems in the confines of this paper; therefore, the author will endeavor to present the installation practices under the broader categories into which these various systems can be placed along with the guidance of how to address individual systems that will be contained within these categories.

Engineered Cementitious Liners (ECL) – the current generation of cementitious lining materials have mix designs that follow a much different formulation than that of a shotcrete or even the cement mortar linings typically used in water transmission piping. They are application-specific formulations of fiber-reinforced cement-based mortar systems engineered for the environmental conditions normally found in sewers. The most successful of these type systems are, in this author's opinion, applied to the wall using a high velocity centrifugal casting in place process incorporating a bi-directional spinner head. These systems are literally "flung" onto the wall surface without air at a velocity that ultimately produces a densely packed mortar lining with little or no rebound. This process can be described as the inverse of the cement mortar lined pipe manufacturing process where the pipe is spun while the cement mortar is being dropped onto the pipe wall producing a uniformly placed, densely packed liner via the centrifugal force generated by the pipe's spinning motion.

A second method of applying the ECL to the manhole wall is by using a spray nozzle such as those used in the shotcrete process. Using this technique, the fluid mortar mix is pumped to a nozzle where air is introduced to blow the mortar material onto the wall surface. In this lining process it is generally recommended to hold the nozzle within 6 to 8 inches of the wall surface with the nozzle man directing its movement to ensure the maximum thickness per pass is not exceeded. Because air is being incorporated into the mortar mix stream there can be a significant amount of rebound of the material off the wall and thus densification of the mortar mix will suffer, necessitating troweling closely behind the spraying operation. That being said, during troweling the installer must be careful not to over-trowel the ECL as this can also compromise the quality of the hardened liner.

Using either application methodology, once the surface preparation has been completed the needed thickness of the material is delivered onto the wall surface in two or more passes. The wall surface should be dampened if the environmental conditions have not already caused this to be so. The amount of material placed in any one pass is based upon the thixotropic properties inherent in the mortar mix design. The performance of the cement mortar is assured by the installer following the manufacturer's stated amount of water to be added to the dry mix and the maximum thickness to be applied per pass explicitly. The surface of each "layer" should not be troweled smooth in order to maintain a proper surface profile for the subsequent layer to create a mechanical bond as well as a chemical bond between the two. If required by the engineer the finished surface may receive a brushed finish to produce a smoother surface profile, but any such working of the mortar should be limited as stated above it can alter the quality of the hardened liner significantly.

Figures 1 & 2. The figure on the left shows how the ECL is sprayed in place using a shotcrete type nozzle versus centrifugal casting in place which can deliver the ECL at a high velocity that produces good densification without the need for any troweling.

During the ECL's curing process caution must be taken to minimize exposure of the applied mortar to sunlight and air movement. If application of additional coats is to be longer than 15 minutes it is generally wise to cover the manhole. Further, in extremely hot and arid climates the manhole should be shaded while the work is in process. Where the humidity level is below 70%, the liner should be kept damp for the first 72 hours; or a topcoat should be applied to prevent excessive loss of moisture.

Holding times vary somewhat from manufacturer to manufacturer, but as a general rule: return to service should be approximately eight (8) hours for standard manholes, while twelve (12) hours is recommended for manholes receiving forcemain discharges.

Polymeric Coating and Liners – are epoxy resin systems, fiber-reinforced epoxy resin systems, polyurethane resin systems, and polyurea resin systems. There are many formulations of these resin systems; some of which are formulated with the intent of being applied to a damp surface such as will be the case in a buried manhole. These two-part polymeric systems consist of a resin and a hardener which must be combined precisely to the ratios stated by the manufacturer. Altering this ratio in the field changes the performance of these systems significantly and voids the expectation of the resin system conveyed in the materials submittal information. Additionally, it is important to take notice as to whether the ratio given in the submittal information is stated as being "by volume" or "by weight". This means that "cutting back" on the amount of hardener to be used because the resin system was stored at too high a temperature is not an allowable option for the installer. If the temperature of the resin and the hardener is such that the working time will not provide a suitable working time window for the material to be applied in the manhole; the resin should be moved to a location where it can cool down to the proper temperature for the desired working time.

