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Demonstration and Evaluation of Innovative Rehabilitation Technologies for Water Infrastructure Systems

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Abstract

The needs associated with the deteriorating water infrastructure are immense and have been estimated at more than \$1 trillion over the next 20 years for water and wastewater utilities. To meet this growing need, utilities require the use of innovative technologies and procedures for managing their systems. The U.S. Environmental Protection Agency (USEPA) developed a demonstration program for pipe rehabilitation methods to help fill this gap. The program's objective is to evaluate pipe rehabilitation technologies that can increase the effectiveness of the operation, maintenance, and renewal of pipelines. This paper provides an impartial assessment of the effectiveness and cost of four innovative technologies for water distribution and wastewater collection pipes. The technologies demonstrated include spray-on polymeric lining and cured-in-place pipe (CIPP) lining for water mains; and spray applied geopolymer mortar and an internal pipe sealing system for wastewater mains.

Introduction

Many pipeline owners need pipe rehabilitation methods to maintain their systems. Innovations are constantly being made or coming to the market, but impartial information is rarely available. The U.S. Environmental Protection Agency (USEPA) set out to make that information available to utilities and municipalities by instituting a pipe rehabilitation technology demonstration program. The program's objective is to evaluate pipe rehabilitation technologies that can increase the effectiveness of the operation, maintenance, and renewal of pipelines.

Multiple innovations were recommended for demonstration under a thorough review of available methods (USEPA 2009, 2010a, b, 2013). This paper presents the results from four technology demonstrations completed under this program. This paper provides an assessment of the technical effectiveness, range of applicability, and cost of each method. Decision support tools and approaches are limited because of the lack of credible data (Matthews et al. 2012c) and the automated systems that exist require periodic updating to

keep up with industry developments (Matthews and Allouche 2012). The results of a similar program to demonstrate innovative condition assessment technologies was previously published by Selvakumar et al. (2014a).

Innovative Technology Demonstrations

Four technology demonstrations (Table 1) were accomplished in this program and complete reports can be accessed through the website (<http://nepis.epa.gov/>) (USEPA 2012a, b, 2014, 2016). Although the first two demonstrations were completed in 2010, those technologies are still emerging in the market place.

Spray-On Polymeric Lining

Spray-on polymer linings are an improvement over cement mortar lining (CML) in terms of structural capabilities. The linings are comprised of resins and hardening agents and form thermoset materials when combined. Of the three primary polymer systems used for pipe rehabilitation, polyurethanes and polyureas typically cure in 2 h or less, whereas epoxy-based linings take at least 6 h (Ellison et al. 2010).

Polyurea linings use isocyanate compounds as the prepolymer and polyamines for the hardening agents (Primeaux 2004). Polyurea linings typically cure quickly (less than 5 min in some cases) compared with epoxies. The lining thicknesses vary between 3.5 and 5 mm, although higher builds are possible. The polymer used in this demonstration used a base white thixotropic liquid and an activator black thixotropic liquid, which formed a gray finish when cured.

The polymer lining is designed for use in pressure pipes from 100–300 mm (4–12 in.) in diameter for lengths of 150 m (500 ft). Slight bends of up to 22.5° can be navigated, but straight runs are preferred. A key benefit is that the polymer will rarely block a service connection, so service restatements are not typically required.

Demonstration #1 in Somerville, NJ

In August 2010, the first field demonstration took place. The host pipe was cast iron, unlined, 409 m (1,340 ft) long that was installed in two different decades (1930s and 1950s). The host had an inner diameter (ID) of 250 mm (10 in.), a wall thickness of 14.4 mm (0.57 in.), and was buried 1.2 m (4 ft) on average. Operating pressures ranged between 585 and 620 kPa (85 and 90 psi), and flows were 6.62 million L (ML) per day (1.75 million gallons per day, MDG).

The demonstration activities, which included excavations, sample collection, bypass, hydraulic tests, pipe access, pipe cleaning and inspection, are described in detail in the report “Performance Evaluation of Innovative Water Main Rehabilitation Spray-on Lining Product in Somerville, NJ” (USEPA 2012a). Some problems occurred during cleaning, which contributed to delays in the schedule, because the pipe must be clean and dry before lining.

