

ADVANCED GEOPOLYMER PIPE & STRUCTURE LINING SYSTEM

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ABSTRACT

Asset owners and engineers throughout the world are in search of cost-effective and environmentally friendly solutions that serve infrastructure issues. Geopolymers have long been known to provide enhanced physical performance to traditional cementitious binders with the added advantages of significantly reduced greenhouse emissions and superior chemical resistance. However, they have not generally been contractor-friendly. This presentation will review a geopolymer mortar system that has been used in the U.S. since 2011 and is becoming a preferred solution for trenchless rehabilitation.

KEYWORDS

Geopolymers, Rehabilitation, Pipe Lining, Storm Water, Sanitary Sewer, Culvert, Trenchless

1. INTRODUCTION

Throughout the world today, nations currently face enormous challenges in how to address their decaying infrastructure. Whether roads, bridges, tunnels, or buildings on which our everyday livelihood and quality of life depend, these systems are all in a serious state of disrepair; many are on the verge of outright failure. While some of these systems are clearly visible to the public, there are vast underground networks hidden from the naked eye that must provide clean drinking water and removal of waste water for processing. In fact, the American Society of Civil Engineers (ASCE) 2013 report on America's infrastructure gives a D⁻ score to the waste water category. Specifically, the report states:

“Capital investment needs for the nation's wastewater and storm water systems are estimated to total \$298 billion over the next twenty years. Pipes represent the largest capital need, comprising three quarters of total needs. Fixing and expanding the pipes will address sanitary sewer overflows, combined sewer overflows, and other pipe-related issues. In recent years, capital needs for the treatment plants comprise about 15%-20% of total needs but will likely increase due to new regulatory requirements. Storm water needs, while growing, are still small compared with sanitary pipes and treatment plants. Since 2007, the federal government has required cities to invest more than \$15 billion in new pipes, plants, and equipment to eliminate combined sewer overflows¹.”

In addition to the high economic costs of insuring that the nation's water supply is safe and functional, there are a series of environmental costs that have to be addressed. First, when thinking of the public safety concerns related to failing or degrading sewer or storm water pipeline, toxins or contaminants can leak from these pipes into the neighboring soil and water, creating a myriad of issues. A series of recent articles²⁻⁴ explain, in great detail, the extent of this problem - a problem which is well known to the EPA's water division⁵. Second, simply digging up and replacing the decaying infrastructure has its own environmental issues including: (1) disruption of local environments above and around the piping, (2) possible additional contamination of soil and ground water from the disruption of the existing piping and (3) enormous expense to the tax payer in bypassing these systems while new systems are installed. Finally, many of the current technologies used to address the problem, including the “trenchless” or “no-dig” concepts, have their own significant environmental issues. Cure-in-place-pipe (CIPP) uses styrene-containing resin systems to create a new pipe inside the old pipe, but these systems have the potential to leach contaminants into the water systems. Standard concrete or

cement techniques using high levels of Portland cement create large quantities of greenhouse gases both in their production and use. In addition to these environmental concerns, each of these systems has technical drawbacks that make long term solutions tenuous.

Milliken Infrastructure Solutions, LLC has developed a revolutionary geopolymer mortar material – *GeoSpray™* – for use as a trenchless technology that addresses cost and environmental concerns. GeoSpray is a styrene- free, easy-to-install pipe within the old pipe. The technology can be employed regardless of the condition of the original pipe. GeoSpray allows a contractor to reconstruct a new structural storm or sewer pipe on-site using spray technology often referred to as Centrifugally Cast Pipe. The “new-pipe-within-a-damaged-pipe” technology results in improved strength and flow characteristics. The GeoSpray system offers a cost advantageous solution to contractors and asset owners alike. The environmental benefits of the GeoSpray system include: (1) use of industrial waste materials that would otherwise be landfilled, (2) substantial reduction in environmental disruption from the use of a trenchless technology, (3) significantly reduced CO₂ emissions when compared to standard cement materials, and (4) replacement of styrene-based resin alternative CIPP solutions. To date, the GeoSpray technology has been applied to over 150 individual structures. This constitutes more than 6,100 linear metre’s and 4.6 million kilograms of GeoSpray that has been installed to repair decaying infrastructure.