Epoxy resin systems formulated for protection and renewal of wastewater structures are 100% solids epoxies with thixotropic characteristics that allow them to be sprayed on horizontal, vertical, or overhead surfaces. They are moisture tolerant, self-priming systems that can be applied at a single coat thickness varying anywhere from 8 to 250+ mils. Although dry substrates would be preferred, it is an important part of the manufacturer's formulation process to ensure that bonding can occur under the damp and sometimes adverse conditions present in these structures.

As with any bonded coating or liner, proper surface preparation is essential to ensure maximum and proper adhesion; the purpose being to provide a clean, sound substrate with an adequate profile and surface porosity to provide a strong bond between the resin and the substrate. Mechanical abrasion is preferable whenever practical. Mechanical abrasion can be accomplished using high pressure water cleaning, acid etching, abrasive blasting, shot blasting, hand tooling or brush hammering. In cases where mechanical cleaning is not practical, or oil and grease have had an opportunity to penetrate deep into the substrate, it may be necessary to chemically clean the surface. Whichever method(s) are used, they should be performed in a manner that provides a uniform, sound, clean surface that is not excessively damaged. The resultant surface profile should be at least a CSP-4 (concrete surface profile 4) in accordance with the ICRI Technical Guideline No. 03732 (International Concrete Repair Institute). The Figure 3 below is taken from that guideline for illustration purposes.

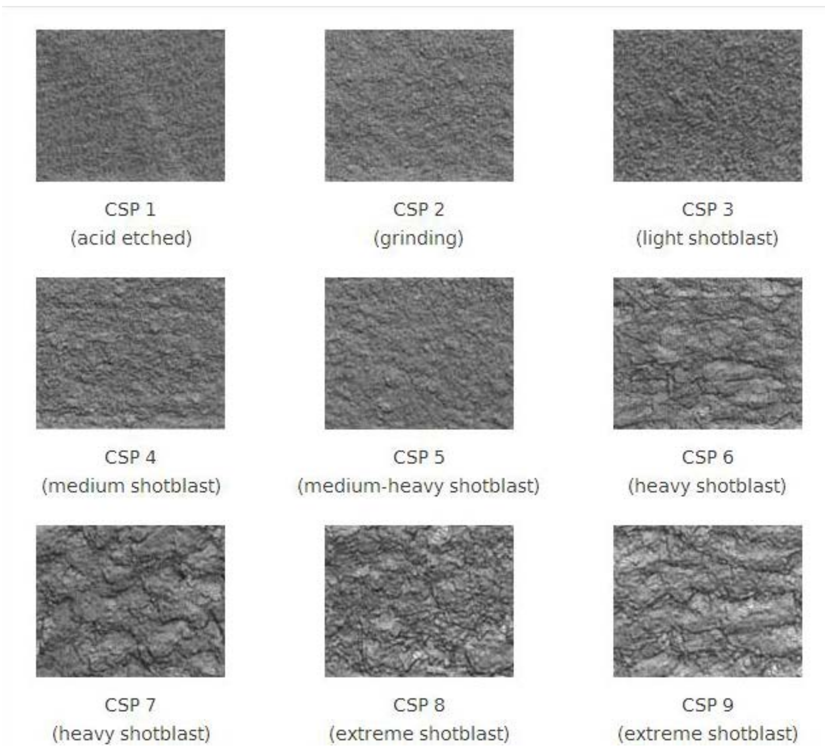

Figure 3. Illustration of the wall surface profiles specified by coating and lining material manufacturers for obtaining proper adhesion of their products with the existing wall surface.

Repairs and patching necessary for the final surface preparation varies from structure to structure. The following is a summary of what may be required.

1. Any area exhibiting movement or cracking due to expansion and contraction should be grouted and patched according to the appropriate crack repair and expansion joint procedure provided by the manufacturer.
2. All surfaces that show exposed structural steel, spalling greater than 0.75 inches deep, or cracks greater than 0.375 inches wide, need to be patched using a quick-setting, high strength cement mortar or a high-build, non-sagging epoxy grout. These holes should be filled in lifts according to the manufacturer's recommendations.
3. In masonry structures where the loss of mortar has created gaps greater than 0.25 inches in diameter between the bricks or blocks, these voids should generally be filled using a compatible high early strength mortar.
4. Surfaces shall be free of active leaks before coating or lining is commenced. Leaks may be stopped with the use of quick-setting hydraulic cement mortar, water reactive gels and grouts, epoxy grout, or equal.
5. When using any of the above referenced repair products it is important to make the finished surface of the repair consistent with the required surface profile for proper adhesion.