The hybrid polyurea/polyurethane lining took place over the course of a work week. The material is applied through a head that spins the material onto the pipe wall. Ridging of the lining material was seen in postlining video as was shadowing/incomplete coverage at service connections and some joints. Postlining flow tests revealed decreased flows, which led to further inspection of the liner, which had ultimately delaminated from the host pipe and collapsed (Fig. 1). The entire pipe was abandoned in place and with a new 300 mm (12 in.) ductile iron pipe installed over the next few weeks.

Ultimately, this demonstration was seen as a success because it helped identify a critical problem with this material. The failure was attributed to moisture conditions which prevented a proper chemical reaction from occurring, resulting in a lining collapse. The product was removed from the market for further research and development and reintroduced using a new formula the following year (Matthews et al. 2012b, 2013, 2014; Selvakumar et al. 2015).

Cured in Place Pipe (CIPP)

CML has been the most used water main rehabilitation method for years, but it is only a nonstructural corrosion barrier (Class I). CIPP liners are capable of providing fully-structural (Class IV) repairs, which has helped CIPP grow in the pressure main market. The CIPP liner used on this project is made up of a woven polyester fabric with an internal polymeric membrane for water tightness. The CIPP liner is impregnated above the access pit in a truck before being pulled into the host pipe. The liner is designed according to ASTM F1216 (ASTM 2009) and installed according to ASTM F1743 (ASTM 2008).

Available in diameters from 150 to 300 mm (6 to 12 in.), the CIPP can be used in pipes operating up to 1,030 kPa (150 psi). The liner can be installed in lengths up to 250 m (800 ft) between access points. After pressurization, hot water is circulated for 90 min and curing takes place over the next 12 h. Service connections are reinstated internally with a cutting drill, though 10% or more may need external restatements. As part of this study, the reported mechanical properties (shown in Table 2) were evaluated using actual samples from the field, with the average measured value being reported in the table for each parameter.

Demonstration #2 in Cleveland, Ohio

The second demonstration occurred in September 2010 in Cleveland, Ohio. The host pipe was 150-mm (6-in.) cast iron pipe, 622 m (2,040 ft) long. The host pipe had an average wall thickness of 12.7 mm (0.50 in.), and was 1.8 m (6 ft) deep on average. Operating pressures were 414 kPa (60 psi), and flow was 3.26 million L=day (0.86 MGD). The demonstration activities, which included excavations, sample collection, bypass, hydraulic tests, pipe access, pipe cleaning and inspection, and service plugging, are described in detail in the report "Performance Evaluation of Innovative Water Main Rehabilitation Cured-in-Place Pipe Lining Product in Cleveland, OH" (USEPA 2012b). The CIPP lining took place over the course of a week and included seven lining runs. Seventeen (17) of 63 service connections (27%) had to be externally reinstated. This was attributed to: flush connections;

connections located in CIPP folds, blocked connections, and deformed or misaligned corporation stops.

Results of the testing showed the liner performed as a fully structural (Class IV) material (Table 2). Flow testing postlining revealed an average C factor of 112, slightly less than the expected 120. It was much higher than the prelining factor (79), resulting in a 43% increase in flow. Final lining is shown in Fig. 2.

The costs were US\$4.03/m per mm of diameter (US\$31.23/lf per in. of diameter) for the lining, and it resulted in a field applied carbon footprint of 23,986 kg (52,880 lb) of carbon dioxide (CO₂), as calculated with the *e-Calc* tool (Sihabuddin and Ariaratnam 2009). The CO₂ footprint was estimated to be approximately half of the CO₂ from a similar sized open cut excavation project (if feasible) (Matthews et al. 2012a, 2013, 2014; Selvakumar et al. 2015). This indicates an open cut excavation project of a 150-mm (6-in.) cast iron pipe, 622 m (2,040 ft) long would result in a CO₂ footprint of approximately 48,000 kg based on *e-Calc*.

