Global Review of Spray-On Structural Lining Technologies [Project #4095]

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OBJECTIVES:

The purpose of this project was to examine the structural abilities of spray-on linings. Although the history and structural properties of cement mortar lining was also discussed, the focus was largely on polymeric linings: epoxy, polyurethane, and polyurea, and what structural benefits might be obtained from using these linings.

BACKGROUND:

The spray application of linings to water pipes is the oldest method of pipeline rehabilitation, but since its inception, this method has often been characterized as "non-structural." The primary purposes of spray-on linings have been to stop internal corrosion, restore hydraulic capacity, and eliminate water quality deterioration arising from iron or steel corrosion and associated scaling. However, it's also been recognized that spray-on linings provide some structural benefit, primarily by spanning across rust holes and other areas of weakness in the pipe. In 1940, the City of Detroit determined through testing that 0.5-inch (12 mm) cement mortar lining could in fact span a 6-inch (150 mm) hole, resisting over 200 psi (13 bar) of internal pressure.

Despite this hole-spanning ability, the structural benefits of spray-on linings have often been considered insignificant, partly due to the inherent cracking and other weaknesses of unreinforced cement mortar, the first spray-applied lining. Although hole spanning could occur, the structural value of the unreinforced cement mortar lining was not considered reliable. Early polymer linings were also considered non-structural because when applied at a nominal thickness of only 1 mm, these epoxy linings could not span significant holes or other weaknesses. If applied at greater thicknesses, slumping of the lining material often occurred.

In the last decade, the industry has seen the development and adoption of faster-curing polyurethane and polyurea linings. Because these linings cure more quickly, they are more easily applied at greater thicknesses. Many of these polyurethane and polyurea linings also exhibit considerable tensile strength, making their use for structural rehabilitation potentially attractive.

APPROACH:

This study was initiated with an expert workshop and an extensive literature review. The workshop led the research team to various unpublished reports, which provided most of the testing information that is presented. This research also led to the development of new laboratory tests performed on samples of in-situ lined cast iron pipe. Case studies were also developed, which describe how these linings are currently being applied in North America and the United Kingdom.

RESULTS/CONCLUSIONS:

Manufacturer Sponsored Tests

Hole and Gap Spanning

There is no question that spray-on linings have the ability in the short term to span holes and gaps in water mains. In fact, with high-build applications, the spanning can be impressive. A variety of tests performed on different products in recent years (mostly under the sponsorship of manufacturers) have demonstrated this. These tests show that high-build polymer linings have the ability to span rather large holes and large gaps in host pipelines while resisting normal water system pressures, and can also sustain very high pressures when spanning smaller holes.

Hoop Strength

Calculations and at least one manufacturer test confirm that high-build polymer linings also have the potential to fully resist short-term hoop stresses induced by normal water pipeline pressures. But because of significant differences in elastic moduli between the flexible polymer linings and the stiffer host pipes, polymer linings should not be expected to add significant strength to a host pipe. Also, the mechanism by which the hoop stresses would pass from the host pipe to the lining is not clear. A well-adhered lining would tear if the host pipe fractures.

Test Limitations

It must be noted that the tests results presented above were all short in duration. The long-term performance of any plastic material depends on how much the material creeps. The standard strength criterion used in the design of most plastic pipe materials is the 100,000-hour (11.4 year) value. Other considerations in determining the long-term design strength of a plastic material are its resistances to slow crack growth and chemical degradation. It appears that few long-term strength tests and no long-term degradation tests have been performed on these materials.

Fracture Resistance

It has been well demonstrated that high-build polymeric linings can successfully span a small crack in a pipe. But a fundamental question is whether a lining can withstand the cracking of the pipe itself. The ability to withstand a pipe fracture would reduce the chance that a pipe fracture would produce a large, sudden release of water. Tests performed on one polyurea lining material for the manufacturer showed that the lining could endure a fracturing of the host pipe caused by bending of the pipe. Other tests by the manufacturer showed that once the pipe cracked, large angular and shear deflections could be endured without damage to the lining. However, a lack of internal pressure was considered a significant issue by the research team. With internal pressure, a frictional bond would exist between the lining and the pipe wall in addition to whatever bond had developed through adhesion of the polymer. Moreover, the team believes it is important to test old pipelines lined in the field because the roughness of decades-old pipe pitted by corrosion might result in considerably more friction between the lining and substrate.

