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SolidCast Polymer Tunnel Segments: The Corrosion Resistant Solution for Sanitary Sewer Tunnels

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ABSTRACT: Precast concrete segments have been used in sanitary sewer tunnel design for decades. Federal mandates (reduction in heavy metals and I & I), and system design changes (increased retention times) and other factors have exacerbated corrosion problems. In an effort to combat the ever-growing effect of microbiologically induced corrosion, owners, engineers, and designers have been specifying thin-film lining systems to protect precast concrete segments. These systems have compatibility and installation issues. Chemical additives or calcareous aggregates have been utilized in precast concrete, but have only proven to retard the rate of corrosion and do not eradicate the problem.

Solid cast polymer segments are stronger than precast concrete, do not require linings or coatings, are impervious to ground water infiltration, and, above all, are inherently corrosion resistant through and through.

THE INDUSTRY

The primary function of a sanitary sewer tunnel lining system is to convey sewage. The methods and systems through which soft ground sanitary sewer tunnels are created have developed dramatically through the centuries. Sanitary sewer tunnel lining systems have historically come in the form of timber, stone, brick, cast-iron, fabricated steel, and concrete. The driving forces in choosing any tunnel lining system are structural integrity, constructability, and cost. The rate of technological advancement in tunnel linings is in direct proportion to its economic benefits. The owner or general contractor is the primary motivator for selecting any new and innovative tunneling technology. The owner or contractor must realize a financial benefit before the success of any new construction technology gets off the ground. Basic cost savings come in the form of faster installation and/or lower-cost materials. The over-all cost analysis, however, becomes more complex when one takes into consideration the present and future value of the lining system, which includes lining maintenance and life-cycle costs.

THE PROBLEM

Precast Portland cement concrete sanitary sewer tunnel segments have been the liner of choice in North America for the last 10-15 years. Concrete segments offer the tunneling industry the benefits of a sound structural environment coupled with lower material and installation costs. An increased concern regarding the effects of severe biologically induced corrosion in sanitary sewer systems has, however, generated a new awareness and focus on corrosion protection systems because concrete segments, independently and without a protective lining, are not corrosion resistant.

Federal, state, and local governments have mandated the reduction of heavy metals disposal in sewer systems because heavy metals are difficult and costly to remove at sewage treatment plants. Furthermore, municipalities are requiring reductions in inflow and infiltration (I & I), because they lead to significantly greater sewer treatment costs as well as damaged sewer lines. Prior to these legislative policies, biologically induced corrosion was considered to be a negligible concern. Also, it was believed that corrosion occurred in the warmer regions of North America where bacterial corrosion was thought to flourish. Until recently, most municipalities practiced the “out of site, out of mind” method of sewer system maintenance. Today, municipalities typically have systems in place to monitor and inspect their sewer pipes, manholes, and tunnels. Longer retention times, low flowing plumbing fixtures, and heavy chemical pre-treatment are among several additional factors that have aided in the escalation of corrosion problems throughout North America.

THE CURRENT TECHNOLOGIES

Consensus is that severe corrosion does exist in most sewer systems in North America. Owners, engineers, and designers now focus their efforts on dealing with this important issue. Until recently, the most widely utilized and cost effective material used in segmental tunnel construction has been Portland cement concrete. Portland cement concrete, however, is not corrosion resistant. Initially, owners unsuccessfully tried coating pipe, manholes, and other sewer structures with coal tar epoxy coatings. These thin coatings did not adhere well to the concrete, nor were they resistant when exposed to high concentrations of sulfuric acid. In turn, these coatings failed to give long-term protection to the concrete. Of late, some owners, engineers, and designers have been specifying more sophisticated thin-film coats and/or plastic liners as a method to combat corrosion. Other owners, engineers, and designers are requiring the addition of chemical additives mixed into the concrete to decrease permeability and retard the rate of corrosion.

Most of the higher quality coatings recommended for tunnel lining applications are thermosetting resin bonded products, such as chemically resistant epoxies and urethanes. However, surface preparation, which includes the monitoring of humidity and air temperature, during installation, is critical. These coatings are usually installed at a thickness ranging between 10-125 mils. Unfortunately, coatings are highly susceptible to pinholes, chipping, delamination, and cracking, which exposes concrete substrate to corrosive acids.

