GeoSpray™ GeoPolymer Mortar System and Concrete Cloth for Structural Rehabilitation/Repair of Sewer and Storm Infrastructure

Presented by David Keaffaber, P.E.
Midwest Region Manager
45 Facilities Around the World
Milliken Infrastructure Solutions
Providing Material Systems for Repair & Rehabilitation
Fiber Reinforced Polymers For Concrete Repair & Strengthening
Concrete Impregnated Fabric
What is Concrete Cloth™?

A flexible cement-impregnated fabric that hardens when hydrated to form a thin, durable concrete layer.

Concrete Cloth™ (“CC”) consists of:

- Dry concrete mix
- Reinforcing fiber matrix
- Fabric top surface
- PVC bottom coating

CC Section View
Fabric top surface
Concrete mix and reinforcing fibers
Water impermeable PVC coating
Thickneses and Roll sizes available

3 thicknesses available are:

- CC5 (5mm)
- CC8 (8mm)
- CC13 (13mm)
Concrete Cloth™ comes in two roll varieties:

Portable Batched Rolls

Bulk Roll
Why Choose Concrete Cloth?
Asset Owner Benefits for Ditch Lining

If your location is:

- Remote, or
- Difficult to access with standard concrete equipment.

If you have limited time:

- Simple, installs quickly, and
- You don’t have to go back to the site to remove forms.

If you have limited labor or equipment:

- A small crew can do the job, and
- You don’t need specialized equipment.

If you cannot stop the water flow:

- It even cures under water.
Minor Invert deterioration
Concrete Cloth™
Concrete Impregnated Fabric
Concrete Cloth Case Study
Culvert Outlet Repair - Michigan

Project Details
Date: September, 2013
Owner: Michigan Department of Transportation
Application: M10 Median Culvert Outlet Washout Repair

Water blew out a 36 inch diameter culvert. Repair included a Concrete Cloth outlet/channel lining/spillway lining down to the nearby stream.
Concrete Cloth Case Study
Culvert Outlet Repair - Michigan

Collapsed 36” CMP Culvert with Outlet Scour
Outlet channel before and after re-grading
Completed Concrete Cloth Installation
After placement of RipRap in the stream outlet
Bridge approach drain was eroding exposing the pipe and the downstream outlet to scour. Repair included a Concrete Cloth outlet/channel lining lining down to the nearby stream.
Eroding Drain Inlet and Outlet
Concrete Cloth Case Study
Pavement Drain and Outlet Repair - Newayo, Michigan

Completed Concrete Cloth Installation
Ohio State Route 579 Bridge
Toledo, OH

Slope Foundation Protection Erosion Control

Installation Completed
September, 2015
Slope Preparation
Bridge Abutment Slope Protection
Project Details

• Date: July 18, 2013
• Location: Blair County, Pennsylvania
• Application: Roadside Drainage Ditch

- Due to steep grades, the Pennsylvania DOT installed a number of cross culverts years ago in order to capture storm water runoff and outlet it on the downslope side of the roadway. On one stretch, the DOT wanted to improve erosion protection.
Failing Metal Culvert

Invert deterioration from corrosion and abrasion
Pipe Rehabilitation Technology

Milliken Infrastructure Solutions, LLC
Centrifugal Casting Concrete Pipe (CCCP) / Spin Casting of Geopolymer (SCGP) using GeoSpray

- Rapidly distributes material within the pipe’s internal circumference
- Forms a strong, low permeability, cement lining
- Depending upon design & thickness, creates a “pipe within a pipe” and does not rely on the integrity of the host structure
- While not generally required, it is compatible with most common reinforcement technologies
Structural Rehabilitation
Application Sled
What is a GeoPolymer?

• Not a Plastic
  • Not HDPE/PVC/Epoxy

• Looks and feels like cement
  • Workability
  • Material Properties
  • Service Life

• Chemical structure like natural stone
  • Monolithic
  • Durable
  • Corrosion Resistant
Geopolymers or alkali cements consist predominantly alumino-silicates or polymer Si-O-Al bonds and are similar in chemical make-up to natural Zeolites. Traditional starting materials for geopolymers cements are fumed silica, fly ash & metal slag.