2. GEOPOLYMERS

Geopolymer is a term originally coined by French researcher Joseph Davidovits to describe a class of “cement” formed from aluminosilicates. While traditional Portland cement 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. In various parts of the world, this type of material is also industrially known as “alkali-activated cement” or “inorganic polymer concrete”.⁷ Geopolymers are known to provide comparable or better performance to traditional cementitious binders but with the added advantages of significantly reduced greenhouse emissions, increased fire and chemical resistance, and reduced water utilization. The use of geopolymers in modern industrial applications is becoming increasingly popular based on both their intrinsic environmental and performance benefits. Historically, trial applications of geopolymers were first used in some concrete applications by Glukhovsky and co-workers in the Soviet Union post WWII; the geopolymer was then known as “soil cements”.⁷ Figure 1 shows a typical aluminosilicate structure that is common among many geopolymer materials.

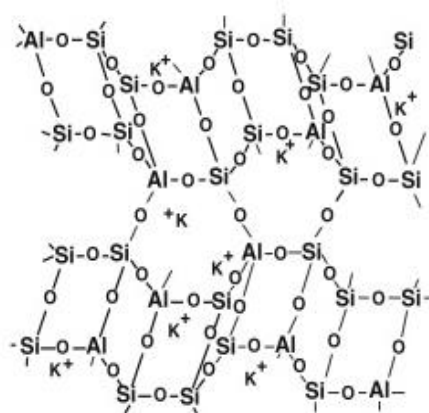


Figure 1: Example Aluminosilicate Geopolymer Structure⁷

2.1 GEOSPRAY

GeoSpray is a proprietary geopolymer mortar specially formulated by Milliken Infrastructure Solutions, LLC to meet all the physical and chemical requirements of sewer and storm water structures. The material is designed for ease of use. Water is added to GeoSpray at the job site where it can be easily centrifugally sprayed inside an existing structure. The exact formulation of GeoSpray is a trade secret, but generally speaking, it contains a mixture of the standard materials that are used in the production of calcium-aluminosilicates. Other components include, but are not limited to, blast furnace slag, reactive silicas, metal oxides, mine tailings, coal fly ash, metakaolin, calcinated shale, natural pozzolans, and natural/processed zeolites. Additional bio-based admixtures are included in the formulation in order to allow the composite material to set-up quickly and easily hydrate with a single addition of water. A summary of the physical properties of GeoSpray as compared to conventional concrete pipes is included in Table 1.

Test Method	Duration	GeoSpray	Conventional Repair Mortar
Compressive Strength ASTM C-39/C-39M-09a/C-109	1 Day 28 Days	Min. 2,500 psi / 17 MPa Min. 8,000 psi / 55 MPa	5000 psi / 34 MPa
Flexural Strength ASTM C-78	7 Day 28 Days	1200 psi / 8.3 MPa (C-78) 1300 psi / 9 MPa (C-78)	500 psi / 3.4 MPa
Modulus of Elasticity ASTM C-469 - 02	1 Day 28 Days	3,000,000 psi / 20700 MPa 6,500,000 psi / 44800 MPa	3,000,000 psi / 20700 MPa
Bond Strength to Concrete ASTM C-882/C-882M-05	1 Day 28 Days	Min 1,300 psi / 9 MPa Min. 2,500psi / 11 MPa	N/A
Set Time ASTM C-807 - 08 Initial Cure Time	Initial Set Final Set	60 - 75 Minutes 90 - 110 Minutes	120 Minutes 300 minutes
Freeze Thaw Durability ASTM C-666	300 Cycles	100% Zero loss	80% to 90% 10% to 20% degradation
Sulfate Resistance (% expansion) ASTM C-1012-04	6 Weeks	0.011 % Expansion	0.038% to 0.044% Expansion
Shrinkage ASTM C-1090	28 Days	0.07%	0.35% to 0.50%
Tensile Strength ASTM C-496	28 Days	Min. 750 psi / 5.2 MPa	400 psi / 2.7 MPa
Abrasion Resistance ASTM C-1138	6 Cycles @ 28 Day Maturity	0.67% Loss	5.60% Loss
Chloride Ion Penetration by Ponding ASTM C-1543	90 days ponding	0.014 % wt Cl at 55-65 mm	N/A
Antimicrobial Activity ISO 22196	24hrs	99.7% Reduction	N/A

Table 1. Typical properties of GeoSpray compared to Conventional Cement Based Repair Mortars

