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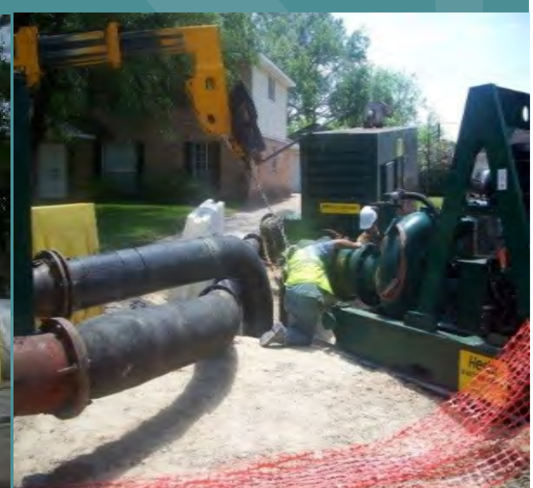
Performance Evaluation of an Innovative Fiber Reinforced Geopolymer Spray-Applied Mortar for Large Diameter Wastewater Main Rehabilitation in Houston, TX



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PERFORMANCE EVALUATION OF AN INNOVATIVE FIBER REINFORCED GEOPOLYMER SPRAY-APPLIED MORTAR FOR LARGE DIAMETER WASTEWATER MAIN REHABILITATION IN HOUSTON, TX

by

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DISCLAIMER

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ABSTRACT

Many utilities are seeking emerging and innovative rehabilitation technologies to extend the service life of their infrastructure systems. However, information on new technologies is not always readily available and not easy to obtain. To help to provide this information, the U.S. Environmental Protection Agency (EPA) developed an innovative technology demonstration program to evaluate technologies that have the potential to reduce costs and increase the effectiveness of the operation, maintenance, and renewal of aging water distribution and wastewater collection systems. The intent of this program is to make the technologies' capabilities better known to the water and wastewater industries.

This report describes the performance evaluation of a fiber reinforced geopolymer spray-applied mortar, which has potential as a structural alternative to traditional open cut techniques used in large-diameter sewer pipes. Geopolymer is a sustainable green material that incorporates recycled industrial byproducts and has been shown to have improved chemical and physical properties compared with ordinary portland cement (OPC). GeoSpray™, produced by Milliken Infrastructure Solution, LLC (Milliken), was used to rehabilitate a 60-in. reinforced concrete pipe (RCP) sewer main in Houston, Texas. The 25-ft depth of the pipe and other site-specific conditions precluded open cut excavation and the need for a shortened bypass time contributed to the selection of the GeoSpray™ technology. The project was completed in a two-week timeframe including four spraying passes on 160 ft of 60-in. RCP. The host pipe was severely deteriorated with corroded and exposed steel reinforcements and several locations of heavy water infiltration, which led to the product being manually spray applied by hand rather than using a sled.

The material was successfully installed in a severely deteriorated pipe environment. The post-lining inspection via closed-circuit television (CCTV) showed the rehabilitated pipe to be infiltration free, with no signs of exposed rebar or cracking, and no significant defects were noted in the GeoSpray™ lining the day after application. A lining thickness of approximately 3.3 in. was sprayed in the pipe, which is more than the design minimum value of 1.9 in. The third-party test results for compressive strength averaged 8,635 pounds per square inch (psi) at 28 days, which is above the manufacturer stated claim of 8,000 psi at 28 days. However, the samples collected by the research team tested under the manufacturer-stated claims (e.g., measured at 7,881 psi or 1.5% below specification for compressive strength). Based on the lower density of the mixture, it is hypothesized that the lower values in these samples were attributable to light rain experienced during sample collection. However, it is assumed that the rain had no impact on the material sprayed in the pipe as the mixer was covered during the installation. Overall, it is recommended that sampling and testing procedures be further examined to ensure that the quality control (QC) samples are indicative of the final material properties as installed in the field. Recommendations are made related to measuring the "as installed" lining thickness, bond strength testing, and the use of shaker tables to minimize voids.

For structurally rehabilitating a 60-in. pipe via geopolymer spray-applied lining, the costs would range from $400 to $600 per linear foot (for projects of similar complexity and including bypass pumping). The project resulted in an estimated carbon footprint of 24.10 short tons (48,200 lb) of carbon dioxide (CO_2) equivalents, which was gauged to be 60% less than an equivalent excavation project (if feasible). In addition, CO_2 equivalent emissions from the manufacture of geopolymers have been shown in the literature to be as much as 65% to 90% less than emissions for OPC.

ACKNOWLEDGMENTS

This report has been prepared with input from the research team, which includes Battelle, the Trenchless Technology Center (TTC) at Louisiana Tech University, and Dr. Ray Sterling. The technical direction and coordination for this project was provided by Dr. Ariamalar Selvakumar of the Urban Watershed Management Branch. The project team would like to acknowledge several key contributors to this report in addition to the authors listed on the title page. The demonstration would not have been possible without the cooperation of the City of Houston. Cooperation from Inland Pipe Rehabilitation (IPR) and Milliken Infrastructure Solutions, LLC (Milliken) was crucial for this project and the authors would like to thank Chuck Slack, Steve Henning, and Nick Banchetti from IPR; Luke Keenan and Bob Atkin from Milliken; and the IPR field crew for their assistance and work throughout this project. Key contributors from the TTC included Rashedul Alam and Erez Allouche for the experimental work.

Finally, the authors would like to thank Mr. Daniel Murray and Mr. Raymond Frederick of Urban Watershed Management Branch for their timely review of the report.

EXECUTIVE SUMMARY

Introduction

Many utilities are seeking emerging and innovative rehabilitation technologies to extend the service life of their infrastructure systems. However, information on new technologies is not always readily available and not easy to obtain. To help to provide this information, the U.S. Environmental Protection Agency (EPA) developed an innovative technology demonstration program to evaluate technologies that have the potential to reduce costs and increase the effectiveness of the operation, maintenance, and renewal of aging water distribution and wastewater collection systems. The intent of the program is to make the technologies' capabilities better known to the water and wastewater industries. The specific technology metrics evaluated under this program include technology maturity, feasibility, complexity, performance, cost, and environmental impact. This report describes the performance evaluation of the Milliken Infrastructure Solutions, LLC (Milliken) GeoSpray™ fiber reinforced geopolymer spray-applied mortar product that was used to rehabilitate a sewer main in Houston, Texas.

Demonstration Approach

The demonstration of innovative technologies requires clear and repeatable testing criteria if the technologies are to be understood and accepted. As summarized in this report, a protocol was developed to provide a consistent approach and a guide for conducting field demonstrations in a manner that encourages acceptance of the outcomes and results by wastewater utilities. The demonstration protocol addressed issues involved in gaining the approval for the use of innovative technologies by:

- Providing for independent verification of the claims of technology developers.
- Sharing information about new technologies among peer user groups.
- Supporting utilities and technology developers in bringing new products to a geographically and organizationally diverse market.

Several innovative technologies were identified that have the potential to be demonstrated and that would provide a benefit to advance the state-of-the-technology. The majority of sewer rehabilitation tends to use cured-in-place pipe (CIPP), but new innovations are continually entering the market. The Battelle team received an agreement from Milliken, which developed GeoSpray™, to participate in the EPA Demonstration Program.

Cementitious linings can be applied to gravity sewers, but the corrosive environment makes the application of ordinary portland cement (OPC) and concrete prone to deterioration. To combat the corrosive environment, innovative geopolymer materials have been developed to provide higher material strength and to increase corrosion resistance compared to conventional OPC based mortars. GeoSpray™ is composed of a proprietary micro-fiber reinforced, dense geopolymer mortar that can be spray applied. It cures quickly providing a shortened bypass time, which allows the pipe to be re-established more rapidly than OPC based mortars.

GeoSpray™ is designed for use in storm and sanitary sewer pipe rehabilitation applications in diameter ranges of 30 to 200 in. (750 to 5,000 mm). The renewal length will vary depending on the pipe diameter and required thickness and is typically ranges from 100 to 300 ft (30 to 100 m) per day for a 1.5-in. (38 mm) thick lining. Bends of any degree are feasible, but straight runs are preferred. Laterals are plugged prior to lining and do not require reconnection, only the removal of the plugs. The lining is typically sprayed at a minimum thickness of 1.5 in. (38 mm) for structural repairs or 0.5 in. (12.5 mm) for corrosion protection. The work time is 60 to 90 minutes at 80°F (27°C).

Geopolymer Demonstration

Field demonstration of GeoSpray™ for the rehabilitation of a 60-in. was conducted on a 160 ft long, 60-in. reinforced concrete pipe (RCP) in Houston, Texas in April-May, 2013. For this project, the 25-ft depth of the pipe and other site-specific conditions precluded open cut excavation and the need for a shortened bypass time contributed to the selection of the GeoSpray™ technology. To successfully execute the planned demonstration, site preparation activities that were required included: installation of the temporary bypass system; closed-circuit television (CCTV) inspection and cleaning of the pipe; and repair of infiltration prior to lining. The GeoSpray™ was manually applied at this site because of the severe deterioration of the host pipe, which caused high levels of water infiltration. When a pipe wall is compromised and infiltration is heavy, manual spraying provides the advantage of being able to address serious infiltration locations by hand-applying a thicker liner in a single pass. The material was successfully installed in a severely deteriorated pipe environment. The entire project was conducted over a period of 11 days and a total thickness of approximately 3.3 in. of the GeoSpray™ material was applied over four spraying days. The post-lining inspection via CCTV showed the rehabilitated pipe to be infiltration free and no significant defects were noted in the GeoSpray™ lining the day after application.

Demonstration Results

While the spray lining process is classified as conventional, the GeoSpray™ lining product is classified as innovative in terms of maturity based on its formulation (i.e., geopolymer) and usage. The outcome of the technology evaluation is described in the technology evaluation metrics listed below:

Technology Maturity Metrics

- Innovative material installed using a conventional methodology.
- Corrosive resistance was not validated, but geopolymer is a proven improvement over OPC.
- Some third-party data are available, but long-term testing is needed.

Technology Feasibility Metrics

- Project met the owner’s expectations and requirements.
- The material was successfully installed in a severely deteriorated pipe environment.
- Because of the severe deterioration of the host pipe and high levels of water infiltration, the lining was manually spray-applied by hand versus application via a spray sled.

Technology Complexity Metrics

- Beneficial for wastewater utilities with deteriorating large-diameter mains in corrosive environments.
- Requires trained professionals, but the lining process is not complex; therefore, contractors or utility personnel could be trained to install this product.
- The project spanned a total of 11 working days, including unanticipated delays in setup of the host pipe by the wastewater treatment plant (WWTP) due to flows entering into the manhole at the WWTP that initially could not be shut off.

Technology Performance Metrics

- The post-lining inspection via CCTV showed the rehabilitated pipe to be infiltration free, with no signs of exposed rebar or cracking, and no significant defects were noted in the GeoSpray™ lining the day after application.
- Calculations based on the amount of material sprayed each day and length of coverage showed that the spray-applied thickness was approximately 3.3 in., which was more than the design minimum value of 1.9 in.
- Third-party test results for all four days of spraying showed that the quality control (QC) samples met design specifications. The compressive strength at 28 days averaged 8,635 psi compared to the manufacturer's design specification of 8,000 psi.
- Mechanical testing by the research team indicated that the QC samples were lower than the manufacturer claims of performance. For example, the compressive strength at 28 days was measured at 7,881 psi (or 1.5% lower than the manufacturer's specification). Based upon the lower than expected density of the mixture (by 3.6%), it is hypothesized that the lower values in these samples were attributable to light rain experienced during sample collection. However, it is assumed that the rain had no impact on the material sprayed in the pipe as the mixer was covered during the installation.
- Because of the manual application of the GeoSpray™ material, not all of the typical QC parameters could be collected on a continuous basis associated with the sled application. However, the slump test results were consistent for each day of spraying, which suggests that a uniform water/cement ratio was achieved.

Technology Cost Metrics

- The costs associated with projects similar to this range from $400 to $600 per linear foot.

Technology Environmental and Social Metrics

- Social disruption was minimal since traffic was only affected at one manhole and drivers were able to access their homes throughout the project.
- An estimated 24.10 short tons (48,200 lb) of CO_2 equivalents were emitted from on-site operations. A similar open cut project, although impractical due to the site conditions, would emit 120,000+ lb of CO_2 equivalents.
- CO_2 equivalent emissions from the manufacture of geopolymers have been shown in the literature to be as much as 65% to 90% less than emissions for OPC.

Conclusions and Recommendations

An innovative, spray-applied, fiber-reinforced geopolymer mortar was used to rehabilitate a 60-in. RCP sewer main in Houston, Texas. The 160-ft long and 25-ft deep host pipe was severely deteriorated with exposed and missing steel reinforcements and several locations of heavy water infiltration. The material was successfully installed in a severely deteriorated pipe environment. The site conditions required the lining to be spray applied by hand rather than using a sled.

Overall, it is recommended that sampling and testing procedures be further examined to ensure that the QC samples are indicative of the final material properties as installed in the field. Recommendations are made related to measuring the "as installed" lining thickness, bond strength testing, and the use of shaker tables to minimize voids.