- Geopolymers can be produced from commercially available industrial waste streams, creating a highly environmentally friendly product.
- The chemical reactions of geopolymer create only a fraction of the CO$_2$ emissions of standard cementitious materials.
- Geopolymers have excellent chemical and thermal resistance and can essentially be considered engineered stone.

Typical Geopolymer Structure

Source - J. Davidovits · Geopolymer Chemistry and Applications, 3rd ed.
GeoSpray offers significant physical, environmental, chemical, and economic advantages over traditional materials.

<table>
<thead>
<tr>
<th></th>
<th>Portland Cement</th>
<th>GeoSpray™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Strength</td>
<td>Variable</td>
<td>Excellent</td>
</tr>
<tr>
<td>Early Strength</td>
<td>Variable</td>
<td>Excellent</td>
</tr>
<tr>
<td>Acid Resistance</td>
<td>Poor</td>
<td>Very Good</td>
</tr>
<tr>
<td>Self-Adhesion</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>% Recycled Content</td>
<td>&lt;10%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Single Pass Thickness</td>
<td>X</td>
<td>2X-3X</td>
</tr>
<tr>
<td>Total Installed Cost</td>
<td>$$</td>
<td>$</td>
</tr>
</tbody>
</table>

Old Tech | Emergent Tech
## Milliken Products

### GeoSpray Physical Properties

#### GeoSpray™ Geopolymer Mortar

**Flexural and Tensile Strength are 2-3x better**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Duration</th>
<th>GeoSpray</th>
<th>Conventional Repair Mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength, ASTM C-39/C-39M-09a/C-109</td>
<td>1 Day, 28 Days</td>
<td>Min. 2,500 psi / 17 MPa, Min. 8,000 psi / 55 MPa</td>
<td>5000 psi / 34 MPa</td>
</tr>
<tr>
<td>Flexural Strength, ASTM C-78</td>
<td>7 Day, 28 Days</td>
<td>1200 psi / 8.3 MPa (C-78), 1300 psi / 9 MPa (C-78)</td>
<td>500 psi / 3.4 MPa</td>
</tr>
<tr>
<td>Modulus of Elasticity, ASTM C-469 - 02</td>
<td>1 Day, 28 Days</td>
<td>3,000,000 psi / 20700 MPa, 6,500,000 psi / 46500 MPa</td>
<td>3,000,000 psi / 20700 MPa</td>
</tr>
<tr>
<td>Bond Strength to Concrete, ASTM C-882/C-882M-05</td>
<td>1 Day, 28 Days</td>
<td>Min. 1,300 psi / 9 MPa, Min. 2,500 psi / 11 MPa</td>
<td>N/A</td>
</tr>
<tr>
<td>Set Time ASTM C-807 - 08, Initial Set</td>
<td>60 - 75 Minutes</td>
<td>60 - 75 Minutes</td>
<td>120 Minutes</td>
</tr>
<tr>
<td>Set Time ASTM C-807 - 08, Final Set</td>
<td>90 - 110 Minutes</td>
<td>90 - 110 Minutes</td>
<td>300 minutes</td>
</tr>
<tr>
<td>Freeze Thaw Durability, ASTM C-666</td>
<td>300 Cycles</td>
<td>100%, Zero loss</td>
<td>80% to 90%, 10% to 20% degradation</td>
</tr>
<tr>
<td>Sulfate Resistance (% expansion), ASTM C-1012-04</td>
<td>6 Weeks</td>
<td>0.011% Expansion</td>
<td>0.038% to 0.044% Expansion</td>
</tr>
<tr>
<td>Shrinkage, ASTM C-1090</td>
<td>28 Days</td>
<td>0.07%</td>
<td>0.35% to 0.50%</td>
</tr>
<tr>
<td>Tensile Strength, ASTM C-496</td>
<td>28 Days</td>
<td>Min. 750 psi / 5.2 MPa</td>
<td>400 psi / 2.7 MPa</td>
</tr>
<tr>
<td>Abrasion Resistance, ASTM C-1138</td>
<td>6 Cycles @ 28 Day Maturity</td>
<td>0.67% Loss</td>
<td>5.60% Loss</td>
</tr>
<tr>
<td>Chloride Ion Penetration by Ponding, ASTM C-1543</td>
<td>90 days ponding</td>
<td>0.014% wt Cl at 55-65 mm</td>
<td>N/A</td>
</tr>
</tbody>
</table>
GeoSpray Advantages