GeoSpray has been specially formulated to provide several key benefits to the contractor and asset owner. First, GeoSpray, unlike traditional geopolymers, is a “just add water” job site solution. Traditional geopolymer formulations require the alumino-silicates to be combined with a solution of sodium or potassium silicates that have been dissolved in water. With GeoSpray, the entire system is contained within original powder formulation, allowing a single step addition. Second, the proper selection of proprietary aggregates allows the GeoSpray to maintain easy pumpability up to 152m within a pipe and still be centrifugally cast without clogging or damaging nozzle performance. To achieve this standard of performance, traditional cement or geopolymer formulations would require much higher water ratios which would degrade their ultimate strength and require a much thicker final product during the installation to meet the flexural strength requirements of the rehabilitation.

2.0 GEOSPRAY APPLICATION

To apply GeoSpray in the field, the damaged pipe is cleaned in place, typically with high pressure water blasting of 3,500 psi or more. In order to insure adhesion of the GeoSpray to the damaged substrate, it is sometimes necessary to perform an addition cleaning with an environmentally friendly detergent to remove excess oil and grease from the existing pipe walls. If there are large leaking holes, the pipe can be simply

plugged with a thin application of the GeoSpray material, a plugging compound or a hydraulic cement. Finally, the geopolymer mortar is centrifugally cast from atop a sled, which is slowly removed from the pipe to provide a uniform application. Typical application thicknesses range between 38 to 75 mm (1.5 – 3 inches), depending on the type of pipe, local soil and water conditions, current condition of the existing pipe, and the design life requirements of the particular pipe in question. Figure 2 shows a series of images in the repair of a storm water culvert made of corrugated metal from the original deteriorated pipe to the completely restored system.

GeoSpray has been installed in nearly 20 US states along with Australia, Hong Kong and Malaysia.

3.0 COMPARISON BETWEEN ALTERNATIVE TECHNOLOGIES

Currently, there are multiple alternative technologies to solve the crisis in water infrastructure. The first and most costly alternative is dig and replace. This obviously involves the complete replacement of a pipe by digging up the old piping system which is often impractical inside major cities due to the disruption of everyday life. A second set of alternative technologies are what is referred to as “trenchless.” Trenchless technologies include CIPP, concrete spray or lining, and slip lining. Environmental benefits of GeoSpray will be directly compared to the competitive technologies



Figure 2: From left to right (a) Leaking storm water culvert (b) Centrifugal application of GeoSpray(c) Completed Repair

3.1 ENVIRONMENTAL BENEFITS

A. Trenchless Technologies: Trenchless technologies, by their nature, have the environmental benefit of creating minimal disruption to the surrounding infrastructure. They use the already existing infrastructure and avoid clearing land, digging, and destruction of plant life. These advantages are of significant importance when the degraded pipes or culverts are in environmentally sensitive natural habitats. In contrast, the traditional open trench replacement method creates significant obstacles. The EPA has long recognized the benefit of trenchless technologies and has commissioned several studies documenting their improved environmental impact.⁸

B. Use of Recycled Industrial Waste: All of the alternative technologies rely mainly on the use of virgin raw materials. Whether it is a new pipe, CIPP made of non-woven textiles with styrene-based resins, or the use of Portland cement, all require new raw materials to provide adequate quality control of the final physical properties of the new or repaired infrastructure. Geopolymers have long been recognized as a safe and effective method for permanently binding inorganic waste streams. The GeoSpray geopolymer mortar contains over 60% post-industrial waste as the starting raw materials; a much greater percentage than can be incorporated in any of the other technologies. These industrial waste stream materials are covalently bonded into the materials as the geopolymer undergoes condensation. In addition, the metals and other minerals contained in these waste streams are permanently sequestered by the material and have been shown to not leach into the environment.⁷

C. Styrene-Free Chemistry: Styrene is a volatile compound that quickly mixes with air and water streams. The EPA has defined styrene as a priority pollutant. The use of styrene-based resins in CIPP technologies is particularly hazardous due to both the confined spaces involved and cure conditions. The Virginia Transportation Research Council has shown that an accidental release of uncured resin leads to higher than permissible levels of styrene in the environment. The higher levels have been directly related to fish kills as shown in Figure 3. It has been recommended that the Virginia DOT stop using CIPP processes until such time

as it can be shown to be safe to the water supply.⁹ GeoSpray is an entirely styrene-free system, using traditional inorganic chemistry.