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ABBREVIATIONS AND ACRONYMS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BPA	bisphenol A
CCTV	closed-circuit television
CI	Chloride Ion
CIPP	cured-in-place pipe
EPA	Environmental Protection Agency
HDPE	high density polyethylene
hp	horsepower
IPR	Inland Pipe Rehabilitation
ksi	kilopound per square inch
MGD	million gallons per day
NRMRL	National Risk Management Research Laboratory
OPC	ordinary portland cement
pcf	pounds per cubic foot
psi	pounds per square inch
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RCP	reinforced concrete pipe
SOT	state-of-technology
STREAMS II	Scientific, Technical, Research, Engineering, and Modeling Support II
TCLP	Toxicity Characteristic Leaching Procedure
TO	Task Order
WWTP	wastewater treatment plant

Section 1.0: INTRODUCTION

1.1 Project Background

Many utilities are seeking emerging and innovative rehabilitation technologies to extend the service life of their infrastructure systems. However, information on new technologies is not always readily available and easy to obtain. To help to provide this information, research is being conducted as part of the U.S. Environmental Protection Agency's (EPA's) Aging Water Infrastructure Research Program to evaluate promising innovative technologies that can reduce costs and improve the effectiveness of the operation, maintenance, and renewal of aging drinking water distribution and wastewater collection systems. This research includes field demonstration studies of emerging and innovative rehabilitation technologies, which is intended to make the capability of these technologies better known to the water and wastewater industries, allowing their applications to be promoted in the U.S. The specific technology metrics evaluated under this program include technology maturity, feasibility, complexity, performance, cost, and environmental impact.

Several emerging and innovative technologies were identified based upon industry experience and extensive state-of-technology (SOT) reports (EPA, 2010a; 2010b; 2013). It has been found that well documented and publicized demonstration projects can play an important role in accelerating the development, evaluation, and acceptance of new technologies. A successful demonstration project provides substantial value to utilities, manufacturers, technology developers, consultants, service providers, and contractors. The benefits of a technology demonstration program to these various groups are summarized below:

Benefits to Utilities

- Reduced risk of experimenting with new technologies and new materials on their own
- Increased awareness of innovative and emerging technologies and their capabilities
- Assistance in setting up strategic and tactical rehabilitation plans
- Understanding of technology environmental impact and social cost
- Identification of design and quality assurance/quality control (QA/QC) issues

Benefits to Manufacturers/Technology Developers

- Opportunity to advance technology development and commercialization
- Opportunity to accelerate the adoption of new technologies in the U.S.
- Opportunity to better understand the needs of utilities

Benefits to Consultants and Service Providers

- Opportunity to compare performance and cost of similar products in a consistent manner
- Access to standards and specifications for new technologies
- Education of best practices on pre- and post-installation procedures and testing

Benefits to Contractors

- Identification of successfully implemented QA/QC protocols
- Identification of successfully implemented installation procedures including surface preparations
- Understanding of regulations related to the use of new renewal technologies

This report provides an assessment of the effectiveness, expected range of applications, and cost of the demonstrated technology to assist utilities in better decision-making on whether rehabilitation or replacement is more cost-effective and in selecting rehabilitation technologies for use. The field demonstration described in this report resulted in the successful installation of a fiber reinforced geopolymer spray-applied mortar on 160 ft of a 60-in. reinforced concrete pipe (RCP) wastewater collection main in Houston, Texas. Geopolymer is a cementitious material formed by alkali activation of aluminosilicate powder (e.g., typically materials with high percentages of silica and alumina), which does not require the presence of ordinary portland cement (OPC) (Vaidya and Allouche, 2011). Geopolymers have been shown to have improved chemical and physical properties compared to OPC such as increased corrosion resistance and high compressive strength (Kupwade-Patil and Allouche, 2013). Geopolymers are also sustainable green materials that incorporate up to 50% of the raw material as recycled industrial byproducts (e.g., fly ash) and provide an environmental benefit through a reduced carbon footprint compared to OPC. Davidovits (2011) reported that approximately 60% less energy is required to produce a standard geopolymer as compared to Portland cement, and 80-90% less CO_2 is emitted.

The activities involved with spray-applied mortar installation, which included pre-installation activities such as bypass construction; pipe wall cleaning and preparation; installation activities; and post-installation activities such as visual inspection and laboratory testing are presented in this report. This report conducts a full product evaluation based on the field demonstration results.

1.2 Project Objectives

The project objectives are to:

- Evaluate, under field conditions, the performance and cost of an innovative, fiber reinforced geopolymer spray-applied mortar used to rehabilitate a 60-in. RCP wastewater collection main in Houston, Texas.
- Document the results of the demonstration and provide recommendations related to product installation and QA/QC measures.

This research was conducted for the EPA National Risk Management Research Laboratory (NRMRL) under Task Order (TO) No. 01 titled *Field Demonstration and Retrospective Evaluation of Rehabilitation Technologies for Wastewater Collection and Water Distribution Systems* of the Scientific, Technical, Research, Engineering, and Modeling Support II (STREAMS II) Contract No. EP-C-11-038. The report describes data collection, analyses, and project documentation in accordance with EPA NRMRL's Quality Assurance Project Plan (QAPP) Requirements for Applied Research Projects (EPA, 2008) and the project-specific QAPP (Battelle, 2012).

1.3 Report Outline

The report is organized into the following sections:

- **Section 2.0 Demonstration Approach**. Discussion of the demonstration program approach including an overview of the innovative rehabilitation technology.
- **Section 3.0 Geopolymer Demonstration**. Documentation of the field demonstration including site preparation, pipe cleaning, QA/QC procedures, sample collection, and site restoration.
- **Section 4.0 Demonstration Results**. Discussion of the demonstration results and assessment of the technology based on comparison with the outlined evaluation metrics.
- **Section 5.0 Conclusions and Recommendations**. Summary of the demonstration including effectiveness of the demonstrated technology and recommendations for areas needing further examination.

Section 2.0: DEMONSTRATION APPROACH

This section outlines the overall approach to the field demonstration and provides an overview of the innovative rehabilitation technology and site selection for this task.

2.1 General Approach

The demonstration of innovative technologies requires clear and repeatable testing criteria if the technologies are to be understood and accepted. A protocol was developed to provide a consistent approach and a guide for conducting field demonstrations in a manner that encourages acceptance of the outcomes and results by wastewater utilities (as summarized in Table 2-1 and Section 4). The demonstration protocol addressed issues involved in gaining the approval for the use of innovative technologies by:

- Providing for independent verification of the claims of technology developers;
- Sharing information about new technologies among peer user groups; and
- Supporting utilities and technology developers in bringing new products to a geographically and organizationally diverse market.

A QAPP was developed, which outlined the approach to plan, coordinate, and execute the field demonstration protocol with the specific objectives of evaluating, under field conditions, the performance and cost of an innovative, fiber reinforced geopolymer spray-applied mortar for wastewater main rehabilitation.

The QAPP described the overall objectives and approach to the EPA's field demonstration program, the technology and site selection factors considered, and the features, capabilities, and limitations of the selected technology, which are summarized below (Battelle, 2012). The demonstration protocol was executed by completing the following steps:

- Prepared and obtained EPA approval for the QAPP;
- Gathered relevant data for demonstration opportunities meeting the selection criteria;
- Secured a commitment from the technology developer and contractor to use one of their projects as the demonstration study;
- Documented and conducted the field demonstration as outlined in the demonstration protocol;
- Processed and analyzed the results of the field demonstration; and
- Prepared a report and peer reviewed article summarizing the results.

This demonstration report not only records the use of the fiber reinforced geopolymer spray-applied mortar technology, but also provides a documented case study of the technology selection process, design, QA/QC procedures, and the preparation for life-cycle management of the asset. In performing the field demonstration, the technical and QA/QC procedures specified in the QAPP were followed unless otherwise stated. Special aspects of the EPA demonstration program which were aimed at adding value to the wastewater rehabilitation industry are described below.

- **<u>Consistent Design Methodology</u>.** An important role of this task is to identify design parameters and specifications for the selected technologies and to document the application of a consistent design methodology based on the vendor recommendations or industry defined standards.
- **<u>QA/QC Procedures</u>.** The success of a rehabilitation project depends largely on proper installation controls and post-installation inspection and assessment. The level of qualification testing and QA requirements typically vary by technology without a clear quality standard. This task provided an opportunity to examine current QA practices and identify areas for improvement. For technologies lacking an industry quality standard, QA/QC procedures recommended by the vendor and utility should be reviewed and adopted (as appropriate).
- **<u>Technology Range of Applications</u>.** The demonstration provides an assessment of the short-term effectiveness and cost of the selected technologies in comparison with the respective vendor specifications and identifies conditions under which each technology can be best applied. This effort also provides suggestions on necessary improvements for the technology itself, the installation procedures, and QA/QC procedures. Several metrics are identified that can be used to evaluate and document rehabilitation technology application, performance, and cost, which are summarized in Table 2-1.
- **<u>Life-Cycle Performance</u>.** Long-term performance data for rehabilitation systems is needed. These data will enable decision makers to make better cost-benefit decisions. This report will assist utilities in developing life-cycle plans for the ongoing evaluation of rehabilitation technology performance by collecting baseline data to enable comparative evaluation of the systems' deterioration during subsequent retrospective investigations.

Table 2-1. Framework of Technology Metrics to be Evaluated

Technology Maturity Metrics
• Maturity is innovative (recently commercialized), emerging (not widely used in the U.S.), or conventional. • Availability of supporting performance data and patent citation (if applicable). • Comments and feedback from utility owners and consultants with experience from previous pilot studies.
Technology Feasibility Metrics
• Applicability of the technology in meeting the rehabilitation requirements. • Suitability of the technology to the operating conditions of the host pipe. • Consideration of failure modes and documentation of design procedures.
Technology Complexity Metrics
• Adaptability to and widespread benefit for small- to medium-sized utilities. • Level of training required, pre- and post-installation requirements, and maintenance requirements. • Time and labor requirements for the overall rehabilitation project. • Evaluation of the installation process, procedures, and problems encountered. • Documentation of the efficiency of the reinstatement of laterals, etc.
Technology Performance Metrics
• Evaluation of manufacturer-stated performance versus actual performance. • Expected visual appearance and geometric uniformity after installation. • Ability to achieve design specifications.
Technology Cost Metrics
• Document costs including design, capital, operation and maintenance, traffic and surface footprint, and calculate a unit cost. • Estimate an average level of social disruption (although social cost calculation is beyond the project scope).
Technology Environmental and Social Metrics
• Assess utilization of chemicals or waste byproducts that have an unintended impact on the environment. • Assess quantity of waste byproducts produced (e.g., wastewater volume, soil requiring off-site disposal). • Evaluate the overall "carbon footprint" of the technology compared to open cut.

2.2 Technology Selection Approach

The Battelle team identified several innovative technologies in the SOT reports that have the potential to be demonstrated and that would provide a benefit to advance the state of the technology (EPA, 2010a; 2010b; 2013). As new innovations are continually coming to market, this SOT information will be supplemented during Task 1 to include emerging technologies of interest (such as the technologies summarized in Table 2-2).

Table 2-2. Selected Innovative Rehabilitation Technologies

Technology (Vendor)	Technology Description	Rationale for Demonstration
Wastewater Rehabilitation		
3S Panels (National Liner)	Composite pipe consists of 3S segmental panels, host pipe, and 3S grout. Panels are made of transparent polyvinyl chloride, allowing visual confirmation of uniform grouting.	Circular or noncircular; visual confirmation of uniform grouting; used where bypassing is not feasible, large diameter.
GeoSpray™ (Milliken)	Fiber reinforced geopolymer mortar designed for spray applications. Designed to adhere to the surface to build thickness.	Fast return to service; high durability; near-zero porosity; high resistance to acid; green material.
Water Main Rehabilitation		
Melt-in-place pipe (Aqualiner)	Thin thermoplastic polymer composite liner for 6 in. to 12 in. diameters. Glass fiber reinforced polypropylene and a woven tube. Heated with a pig that melts the thermoplastic.	Performs as a Class IV liner capable of independently handling internal pressure and external loads.
Automate Leak Repair (Curapipe)	Pig train contains curing substances under pressure that plug leaks as the pigs travel down the main. The substances harden to plug leaks.	Innovative technique for leak repair; can be deployed through hydrants.
PipeArmor (Quest Inspar)	High build polyurea lining material that can be spray applied. Fast curing can potentially allow for fast return to service.	Can be applied to a Class IV lining level capable of independently handling internal pressure and external loads.

The technology selection criteria identified by the project team follow the general guidelines below:

- **Maturity.** Novel and emerging technologies that are commercially available are desired. Technologies should be truly novel and more than an incremental improvement over conventional methods (EPA, 2009).
- **Feasibility.** The potential of the proposed technology as a compliance strategy for the site-specific conditions should be identified. The nature of the problem faced in the pipe will ultimately drive technology selection.

- **<u>Complexity</u>.** Technology adaptability to and widespread benefit for small- to medium-sized utilities is desired (EPA, 2009). The complexity refers to the level of training required for the installer, pre- and post-installation requirements, and maintenance requirements.
- **<u>Performance</u>.** This criterion is evaluated based on the capabilities and limitations of the technology and investigation of potential advances over existing and competing technologies. Vendor performance claims will be compared to actual performance in the field.
- **<u>Cost</u>.** Cost of installation (direct cost) and cost for periodic inspection and cleaning (indirect cost) are critical factors. The typical installation cost on a per-unit basis will be provided. Warranties or guarantees on performance should be provided.
- **<u>Environmental</u>.** Technologies may use chemicals or produce waste byproducts that have an unintended impact on the environment or water quality. Technologies that reduce the overall carbon footprint of the project compared to open cut are desired (EPA, 2009).

2.2.1 Overview of Innovative Sewer Main Rehabilitation. Through the course of previous EPA research efforts, it was recognized that many wastewater utilities in the U.S. utilize trenchless rehabilitation technologies (EPA, 2009). However, the majority tends to use cured-in-place pipe (CIPP) and as additional innovative technologies come to the market demonstration of their capabilities is needed. The Battelle team received an agreement from GeoTree Technologies and its parent company Milliken, which developed GeoSpray™ (see Table 2-2), to participate in the EPA Demonstration Program. This rehabilitation technology, which is designed for gravity sanitary and storm sewers, is described in detail below.