Environmental Benefits

• GeoSpray is produced from commercially available industrial waste streams, creating a highly environmentally friendly product, Greater than >50% post-industrial recycled.

• These materials are introduced and serve as “alternative cementitious” binders as well as “contributing fillers”, such that every particle within GeoSpray is providing some cross-linking characteristic.

• The production method & chemical reaction of GeoSpray create only a fraction of the CO₂ emissions of other cementitious materials.
GeoSpray Advantages
Self Bonding

Experimental Parameters:

• On the first day a series of 2” by 4” cylinders were cast half full and cured with on an approximately 45 angle.

• On subsequent days (1, 7, 14 and 28) the top half of the cylinders were cast and filled creating a 45 angled joint in the center of the cylinders.

• Compressive strength tests were conducted 28 days after the top half of the cylinders were cast.
GeoSpray Advantages
Self Bonding

Results:

• Samples cast of GeoSpray (both halves) when tested under compression did not break at the joint.

• The chemical nature of GeoSpray allows for chemical bonding across the interface even with pours 28 days apart resulting in a monolithic structure.

• Samples cast of competitive cement mortars always broke along the angled joint essentially creating 2 separate layers.

*This unique property of geopolymers allows project flexibility in variable weather conditions as the covalent bonds prevent cold joint shear failure*
GeoSpray Advantages
Corrosion Resistance

GeoSpray™ AMS
Corrosion Resistant Geopolymer System

Microbial-Induced-Corrosion (MIC) Mechanism

Aerobic H₂SO₄ Production and Corrosive Attack Above Water Line

H₂S Gas Emission

Anaerobic Generation of H₂S Below Water Line in Septic Effluent
• When samples were further exposed to higher levels of sulfuric acid (7% $\text{H}_2\text{SO}_4$) GeoSpray AMS samples showed some signs of surface level corrosion after 84 days.

• GeoSpray AMS samples performed significantly better than standard portland cement samples which lost greater than 50% of their original weight.
Centrifugally spun cement-mortar lining is noted to have a Manning coefficient of 0.009 or 0.010 on pipes in service 20 years or more.

ACPA has a conservative design value of 0.012 for concrete pipe lining.

When lining corrugated metal pipe Manning’s n values will likely be reduced to a range of 0.016 to 0.018 as the lining fills in some of the corrugation.

Option to adjust the desired roughness of the surface by hand finishing techniques.

Improving Manning’s \( n \)

Hand trowelled finish reduces roughness to the finish of smooth concrete pipe.
Slip Lining Drawbacks

- Open Area Reduction
- Requires work beyond inlet/outlet
- Requires Extra ROW or temporary access permits
- Wetland impact requiring ACOE permits
- Temporary haul road construction and removal
- Increases culvert new design standard requirement for aquatic organism
GeoSpray CCCP Advantages
Effective and Efficient

• Lower total system cost than alternative methods
  Installation + ongoing operating costs
• Point of failure repair
• Less risk exposure from weather
• Less disruptive to the community
  Less cost associated with road closures, non-productive labor, traffic delays, impact to local business, etc.
• More quickly implemented
  Less cure/set-up time
All required equipment is housed in a single 24 ft box truck, with a hopper and materials storage. All repair equipment fits down a standard 24 inch diameter manhole.
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GeoSpray Advantages
Application Flexibility