D. Reduction in CO₂ Emissions: A great amount of CO₂ is emitted during the production of Portland cement, which is one of the main reasons often cited for global warming. Life cycle analysis studies have shown that for every ton of Portland cement made anywhere in the world, approximately one ton of carbon dioxide is released into the atmosphere. In contrast, GeoSpray does not require extremely high-temperature treatment of the limestone but instead relies on a low-temperature processing of naturally occurring or direct man-made aluminosilicates (kaoline or fly ash). It was reported by Davidovits⁷ that about 60% less energy is required to produce a standard geopolymer as compared to Portland cement, and 80-90% less CO₂ is emitted.

In addition to the more environmentally friendly product, the process benefits of trenchless technologies from a CO₂ emission standpoint have been quantified by the North American Society of Trenchless Technology (NASTT) in a 2007 report. The authors consider the CO₂ emissions from (a) increased fuel consumption due to traffic delays (b) increased travel distances for detours around open cut repairs (c) fuel consumption of construction machinery and equipment involved in excavation, compaction, backfilling and repaving operations, (d) fuel consumption used to haul materials to and from work sites, and (e) specific manufacturing material such as pipes, asphalt, concrete, back fill materials and other chemicals. As shown in Figure 4, their report found the greenhouse gas emission using a trenchless solution can be reduced by approximately 90% depending on specific conditions based on estimated annual average daily traffic (AADT).¹⁰

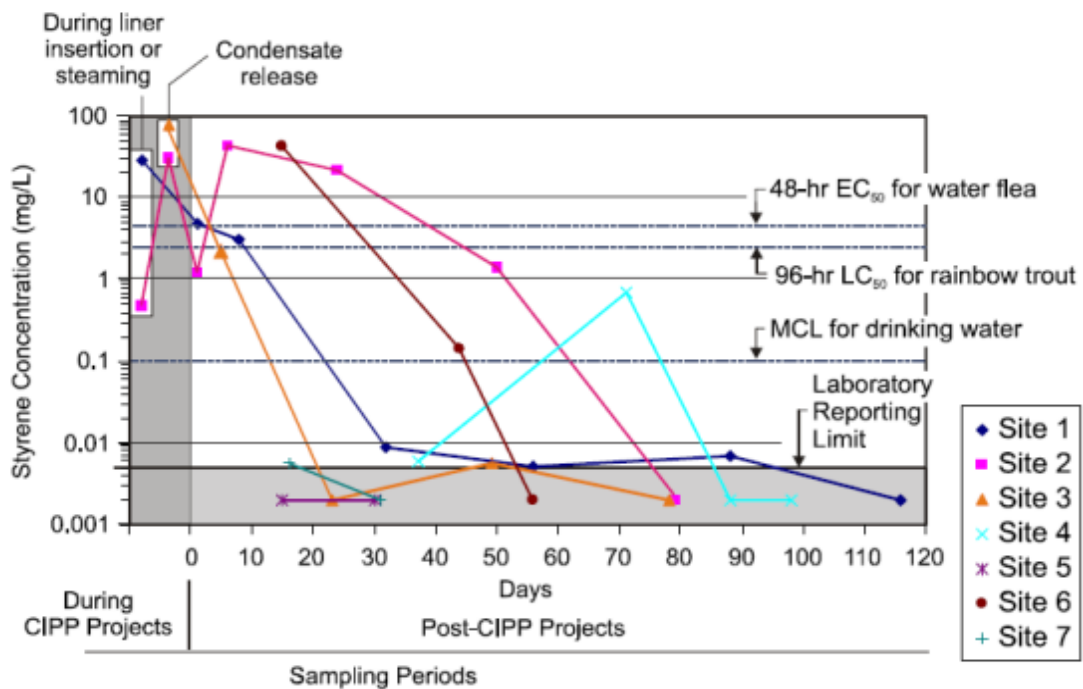


Figure 3: Styrene concentrations in water samples during and after CIPP installations at various sites as part of a VDOT study⁹

