CONSTRUCTION SPECIFICATION FOR THE REHABILITATION OF GRAVITY PIPE AND BOX CULVERT BY GEOPOLYMER SPRAY-ON LINER

TABLE OF CONTENTS

468.01 SCOPE

This specification covers the requirements for the rehabilitation of an existing pipe culvert or sewer using an approved structural geopolymer spar-on lining system.

468.02 REFERENCES

This specification refers to the following standards, specifications, or publications:

Ontario Provincial Standard Specifications, Construction

OPSS 409 Closed-Circuit Television (CCTV) Inspection of Pipelines
OPSS 411 Construction Specification for the Cleaning and Flushing of Culverts, Pipe Sewers, Catchbasins, Maintenance Holes, Ditch Inlets, and Oil-Grit Separators
OPSS 490 Construction Specification for Site Preparation
OPSS 491 Preservation, Protection, and Reconstruction of Existing Facilities
OPSS 517 Construction Specification for Dewatering
OPSS 539 Construction Specification for Temporary Protection Systems
OPSS 919 Formwork and Falsework
OPSS 929 Abrasive Blast Cleaning - Concrete Construction

Ontario Provincial Standard Specifications, Material

OPSS 1301 Cementing Materials
OPSS 1302 Water

Ontario Ministry of Transportation Publications

MTO Forms:

PH-CC-701 Request to Proceed
PH-CC-702 Notice to Proceed

CSA Standards

S6-19 Canadian Highway Bridge Design Code

American Society for Testing and Materials (ASTM):

C33/C33M-18	Specification for Concrete Aggregates
C39/C39M-21	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C78/C78M-22	Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C172/C172M-17	Practice for Sampling Freshly Mixed Concrete
C267-20	Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes
C469/C469-22	Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C496/C496M-17	Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C666/C666M-15	Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C807-21	Test Method for Time of Setting of Hydraulic Cement Mortar by Modified Vicat Needle
C882/C882M-20	Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
C1090/C1090M-15	Test Method for measuring Changes in Height of Cylindrical Specimens of Hydraulic-Cement Grout

American Concrete Institute (ACI):

ACI PRC-305-20	Guide to Hot Weather Concreting
ACI PRC-306-16	Guide to Cold Weather Concreting

468.03 DEFINITIONS

For the purpose of this specification, the following definitions apply:

Applicator means a manufacturer-certified product application company for the construction of the polyurethane liner as per the manufacturer's requirements and to its satisfaction.

Design Engineer means the Engineer retained by the Contractor who produces the design and Working Drawings and other engineering documents required of the Contractor.

Design Checking Engineer means a separate Engineer from the design Engineer retained by the Contractor who checks the design and Working Drawings and other engineering documents prepared by the design Engineer required of the Contractor.

Geopolymer means organic, typically ceramic, materials that form long-range, covalently bonded no-crystalline networks or chains of mineral molecules.

Geopolymer Liner means a geopolymer material acting as lining inside the host pipe.

Host Pipe means existing original pipe culvert or sewer requiring rehabilitation.

Manufacturer's Site Representative means a technical representative who is specialized and experienced in spray-on structural geopolymer liner for host pipe and who will be present on site during the host pipe preparation and spray-on lining application work.

Resin means an organic polymer, solid or liquid; usually thermoplastic or thermosetting.

Spray-On Lining means a method for applying a lining of cement mortar or resin by rotating a spray head which is winched through the existing pipe culvert or sewer or applying a lining of cement mortar or resin by hand.

468.04 DESIGN AND SUBMISSION REQUIREMENTS

468.04.01 Design Requirements

The engineering design of the geopolymer liner shall be in accordance with the applicable ASTM standards and as specified in the Contract Documents with the following criteria:

a) Design conditions shall assume fully deteriorated condition of the host pipe.

b) Parameters for design shall be according to Table 1.

468.04.02 Submission Requirements

468.04.02.01 Working Drawings

Three copies of written procedures and Working Drawings showing the design calculations for the wall thickness of the geopolymer liner in the host pipe shall be submitted to the Contract Administrator a minimum of 2 weeks or as per the Contract Documents, prior to commencement of the geopolymer liner installation. Prior to making a submission, the seal and signature of a design Engineer and design checking Engineer shall be affixed on the written procedures and Working Drawings verifying the drawings are consistent with the Contract Documents. The written procedures and Working Drawings shall include the following:

a) The Working Area layout;

b) A work plan outlining the materials, procedures, methods and schedule to be used to execute the work;

c) A traffic control plan;

d) A safety plan including the company safety manual and emergency procedures;

e) The requirement or restriction for man entry into the host pipe to perform geopolymer liner operations shall be specified;

f) Material mixture and installation procedures for repairs and/or filling voids;

g) A work plan including all materials and methods for any repairs necessary to the host pipe prior to the geopolymer liner application;

h) Method to verify applied thickness of the finished product during the installation of the geopolymer liner at the plastic and hardened states;

i) Dewatering or temporary flow by-pass plan, when specified in the Contract Documents;

j) A containment and contingency plan in conformance with the Contract Documents for the following potential conditions:

i. Improper placement of the geopolymer liner
ii. Damage to the host pipe or box culvert
iii. The liner's failure to achieve structural integrity
iv. Potential environmental impacts, emergency containment and clean-up procedures