Anchor-backed sheet linings have been successfully used to protect precast concrete sanitary sewer structures for over 40 years. PVC and HDPE lining systems have excellent chemical resistance and are either mechanically or chemically attached to the concrete substrate. These thin sheet lining systems are limited in size, however, creating many seams and joints that must be heat-welded when used over large surface areas. Heat-welding, unfortunately, is both time-consuming and expensive. In a 12' diameter segmental tunnel there may be as many as 20' of heat-welded seams and joints for every lineal foot of tunnel installed.

Each of these thin-film lining systems has substrate compatibility and installation issues that must be addressed during the bidding process and monitored during the installation process. Due to the permeability of the concrete segments, consideration must be made regarding the vulnerability of all coatings and linings systems to the external hydrostatic head pressure. As they relate to the full thickness of a segmental tunnel liner, the thickness of a thin-film lining or coating represents approximately 1% of the total corrosion resistance of the entire structure. For example, a 100 mil lining is only 1% of the thickness of a 10" thick concrete segment. Furthermore, the combination of incorporating thin-film liners with concrete segments can significantly extend the completion time and/or disrupt the schedule of the project.

In an effort to continue utilizing Portland cement concrete as the primary material of construction for sanitary sewer tunnels, some concrete segment manufactures are encouraging the addition of products such as chemical add-mixtures, silica fumes, fly ash, and/or calcareous aggregates with Portland cement binders to increase corrosion resistance in tunneling segments. To date, these alternatives offer a negligible decrease in the rate of corrosion. Ultimately, considerable testing has proven sulfuric acid will continue to chemically attack Portland cement binders.

INNOVATIVE TECHNOLOGIES

Solid cast polymer is a thermosetting polymer matrix blend comprised of inert, inorganic mineral fillers such as quartz, silica, and select reinforcing media (Figure 1). The fillers consist of 90% (by weight) of the total matrix composition. Generally, the resin binder materials in solid cast polymer are patented thermosetting resin systems comprising approximately 10% (by weight) of the total matrix composition. These components are combined and cured to produce a highly corrosion resistant, extremely strong concrete-like matrix. Characteristically, solid cast polymer is approximately 3-5 times stronger than Portland cement concrete (Figure 2). Solid cast polymer is typically produced by the static-cast vibration method. Similar to the mixing methods used in the production of Portland cement concrete segments, blended solid cast polymer matrix is poured into a segment mold and vibrated to compaction. The density (wt./cu.ft.) of solid cast polymer ranges between 145-150 lbs./cu.ft., which again is similar to that of Portland cement concrete. Although there is no all-inclusive ASTM standard for solid cast polymer tunneling segments, chemical resistance and physical property testing of solid cast polymer is performed in accordance with ASTM and ACI procedures.

Solid cast polymer has been in use in the construction of sanitary sewer structures for over 25 years. The practicality of introducing a new segmental tunnel lining system to the tunneling industry, however, is a difficult task. As a rule, for a new system to be adopted, it must show a cost benefit of between 10% and 15% when compared to existing methods. Contractors are hesitant to consider untried methods for high-risk tunneling projects unless they receive a greater return than what is obtainable by existing well-tried methods. Additionally, the owners' considerations include over-all project completion time and product longevity.

The new generation of innovative solid cast polymer segmental tunnel linings systems are meeting these challenges because they are inherently corrosion resistant, impermeable, faster to install, and ultimately more cost effective.

Inherently Corrosion Resistant

Solid cast polymer is corrosion resistant through and through. Solid cast polymer does not require protective linings, coatings, or gel coats. This material of construction can be scratched, chipped, cut, or drilled without sustaining any detrimental affects to the structural integrity of the lining system. Solid cast polymer was originally developed for severe chemical, physical, and temperature exposures inherent to the chemical processing industry.

Impermeable

Solid cast polymer segments are non-porous, eliminating ground water inflow, infiltration, or wastewater exfiltration.

Faster Installations

The strength of solid cast polymer allows for thinner segment designs resulting in easy handling and the employment of lighter-duty equipment.

More cost effective

Through extensive empirical corrosion testing solid cast polymer has proven to exhibit a life expectancy in excess of 300 years.

SOLID CAST POLYMER vs. POLYMER CONCRETE

In general, solid cast polymer and conventional polymer concrete are similar in that they both are thermosetting resin-binder technology systems. This is where the similarity ends. Although standard polymer concrete displays improved chemical resistance and increased physical properties over Portland cement concrete, it does exhibit some limitations. Many polymer concrete materials display excessive shrinkage, which can prevent the installation of steel reinforcement. Most styrenated polyester resin systems can also display some long-term distortion and loss of strength.