2.2.2 Overview of Fiber Reinforced Geopolymer Spray-Applied Mortar. The use of cementitious geopolymer spray-applied mortar has shown potential as a cost-effective means of rehabilitation for gravity sewers. Cementitious linings can be applied to gravity sewers, but the corrosive environment makes the application of OPC and concrete prone to deterioration (EPA, 2010b). To combat the corrosive environment, innovative geopolymer materials have been developed to provide higher material strength and to increase corrosion resistance compared to conventional OPC based mortars. Geopolymer is a term originally coined by Davidovits (1991) to describe a class of cement formed from aluminosilicates. While traditional OPC relies on the hydration of calcium silicates, geopolymers form by the condensation of aluminosilicates. The kinetics and thermodynamics of geopolymer networks are driven by covalent bond formation between tetravalent silicon and trivalent aluminum. The molar ratio of these key components along with sodium, potassium, and calcium have been shown to affect set time, compressive strength, bond strength, shrinkage, and other desired properties.

Milliken's GeoSpray™ material is composed of a proprietary micro-fiber reinforced, dense geopolymer mortar that can be spray-applied. As shown in Table 2-3, the GeoSpray™ product consists primarily of fly ash, sand, aggregate, silica, some OPC, and unspecified proprietary ingredients. GeoSpray™ forms a crystalline structural solution for a high resistance to acids and greater surface durability. Figure 2-1 is a schematic of the GeoSpray™ process, which requires the use of a hopper, high shear mixer, pump, and application unit. The hopper feeds the material to the high shear mixer where water is added to obtain the appropriate water to cement ratio before the freshly mixed product is pumped to the pipe via a black pressure hose. Once applied, the GeoSpray™ cures quickly providing a shortened bypass time, which allows the pipe to be re-established more rapidly than with conventional OPC based mortars. It is resistant to environmental factors such as heat and cold through batch temperature control. It can adhere to both organic and inorganic materials (e.g., properly prepared cement and brick surfaces) and can be used for filling voids and patching.

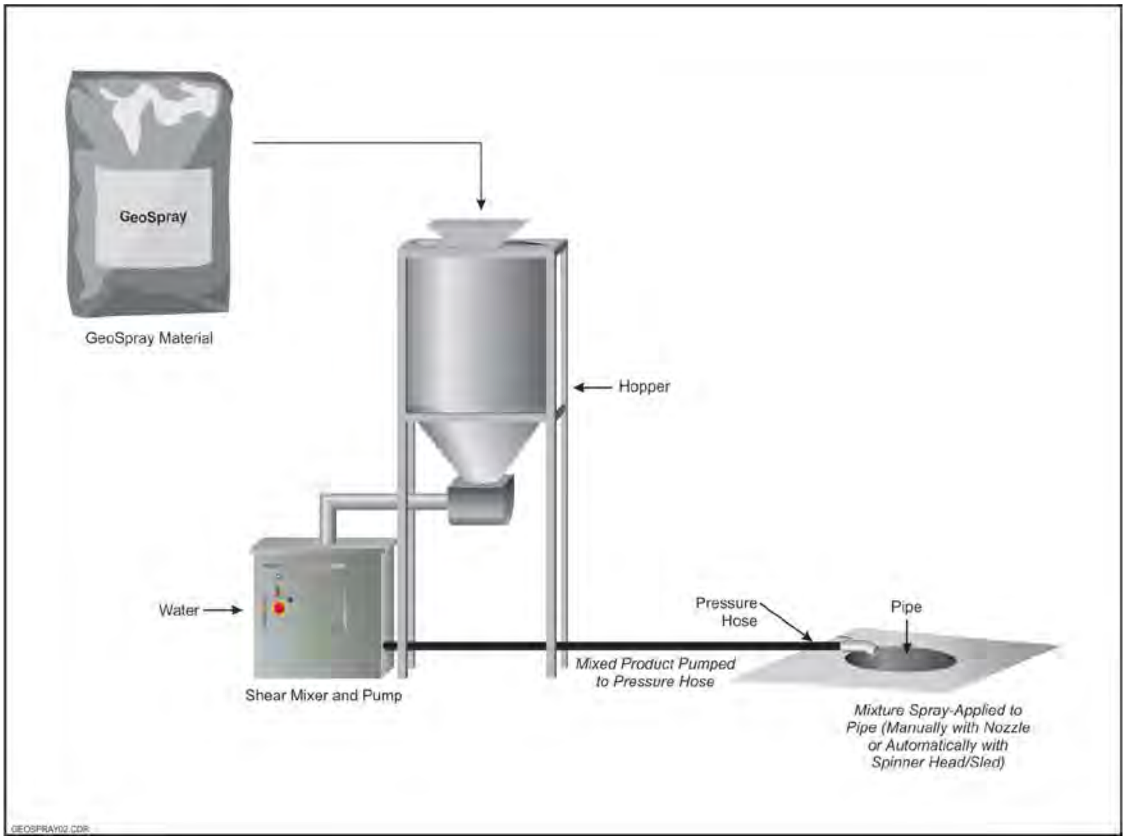

Figure 2-1. Schematic of GeoSpray™ Process

Table 2-3. Chemical Ingredients of GeoSpray™ Material

Chemical Entity/Ingredient	CAS No.
Crushed stone or gravel	N/A
Sand	N/A
OPC	65997-15-1
Proprietary ingredients	N/A
Fly ash	N/A
Crystalline silica	14808-60-7

Milliken's GeoSpray™ is a dark gray mortar that has a dry unit weight of 127.7 pounds per cubic foot (pcf) and a wet unit weight of 139.3 pcf. The largest particle size is 0.3 mm. A 100-lb bag is added with 18 lb of water, which yields 0.86 ft^3 of as spray applied:

- 6.88 ft^2 at a thickness of 1.5 in.
- 10.32 ft^2 at a thickness of 1 in.
- 20.64 ft^2 at a thickness of 0.5 in.

Physical properties for GeoSpray™ are shown in Table 2-4 (Milliken, 2013b).

Table 2-4. Material Properties of GeoSpray™

Property	Standard	Duration	Value
Compressive Strength	ASTM C39/C109	1 Day 28 Days	2,500 psi 8,000 psi
Flexural Strength	ASTM C293 (C78)	7 Days 28 Days	650 psi (1,200 psi) 800 psi (1,300 psi)
Modulus of Elasticity	ASTM C469	1 Day 28 Days	3,000 ksi 6,500 ksi
Bond Strength	ASTM C882	1 Day 28 Days	1,300 psi 2,500 psi
Set Time	ASTM C807	Initial Set Final Set	60-75 minutes 90-110 minutes
Freeze Thaw Durability	ASTM C666	300 Cycles	100% Zero loss
Sulfate Resistance (% expansion)	ASTM C1012	6 weeks	0.011%
Shrinkage	ASTM C1090	28 Days	0.07%
Tensile Strength	ASTM C496	28 Days	750 psi
Abrasion Resistance	ASTM C1138	6 Cycles @ 28 Days	0.67% Loss
Chloride Ion (CI) Penetration by Ponding	ASTM C1543	90 Days Ponding	0.014% CI @ 55-65 mm

The GeoSpray™ lining is designed for use in storm and sanitary sewer pipe rehabilitation applications in diameter ranges of 30 to 200 in. (750 to 5,000 mm). The renewal length will vary depending on the pipe diameter and required thickness and is typically ranges from 100 to 300 ft (30 to 100 m) per day for a 1.5-in. (38 mm) thick lining. Bends of any degree are feasible, but straight runs are preferred. Laterals are plugged prior to lining and do not require reconnection, only the removal of the plugs. The lining is typically sprayed at a minimum thickness of 1.5 in. (38 mm) for structural repairs or 0.5 in. (12.5 mm) for corrosion protection. A 0.5-in. (12 mm) thickness would typically be applied if a lining is designed for additional corrosion protection of a structurally sound pipe. The work time is 60 to 90 minutes at 80°F (27°C). The field demonstration program will allow evaluation of the main benefits claimed and limitations cited by the manufacturer as follows (Milliken, 2013a):

Main Benefits Claimed

- Restores structural integrity for fully-deteriorated pipes
- High flexural bond and ultimate strength
- Low permeability
- Adheres to various surfaces (i.e., brick, rock, concrete, corrugated metal, and cast iron)
- Surface does not need to be dry (but no free water can be present; see limitations below)
- 60 to 90 minute work time
- Adapts to any shape, including bends, curves, and angles
- Non-clogging and highly flowable/pumpable for ease of use in spin or spray casting
- Non-abrasive nature leads to spinner heads, hoses, and equipment requiring less repair and maintenance

- Easier to clean from hoses and equipment
- Green material made from natural mineral polymers and 50% recycled industrial waste content
- Styrene and bisphenol A (BPA) free and contains no leachable toxins when subjected to the EPA Toxicity Characteristic Leaching Procedure (TCLP)
- Trenchless process with relatively small aboveground footprint and access requirements compared to open cut or CIPP

Main Limitations Cited

- Requires a surface free of all dirt, grit, roots, grease, sludge, and debris
- Must be applied to a damp surface with no free water
- Temporary stoppage of flow or bypass may be required
- During cold weather conditions, the geopolymer cannot be placed when the temperature is 37°F and falling without additional measures to maintain its temperature above that threshold (e.g., heaters and thermal breaks)
- During hot weather conditions, chilled water may be used to mix the geopolymer to maintain its temperature below 90°F
- Materials contain highly alkali cement and chemicals that may cause eye and skin sensitization

2.2.3 Design of Cementitious Geopolymer Spray-On Lining. Appendix A includes the design specifications for the Houston, Texas field demonstration site. The design approach is based on Young and Budynas (2002) for two cases: (1) round or oval pipes; and (2) square and rectangular pipes. Each case can be designed for either a partially or fully deteriorated pipe. The first design equation calculates minimum lining thickness based on resistance to hydrostatic buckling for case (1) as follows:

$$t_{pd}{}^{2.5} = N\frac{P_w l r^{1.5}(1-\mu^2)^{0.75}}{0.807E} \quad \text{(Equation 1)}$$

t_{pd} = minimum thickness required, partially deteriorated pipe (inches)
P_w = external hydrostatic pressure due to groundwater (psi) = $0.433(H_w + D/12)$
H_w = height of ground water above pipe (feet)
D = inside diameter of the host pipe (inches)
l = effective length caused by surface traffic wheels (inches)
r = inside radius of the host pipe (inches) = $D/2$
μ = Poisson's ratio of concrete (0.15)
N = safety factor (2.0 default)
E = initial long-term modulus of elasticity (ksi) = 2,000 (Vipulanandan and Moturi, 2010)

The second design equation calculates minimum lining thickness for a fully deteriorated pipe based on resistance to hydrostatic buckling and soil and live loads for case (1) as follows. The design for this project was provided by a registered Professional Engineer and is shown in Appendix A.

$$t_{fd}{}^{2.5} = N\frac{W_t l r^{1.5}(1-\mu^2)^{0.75}}{0.807E} \quad \text{(Equation 2)}$$

t_{fd} = minimum thickness required, fully deteriorated pipe (inches)
W_t = total loads (psi) = $P_w + W'_s$

P_w	=	external hydrostatic pressure due to groundwater (psi) = $0.433(H_w + D/12)$
H_w	=	height of ground water above pipe (feet)
D	=	inside diameter of the host pipe (inches)
l	=	effective length caused by surface traffic wheels (inches)
W'_s	=	soil and live loads (psi) = $W_c/12/D$
W_c	=	loads on pipe (lb/ft) = $C_d \times w_s \times (B_d/12)^2$
C_d	=	load coefficients $= \frac{1-e^{-2k\mu'} \times \frac{H}{B_d}/12}{2k\mu'}$
ku'	=	soil coefficients
H	=	depth of cover from ground surface to top of pipe (feet)
B_d	=	width of trench (inches) = D + 24 in.
w_s	=	unit weight of soil (pounds/cubic ft)
r	=	inside radius of the host pipe (inches) = $D/2$
μ	=	Poisson's ratio of concrete (0.15)
N	=	safety factor (2.0 default)
E	=	initial long-term modulus of elasticity (ksi) = 2,000 (Vipulanandan and Moturi, 2010)

2.2.4 Installation of Cementitious Geopolymer Spray-On Lining. The following is a brief overview of the major steps involved in the application of a geopolymer spray-on lining:

- Site preparation including permits and traffic control
- Pipe cleaning and preparation
- Pre-lining inspection
- Sealing of active leaks
- Repair of invert and large voids
- Application of geopolymer spray-on lining
- Post-lining inspection
- Site cleanup and disposal of waste

2.2.5 QA/QC of Cementitious Geopolymer Spray-On Lining. The vendor's recommended QA/QC procedures for the acceptance and certification of the GeoSpray^{TM} product are included in Appendix B. The QA/QC steps that should be used to evaluate the performance and proper application of the lining include:

- **Material Packaging.** Material should be delivered in packaged and sealed condition and free of moisture. Materials that have been exposed to moisture or have visible damage to the packaging should not be used.

- **Proper Surface Preparation.** The pipe surface shall be thoroughly cleaned and made free of all foreign materials including dirt, grit, roots, grease, sludge, and all debris or material that may be attached to the wall or bottom of the pipe.

- **Seal Active Leaks.** The work consists of hand applying a dry quick-setting cementitious mix designed to instantly stop running water or seepage in all types of concrete and masonry structures. The contractor should apply an approved quick-setting mortar in accordance with manufacturer's recommendations.