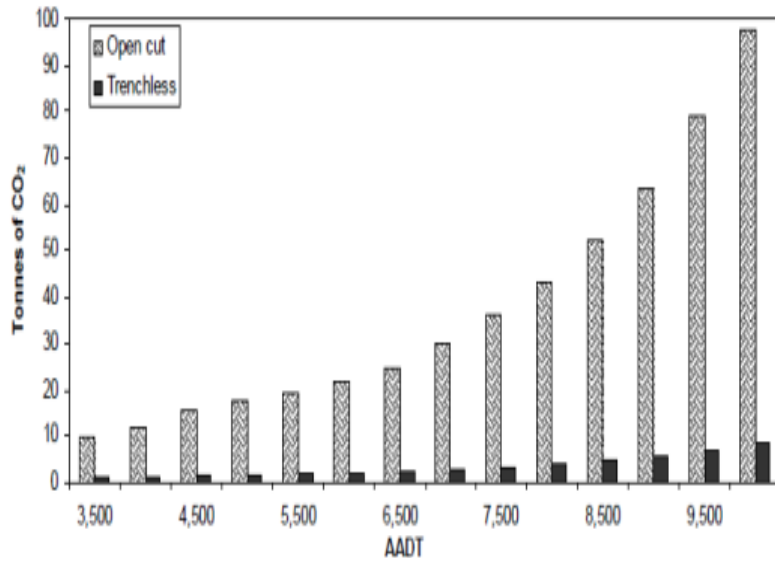


Figure 4: Comparison CO₂ Emissions of traditional open cut versus trenchless pipe repair¹⁰

3.1 COST BENEFITS:

It has been well established that the cost of trenchless technologies, where a pipe can be repaired instead of replaced, are significantly lower than dig and replace options. Estimates suggest trenchless technologies of any kind have a 50 to 70% advantage over the cost of open trench solutions. A simulation based on raw material cost and labor rates is shown in Figure 5. Among trenchless technologies, GeoSpray is the most cost effective method for waste water and storm water pipe repair for pipes of greater than 900mm in diameter. As the pipe diameter increases, the cost of repairs begin to dramatically increase due to the cost of materials and labor required to clean, prepare, and repair the pipe. GeoSpray and its patented method of installation keeps the costs 20 to 50% lower in comparison to CIPP, the market's leading solution. Finally, from the asset owner position, the lifetime of the infrastructure can be extended by more than 50 years based on standard design life calculations.

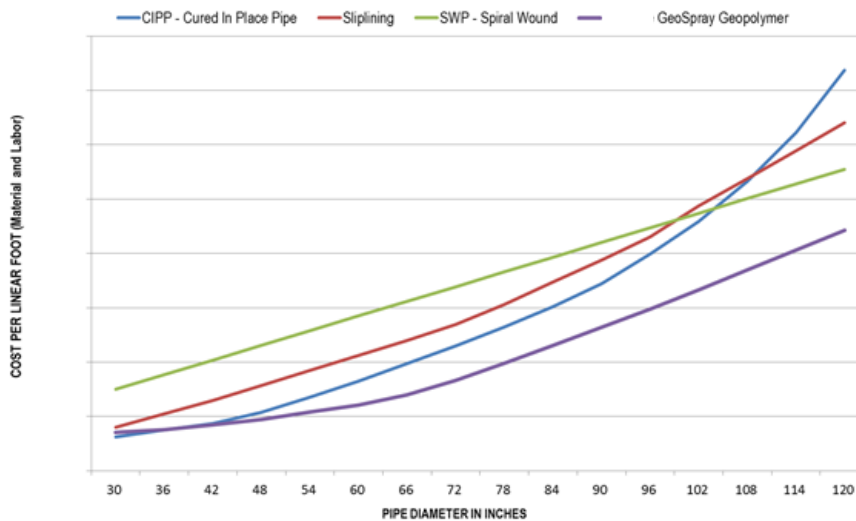


Figure 5: Cost comparison of competitive trenchless technologies

4.0 INSTALLATION CASE STUDY – CULVERT

The North Carolina Department of Transportation (NC DOT) was looking for a challenging project to complete their first project with GeoSpray. Along the banks of the Roanoke River in the city of Weldon, NC they found just the right project. A culvert with significant invert corrosion that is often completely submerged was not only structurally compromised but was creating erosion issues that were beginning to threaten neighboring private homes. The 108 inch (~275 cm) diameter corrugated metal pipe (CMP) was approximately 85 feet (~26 m) in length and connects incoming streams to the Roanoke River. The pipe is buried 25 feet (~ 8 m) the only access road to a commercial water treatment plant and a cotton and soy bean farm. The NC DOT had already repaired and stabilized the bank on the river side of the culvert with a steel embankment and was confronted with the problem of how to extend the life of the failing culvert.