Laboratory Tests Performed for this Study

A testing plan was developed to further investigate the fracture resistance of this polyurea lining within old cast iron pipe. The primary purpose was to determine whether the internal pressure would create a frictional bond that would cause tearing of the lining when the pipe fractures. The lining survived in all five tests, with 50 psi (3.4 bar) of pressure within the pipes. The linings did not tear because they readily detached from the inside walls of the host pipes. In fact, the detachment was such that in all cases, pressure was released immediately when the pipes cracked. Water flowed though the annulus between the pipe wall and lining and out the fracture.

Unfortunately, these tests were determined to be inconclusive in demonstrating the survival of a lining during fracture of a pressurized pipe. There was evidence that the lining was at least partially detached from the host pipe before testing was started, and because of a change in the testing protocol, water had been allowed to enter the annulus prior to the fracture. This meant that pressure was likely equal on both sides of the lining and no added frictional bond existed.

The laboratory examinations found that the adhesion of this particular lining was so low that other issues arose regarding how well the lining might perform as either a structural lining or a corrosion barrier. Other tests performed for this study found relatively high long-term creep and relatively low resistance to slow crack growth for this particular lining. Creep rates and slow crack growth resistance are factors that need to be considered in determining the long-term structural performance of any plastic pipe material.

Health Concerns

This report also examines health issues related to polymer linings, particularly whether harmful chemicals can leach from these linings. An extensive literature review showed that where the lining materials have been certified in accordance with ANSI/NSF Standard 61 and where work has been accomplished in accordance with strict application standards, threats to health are minimal. In fact, a good deal of evidence points to the public health benefits of cleaning and lining cast iron mains, with reductions in biofilm, heterotropic plate counts, coliform, and disinfectant demand.

One particular health issue is whether mains can be safely returned to service in less than one day, prior to confirming through testing that harmful bacteria are absent. One-day return to service is an important cost-saving issue as it avoids the need to establish bypass piping systems prior to lining. By some estimates, the cost of lining might be reduced by 30 percent, if bypass piping is not used. In the U.K., one-day return to service has become common and the results from years of tests on thousands of miles of pipeline have given the utilities confidence in the techniques that are used. In the United States, one-day return to service has been tried, but is not yet practiced due to market resistance that includes a greater number of regulatory agencies, a greater number of utilities, and a smaller overall market for water main rehabilitation.

APPLICATIONS/RECOMMENDATIONS:

The objective of this study was to provide a technical assessment of spray-on linings for North American water main applications, barriers to their acceptance, and methods to overcome these barriers. In many respects, linings are already well accepted in North America and have been for decades. Some cities, such as Los Angeles, have completely eliminated unlined pipe in their systems through long-running programs of spray-on lining. Without question, spray-on lining is the most common method of water main rehabilitation in the United States, but compared to the U.K., the level of activity is low. The reasons are the younger age of U.S. infrastructure, the greater fragmentation of the U.S. market, the greater diversity of regulators, and the less congested streets. These factors allow deferral of work, favor a traditional approach, and make the cost of open-trench replacement appear more competitive. The fact that open-trench replacement produces a new pipeline with well-defined expectations, whereas spray-on lining achieves a less certain life extension, no doubt limits the current acceptance of spray-on lining in the U.S. market. The current characterization of such linings as “non-structural” contributes to this lower acceptance.

Compared to other water main rehabilitation techniques, spray-on linings have many attractive features, including the ability to achieve one-day return to service, nearly effortless service reconnections, minimal community impacts, and low installation costs. Less certain are the structural benefits of these linings. This report should remove some of this uncertainty through engineering calculations, manufacturer-sponsored testing, and the testing performed specifically for this project. Undoubtedly, they can span gaps and holes in a deteriorating main leading to less leakage. With less leakage, the pipes will also experience lower rates of external corrosion and less risk of breakage from loss of soil support. This will extend the lives of the mains.

Even with the publication of this report, it will remain difficult to predict exactly how much pressure can be sustained by linings spanning holes and gaps. The answers will depend on the particular qualities of the products, the thicknesses of the linings, the sizes of the holes or gaps, and the time durations. Pressures have been sustained for short durations, but long-term creep can be a very significant factor—more testing is clearly needed. More tests are also needed to determine whether a lining can indeed survive the fracturing of the pipe when under pressure.

One of the lining manufacturers has indicated that both the long-term strength tests and the pressurized pipe fracture test advocated by this report will soon be undertaken by a well-known third-party research laboratory. With data from these tests, additional knowledge will be gained, likely leading to better products and application methods.

RESEARCH PARTNER:

U.S. Environmental Protection Agency

PARTICIPANTS:

In all, 47 individuals donated time and effort to this project, including participation in the workshop, access to unpublished research, and consultation on technical issues.

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