- **Invert Repair.** The work consists of mixing and applying GeoSpray^{TM} to fill all large voids and repair inverts prior to spraying or centrifugally casting the pipe. For invert repairs, flow must be temporarily restricted by inflatable or mechanical plugs prior to cleaning.

- **Equipment.** The application equipment should:

- Have a mortar feed, high shear mixer, and pump as a single operating unit.
- Have sensors that maintain uniform operation of each function.
- Have a visible display for the rate of water addition. The water/cement ratio must be maintained below 20%.
- Measure the back pressure on the discharge side of the pump. The back pressure should be maintained below 25 bars.
- Have a spinner head capable of spraying in a clockwise and counter clockwise direction.
- Have a spinner head attached to a reciprocating mechanism to layer the materials.
- Have a retraction system capable of pulling the spinner head at a minimum rate of 4 in. per minute with no more than +/-5% tolerance.
- Have a retraction system with a visible display that monitors the rate of retraction.
- Monitor and record the rate of retraction, material discharge volume, dry material usage, and length of pipe covered on a daily basis.
- Be in clean and good working condition and maintained to manufacturers' standards.
- Be free of blockage or debris.

- **Lining Thickness.** The lining thickness is the key design parameter and should be verified during the spray-on lining application through continuous monitoring by the operator of the speed of the sled (e.g., rate of retraction) and the volumetric rate of application by the spray head, which is measured with a flow gauge. This is computed as the volume of material sprayed at each location along the pipe to ensure the minimum thickness is met. If the lining material is sprayed and hand troweled, the thickness should be verified in the pipe with a thickness gauge. In addition, the total quantity of GeoSpray™ placed on a daily basis is recorded and compared to the linear feet of pipe covered and pipe diameter to estimate the overall thickness applied.

- **Lining Sample Properties.** The material properties should be measured and compared to the manufacturer and design minimum requirements (Table 2-4). The tests required to be performed for acceptance and certification of the product by the vendor are summarized in Appendix B and include the compressive strength (ASTM C109), slump (ASTM C143), and temperature of the batch water, dry powder, ambient air in pipe, ambient air in mixer, and sampled material (ASTM, 2012b). It is recommended that testing should occur at a minimum of one test for every 10 cubic yards or 32,000 lbs of material placed. In addition, testing should occur on the first day and last day of spraying and at a minimum every other day in between. The person responsible for collecting the test samples should be an American Concrete Institute (ACI) Certified Concrete Field Testing Technician, Level 1.

2.3 Site Selection Approach

To ensure that the field demonstration results are acceptable and useful to the user community, the field demonstration site and the condition of the selected test pipe had to be representative of typical applications for the geopolymer technology. Therefore, the operational conditions (e.g., pipe type, structural integrity, etc.) and environmental conditions (i.e., subsurface conditions) of potential host sites had to be appropriate for the technology. Another important consideration in site selection was the wastewater utilities' willingness to participate in the study.

2.3.1 Site Selection Factors. Site selection was largely dependent on the utilities' rehabilitation needs, their understanding of the condition of pipe assets within their system, the availability of time and resources to contribute to the study, and a strong motivation to advance the state of emerging and innovative technologies. The site selection process also depended on the willingness of local stakeholders (such as the city, county/parish, neighborhood residents) to host a field demonstration that may involve surface disruption in their right-of-ways or temporary bypassing of their utilities. The following factors were considered in the site selection process for the demonstration program:

- **Utility Commitment.** Is the utility willing to use an emerging rehabilitation technology and to provide the required time and resource commitments to the project?
- **Perceived Value.** What is the number of interested utility participants? Is the technology and/or test pipe rehabilitation need of national-scale versus regional-scale interest?
- **Regulatory/Stakeholder Climate.** Are local/state officials willing to work with the utility concerning requirements to permit use of an emerging technique? Will the local stakeholders consent to the potential disruption caused by the construction activities?
- **Test Pipe and Site Conditions.** Are the test pipe operating and environmental site conditions suitable when compared to the technology's application limitations?
- **Site Access and Safety.** Are site conditions (i.e., site access, space requirements, etc.) suitable for a safe and secure field demonstration?

The site selection process for this demonstration involved employing a collaborative approach with the technology developer and installer in an effort to identify candidate sites for the planned demonstration study. As part of this process, a dialogue with Milliken and Inland Pipe Rehabilitation (IPR) was initiated. Milliken indicated that GeoSpray™ was being planned for a project in Houston on a critical main entering into the wastewater treatment plant (WWTP). The overall responsibilities of the technology vendor (Milliken) and installer (IPR) were defined as follows:

- Provide vendor specifications, design, and installation information for the technology
- Provide the technology for evaluation during the field demonstration
- Provide equipment and labor needed for the duration of the demonstration
- Provide data from the field demonstration to verify performance and cost of the technology
- Review and provide comments on the draft field demonstration report

2.3.2 Site Description. The City of Houston is located in southeastern Texas near the Gulf of Mexico. The city has an estimated population over 2.1 million and is the fourth largest city in the U.S. The City of Houston Public Works Wastewater Operations Division operates and maintains 40 WWTPs treating an average of 277 million gallons per day (MGD) and 6,250 miles of sewer pipelines ranging in size from 6 in. to 144 in.

The test pipe used for this demonstration was a fully deteriorated 60-in. RCP sanitary sewer pipe approximately 160 ft long and 25 ft deep. The main was located under the White Oak Bayou just south of Tidwell Road in northwest Houston (see Figure 2-2 with pipe alignment highlighted in red). The upstream manhole was located in the backyard of a house on Oak Shadows Drive and the downstream manhole ended at the Northwest WWTP located on Magnum Road.

GeoSpray™ was selected to rehabilitate the 60-in. RCP sewer main primarily because of the need for a shortened bypass time for this critical pipe leading into the WWTP. Also, the 25-ft depth of the pipe and other site-specific conditions precluded open cut excavation. The City of Houston selected GeoSpray™ because of positive past experience on rehabilitation projects within their collection system where the pipe needed minimal capacity reduction and site excavation.

Figure 2-2. Aerial Photo of Demonstration Site Location

Section 3.0: GEOPOLYMER DEMONSTRATION

This section outlines the activities involved with the GeoSpray^{TM} field demonstration including site preparation, technology application, post-demonstration field verification, sample collection, and site restoration.

3.1 Site Preparation

To successfully execute the planned demonstration, various site preparation activities were required. These activities included: installation of the temporary bypass system; closed-circuit television (CCTV) inspection; cleaning of the pipe; and repair of any infiltration prior to lining. Details relating to these site preparation activities are provided in this section.

3.1.1 Safety and Logistics. Throughout the demonstration project, the bypass access manhole (or Manhole #1) was secured. It was located upstream from the lining access manhole at the intersection of Oak Shadows Drive and Deepcreek Lane. Manhole #1 was surrounded with barriers around the clock and the bypass pipes were secured behind temporary fencing (Figure 3-1). IPR was responsible for traffic control throughout the demonstration. The demonstration took place over the course of two weeks from finishing the bypass setup (week of April 22) to the final day of spraying (May 7). A typical day began around 7:00 a.m. and activities each day were normally completed by 7:00 p.m. (12-hour duration).

Figure 3-1. Barriers Surrounding Manhole #1

The Battelle team had one staff member on site each day for the majority of the site preparation activities and three staff members were on site for the first full day of spray lining to gather samples. The Battelle team maintained coordination with IPR throughout the demonstration project to ensure that field data were collected as planned in the QAPP. Level D personal protective equipment including hard hats, safety glasses, steel-toed shoes, and safety vests were required for all site visitors.

3.1.2 Installation of Bypass. IPR laid out the bypass prior to the week of April 22, 2013. The bypass system included three 16-in. high density polyethylene (HDPE) bypass pipes, which converged into two pipes (Figure 3-2, left) before heading downstream. The bypass piping had to run parallel to an open channel, which is connected to the White Oak Bayou, before crossing the channel on a bridge and then heading to the WWTP (Figure 3-2, right). Three large 50-horsepower (hp) pumps ran continually to divert the flow from the 60-in. collection main to the WWTP (Figure 3-3).

Figure 3-2. Bypass Pipes Converging (left) and Laying Parallel to an Open Channel (right)

Figure 3-3. Bypass Pumps at Manhole #1

3.1.3 Pipe Cleaning and Inspection. Cleaning and inspection took place over the course of four days (Monday through Thursday). Cleaning began on Monday, April 22 by launching the cleaning nozzle from the downstream manhole (Manhole #3) to the upstream lining access manhole located in a backyard (Manhole #2 in Figure 3-4). Cleaning was accomplished using water from a self-contained water truck that was capable of holding more than 500 gallons of water and providing the compressed air needed for pressure washing to clean all foreign material attached to the pipe surface (e.g., dirt, grit, sludge, etc.). Only water was used; it was not necessary for this project to employ detergent or muriatic acid (as recommended if significant grease and oil are present). The exact volume of wash water could not be tracked because the water was discharged directly into the sanitary sewer for disposal. During the cleaning, approximately 6 cubic yards of debris was removed from the pipe.

Figure 3-4. Manhole #2 Located in a Backyard

The pre-lining CCTV inspection showed the 60-in. RCP host pipe was severely deteriorated with rebar exposed and several infiltration locations gushing water prior to lining (Figures 3-5 and 3-6). Table 3-1 presents the pre-lining CCTV inspection results, which confirmed the fully-deteriorated condition of the host pipe.

Table 3-1. Pre-Lining CCTV Inspection

Item	Location	Distance (ft)	Comment
Manhole #2	N/A	0	Upstream Manhole
Infiltration	12:00 o'clock	48	Water seeping in
Infiltration	12:00 o'clock	79	Water seeping in
Infiltration	12:00 o'clock	92	Water seeping in
Infiltration	12:00 o'clock	101	Water seeping in
Infiltration	12:00 o'clock	105	Water seeping in
Infiltration	3:00 o'clock	135	Water gushing in
Metallic Object	7:00 o'clock	139	Unidentified metallic object
Infiltration	Multiple	143-153	Water gushing in multiple locations
Rebar Exposed	Multiple	0-160	Rebar exposed throughout the pipe
Manhole #3	N/A	160	Downstream Manhole

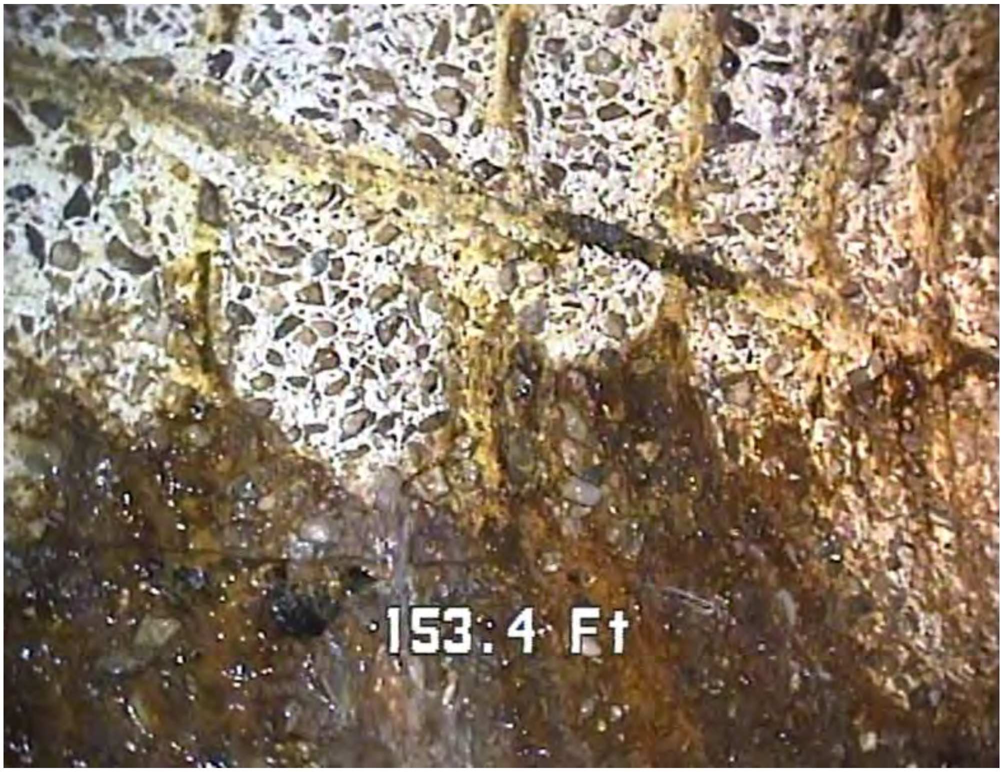

Figure 3-5. Typical Condition of the Host Pipe Prior to Lining

Figure 3-6. Infiltration Entering the Host Pipe Prior to Lining

3.1.4 Infiltration Repair. After cleaning and debris removal, several infiltration locations had to be repaired prior to lining because the GeoSpray™ material cannot be applied to a surface with free water. The contractor used a moisture activated chemical grout from Avanti (AV-202) which is designed to seal active water leaks in large cracks in concrete structures (Figure 3-7). The grout was applied using a spray nozzle and took place on Friday and Saturday prior to lining. The repairs took longer than expected due to flows spilling into the manhole at the WWTP that could not be shut off, which delayed the time workers could get into the pipe. The uncontrolled flows were part of the WWTP system that was not controlled by the contractor, but by the WWTP and was not related to the project bypass system. A total of 40 gallons of grout was used to plug the various infiltration locations.

Figure 3-7. Chemical Grout Material

3.2 Technology Application

The geopolymer lining of the test section took place between Saturday, April 27 and Tuesday, May 7, 2013. The lining process included: loading the dry material into a hopper and mixing the material with water; conveying the fresh mixed product to spray head; spraying; and finishing.