Spray-Applied Geopolymer Mortar

This product is made from spray-applied geopolymer mortar that is reinforced with microfibers. The product consists fly ash, aggregates, silica, some ordinary portland cement (OPC), and other unspecified proprietary ingredients. It forms a robust matrix that is highly resistant to acids and provides greater surface durability. It cures and hardens quickly, allowing for shortened bypass time and faster reinstatement of pipes compared with conventional OPC based mortars that may require longer curing periods. In addition, environmental and incidental factors such as heat, cold, and batching temperature have low effects. With proper surface preparation, it can be applied to both organic and inorganic materials.

This mortar is a gray color with a dry unit weight of 2,046 kg/m³ (127.7 pounds per cubic ft, pcf) and 2,231 kg/m³ (139.3 pcf) wet unit weight. Typically, a 45-kg (100-lb) bag of powder is mixed with 8.2 kg (18 lb) of water yielding 0.024 cubic m (0.86 cubic ft) of as spray applicable mortar. This amount can be applied to a surface area of 0.639 m² (6.88 ft²) at a thickness of 37.5 mm (1.5 in.), or 0.959 m² (10.32 ft²) at a thickness of 25 mm (1 in.), or 1.918 m² (20.64 ft²) at a thickness of 12.5 mm (0.5 in.).

The mortar can be used in gravity sewer applications for diameters from 750 to 5,000 mm (30 to 200 in.) in lengths between 30 and 100 m (100 and 300 ft) per day for a 37.5 mm (1.5-in.) thickness. Bends are not a limitation because the material is hand applied, and any laterals are plugged prior to spraying. The minimum thicknesses are 12.5 mm (0.5 in.) for corrosion protection and 37.5 mm (1.5 in.) for structural repairs. The time that the materials can be applied before curing is 60–90 min at 27°C (80°F).

Demonstration #3 in Houston, Texas

The field demonstration took place in 2013 in Houston, Texas on 49 m (160 ft) of 1,500 mm (60-in.) diameter reinforced concrete pipe (RCP). Open cut excavation was eliminated as an

option because of the depth of the main 7.6 m (25 ft) and the need for a short time on bypass piping. If the pipe were to be replaced through open cut construction, the bypass time would have been many weeks longer.

The demonstration activities, which included bypass, pipe access, pipe cleaning, and infiltration repair are described in detail in the report “Performance Evaluation of an Innovative Fiber Reinforced Geopolymer Spray-Applied Mortar for Large Diameter Wastewater Main Rehabilitation in Houston, TX” (USEPA 2014). The materials were not robotically applied because of the severe deterioration and the need for manual application to ensure thicker coverage at damaged areas. The project took place over the course of 11 working days, and a total lining thickness of 82.5 mm (3.3 in.) was sprayed. Postlining visual inspections confirmed that the pipe was successfully rehabilitated with no visible leaks or defects as shown in Fig. 3.

Third-party testing showed that compressive strength exceeded the design, 55.54 MPa (8,635 psi) versus 55.16 MPa (8,000 psi) at 28 days. Additional samples collected by the research team tested slightly lower than design, and this was attributed to a light rain that took place during sample collection. The assumption is that the weather had no impact inside the pipe; therefore, the material should be within design. A recommendation from this project is to determine what quality control (QC) samples could be used to better represent what is spray inside the pipe.

The cost to rehabilitate a 1,500 mm (60-in.) sewer pipe with a spray-applied geopolymer coating ranges from \$1,300 to \$1,950 per m (\$400 to \$600 per ft) for projects of a similar configuration. This demonstration project had a calculated carbon footprint of 21,900 kg (more than 48,000 lb) of CO₂ equivalents. This is likely 60% less than an excavation project for a comparable configuration (if feasible). It is worth noting that CO₂ emissions from geopolymer manufacturing can be 65–90% less than that of OPC (Matthews et al. 2015; Selvakumar et al. 2014d).