Shape
- Non-round, elliptical, egg shaped
- Manholes, wet-wells, junction boxes

Length
- Short lines, culverts, point repair
- Longer sewer and storm segments

Diameter
- From 36 inches to 180 inch
- Varying diameter in a single run

Ovality
- Ovality greater than 10%
- Box culverts and structures
GeoSpray Advantages
Application Flexibility

Angles
- Bends, curves, and change in elevation

Laterals
- Monolithically tied to structure

Host pipe material
- Brick, Rock, Concrete
- Corrugated Metal or Cast Iron

Host pipe condition
- Slightly to fully deteriorated
Standard Practice for
Installing a Protective Cementitious Liner System in
Sanitary Sewer Manholes

This standard is issued under the fixed designation F 2551; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

A sanitary sewer manhole may be repaired or rehabilitated by applying a prepackaged cementitious liner to the interior surface after it has been properly prepared and cleaned. Sanitary sewer manholes can be damaged by dynamic loading, abrasion, erosion, and corrosion.

An ASTM Standard exists for coating of manhole with cementitious/geopolymer systems that describes the quality control and general process requirements.
Manhole Being Coated
Technology Cost (Material + Labor) Comparison

- CIPP
- Slipline
- SPR
- GeoSpray

Cost Per Linear Foot (Materials and Labor) vs. Pipe Diameter (inches)
GeoSpray DOT Approvals
November - 2015

Approved for Use
Conditional Approval
Application submitted - pending
Approved for field testing
GeoPolymer Case Studies
City of Fort Worth - Texas

Five Multi-cell 84” CMP Culverts

Installation Completed
2013
The active creek bed was dewater and flow through the culverts were diverted. The pipes were then cleaned and pressure washed in preparation for lining.

The deteriorated condition of the pipes caused significant safety concerns due to the heavy industrial traffic that is common on this road. Flooding of the road was also a common occurrence.
GeoSpray was used not only to rehabilitate the pipes, but also to rehab the head wall.

Carefully calculated and monitored application of the material provided improved flow characteristics and stopped flooding that had been common place.

The contractor was able to guarantee a fully structural rehabilitation of the existing infrastructure, and the asset owner renewed the culverts without public disruption.
SR 446-Indiana DOT
Bloomington, Indiana
Culvert Rehabilitation Case Study

Installation Completed
September 2015
Project Details:

• The Indiana DOT was looking for a site to demonstrate the lining capability of a geopolymer cement mortar. SR 446 provided a pipe that allowed for good access and viewing.

• Corroded & deteriorating CMP Culvert
  • 275 linear feet of 84 inch diameter
  • Bolted multiplate corrugated metal pipe

• Contractor - Temple and Temple
GeoSpray Case Study
SR 446 - Bloomington, Indiana

Project Details:

• The Indiana DOT was looking for a site to demonstrate the lining capability of a geopolymer cement mortar. SR 446 provided a pipe that allowed for good access and viewing.

• Corroded & deteriorating CMP Culvert
  • 275 linear feet of 84 inch diameter
  • Bolted multiplate corrugated metal pipe

• Contractor - Temple and Temple
Additional Key Job Requirements:

• The culvert was originally specified to be rehabilitated with cured in place pipe (CIPP).

• SR 446 culvert under 30+ of fill.

• Sections of invert have corroded completely through with significant sections of ground water infiltration.
Small working footprint allowed for very limited disruption to traffic with no lane closures.
Invert was repaired by hand spraying GeoSpray mortar into the invert voids.
A 1.5 inch structural GeoSpray liner was applied in 2 passes.
GeoSpray Case Study
SR 446 - Bloomington, Indiana

The entire rehabilitation was completed in seven days with little to no disruption of the private and commercial neighbors.
River Road
Weldon, North Carolina

Culvert Case Study

Installation Completed
November 2013
Project Details:

- NCDOT was looking for a challenging first application site for GeoSpray in North Carolina, and they found it on River Rd in Weldon NC.