3.2.1 Technology Application Equipment and Process. The GeoSpray™ lining process requires the use of several pieces of equipment including the hopper, high shear mixer, pump, and application unit. The hopper is an elevated storage unit into which powdered material is emptied. The bagged material was delivered to the site in 2,000 lb bags, which were kept dry under a tarp. None of the bags had any visible damage to their packaging. The hopper serves the purpose of a temporary storage and material dispensing/feeding unit throughout the operations (Figure 3-8, left). The high shear mixer (Figure 3-8, right) was used since the water to cement ratio was low and the final product was expected to gain viscosity during mixing. The freshly mixed product was pumped to the pipe via a black pressure hose (Figure 3-9, left) approximately 105 ft from the pipe and spray applied to the wall via a spray nozzle (Figure 3-9, right). After spray, the material was smoothed by hand using a trowel. Typically, GeoSpray™ is manually applied in situations of severe deterioration where water is infiltrating and void filling is necessary. In this case, the pipe had less than half of its original pipe wall thickness in the majority of the pipe and had severe infiltration as the pipe was beneath an active bayou. When a pipe wall is compromised, as in this instance, and infiltration is heavy, manual spraying provides the advantage of being able to address serious infiltration locations by hand applying a thicker liner in a single pass. The material was sprayed and trowelled within 30 minutes of being mixed, which is within the work time of 60 to 90 minutes. There were no significant operational issues or downtime noted for the equipment during spraying operations when the research team was on site on April 27, 2013. No issues were noted with the maintenance or cleaning of spray heads, hoses, or other equipment when the research team was on site on April 27, 2013. However, on the final day of spraying, some operational issues were noted by the contractor in the spray logs for May 7, 2013 related to the replacement of the spinner bearings, gasket repairs, hose repairs, mixing tube issues, and hopper repair.

Figure 3-8. Hopper (top left) and High Shear Mixer (top right) and View of Application System

Figure 3-9. Black Pressure Hose (left) and Spray Nozzle (right)

3.2.2 Sample Collection. Each day prior to spraying, an independent lab would collect samples for QC checks. Prior to the first spraying on Saturday, April 27, the research team also collected samples as described in the QAPP (Figure 3-10). This included five cylinders for compressive strength via ASTM C109 (2008a), five beams for flexural testing via ASTM C78 (2010a), three cylinders for modulus of elasticity via ASTM C469 (2002), and a small cylinder for set time via ASTM C191 (2008b). The samples were collected during a light rain and it was suspected that this additional moisture negatively impacted the test results (see Section 4.4 for further discussion).

During the development of the QAPP, the product manufacturer stated that bond strength was typically measured at each site via ASTM C882 (2005) and that the research team would be able to verify the results. For this reason, it was included as a critical measure in the QAPP. However, during the demonstration, the contractor informed the research team that bond strength is rarely measured in the field unless specifically stated in the contract. For this project, it was not stated in the contract and therefore the bond strength was not measured by the contractor or the research team. It is recommended that the bond strength be measured at future project sites as a key QC measure.

Figure 3-10. Collecting Fresh Material from the Pressure Hose (left) and Preparing Samples (right)

3.2.3 Geopolymer Spraying. The geopolymer spraying operation took a total of four days, and the entire project was conducted over a period of 11 days (see Table 3-2). The contractor estimated that a 2-in. thick coating was sprayed along the entire 160-ft section over the course of the first three spraying days (i.e., April 27, April 30, and May 1) and then an additional 1-in. thick coating was sprayed the entire length of the pipe on the final spraying day (May 7) for a total target lining thickness of 3-in. The minimum design thickness was 1.88 in. (see Appendix A). The calculated lining thicknesses for each day of spraying varied from the contractor estimates as discussed in Section 4.4. After each pass, the hoses were removed and the machine and hoses were cleaned with soap and water. The contractor spray logs did not keep track of the water/cement ratio; however, this was checked via a slump test, which was within the typical range (i.e., less than 1 in.) each day of spraying (see Table 3-2). Since the spray sled was not used, those related QC parameters such as back pressure and rate of retraction of the sled were not tracked. The water addition rate and pump speed were tracked at the beginning, middle, and end of each spray run (see Table 3-2).

Table 3-2. Summary of Geopolymer Spraying Application Data

Date	Duration (min.)	Dry Material (lbs)*	Distance (ft)	Thickness (in.)*				
4/27/13	80	6,000	~30	2.0	160-162	8	105	0.25
4/30/13	190	12,000	~70	2.0	180-200	9-10	140	0.25
5/1/13	160	12,000	~60	2.0	200	10	210	0.25
5/7/13	300	18,000	160	1.0+	179-182	10	225	0.25

* Contractor provided estimates of lining thickness and dry material per verbal communication from vendor to Battelle at time of project.

3.3 Post-Demonstration Field Verification

The post-lining inspection via CCTV showed the rehabilitated pipe to be free of infiltration, with no signs of steel reinforcement rebar or cracking. Figure 3-11 shows the lined pipe prior to spraying the final 1-in. coating and Figure 3-12 shows the fully lined pipe. The research team reviewed the post-lining CCTV taken the day after the final coating was applied and no significant defects in the coating were noted.

Figure 3-11. Lined Pipe Prior to Final 1-in. Coating

Figure 3-12. Post-Lining Inspection of Fully Lined Pipe

Section 4.0: DEMONSTRATION RESULTS

This section presents the results of the field demonstration including an assessment of the technology based on the evaluation metrics defined in Section 2.1 and Table 2-1. The specific metrics that were used to evaluate and document the application of the GeoSpray™ product for the rehabilitation of a large diameter wastewater main are described below.

4.1 Technology Maturity

While the spray lining process is classified as conventional, the GeoSpray™ lining product is classified as innovative in terms of maturity based on its formulation (i.e., geopolymer) and usage. The product is a sustainable green material in terms of environmental benefits (i.e., reduced carbon footprint compared to OPC) and the use of recycled industrial byproducts (e.g., fly ash) for as much as 50% of the raw material.

The manufacturer reports that GeoSpray™ has been applied to over 150 structures in 11 states including California, Florida, Georgia, Louisiana, Michigan, North Carolina, Ohio, South Carolina, Tennessee, Texas, and Washington. Representatives from the City of Houston considered GeoSpray™ to be a useful technology option in their tool box. City representatives said they have had positive experiences in various locations, especially for heavily deteriorated pipes, odd shape pipes, and pipes that needed minimal capacity reduction and site excavation. They noted that intensive bypass is required, but they have not had any notable issues.

4.2 Technology Feasibility

The GeoSpray™ lining was designed to provide a structural solution to the failure of a 60-in. RCP wastewater pipe. The host pipe was 25 ft. deep and was located underneath an open channel bayou, which essentially precluded an open cut replacement approach. The technology was found to be feasible and met the rehabilitation requirements by providing a monolithic, structural lining within the fully-deteriorated host pipe. The post-lining inspection via CCTV showed the rehabilitated pipe to be free of infiltration, with no signs of steel reinforcement rebar or cracking, and no significant defects noted in the GeoSpray™ lining the day after application.

The installation process was also found to be suitable to the conditions of the host pipe. Proper adherence of the cementitious liner to the host pipe depends on several factors such as cleaning of the host pipe prior to the liner application to remove loose debris and the elimination of any standing water or free water on the pipe surface. For this demonstration, the cleaning process was found to be satisfactory in preparing the surface as noted in the pre-lining CCTV inspection and a moisture activated chemical grout was used to successfully seal active infiltration areas within the host pipe. During the demonstration, no challenging situations were encountered outside of flow control obstacles at the WWTP, which were not directly related to the technology implementation. The flow control issues did cause a delay in the initiation of the spray lining process until the matter could be resolved and standing water was removed from the pipe. The severe deterioration and infiltration in the host pipe also prevented the use of the sled and required the lining to be hand sprayed. In addition, moderate temperatures are required during the application process (between 37°F to 90°F). The ambient temperature during the field demonstration ranged from 62°F to 87°F and all of the process temperatures monitored also conformed to this requirement (see Section 4.4).

4.3 Technology Complexity

The spray lining process is not a complex procedure; therefore, it is conceivable that contractors and/or wastewater utility personnel could be trained to install this product. The vendor recommends that the supervisor and equipment operator should have a minimum of 80 hours of training on the materials, equipment, and process prior to deployment in the field. The dry cementitious powder comes in a bag, which is then mixed with water and sprayed just as any other commercial product. The typical lining crew throughout the project included one foreman and five to six laborers. During the actual lining, the foreman operated the mixer, while two laborers remained aboveground. Three laborers were also located in the pipe, with one spraying and two finishing the surface with trowels. In terms of operation and maintenance, repairs of the spray equipment were required on one out of four days of spraying, but lining operations were able to proceed as scheduled after the repairs were made. In terms of QA/QC, the person responsible for collecting tests samples and performing tests should be an ACI certified field testing technician who has experience in following ASTM procedures in handling, storing, and transporting the samples.

4.4 Technology Performance

The technology performance was assessed through the ability to achieve the desired product thickness within the host pipe and through the collection of samples to measure key properties of the GeoSpray^{TM} material as prepared on site during the field demonstration. Since the sled was not used due to the heavy deterioration and infiltration of the pipe, parameters such as the retraction rate of the sled could not be tracked to determine the field applied thickness. Instead, an estimate was obtained based on the volume of dry material sprayed and the length of pipe covered each day (Table 4-1). The assumptions made to make this calculation are that the length of pipe sprayed each day had full 360° coverage of lining and that the entire material placed into the hopper was used for spraying. For example, on 4/27/13, 6,000 lbs of material was sprayed inside the 60-in. pipe for a distance of 30 ft. The product yield is given to be 0.86 ft^3/100 lbs of dry material, resulting in 51.6 ft^3 of material being sprayed (6,000 x 0.86/100). The area of pipe sprayed is the circumference of the 60-in. (5 ft) pipe, which is 188 in (15.7 ft) by the length sprayed (15.7 ft x 30 ft), which is 471 ft^2. The calculated thickness is then given by dividing the yield by the area of pipe sprayed (51.6 ft^3 by 471 ft^2), which 0.11 ft or 1.3-in. Based on these calculations, the field applied thickness was approximately 3.3 in. total (see Table 4-1), which was well above the design value of 1.88 in. (see Appendix A). It should be noted that the contractor estimated lining thickness provided on the spray logs appeared to be an overestimate compared to the calculated thickness for the first three spraying days (from 50% to 75% higher). The contractor estimated thickness on the fourth day of spraying was underestimated (by 100%). Overall, the total calculated thickness of 3.2 to 3.4 in. was higher than the contractor estimated total thickness of 3.0 in. for the entire 160-ft application. Given the importance of the lining thickness to the rehabilitation design, it is suggested that the "as installed" lining thickness be checked in the field on a regular basis to verify the calculated results and the contractor estimates.

Table 4-1. Summary of Spray Lining Thickness Estimates

Date	Dry Material (lb)*	Distance (ft)			
4/27/13	6,000	~30	2.0	1.34	3.4
4/30/13	12,000	~70	2.0	1.15	3.2
5/1/13	12,000	~60	2.0	1.34	3.4
5/7/13	18,000	160	1.0+	2.06	N/A

*Contractor provided estimates of lining thickness and dry material at time of project.
N/A = not applicable

The results of the laboratory evaluation compared with the manufacturer stated claims are shown in Table 4-2. The testing results are tabulated both for the results from this study and from the third-party laboratory contracted as part of the project for the City of Houston (see Appendix C). The testing results are then compared to the design specifications as discussed below.

Table 4-2. GeoSpray™ Performance Data Comparison

Property	Standard	Result		
Field Applied Thickness	Young and Budynas (2002)	3.3-in.	N/A	1.88-in.
Compressive Strength	ASTM C109 (28 day)	7,881 psi	8,635 psi	8,000 psi
Flexural Strength	ASTM C78 (28 day)	641 psi	N/A	1,300 psi
Modulus of Elasticity	ASTM C469 (28 day)	6,500 ksi	N/A	6,500 ksi
Set Time (Final Set)	ASTM C191	75 minutes	N/A	100 minutes (per ASTM C807)
Slump	ASTM C143	1-in.	0.25-in.	1-in.
Density	ASTM C138	134 lb/ft^3	N/A	139.3 lb/ft^3
Bond Strength	ASTM C882 (28 day)	N/A	N/A	1,600 psi

Compressive strength is a material's maximum resistance to axial loading and is the most important property of hardened cementitious materials. The compressive strength was measured per ASTM C109 (2008a; Figure 4-1, left) for two cylinders at 7 days, 14 days, and 28 days. The 28-day strength was approximately 98.5% of the manufacturer's stated strength (see Figure 4-2). The third-party test results averaged from three days of spraying and sample collection showed the compressive strength exceeded the manufacturer's stated strength at 28 days by 8% (see Appendix C). Since the third-party test results were above the manufacturer's stated strength, the slightly lower 7,881 psi measured by the research team was not deemed to be a significant issue.

Flexural strength and modulus of elasticity are less important for cementitious materials, but must still meet minimum requirements to resist tensile forces. The flexural strength was measured per ASTM C78 (2010a; Figure 4-1, right) for two beams at 14 and 28 days. The 28-day strength was approximately 50% of the manufacturer's stated strength. The modulus of elasticity of the beams was approximately 95% of the manufacturer's stated strength. Third-party flexural tests were not required.