Internal Pipe Sealing System

The use of internal pipe seals are a cost-effective alternative to full-length liners and traditional open cut replacements, particularly when only spot repairs are required. These systems can be applied to gravity sewers, because the materials used (i.e., stainless steel, rubber) are corrosion resistant. These seals can be installed quickly in low flow conditions, eliminating the need to bypass pump. The seals are also easy to install and do not require specialized knowledge or equipment.

Pipe-Seal-Fix is composed of an AISI 316 L or 316 Ti stainless steel sleeve and an ethylene propylene diene monomer (EPDM) rubber gasket. The corrosion-resistant sleeve has a unique locking mechanism that cannot unlock once expanded into place inside the pipe. The sleeve has two rows of teeth that are pushed into it to expand the interlocking pinions. It does not require any curing; the packer used to expand the sleeve in place just needs to be pressurized to 275 kPa (40 psi) to ensure the locks are fully expanded.

The Pipe-Seal-Fix system is designed for use in storm and sanitary sewer pipe rehabilitation applications in diameter ranges of 200–600 mm (8–24 in.). The renewal length is technically unlimited because sleeves can be placed consecutively, but the system is designed primarily as a spot repair alternative to full-length lining. Bends and offsets above 10% can cause difficulty because the sleeves are rigid (Pipe-Robo-Tec 2015).

Demonstration #4 in Baltimore, Maryland

Two field installation events of the robotically installed internal joint seals were observed including a 250 mm (10 in.) pipe in the City of Santa Fe, Texas and a 200 mm (8 in.) vitrified clay pipe (VCP) in Baltimore, Maryland. Both field sites had pipes that had been previously lined with CIPP that had defects requiring repair. The Santa Fe, Texas pipe was located 3 m (10 ft) below the ground surface and had a liner failure at the joint allowing a large volume of groundwater to infiltrate the pipe. The Baltimore, Maryland pipe was a 200 mm (8 in.) VCP lined with 88 m (290 ft) of CIPP, which had a defect near a downstream manhole that was allowing sanitary flow to exfiltrate the pipe. A closed-circuit television (CCTV) scan of the defect was not available for the Baltimore site. A full account of the activities can be found in the report “Testing and Performance Evaluation of an Innovative Internal Pipe Sealing System for Wastewater Main Rehabilitation” (USEPA 2016).

Both locations had previously been lined with CIPP, but had significant defects allowing infiltration or exfiltration of the sewer flow. The internal pipe sealing system could not be installed at the Santa Fe, Texas location owing to sagging and the ovality of the defective CIPP liner. The system was successfully installed manually in Baltimore, Maryland. An inspection of the seal after installation confirmed the repaired section was sealed, with zero exfiltration (Fig. 4).

The system was also tested through external hydraulic testing in the laboratory on three 200 mm (8 in.) steel pipes. The laboratory testing showed the seals were leak free for 2.5 h above 100 kPa (15 psi), which is approximately twice the external hydraulic design pressure of 50 kPa (7.25 psi). The cost for the Baltimore, Maryland installation was approximately \$756 for the spot repair of a 200 mm (8-in.) sewer main. The project had a negligible carbon footprint because the equipment required for the installation was minimal. The technology shows promise as a low-cost and rapid trenchless repair approach. Access requirements should be assessed based upon site-specific conditions to ensure feasibility of the robotic-assisted installation, especially in previously lined pipes.

Conclusion

The results of the study are beneficial for pipeline managers and owners interested in repairing their assets with innovative technologies. Table 3 summarizes the results of four technology demonstrations including cost and environmental impacts. Out of the four demonstrations, one technology failed, which resulted in the removal of the product from the market to allow for its improvement. The water main CIPP field study was successful, but continued development was recommended for the process of reopening the lateral connections. The spray-applied geopolymer was also successful, although additional QC

procedures are recommended to ensure proper installations. The internal sealing system shows promise as a low-cost and rapid trenchless repair approach; however, access requirements should be assessed based upon site-specific conditions to ensure feasibility of the robotic-assisted installation, especially in previously lined pipes.