- Corroded & deteriorating CMP Culvert
  - 85 linear feet of 108 inch diameter
  - 70,000 lbs of GeoSpray applied

- Contractor - IWPC - IPR Great Lakes
Additional Key Job Requirements:

• The north face of the culvert had already been repaired with metal bracing to prevent on-going erosion and potential damage to nearby housing.

• River Rd is the only access road to an industrial waste treatment plant and 2 local farms.

• During many parts of the year the culvert is completely submerged causing significant areas of corrosion and water infiltration.
The 108 inch CMP culvert was missing significant material in the invert and was in need of repairs.

An 8 inch hydraulic by-pass was used to divert flow and allow traffic over the single lane road during the entire rehabilitation.
A 2.5 inch structural GeoSpray liner was applied in 4 passes.

The entire rehabilitation was completed in seven days with little to no disruption of the private and commercial neighbors.
Rock Springs, Wyoming

Arched Culvert Case Study

Installation Completed
May 2014
Project Details:

• Rock Springs, Wyoming

• Arched Storm Culvert
• 700 Linear Feet of CMP
• 48 Inch High
• 72 Inch Wide
• 126,000 lbs of GeoSpray Applied

• Contractor - IPR South Central
The initial culvert was in very poor shape with most of the invert corroded and lost with soil voids as deep as 2 ft below the pipe.

Significant damage also existed in the crown with some sections caved in.
Prior to repair the pipes required bracing for safe operation.

The finished culvert created a new structural system, integrated with the junction boxes.
The project was completed in under 1 week with no disruption to traffic along the roadway
Fort Worth, Texas

Non-Round Storm Sewer Case Study

Installation Complete
June 2013
GeoSpray Case Study
Arched Storm Water - Fort Worth, TX - USA

Project Details:

• Work Order issued by the City of Fort Worth, Texas for trenchless repair existing RCP Storm Water

• Deteriorated RCP
  • 634 linear ft of 80” x 84” arched
  • 296 linear ft of 102” x 84” arched

• Contractor - IWPC - IPR Great Lakes

• Engineering called for rebar to be placed in the square bottoms of the pipes, and carbon fiber to provide additional support to the arched roof.
Original arched storm water pipe with severely damaged invert.

The first step was to install a rebar cage along the bottom corners of the pipe to support a rounded bottom.
The completed rebar support system with initial repairs completed to the invert.

The lower corners of the pipe were then rounded with a hand sprayed application of GeoSpray.
After the first pass of GeoSpray was completed on the pipe, a carbon fiber grid was applied to the top section to help with additional structural support.

A final pass of GeoSpray was applied finishing the application process.
Garden State Parkway

Arched CMP Culverts

Completed
October 2014
GeoSpray Case Study
Garden State Parkway - NJ, USA

Project Details:

7 Arched CMP culverts running under the Garden State Parkway (owned by the New Jersey Turnpike Authority) were inspected and determined to be corroding. The dimensions of the structures were as follows:

1. 315 Linear Ft of 160” x 101” pipe
2. 315 Linear Ft of 60” x 40” pipe (3 Culverts)
3. 375 Linear Ft of 60” x 42” pipe (2 Culverts)
4. 150 Linear Ft of 112” x 75” pipe

A majority of the pipes were filled with significant amounts of silt and debris. Several sections had completely collapsed.

• Contractor - Inland Pipe Rehab
Most of the culverts were at least 40% filled with silt, so the pipes were thoroughly cleaned of the material and then pressure washed and inspected.

Because the inverts of the pipes were severely corroded, they were rebuilt and then prepared for GeoSpray material application.
Once cleaned, a first pass of material was applied by shotcrete methods to the corners of the pipe to insure that enough material was placed in those area as required by the engineering design.

Then the material was applied by spin casting the entire pipe to cover the crown and invert. The by-pass pipe was run through the pipe to avoid disruption of the highway and it was adjusted from side to side as the pipe was rehabbed.
Any laterals were plugged and sprayed passed, this create a structure that “feathers” in the material past the opening of laterals.