Figure 4-1. Compressive Testing (left) and Flexural Testing (right)

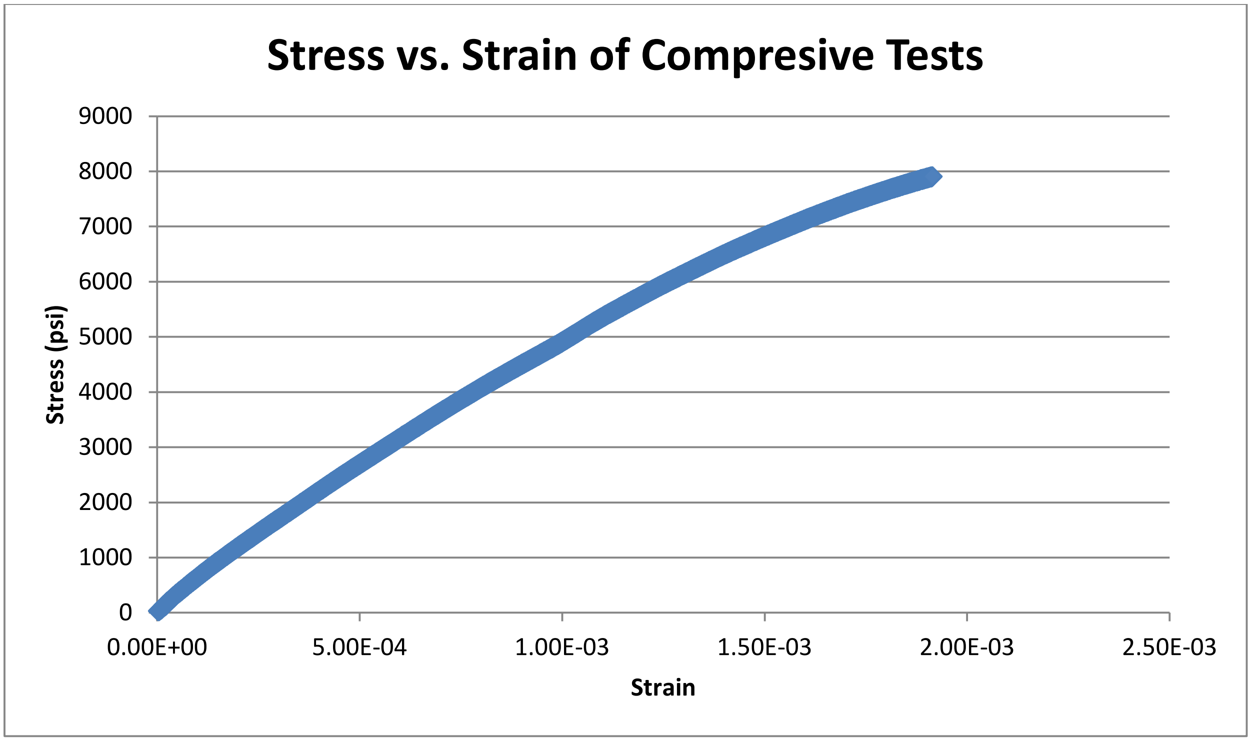

Figure 4-2. Stress/Strain Curve for Compressive Samples

The final set time was measured per ASTM C191 (2008b; Figure 4-3, left) for five cubes and was 75% of the manufacturer stated set time of 100 minutes. By comparison, shotcrete typically can have final set times in the range of 4 to 7 hours, which can be shortened depending on the presence of certain admixtures (Belie et al., 2005). The material slump per ASTM C143 (2010b; Figure 4-3, right) was within the standard range (e.g., <1.0) and was used to verify that the material had the proper water/cement ratio. Slump tests are used as a measure of batch variability (uniformity) and changes in slump can indicate variability in the batching process. The slump values were measured at 0.25 in. based upon third-party test results across all four days, which suggests a fairly uniform preparation process across each batch (see Appendix D). The slump value of the sample collected by the research team was 1.0 in., which was within the specification of 1.0, but indicates a potential difference in the batch from the materials tested by the third party.

Figure 4-3. Set Time Testing (left) and Slump Testing (right)

In general, the samples collected by the research team tested under the manufacturer stated claims. Based on the 3.6% lower than expected density of the GeoSprayTM mixture at 134 lb/ft^3 compared to the design specification of 139 lb/ft^3, it is hypothesized that this could be attributable to the light rain experienced during sample collection and preparation. It is also believed that the rain had no impact on the material sprayed in the pipe as the mixer was covered during the installation. The average third-party test results for compressive strength were above the manufacturer stated claim. Additionally, the material is designed for spraying; therefore, pouring in the field without a shaker table can create voids, which might also impact this testing. Current standards only require the use of tamping rods, which may or may not be sufficient for eliminating voids in the samples. The use of a shaker table in the field is recommended as a future practice to minimize voids. The results of the QC testing from the contractor's third-party showed the material to be above the design strength requirements (see Table 4-1).

Temperatures were monitored by the third-party testing lab during the installation process to ensure that they remained within the installation range (i.e., 37°F to 90°F) as summarized in Table 4-3 (see third-party reports in Appendix D).

Table 4-3. Temperature Monitored During Installation

Property				
Batch Water	62°F	51°F	50°F	50°F
Dry Powder	84°F	73°F	78°F	80°F
Ambient within Pipe	77°F	79°F	74°F	79°F
Ambient at Mixing Point	68°F	83°F	76°F	76°F
Sampled Material	84°F	87°F	82°F	80°F

4.5 Technology Cost

The cost to structurally rehabilitate a section of pipe is dependent on a wide variety of variables. These common variables include: pipe diameter, host pipe material, length of pipe to be rehabilitated, pipe condition including corrosion and/or ovality, the amount of cleaning required, the amount of active infiltration, pipe depth, location of access points, and the physical forces on the pipe, including water, soil and traffic loads. This list can be expanded to include limited site access, limited hours of operation, operating in environmentally sensitive areas, along with other site-specific considerations. Other important variables include: location of the project, traffic control concerns, and the largest variable being the amount and type of bypass pumping required. Remote sites that require equipment and personnel to travel long distances can also impact pricing. Locations that require a high degree of traffic control up to and including police officers to direct traffic also increase pricing.

Bypass pumping on large-diameter pipe rehabilitation projects like this can typically be the largest expense of the project. With the large amount of variables associated with each individual project, the contractor provided the following information as a general guideline for structurally rehabilitating a 60-in. RCP sewer main. The costs associated with projects similar to this range from $400 to $600 per linear foot. As stated above, many factors other than the actual lining costs can greatly impact pricing.

4.6 Technology Environmental Impact

Cleaning was accomplished using water from a self-contained water truck that was capable of holding more than 500 gallons of water and providing the compressed air needed for pressure washing to clean all foreign material attached to the pipe surface (e.g., dirt, grit, sludge, etc.). During the cleaning operation, all of the water used was discharged into the bypass manhole and did not require additional processing. The exact volume of wash water could not be tracked because the water was discharged directly into the sanitary sewer for disposal. During the cleaning, approximately 6 cubic yards of debris was removed from the pipe. Since excavations were not required for this project, no soil required off-site disposal. This greatly reduced the carbon footprint of the project when compared to a traditional open cut project. To estimate the carbon footprint, the tool known as e-Calc was used (Sihabbudin and Ariaratnam, 2009). The e-Calc inputs are shown in Figure 4-4.

Equipment Details							Fuel Details		Project Details		
Name	Model	Power (hp)	Model Year	Engine Tech.	Useful Hours	Cum. Hrs Used	Type	Sulfur (%)	Representative Equipment Cycle	Power Used (%)	Use (hrs)
JCB Handler	510-56	114	2005	Tier 2	5000	50	Diesel	0.33	Tractors/Loaders/Backhoes	90	20
Komatsu Track Hoe	PC200 HD	155	2005	Tier 2	5000	50	Diesel	0.33	Tractors/Loaders/Backhoes	90	4
Hertz Pump	Pioneer Prime	50	2005	Tier 2	5000	50	Diesel	0.33	Other Construction Equipment	90	240
Hertz Pump	Pioneer Prime	50	2005	Tier 2	5000	50	Diesel	0.33	Other Construction Equipment	90	240
Hertz Pump	Pioneer Prime	50	2005	Tier 2	5000	50	Diesel	0.33	Other Construction Equipment	90	240
							Diesel	0.33	Other Construction Equipment	90	
							Diesel	0.33	Other Construction Equipment	90	
							Diesel	0.33	Other Construction Equipment	90	

Transport Details					Fuel Details		Project Details			
Name	Make	Model Year	Gross Vehicle Weight (GVW) (lbs.)	Mileage (mi)	Type	Sulfur (%)	Altitude	Number of Trips	Oneway Distance (mi)	Return Distance (mi)
Truck	Chevy 2500	2005	8,501-10,000	1000	Diesel	0.05	Low	30	10	10
Truck	Ford F-350	2005	8,501-10,000	1000	Diesel	0.05	Low	10	20	20
Truck	Peterbilt	2005	16,001-19,500	1000	Diesel	0.05	Low	1	20	20
Truck	Peterbilt Flat	2005	14,001-16,000	1000	Diesel	0.05	Low	1	20	20
Truck	GMC C6500	2005	10,001-14,000	1000	Diesel	0.05	Low	1	20	20
Truck	Isuzu NQR	2005	10,001-14,000	1000	Diesel	0.05	Low	1	20	20

Figure 4-4. Inputs for e-Calc for the GeoSpray™ 60-in. RCP Sewer Main Project

The primary equipment on site were three large Pioneer bypass pumps (see Figure 3-3), which ran nearly continually over the course of the 11-day project. The contractor also used a telescopic handler for attaching the bypass system and a track hoe for various lifting activities. The contractor had four large equipment trucks on site for the duration of the project, which were left at the site each night. In addition, four pickup trucks were on site for various durations to transport staff to and from the site.

The e-Calc outputs are shown in Figure 4-5. The project resulted in a carbon footprint of approximately 23.06 short tons (or 46,100 lb) of CO_2 equivalents from the equipment and 1.04 short tons (or 2,100 lb) of CO_2 equivalents from the vehicles for a total of 48,200 lb. An equivalent open cut project would be difficult to estimate as this pipe segment was located underneath an open channel bayou, which would require a significant amount of work to open cut and is very impractical. From previous studies (EPA, 2012), open cut construction has been estimated to be around 2,000 lb of CO_2 equivalents per day. With depth (26 ft) and surface obstructions (i.e., open channel bayou) of this project, the duration of an open cut project could be estimated to be several months at a minimum, resulting in a minimum impact of 120,000+ lb of CO_2 equivalents.

In terms of CO_2 equivalent emissions of the manufacture of geopolymers, studies have shown that geopolymers produce as much 65% (McClellan et al., 2011) or even as much as 90% less emissions (Davidovits, 2011) when compared to OPC.

Emissions

HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 (S/T)	SOx (lbs)
3.51	10.09	20.40	1.61	1.41	5.71
0.95	2.74	5.55	0.44	0.38	1.55
6.97	55.87	106.95	9.97	7.09	28.67
6.97	55.87	106.95	9.97	7.09	28.67
6.97	55.87	106.95	9.97	7.09	28.67
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
25.4 lbs	180.4 lbs	346.8 lbs	32.0 lbs	23.06 S/T	93.3 lbs

HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 (S/T)	SOx (lbs)
0.20	1.72	2.87	0.13	0.52	0.32
0.13	1.14	1.91	0.09	0.35	0.21
0.02	0.17	0.28	0.01	0.05	0.03
0.02	0.15	0.26	0.01	0.04	0.03
0.02	0.13	0.22	0.01	0.04	0.02
0.02	0.13	0.22	0.01	0.04	0.02
0.4 lbs	3.4 lbs	5.8 lbs	0.3 lbs	1.04 S/T	0.6 lbs

Figure 4-5. Results from e-Calc for the GeoSpray™ 60-in. RCP Sewer Main Project (Installation [top] and Transportation [bottom])

Section 5.0: CONCLUSIONS AND RECOMMENDATIONS

This demonstration of the innovative, spray-applied, fiber-reinforced geopolymer mortar used to rehabilitate a 60-in. RCP that was 160-ft long and 25-ft deep in Houston, TX was deemed successful. The host pipe was severely deteriorated with reinforcing steel exposed and missing and several locations of heavy infiltration, which is why the lining was spray applied by hand rather than using a sled. Table 5-1 summarizes the overall conclusions for each metric used to evaluate the technology.

Table 5-1. Technology Evaluation Metrics Conclusion

Technology Maturity Metrics
• Innovative material installed using a conventional methodology. • Corrosive resistance was not validated, but geopolymer is a proven improvement over OPC. • Some third-party data are available, but long-term testing is needed.
Technology Feasibility Metrics
• Project met the owner's expectations and requirements. • The material was successfully installed in a severely deteriorated pipe environment. • Because of the severe deterioration of the host pipe and high levels of water infiltration, the lining was manually spray applied by hand versus application via a spray sled.
Technology Complexity Metrics
• Beneficial for wastewater utilities with deteriorating large-diameter mains in corrosive environments. • Requires trained professionals, but the lining process is not complex; therefore, contractors or utility personnel could be trained to install this product. • The project spanned a total of 11 working days and this included unanticipated delays in setup of the host pipe by the WWTP due to flows entering into the manhole at the WWTP that initially could not be shut off.
Technology Performance Metrics
• The post-lining inspection via CCTV showed the rehabilitated pipe to be free of infiltration, with no signs of exposed rebar or cracking, and no significant defects were noted in the GeoSpray™ lining the day after application. • Calculations based on the amount of material sprayed each day and length of coverage showed that spray-applied thickness to be approximately 3.3 in., which was more than the design minimum value of 1.9 in. • Third-party test results for all four days of spraying showed that the QC samples met design. The compressive strength at 28 days averaged 8,635 psi compared to the manufacturer's design specification of 8,000 psi. • Mechanical testing by the research team indicated that the QC samples were lower than the manufacturer claims of performance. For example, the compressive strength at 28 days was measured at 7,881 psi (or 1.5% lower than the manufacturer's specification). Based upon the lower than expected density of the mixture (by 3.6%), it is hypothesized that the lower values in these samples were attributable to light rain experienced during sample collection. However, it is assumed that the rain had no impact on the material sprayed in the pipe as the mixer was covered during the installation. • Because of the manual application of the GeoSpray™ material, not all of the typical QC parameters could be collected on a continuous basis associated with the sled application. However, the slump test results were consistent for each day of spraying, which suggests that a uniform water/cement ratio was achieved.
Technology Cost Metrics
• The costs associated with projects similar to this range from $400 to $600 per linear foot.
Technology Environmental and Social Metrics
• Social disruption was minimal since traffic was only affected at one manhole and drivers were able to access their homes throughout the project. • An estimated 48,200 lb of CO_2 equivalents were emitted from on-site operations. • A similar open cut project, although impractical due to the site conditions, would emit 120,000+ lb of CO_2 equivalents. • CO_2 equivalent emissions from the manufacture of geopolymers have been shown to be as much as 65% to 90% less than emissions for OPC.