In reviewing the options, the GeoSpray lining was the most cost effective solutions. Open cut and replacement would have taken the DOT at least 4 weeks and removed the access to the commercial interests beyond the culvert. CIPP technologies were too costly for such a large pipe. Spiral wound and other grouted technologies were also too costly but also reduced the open water way of the pipe significantly which created additional hydraulic issues.

The project was completed by Inland Pipe Rehab in November of 2013. During a one week period job an 8 inch (~20 cm) hydraulic by-pass system was set up, the pipe was pressure washed and cleaned and the infiltration into the pipe was stopped. GeoSpray was applied over 5 passes at 0.5 inches (13 mm) per pass until a final thickness of 2.5 inches (63 mm) was completed. Figure 6 shows images of the pipe before and after repair.



Figure 6: (a) View of Weldon NC Pipe from stream, (b) Pre-rehabilitation condition of pipe, (c) Completed repair, (d) Close up view of CMP wall repair with Geopolymer Lining.

5.0 INSTALLATION CASE STUDY – SANITARY SEWER

In April of 2012, the Metropolitan Sewer District of Greater Cincinnati (OHIO – USA) began repair of severely corroded stacked granite sewer installed during the 1800s. The sewer itself was on an 11 degree incline and required significant repair. There were two distinct lines – (a) a 500 linear ft section of 60 inch diameter pipe and (b) a 600 linear ft section of 36 inch pipe. Traditional dig and replace methods could not be used as the pipe now rest under existing building and roads in the historic downtown district of Cincinnati. CIPP could also not be used due to the jagged nature of the corroded pipe. Geopolymer lining was employed. In the first step the installer, Inland Pipe Rehab, hand sprayed the geopolymer to fill in the voids and jagged nature of the corroded stacked stone. A final pass using automated spray equipment was then completed. Figure 7 displays pictures before and after the repair. The geopolymer lining was chosen because of its superior chemical resistance to standard cement lining products.

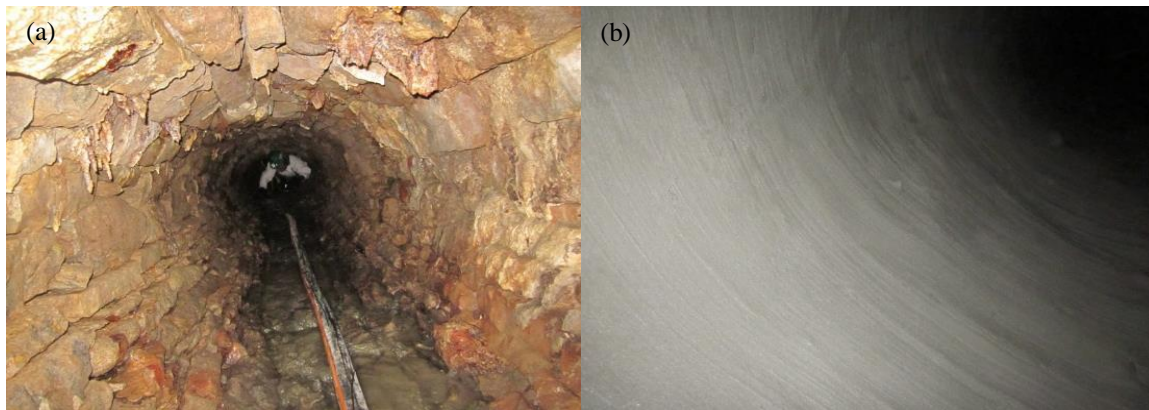


Figure 7: (a) Corroded stacked stone sewer in Cincinnati Ohio before repair, (b) completed relined repair.

6.0 CONCLUSION

Asset owners throughout the United States and the world are in search for cost-effective, economic, and environmentally-friendly solutions to severe infrastructure degradation. GeoSpray, a revolutionary geopolymer mortar system, is the environmentally preferred solution for trenchless storm and sewer water repair. The mix of a proprietary geopolymer formulation has significant environmental advantages over existing trenchless technologies. These advantages include preservation of current sensitive environments, use of over 60% post-industrial waste, reduced water usage, and 80-90% less CO₂ emissions, all with a styrene-free chemistry. Finally, GeoSpray along with its low cost installation methods reduces costs by up to 50% compared to the leading existing technology and extends the lifetime of the infrastructure by more than 50 years

7.0 REFERENCES

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