In contrast, solid cast polymer's super-enhanced resin technology exhibits superior chemical resistance, impermeability, and physical characteristics. To date, third-party test (10,000 hour) results have demonstrated no long-term distortion or loss of strength (Fig. 4). Furthermore, the non-shrink stability and 100% solids quality of solid cast polymers readily supports the incorporation of steel reinforcement.

When compared to Portland cement concrete, the superior strength characteristics of a rigid, yet more ductile, solid cast polymer allow for thinner and lighter weight segment designs. The addition of steel rebar, wire mesh, and steel fibers augment overall physical properties and facilitates thinner-walled structures. The addition of steel reinforcement also insures against total catastrophic failure. A lighter-weight segment may result in the utilization of lighter-duty equipment, improved installation times, and increased jobsite productivity. The constructability and installation methodology of solid cast polymer segments is the same as concrete segments. The utilization of gaskets, circumferential connectors, radial guide rods, bolt-pockets, and grout ports are the same for solid cast polymer segments as they are for Portland cement concrete segments. Solid cast polymer's natural tight matrix cell structure contributes to its impermeability by eliminating ground water infiltration or sewage exfiltration.

Corrosion resistance and strength notwithstanding, solid cast polymer has gained greater industry acceptance due to two key factors. Each factor has a direct correlation to material cost-per-foot of a segmental lining.

Raw Material Costs

As compared to the collective costs of Portland cement concrete segments and a thin-filmed lining system, improvements in resin technology combined with a more competitive market and aided by the economies-of-scale have facilitated in the cost reduction of solid cast polymer raw materials (resin and aggregate).

Manufacturing Costs

The development and improvement of large scale material handling and mixing equipment have greatly advanced the production of solid cast polymer segments. Solid cast polymer manufacturing technology is now capable of producing over 360 yards or 720 tons of solid cast polymer matrix on a continuous and daily basis. Extremely fast cure times also allow manufactures to purchase fewer molds. Combined with the elimination of post-curing, the cost of manufacturing a solid cast polymer segment compared with that of a concrete segment is significantly lower.

PROJECT COSTS

Primary project costs include material, installation, design, and engineering costs, which are established at the time of the contract award. Design and engineering costs, however, can add an additional 20% over and above the awarded construction costs. For example, if $100 million construction contract is awarded, the design and engineering portion can be an additional $20 million, for a total of $120 million primary project costs. Other primary costs can include additional expenditures such as administrative, land acquisitions, and permitting. Supplementary Costs are cost overruns accrued to the project that are unforeseen and may develop for any number of reasons. Examples include the following:

1. Housing and commercial developments revenues
   - Original material and construction methods chosen
   - Revenues lost because of project delays
   - Lost permitting and tax revenues

2. Value of non-commissioned infrastructure, such as electricity and communications

3. Cost of money and interest relative to project funding

4. Additional administrative costs

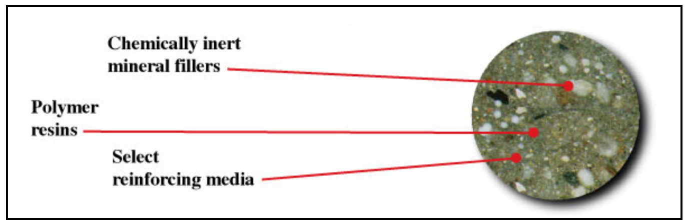
5. Impact of local, state and federal fines stemming from environmental regulations and laws

VALUE ADDED PROPOSITION

Solid cast polymer segments are a value-added product. A monolithic solid cast polymer segment system can significantly reduce both time and installation costs. The primary construction advantage in using a solid cast polymer segment lining system is completion time. It is estimated that a solid cast polymer segmental tunnel installation can reduce the completion time of a tunnel by as much as 50% versus the time to install concrete segments integrated with either a thin-film coating or liner system. The over-all savings to an owner in time, money, and liability are immeasurable.

Thinner solid cast polymer segments can result in a smaller tunnel profile, which allows for a smaller bore resulting in greater production as well as reductions in the spoil and muck to be handled. Further, the impermeability features of solid cast polymer will help mitigate gas and groundwater infiltration during installation.

Based on long-term, independent testing, solid cast polymer segments are presumed to have a life expectancy of over 300 years. Above all, this superior material of construction, which has performed successfully for over 25 years in severe corrosion environments, offers everyone peace of mind.



Physical Property Comparison (Fig. 2)