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References

- ASTM. (2008). "Standard practice for rehabilitation of existing pipelines and conduits by pulled-in-place installation of cured-in-place thermosetting resin pipe (CIPP)" ASTM F-1743, West Conshohocken, PA.
- ASTM. (2009). "Standard practice for rehabilitation of existing pipelines and conduits by the inversion and curing of a resin-impregnated tube" ASTM F-1216, West Conshohocken, PA.
- Ellison D, et al. (2010). "Global review of spray-on structural lining technologies." Water Research Foundation, Denver.
- Matthews J, and Allouche E (2012). "Fully automated decision support system for assessing the suitability of trenchless technologies." *J. Pipeline Syst. Eng. Pract.*, 10.1061/(ASCE)PS.1949-1204.0000095, 55–64.
- Matthews J, Condit W, Selvakumar A, and Sterling R (2012a). "Demonstration and evaluation of an innovative water main rehabilitation technology: Spray-on polymeric lining." *Water Pract. Technol.*, 7(1), 1–15.
- Matthews J, Selvakumar A, and Condit W (2012b). "Demonstration and evaluation of an innovative water main rehabilitation technology: Cured-in-place pipe (CIPP) lining." *Water Pract. Technol.*, 7(2), 1–12.
- Matthews J, Selvakumar A, and Condit W (2013). "Current and emerging water distribution main renewal technologies." *J. Infrastruct. Syst.*, 10.1061/(ASCE)IS.1943-555X.0000121, 231–241.
- Matthews J, Selvakumar A, Condit W, and Sterling R (2014). "Innovative rehabilitation technology demonstration and evaluation program." *Tunnelling and Underground Space Technol.*, 39(1), 73–81.
- Matthews J, Selvakumar A, Sterling R, and Condit W (2012c). "Analysis of wastewater and water system renewal decision making tools and approaches." *J. Pipeline Syst. Eng. Pract.*, 10.1061/(ASCE)PS.1949-1204.0000114, 99–105.
- Matthews J, Selvakumar A, Vaidya SP, and Condit W (2015). "Large-diameter sewer rehabilitation using a spray applied fiber reinforced geopolymer Mortar." *Pract. Period. Struct. Des. Constr.*, 10.1061/(ASCE)SC.1943-5576.0000246, 04014050.
- Pipe-Robo-Tec. (2015). "Pipe-seal-fix and pipe-seal-flex installation manual." http://www.piperobotecusa.com/assets/fix-flex_installation_manual_final.pdf. (6 1, 2015).
- Primeaux D (2004). "Polyurea vs. polyurethane & polyurethane/polyurea: What's the difference?" Polyurea Linings Annual Conf, Polyurea Development Association (PDA), Kansas City, MO, 1–20.
- Selvakumar A, Matthews J, and Condit W (2014a). "Demonstration of innovative large-diameter rehabilitation technology in Houston, TX" *Proc., NASTT's 2014 No-Dig Show, North American Society for Trenchless Technology (NASTT)*, North Vancouver, BC, Canada.

- Selvakumar A, Matthews J, Condit W, and Sterling R (2015). "Innovative research program on the renewal of aging water infrastructure systems." *J. Water Supply: Res. Technol*, 64(2), 117–129.
- Selvakumar A, Tuccillo M, Martel K, Matthews J, and Feeney C (2014d). "Demonstration and evaluation of state-of-the-art wastewater collection systems condition assessment technologies." *J. Pipeline Syst. Eng. Pract*, 10.1061/(ASCE)PS.1949-1204.0000161, 04013018.
- Sihabuddin S, and Ariaratnam S (2009). "Methodology for estimating emissions in underground utility construction operations." *J. Eng. Des. Technol*, 7(1), 37–64.
- USEPA (U.S. Environmental Protection Agency). (2009). "Rehabilitation of wastewater collection and water distribution systems: White paper." EPA/600/R-09/048, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2010a). "State of Technology report for force main rehabilitation." EPA/600/R-10/044, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2010b). "State of technology for rehabilitation of wastewater collection." EPA/600/R-10/078, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2012a). "Performance evaluation of innovative water main rehabilitation spray-on lining product in somerville, NJ." EPA/600/R-12/009, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2012b). "Performance evaluation of innovative water main rehabilitation CIPP lining product in Cleveland, OH." EPA/600/R-12/012, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2013). "State of technology for rehabilitation of water distribution systems." EPA/600/R-13/036, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2014). "Performance evaluation of an innovative fiber reinforced geopolymer spray-applied mortar for large diameter wastewater main rehabilitation in Houston, TX." EPA/600/R-14/443, Office of Research and Development, Cincinnati.
- USEPA (U.S. Environmental Protection Agency). (2016). "DRAFT: Testing and performance evaluation of an innovative internal pipe sealing system for wastewater main rehabilitation." Office of Research and Development, Cincinnati.