Structures renewed using epoxy coatings may be returned to full operational service after they have adequately cured; generally 4 to 6 hours. This time might need to be lengthened if the substrate is too cool (i.e. below 55°F). In these instances the manufacturer should give the installer guidance as to the length of time required at the measured substrate temperature (i.e. one product shows their set time at 77°F to be 2 hours, but 8 hours at 40°F). Because epoxy resins are thermosetting materials, the curing time is inversely proportional to the thickness; the thicker the material thickness applied, the greater the amount of heat that is generated producing a shorter set time.

Polyurethane resin systems are quite similar to epoxy resin systems in their application by spraying except that they are moisture in-tolerant meaning that they need an absolutely bone dry surface to obtain good adhesion. For this reason, installers of these systems are trained to understand the nature of how to dry out a structure by the effective use of grouts, heating, epoxy primers and other special techniques to ensure that this condition is achieved in advance of the spraying on of the resin system.

Polyurethane resin systems typically cure in just a few minutes (i.e. 2 – 4 minutes); which can provide for a quick building of their finished wall thickness. However, this quick cure rate can hinder the resin's ability to properly wet the wall surface to which it is being applied; which, in turn, leads to a greater risk that they will not fully develop the level of adhesion they are capable of in a buried manhole structure. This author and other engineer's experiences have shown that because of the effort put into the quality of the installing individuals training that a fair amount of adhesion is being obtained in the field.

Miscellaneous Methodologies – are cured in place manhole lining systems, structural panel lining systems, and bonded-on thermoplastic coating systems. These systems are different in their installation processes than the spray in place systems already discussed.

Cured in place manhole lining systems are prefabricated tubular liners that are saturated with an epoxy resin system that are subsequently inflated inside the manhole being renewed and then cured either by ambient temperature or hot air (steam infused air).

The structural panel lining system currently being offered commercially in North America consists of a spray applied coating of silicone modified polyurea followed by a layer of closed cell polyurethane foam followed by another layer of silicone modified polyurea. According to the manufacturer of this system an adhesive bond is required with the host structure. Per testing completed by CIGMAT in Houston, the level of bonding of the initial layer of polyurea was between 24 and 95 psi; however, if a primer was used the bonding strength improved to between 249 and 358 psi. This would lead one to conclude that this system should be used in conjunction with a primer being applied first and following the practice already outlined above for preparing the substrate and applying the liner's three-layer sandwich.

The bonded-on thermoplastic coating system is very dependent on obtaining a bond with the wall of the host structure. Per this author's experience, in order to install this system in a manhole reliably the wall surface would first need to be very uniform and of a prepared surface profile between CSP-2 and CSP-3. This is because of the limited amount of epoxy resin contained in the fleece layer would make it very hard to wet out any rougher surface. Surface preparation would follow that given above for the sprayed on thermoset resins with this one additional caveat.

Water-Tightness – in manhole rehabilitation can only be achieved by applying a fully encapsulating monolithic coating or liner in the manhole. When full encapsulation is not performed, or is done using two or more materials, the junctions between the dissimilar materials must be sealed using a preformed, flexible hydrophilic seal. The details of how this should be accomplished should be shown in the contract documents prepared by the project engineer.

Figure 4 – Example of a manhole with the walls and bottom coated monolithically using a polyurethane liner.

5. QUALITY ASSURANCE PRACTICES

Quality control is the responsibility of the installer while quality assurance is the responsibility of the project engineer. The level of construction observation required of the project engineer is directly dependent on the type of coating or liner being installed, the methodology of its application, and the potential risk of not getting a quality installation. Quality assurance testing should be well communicated in the contract documents and then executed with a zeal for obtaining the best installation practical.