It is recommended that sampling procedures be further examined to ensure that QC samples are indicative of the final material properties as installed in the field. The calculated lining thickness was found to vary significantly from the contractor estimates provided in the field. It is important to develop a protocol to measure the lining thickness in the field as part of future QC procedures to verify the calculations. It should be noted that bond strength is rarely measured in the field unless specifically stated in the contract. It is recommended that the bond strength be measured at future project sites as a key QC measure. The material is designed for spraying; therefore, pouring the material in the field may create voids. Current standards only require the use of tamping rods, which may or may not be sufficient for eliminating voids in the samples. The use of a shaker table in the field is recommended as a future practice to minimize voids. Alternatively, a process for obtaining samples directly from the finished coating could be explored, although this is less practical.

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APPENDIX A

DESIGN CALCULATION

Design for City of Houston, Northwest WWTP.

$$t_{pd}{}^{2.5} = 2\frac{11.27x288x30^{1.5}(1-0.15^2)^{0.75}}{0.807(2,000,000)} \quad \text{(Equation 1)}$$

t_{pd}	=	1.28 inches
P_w	=	11.27 psi = *0.433 (21 ft + 60 in./12)*
H_w	=	21 feet
D	=	60 inches
l	=	288 inches
r	=	30 inches = *60 in./2*
μ	=	0.15
N	=	2
E	=	2,000,000 psi

The second design equation calculates minimum lining thickness for a fully deteriorated pipe based on resistance to hydrostatic buckling and soil and live loads for case (1) as follows:

$$t_{fd}{}^{2.5} = 2\frac{29.83x288x30^{1.5}(1-0.15^2)^{0.75}}{0.807(2,000,000)} \quad \text{(Equation 2)}$$

t_{fd}	=	1.88 inches
W_t	=	29.83 psi = *11.27 psi + 18.56 psi*
P_w	=	11.27 psi
H_w	=	21 feet
D	=	60 inches
l	=	288 inches
W'_s	=	18.56 psi = *(13,363 lb/ft/12)* / *60 in.*
W_c	=	13,363 lb/ft = *2.098* x *130 pcf* x $(84\ in./12)^2$
C_d	=	2.098
ku'	=	0.165 (sand and gravel)
H	=	25 feet
B_d	=	84 inches = *60 in. + 24 in.*
w_s	=	130 pounds/cubic ft
r	=	30 inches = *60 in./2*
μ	=	0.15
N	=	2
E	=	2,000,000 psi

Since this pipe is considered to be fully deteriorated, the minimum design thickness comes from Equation 2 and must be greater than 1.88 in.

APPENDIX B

QA/QC PROCEDURES

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Procedures for **Acceptance and Certification** of Milliken Infrastructure Solutions (MIS) GeoSpray™ Geopolymer Mortar

Tests to be performed:

- Compressive Strength
- Slump
- Water Addition Rate and Pump Motor Speed Controller Setting
- Temperature
    - Batch Water
    - Dry Powder GeoSpray™ before mixing
    - Ambient Air Temperature within the pipe
    - Ambient Air Temperature at point of Mixing
    - Temperature of Sampled material
    - Pump Distance
- Calculated Density

Frequency of Testing and Sampling:

The above testing is to be initiated on site and during placement of GeoSpray™. A minimum of one test should be performed with every 10 yards or 32,000 pounds of material placed. Along with material minimums, testing must occur:

The First Day GeoSpray™ is placed or applied at project
At minimum every other day GeoSpray™ is placed or applied at project
The Last Day GeoSpray™ is placed or applied at project

Materials must be tested in accordance with ASTM standards, MIS's GeoSpray™ specification, and the Definitions defined within this document. Tests must be performed by ACI accredited technicians and in a certified third party independent laboratory. MIS recommends using third party independent testing agencies with ACI certified technicians to cast, transport, cure and test.

Definitions

- Sampling-**ASTM C172 Standard practice for sampling freshly mixed concrete.**
    - Size of sample-samples to be used for strength tests a minimum of 28L (1ft.^{3})
        - **Sampling Location Point** – GeoSpray™ sample should be collected at the end of the hose near the discharge point. Only in rare circumstances where this may not be possible, a sample may be drawn from a section of hose at minimum 50 feet from the mixer/pump. All samples taken from anywhere other than the discharge point must be marked and noted. In the event the technician does not have access to the sampling point, samples may be drawn by IPR personnel and IMMEDIATELY transferred to the nearest access point and handed to the ACI certified technician for testing.
- Casting Specimens-**ASTM C31 Standard practice for making & curing concrete test specimens in field.**
    - **Sample Mold Size** - **Use 4" by 8" cylinders ONLY!**
    - **Curing method:**
        - Initial cure – Cylinders must be immediately capped with a water tight sealing

Milliken | Milliken Infrastructure Solutions, LLC cap provided with the molds.

  - Storage
    Immediately after molding the specimens should be stored for a period up to 48H in a temperature range from 68° and 78° F.

- Compressive Strength – Follow **ASTM C39/C39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens** with the following rules applied:
  - **Sample Mold Size** - **<u>Use 4" by 8" cylinders ONLY!</u>**
  - **Curing method:**
    - MIS's GeoSpray™ requires final cure be in a **<u>50% humidity room</u>**. In situations where a 50% cure room is not available, cylinders may be stripped and wrapped in wet burlap and placed in a temperature controlled room. Wet burlap should be kept moist throughout cure. See ASTM C31/31M for required temperature control range. In all cases **<u>DO NOT SUBMERGE SAMPLES IN A LIQUID CURE TANK OR IN WATER</u>!**

- Slump – Follow **ASTM C143/C143M Test Method for Slump of Hydraulic-Cement Concrete** with the following rules applied:
  - **Sampling Location Point** – GeoSpray™ sample should be collected at the end of the hose near the discharge point. Only in rare circumstances where this may not be possible, a sample may be drawn from a section of hose at minimum 50 feet from the mixer / pump. All samples taken from anywhere other than the discharge point must be marked and noted. In the event the technician does not have access to the sampling point, samples may be drawn by IPR personnel and IMMEDIATELY transferred to the nearest access point and handed to the ACI certified technician for testing.

- Water Addition Rate Pump and Motor Speed Controller Setting:
  - Verify and record current water addition setting from the Mixer / pump. "Flow Meter" sight gauge is located on the control side of the equipment. Determine, verify, and report reading at the time of sampling,. (examples.. 160, 190, or 180)
  - Verify and record current "Pump Motor Speed Setting. Pump motor speed control is located on the control side of the equipment. Determine, verify, and report setting (example 1 to 10).

- Temperature Follow **ASTM C1064/C1064M Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete** with the following:
  - Batch Water
    - Pull a sample of the batch water from the "Cleaning Tap" located on the opposite side of the controls of the mixer /pump. Place sample in a cup or vessel and measure and record water temperature.
  - Dry Powder "GeoSpray™ before mixing
    - Draw a sample of GeoSpray™ powder from material feed point. Take temperature and record.
  - Ambient Air Temperature within the pipe
    - Measure and record temperature. In the event access to the pipe is restricted, a temperature reading may be taken by IPR personnel and communicated to the ACI certified technician.
  - Ambient Air Temperature at point of Mixing
    - Measure and record temperature within the pipe at or near placement point.
  - Temperature of Sampled material
    - Place sample in an approved vessel, measure and record GeoSpray™ mortar temperature.

- Calculated Density - Follow **ASTM C39/C39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens** with the following rules applied:
  - Measure, weigh, record, and calculate density of "4 by 8" cylinders prior to breaking.
  - Report calculated density.

Milliken | Milliken Infrastructure Solutions, LLC

Reporting - Report the following information:

Date and time samples are taken
Location and project name
Name of ACI certified technicians performing tests
Slump, temperatures, water addition rate, pump speed setting and results of any other field tests performed
Explain any deviations from referenced standard test methods,
Date and time samples were received in the lab
Curing methods – Report the initial curing method with maximum and minimum temperatures and final curing method.
Compressive results with data and calculations
Density results with Data and calculations

THE FOLLOWING SECTION IS TAKEN DIRECTLY FROM (ASTM C31/31M-10 STANDARD PRACTICE FOR MAKING AND CURING CONCRETE TEST SPECIMENS IN THE FIELD) THIS SECTION INTENDS TO COMMUNICATE AND DEFINE THE IMPORTANT ASPECTS OF ASTM C31/31M-10 AS IT PERTAINS TO MIS's, GEOSPRAY™ GEOPOLYMER MORTAR. IT IS TO BE USED AS A SIMPLE GUIDE. ASTM C31/31M-10 AND STANDARD INDUSTRY PRACTICES REMAIN AS THE OVERRIDING METHOD.

1. Scope

1.1 This practice covers procedures for making and curing cylinder and beam specimens from representative samples of fresh concrete for a construction project.
1.2 The concrete used to make the molded specimens shall be sampled after all on-site adjustments have been made to the mixture proportions, including the addition of mix water and admixtures. This practice is not satisfactory for making specimens from concrete not having measurable slump or requiring other sizes or shapes of specimens.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C125 Terminology Relating to Concrete and Concrete Aggregates
C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C172 Practice for Sampling Freshly Mixed Concrete
C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C403/C403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C470/C470M Specification for Molds for Forming Concrete Test Cylinders Vertically
C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C617 Practice for Capping Cylindrical Concrete Specimens
C1064/C1064M Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

2.2 *American Concrete Institute Publication:*[4]

CP-1 Concrete Field Testing Technician, Grade I
309R Guide for Consolidation of Concrete

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminology C125.

4. Significance and Use

4.1 This practice provides standardized requirements for making, curing, protecting, and transporting concrete test specimens under field conditions.
4.2 If the specimens are made and standard cured, as stipulated herein, the resulting strength test data when the specimens are tested are able to be used for the following purposes:

4.2.1 Acceptance testing for specified strength,
4.2.2 Checking adequacy of mixture proportions for strength, and
4.2.3 Quality control.

5. Apparatus

- *Molds, General*— Molds for specimens or fastenings thereto in contact with the concrete shall be made of nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall hold their dimensions and shape under all conditions of use. Molds shall be watertight during use as judged by their ability to hold water poured into them.

- *Cylinder Molds*— Molds for casting concrete test specimens shall conform to the requirements of Specification C470/C470M.
- *Tamping Rod*—A round, smooth, straight, steel rod with a diameter conforming to the requirements of having a diameter of 3/8 inches +or- 1/16 inch or 10mm +or- 2mm. The length of the tamping rod shall be at least 12 in. [300 mm]. The rod shall have the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.
- *Mallet*—A mallet with a rubber or rawhide head weighing 1.25 +/- 0.50 lb [0.6 +/- 0.2 kg] shall be used.
- *Placement Tools*—of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so concrete is not spilled during placement in the mold. For placing concrete in a cylinder mold, the acceptable tool is a scoop.
- *Finishing Tools*—a handheld float or a trowel.
- *Slump Apparatus*— The apparatus for measurement of slump shall conform to the requirements of Test Method C143/C143M.
- *Sampling Receptacle*—The receptacle shall be a suitable heavy gauge metal pan, wheelbarrow, or flat, clean nonabsorbent board of sufficient capacity to allow easy remixing of the entire sample with a shovel or trowel.
- *Temperature Measuring Devices*—The temperature measuring devices shall conform to the applicable requirements of Test Method C1064/C1064M.

6. Testing Requirements

6.1 *Cylindrical Specimens*—Compressive or splitting tensile strength specimens shall be cylinders cast and allowed to set in an upright position.

Cylinders must be able to be capped and sealed water tight.

The number and size of cylinders cast shall be as directed by the specifier of the tests.

A minimum of six – 4" by 8" cylinders are to be cast with each test. Two cylinders will be broken at a 7 day age, three more at 28 days, and one hold cylinder broken at 56 days or as directed.

6.3 *Field Technicians*—The field technicians making and curing specimens for acceptance testing shall be certified ACI Field Testing Technicians, Grade I or equivalent. Equivalent personnel certification programs shall include both written and performance examinations, as outlined in ACI CP-1.

7. Sampling Concrete

7.1 The samples used to fabricate test specimens under this standard shall be obtained in accordance with Practice C172 unless an alternative procedure has been approved.

7.2 Record the identification of the sample with respect to the location of the concrete represented and the time of casting.

8. Slump, Air Content, and Temperature

8.1 *Slump*—Measure and record the slump of each batch of concrete from which specimens are made immediately after remixing in the receptacle, as required in Test Method C143/ C143M.

8.3 *Temperature*—Determine and record the temperature in accordance with Test Method C1064/C1064M.

9. Molding Specimens

9.1 *Place of Molding*— Mold specimens promptly on a level, rigid surface, free of vibration and other disturbances, at a place as near as practicable to the location where they are to be stored.