No post cutting of laterals was necessary, saving time and expense.

Each of the smaller pipes had 1.5 inches of thickness applied, while 2.1 inches was required for the largest pipe based on independent engineering. The invert was smoothed around the by-pass pipe to insure a complete structural repair.
Existing 60” x 40” brick sewer.
GeoSpray Case Study
KY 9 - Newport, Kentucky - USA

Existing 60” x 40” brick sewer.
A 1.5 inch structural GeoSpray liner was applied in 2 passes.
Structural rehabilitation with a 1.5 inch GeoSpray mortar lining.
GeoSpray Case Study
KY 9 - Newport, Kentucky - USA

Structural rehabilitation with a 1.5 inch GeoSpray mortar lining.
US Highway 59
Houston, Texas
Sanitary Sewer RCP Repair Case Study

Installation Completed
August 2011
Project Details:

- City of Houston, Texas
- Deteriorated RCP
  - 700 linear feet of 72” RCP
  - Under heavily traveled US Highway 59 in northeast Houston
  - Severe infiltration at multiple joints
  - Evidence of significant ground settlement
  - 42 feet of cover above the pipe
- Contractor - IPR South Central
GeoSpray Case Study
Sanitary Sewer RCP - Houston, TX - USA

Additional Key Job Requirements:

• The rehabilitation was originally designed as a CIPP repair. Access holes and cleaning had been completed. Bypass was in place and running.

• Due to high temperatures (>100°F during the summer months) the city deemed the risk of over-the-hole wet out along with early resin set-up as a significant risk.

• The city needed a solution as they did not expect the pipe to last through the Fall - when the risks associated with the CIPP installation would be inline with expectations.
Access port that was created for the CIPP installation was used for the entry into the pipe.

Sever corrosion had occurred within the pipe and at the joints. The pipe was pressure washed and loose material was removed. Water infiltration was stopped at the joints with a hand application of GeoPlug material.
Once the pipe was cleaned and infiltration stopped, the application sled was positioned within the pipe.

The GeoSpray mortar was centrifugally cast from the spray nozzle onto the existing pipe wall to create a whole new pipe structure.

After the GeoSpray was applied, a finish coat of AMS Post Treatment was applied to impart additional corrosion resistance.
“The completed work is a benefit to the community”

David Tajadod - Managing Engineer - City of Houston

See Underground Construction - July 2012 for a complete article - ucononline.com
EPA/Battelle Demonstration
Houston, Texas
Sanitary Sewer RCP Repair - Case Study

Installation Completed
April 2013
GeoSpray Case Study
Sanitary Sewer RCP - Houston, TX - USA

Project Details:

• City of Houston, Texas

• US EPA’s Aging Water Infrastructure Program, conducted a field demonstration along with Battelle Memorial Institute.

• Deteriorated RCP
  • 165 linear feet of 60” RCP
  • 25 feet of cover
  • Directly beneath an open stormwater channel
  • Terminated in local treatment plant

• Contractor – IPR South Central

Final report of demonstration was presented at No Dig 2014 by John Matthews of Battelle.
The RCP was severely deteriorated with exposed corroded rebar and several infiltration locations gushing water that needed to be repaired and controlled before lining the existing structure.
Active infiltration was a concern that had to be repaired prior to lining.

Large sections of the invert of the pipe had also been corroded.
Initial repairs were made and a thin first past of GeoSpray was applied prior to the final thickness.

The 2.5" coating of GeoSpray was applied to the existing structure to create a new pipe inside the old. A final AMS Post Treatment was applied to provide additional corrosion resistance.
“The independent evaluation of the technology showed it is a technically viable structural alternative to traditional repair and replace methods.”

Ariamalar Selvakumar, Ph.D., P.E. - US EPA

John Matthews, Ph.D. & Wendy Condit - Battelle Memorial Institute
Thank You

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