Engineered Cementitious Liners – while these systems can and often do achieve some level of adhesion with the host structure's wall surface, their long-term performance is not predicated on any such bonding having to take place. As presented in an earlier paper (No-Dig 2015, paper number TM2-T4-03), a validation study incorporating over 900 manholes demonstrated that a 0.75-inch thick mortar liner centrifugally cast in place resolved issues such as groundwater inflow, corrosion protection of the remaining manhole wall structure, and any needed structural renovation. Testing of 1.0-inch thick centrifugally cast cementitious rings were shown to be adequate for an external hydrostatic loading exceeding 80 psi (185-feet of head). Key to this performance was producing a dense, high strength cementitious mortar capable of a long service life (typically 50 years, or more) in the environmental conditions that were found during the design phase of the project. Higher strength mortars are known to be more impermeable. That is why one will note that these mortar mix designs typically have compressive strengths of 8000 psi or more.

Quality assurance of an ECL thus mandates that the environmental conditions be verified for each structure and the appropriate ECL be installed for those conditions found. The cementitious mixture used should be confirmed by the owner's construction observer (i.e. recording the mortar mix's packaging identification) as being consistent with the one delivered to the project engineer during the materials submittal process.

The compressive strength of the ECL should be measured using 2-inch cube specimen prepared in molds specific for this purpose (see ASTM C109). The molding of a minimum of 3 (preferably 6) samples shall be made on site by a technician trained in the molding of these test specimen as given in section 10.4 of the standard C109. The sample mold(s) should then be immediately stored in a moist environment and let to rest for a minimum of 24 hours before attempting to remove the specimen from the molds. Specimen faces must be truly plane surfaces to obtain a true representation of the strength of the cementitious mortar. Poorly made specimens require grinding per Note 8 (C109) to produce these planar surfaces; or the sample must just be discarded. It should also be recognized that the 2-inch cube samples, at their best, will return values for compressive strength that are on the order of 15% less than what is actually achieved with the centrifugally cast in place mortar liners in place.

In centrifugally cast in place ECL's the finished thickness of the liner can either be calculated based upon the amount of material used by the installer or by other means. As an example, one manufacturer states that one sack of their material yields 0.5-inches of finished liner thickness per vertical foot for a 48-inch manhole I.D.

Polymeric Coatings and Liners – have been designed to have a minimum finished thickness and/or level of adhesion with the host structure's wall surface. In addition to these two design parameters, there are the in situ performance parameters of water tightness and the finished physical properties of the coating or liner material.

Minimum finished thickness can be obtained using an ultrasonic thickness gage or physical measurement of the thickness at the points where the bond strength testing is accomplished.

Water tightness can be accomplished by holiday detection equipment using the methodology set out in NACE RPO188. An induced holiday should be made in the coating or liner to the substrate to determine what the minimum/maximum voltage should be set to for testing the subject coating or liner. At a minimum, the spark tester should be initially set at 100 volts per 1 mil of the specified finished thickness; but may be increased if it is insufficient to detect the induced holiday. All detected holidays should be marked and repaired in strict adherence to the manufacturer's recommendations (which should have been included in the contractor's submittal documents).

Physical properties' testing is a must on all thermoset resin liners that are designed to be un-bonded shell structures. Samples should be taken on a frequency that assures the engineer and the owner that the proper mix ratio is being delivered by the spray equipment being employed on the project.

6. SUMMARY

It is important that the linkage between the design and the construction of coatings and liners not be broken; and that the risks of falling short of the desired end product get captured with a strong quality assurance program. Incorporated into this quality assurance program should also be the commitment to return to the project site at least 30 days prior to the end of the warranty period to visually evaluate at least 10% of the liners installed. In the instance where defects are found during this visual inspection, an additional 10% of the liners should also be inspected in order to see just how prevalent the defects are. The installer should be invited to attend these inspections in an effort to include him/her in the solution.

With recognized quality assurance comes a better understanding of what is required to ensure that the renewal efforts truly are 50-year improvements and not just a hollow promise. Trenchless renewal truly is a viable option for owners to reset the service life of their assets while capitalizing on their value at the time of their renewal.

7. REFERENCES

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