9.2 *Casting Cylinders*—While placing the concrete in the mold, move the scoop around the perimeter of the mold opening to ensure an even distribution of the concrete with minimal segregation. Each layer of concrete shall be consolidated as required. In placing the final layer, add an amount of concrete that will fill the mold after consolidation.

9.4 *Consolidation*— The methods of consolidation for this practice are rodding.

9.4.1 *Rodding*—Place the concrete in the mold in the required number of layers of approximately equal volume. Rod each layer uniformly over the cross section with the rounded end of the rod using the required number of strokes. Rod the bottom layer throughout its depth. In rodding this layer, use care not to damage the bottom of the mold. For each upper layer, allow the rod to penetrate through the layer being rodded and into the layer below approximately 1 in. [25 mm]. After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. After tapping, spade each layer of the concrete along the sides and ends of beam molds with a trowel or other suitable tool. Overfilled molds shall have excess concrete removed.

9.5 *Finishing*—Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and that has no depressions or projections larger than 1/8in. [3.3 mm].

9.5.1 *Cylinders*—After consolidation, finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits or with a handheld float or trowel.

Tightly secure water tight cap without disturbing the finished surface

9.6 *Identification*— Mark the specimens to positively identify them and the concrete they represent. Use a method that will not alter the top surface of the concrete. Do not mark the removable caps. Upon removal of the molds, mark the test specimens to retain their identities.

10. Curing

10.1 *Curing*

10.1.1 *Storage*—immediately after finishing move the specimens to an initial curing place for storage. The supporting surface on which specimens are stored shall be level to within 1/4in. per ft. [20 mm per m]. If cylinders in the single use molds are moved, lift and support the cylinders from the bottom of the molds with a large trowel or similar device. If the top surface is marred during movement to place of initial storage, immediately refinish.

10.1.2 *Initial Curing*— Immediately after molding and finishing, the specimens shall be stored for a period of 24 hours + or – 6 hours in a temperature range from 68 and 78 °F [20 and 26 °C] and in an environment preventing moisture loss from the specimens. Various procedures are capable of being used during the initial curing period to maintain the specified moisture and temperature conditions. An appropriate procedure or combination of procedures shall be used. Shield all specimens from the direct sunlight and, if used, radiant heating devices. The storage temperature shall be controlled by use of heating and cooling devices, as necessary. Record the temperature using a maximum-minimum thermometer.

10.1.3 *Final Curing:*

10.1.3.1 *Cylinders*—Upon completion of initial curing and within 30 min after removing the molds, cure specimens with free water maintained on their surfaces at all times at a temperature of 73.5 + or - 3.5 °F [23.0 + or - 2.0 °C] using moist rooms complying with the requirements of Specification C511

MIS's GeoSpray™ requires final cure be in a 50% humidity room. In situations where a 50% cure room is not available, cylinders may be stripped and wrapped in wet burlap and placed in a temperature controlled room. Wet burlap should be kept moist throughout cure. In all cases DO NOT SUBMERGE SAMPLES IN WATER!

11. Transportation of Specimens to Laboratory

11.1 Specimens shall not be transported until at least 8 h after final set. During transporting, protect the specimens with suitable cushioning material to prevent damage from jarring. During cold weather, protect the specimens from freezing with suitable insulation material. Prevent moisture loss during transportation. Transportation time shall not exceed 4 hours.

12. Report

12.1 Report the following information to the laboratory that will test the specimens:

12.1.1 Identification number,

12.1.2 Location of concrete represented by the samples,

12.1.3 Date, time and name of individual molding specimens,

12.1.4 Slump, temperatures, water addition, pump motor speed controller setting, and results of any other tests on the fresh concrete and any deviations from referenced standard test methods, and

12.1.5 Report the initial curing method with maximum and minimum temperatures

Document last updated on 9-11-2013

APPENDIX C

THIRD-PARTY TEST RESULTS

HTS, INC. Consultants

416 pickering Street
Houston, TX 77091
713-692-8373
www.htshouston.com

DATE: April 27, 2013
REPORT NO: 13-C-0190-0002

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

GEOSPRAY COMPRESSIVE STRENGTH

Location: **North end of 60" reinforced concrete pipe at junction box 1 (between manhole #1 and #2)**

Set No:	Cylinder ID:	Date Tested:	Age (Days)	Area (sq.in.)	Maximum Load (lbs)	Compressive Strength (psi)	Pass (Y/N)
1	A	05/02/13	7	12.57	79900	6350	
1	B	05/02/13	7	12.57	83850	6670	
1	C	05/23/13	28	12.57	101310	8060	Y
1	D	05/23/13	28	12.57	104410	8310	Y
1	E	06/27/13	56	12.57	124050	9870	
1	F	06/27/13	56	12.57	121610	9670	

Specification: 8000 p.s.i @ 28 days

Cylinders/ Cubes Cast: set/total 6/6

Remarks:

Test Method: ASTM C109

Technician: David Waggner, NICET II (Concrete)

Billing: N/A

Time: Refer to 13-C-0190-0001

Off Site: N/A

HTS, Inc. Consultants
Firm Reg. No. F-3478

HTS, INC. Consultants

416 pickering Street
Houston, TX 77091
713-692-8373
www.htshouston.com

DATE: May 1, 2013
REPORT NO: 13-C-0190-0009 Page 1 of 1

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

GEOSPRAY COMPRESSIVE STRENGTH

Location: **60" reinforced concrete pipe between manhole 2 and manhole 3**

Set No:	Cylinder ID:	Date Tested:	Age (Days)	Area (sq.in.)	Maximum Load (lbs)	Compressive Strength (psi)	Pass (Y/N)
1	A	05/08/13	7	12.57	83560	6650	
1	B	05/08/13	7	12.57	87240	6940	
1	C	05/29/13	28	12.57	109280	8690	Y
1	D	05/29/13	28	12.57	107530	8550	Y
1	E	06/26/13	56	12.57			
1	F	06/26/13	56	12.57			

Specification: **8000 p.s.i. @ 28 days**

Cylinders/ Cubes Cast: set/total 6

Remarks:

Test Method: ASTM C109

Technician: **David Waggner, NICET II Concrete**

Billing: 6.5 RT

Time: Ref. to 13-C-0190-0008

Off Site: N/A

HTS, Inc. Consultants
Firm Reg. No. F-3478

HTS, INC. Consultants
416 pickering Street
Houston, TX 77091
713-692-8373
www.htshouston.com

DATE: May 7, 2013
REPORT NO: 13-C-0190-0013
Page 1 of 1

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061
ATTN: Mr. Chuck Slack

PROJECT: COH Waste Water Treatment Facility

GEOSPRAY COMPRESSIVE STRENGTH

Location: **60" reinforced concrete pipe between manhole 2 and manhole 3**

Set No:	Cylinder ID:	Date Tested:	Age (Days)	Area (sq.in.)	Maximum Load (lbs)	Compressive Strength (psi)	Pass (Y/N)
1	A	05/14/13	7	12.57	78410	6240	
1	B	05/14/13	7	12.57	80310	6390	
1	C	06/04/13	28	12.57	114730	9130	Y
1	D	06/04/13	28	12.57	114000	9070	Y
1	E	07/02/13	56	12.57			
1	F	07/02/13	56	12.57			

Specification: 8000 p.s.i. @ 28 days

Cylinders/ Cubes Cast: set/total 6

Remarks:

Test Method: ASTM C109

Technician: David Waggner, NICET II Concrete

Billing: N/A

Time: Ref. to 13-C-0190-0010

Off Site: N/A

HTS, Inc. Consultants
Firm Reg. No. F-3478

APPENDIX D

THIRD-PARTY DAILY INSPECTION FORMS

HTS, INC. Consultants
416 Pickering Street
Houston, TX, 77091
713-692-8373
www.htshouston.com

DATE: 4/27/2013
REPORT #: 13-C-0190-0001

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

DAILY INSPECTION

A HTS representative reported to the jobsite to perform inspection / testing on "GeoSpray GeoPolymer Mortar". Temperatures were taken on batch water, dry powder "GeoSpray", ambient air temperature at point of mixing. Water addition rate, pump motor speed and pump distance were monitored at time of mixing. Sample was tested for slump, temperature and 6 test cylinders were cast.

Temperature of Batch Water - 62°
Temperature of Dry Powder - 84°
Ambient Temperature within Pipe - 77°
Ambient Temperature at Point of Mixing - 68°
Temperature of Sampled Material - 84°
Slump - 1/4"
Water Addition Rate - 180 gal/hr
Pump Motor Speed Setting - 10
Pump Distance - 105'
Time Sampled - 3:20pm

Remarks:

Test Method:

Technician: David Waggener
NICET II Concrete

Billing: 6.0 OT

Time: 11:00 AM - 5:00 PM

Nonbillable Time:

Orig: Mr. Chuck Slack - RePipe Texas, Inc. (Proposal/Invoice/Reports)
cc: Mr. John Territo - HTS Inc. Consultants (Reports - All)

HTS, Inc. Consultants
Firm Reg. No. F-3478

HTS, INC. Consultants
416 Pickering Street
Houston, TX, 77091
713-692-8373
www.htshouston.com

DATE: 4/30/2013
REPORT #: 13-C-0190-0004

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

DAILY INSPECTION

An HTS, Inc. Consultants representative arrived at the above referenced project to perform inspection/testing on "GeoSpray GeoPolymer Mortar". Temperatures were taken on batch water, dry powder "GeoSpray", ambient air temperature at point of mixing. Water addition rate, pump motor speed and pump distance were monitored at time of mixing. Sample was tested for slump, temperature and 6 test cylinders were cast.

Temperature of Batch Water - 51°
Temperature of Dry Powder - 73°
Ambient Temperature within Pipe - 79°
Ambient Temperature at Point of Mixing - 83°
Temperature of Sampled Material - 87°
Slump - 1/4"
Water Addition Rate - 165 gal/hr
Pump Motor Speed Setting - 8
Pump Distance - 140'
Time Sampled - 10:40 am

60" reinforced concrete pipe between manhole 2 and manhole 3

Remarks:

Test Method:

Technician: David Waggener
NICET II Concrete

Billing: 6.0 RT

Time: 9:00 am - 3:00 pm

Nonbillable Time: N/A

Orig: Mr. Chuck Slack - RePipe Texas, Inc. (Proposal/Invoice/Reports)
cc: Mr. John Territo - HTS Inc. Consultants (Reports - All)

HTS, Inc. Consultants
Firm Reg. No. F-3478

HTS, INC. Consultants
416 Pickering Street
Houston, TX, 77091
713-692-8373
www.htshouston.com

DATE: 5/1/2013
REPORT #: 13-C-0190-0008

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

DAILY INSPECTION

An HTS, Inc. Consultants representative arrived at the above referenced project to perform inspection/testing on "GeoSpray GeoPolymer Mortar". Temperatures were taken on batch water, dry powder "GeoSpray", ambient air temperature at point of mixing. Water addition rate, pump motor speed and pump distance were monitored at time of mixing. Sample was tested for slump, temperature, and 6 test cylinders were cast.

Temperature of Batch Water - 50°
Temperature of Dry Powder - 78°
Ambient Temperature Within Pipe - 74°
Ambient Temperature at Time of Mixing - 76°
Temperature of Sampled Material - 82°
Slump - 1/4"
Water Addition Rate - 200 gal/hr
Pump Motor Speed Setting - 10
Pump Distance - 185'
Time Sampled - 12:45 pm

60" reinforced concrete pipe between manhole 2 and manhole 3

Remarks: **Technician also picked up 1 set of 6 cylinders on this date.*

Test Method:

Technician: David Waggener
NICET II Concrete
Time: 9:00 am - 3:30 pm

Billing: 6.5 RT
Nonbillable Time: N/A

Orig: Mr. Chuck Slack - RePipe Texas, Inc. (Proposal/Invoice/Reports)
cc: Mr. John Territo - HTS Inc. Consultants (Reports - All)

HTS, Inc. Consultants
Firm Reg. No. F-3478

HTS, INC. Consultants
416 Pickering Street
Houston, TX, 77091
713-692-8373
www.htshouston.com

DATE: 5/7/2013
REPORT #: 13-C-0190-0012

TO: RePipe - Texas, Inc.
7600 S. Santa Fe Road
Building E
Houston, TX 77061

PROJECT: COH Waste Water Treatment Facility

ATTN: Mr. Chuck Slack

DAILY INSPECTION

An HTS, Inc. Consultants representative reported to the jobsite to perform inspection/testing on "GeoSpray GeoPolymer Mortar". Temperatures were taken on batch water, dry powder "GeoSpray", ambient air temperature at point of mixing. Water addition rate, pump motor speed, and pump distance were monitored at time of mixing. Sample was tested for slump, temperature, and 6 test cylinders were cast.

Temperature of Batch Water - 50°
Temperature of Dry Powder - 80°
Ambient Temperature Within Pipe - 79°
Ambient Temperature at Point of Mixing - 76°
Temperature of Sampled Material - 80°
Slump - 1/4"
Water Addition Rate - 180 gal/hr
Pump Motor Speed Setting - 10
Pump Distance - 220'
Time Sampled - 2:30 pm

60" reinforced concrete pipe between manhole 2 and manhole 3

Remarks:

Test Method:

Technician: David Waggener
NICET II Concrete

Billing: 4.0 RT

Time: 12:00 pm - 4:00 pm

Nonbillable Time: N/A

Orig: Mr. Chuck Slack - RePipe Texas, Inc. (Proposal/Invoice/Reports)
cc: Mr. John Territo - HTS Inc. Consultants (Reports - All)

HTS, Inc. Consultants
Firm Reg. No. F-3478