(a)

(b)

Fig. 1.
(a) Collapsed polymeric liner; (b) folds and blisters inside the liner (images by authors)

Fig. 2.
Finished CIPP liner (image by authors)

Fig. 3.
Inspection of pipe after geopolymer lining installation (image by authors)

Fig. 4.
Installed internal pipe sealing system (image by authors)

Table 1.

Selected Innovative Rehabilitation Technologies

Technology	Technology Description	Rationale for Demonstration
Water Main Rehabilitation		
Spray-on polyurea coating	Class II/III semistructural polyurea coating capable of 10-min cure.	Able to span gaps and holes. Quick cure can minimize bypass time. Minimal blockage of services.
Reinforced CIPP lining	Class IV fully structural CIPP liner impregnated with a thermoset epoxy resin and cured with hot water.	Stronger than standard CIPP. Services can be reinstating robotically. Liner designed eliminate folds.
Wastewater Rehabilitation		
Spray-on geopolymer coating	Geopolymer mortar designed for spray-on lining applications. Designed to adhere to the surface or itself to build thickness.	Same day return to service possible; durable; low porosity; acid resistant; green material.
Internal spot repair seal	Internal pipe sealing system comprised of a stainless steel sleeve with a unique locking system and rubber gasket.	Robotically installed spot repair technology that can be installed quickly in low flow conditions.

Table 2.

Measured Data for CIPP Liner

Test	Design parameters (ASTM F1216)	Average Measured value
Liner thickness, [mm (in.)]	2.5 (0.1)	4.7 (0.2)
Measured ovality, (%)	N/A	2.5
Tensile strength, [MPa (psi)]	21 (3,000)	65 (9,415)
Flexural strength, [MPa (psi)]	31 (4,500)	55 (7,982)
Flexural modulus, [MPa (psi)]	1,724 (250,000)	2,530 (366,928)
Inner/Outer hardness, Shore D	N/A	41/64
Short-term pressure, [MPa (psi)]	N/A	140 (0.97)
Negative pressure, [kPa(psi)]	−101.4 (−14.5)	−101.4 (−14.5)

Table 3.

Summary of Four Technology Evaluations

Method	Maturity	Technical feasibility	Level of complexity	Field performance	Unit cost ^a	Environmental impact ^a
Spray-on lining for Water Mains	Emerging	Semi-Structural Solution	Requires specialized training	Didn't meet manufacturer-stated claims	\$2.13/m per mm of diameter (\$16.50/ft per in. of diameter)	50% carbon footprint vs. replacement
CIPP lining for Water Mains	Innovative	Fully-Structural Solution	Requires specialized training	Met most manufacturer-stated claims	\$4.03/m per mm of diameter (\$31.23/ft per in. of diameter)	50% carbon footprint vs. replacement
Spray-on mortar for sewer mains	Innovative	For Partial Deterioration in Sewers	Requires some training	Met most manufacturer-stated claims	\$1.07/m per mm of diameter (\$8.33/ft per in. of diameter)	40% carbon footprint vs. replacement
Internal seals for sewer mains	Emerging	Spot Repair Method for Sewers	Requires some training	Met most manufacturer-stated claims	\$800/ repair	<10% carbon footprint vs. replacement

^aCosts and Environmental Impact are project-specific