468.04.02.02 Product Data

A minimum of 2 weeks prior to commencement of the geopolymer liner installation or as per the Contract Documents, manufacturer's product data and installation instructions including handling and storage requirements shall be submitted to the Contract Administrator. This submission shall include required substrate preparations, on-site quality control recommendations, a list of all materials to be used, and safety data sheets (SDS) for each product used.

468.04.02.03 Certifications

The following shall be submitted to the Contract Administrator:

a) A letter of certification from the manufacturer that the product meets or exceeds all technical and packaging requirements.

b) A letter of certification that the equipment to be used for applying the products has been manufactured or approved by the geopolymer liner manufacturer and applicator personnel have been trained and certified for proper use of the equipment. Certification letter shall be dated within 6 months of the bid date. An original third-party verification that materials meet physical properties specified for design at 24hr, minimally ASTM C39 and C882 and 28-day, minimally ASTM C39, C78, C882, and C1090.

c) An original third-party verification of test data for ASTM C666 testing for samples cured 28 Days and subjected to 300 cycles.

d) An original third-party verification of material formulation via X-ray fluorescence (XRF) data as detailed in the material section.

e) Manufacturer's materials warranty certificate.

f) Applicator's job history and reference certificates.

g) Proof of any necessary federal, provincial, or local permits or licenses necessary for the project.

468.04.02.04 Applicator's Qualifications

A certified statement from the manufacturer shall be submitted that states the applicator performing the work has been trained and approved in the handling, mixing and application of the products to be used. Certification letter shall be dated within 6 months of the bid date.

468.04.02.05 Manufacturer's Site Representative

The manufacturer shall assign a site representative for this project. The name and resume of the Site Representative shall be submitted to the Contract Administrator 3 weeks prior to start of the work. The manufacturer's site representative shall:

a) Be on-site during the host pipe surface repair, restoration, and preparation operations.

b) Issue a certification to the Contract Administrator that the host pipe cleaning, surface repair, water infiltration stoppage, drying and preparation are done to the manufacturer's satisfaction, and the host pipe is ready to receive the lining.

c) Be on-site right before and during the lining installation operations.

d) Issue a final certification that the geopolymer liner installation work has been done in conformance with the Contract Documents and the manufacturer's requirements and standards without any hidden or exposed deficiencies that require replacement or repairs of part of or all the work.

468.05 MATERIALS

468.05.01 General

The materials utilized anywhere in the work shall be fully styrene free and non-VOC.

468.05.02 Geopolymer Liner Mortar Material

The geopolymer liner material shall be compatible with the thermal and chemical conditions of the host pipe. If the manufacturer requires data related to weather, temperature and pH of water at the site, the data shall be collected and supplied it to the manufacturer.

The finished geopolymer liner material shall conform to the minimum physical requirements according to Table 2. The physical requirements must be verified by an independent, certified, third party testing laboratory and must be submitted with the bid package.

The geopolymer liner mortar shall be composed of at minimum 70% pozzolanic material selected from the list of: SiO_2, MgO, Al_2O_3, Fe_2O_3 and be verified by third party certified XRF testing.

Maximum particle size of aggregate shall be 2.38 mm and shall be based on 100% of material (excluding fibres) passing the No. 8 sieve.

468.05.03 Thickness of Geopolymer Liner

The minimum thickness of the geopolymer liner shall not be less than 30 mm for all pipes below 1350 mm nominal diameter and not less than 40 mm for pipes equal to and above 1350 mm nominal diameter.

The thickness of geopolymer liner shall be calculated and designed based on the minimum design criteria for a project or as per the Contract Documents. Wall thickness design calculations for each structure to be rehabilitated utilizing the specified geopolymer mortar material must be submitted with all qualified bids, along with supporting formulas that document that version of the formula used.

468.05.04 Delivery of Materials

Liner materials shall be delivered in the manufacturer's original, unopened and undamaged packages. Each package shall clearly identify the following:

a) Manufacturer.

b) Brand name.

c) Contents.

d) Stock number.

e) Best before or expiry date, if applicable.

Packages showing indications of damage that may affect condition of contents or when the delivered quality of certified geopolymer liner product is deemed to be unacceptable by the Contract Administrator, the product shall be rejected.

468.05.05 Storage of Materials

Materials shall be stored in original packaging and under protective cover to protect from damage.

Materials shall be stored at temperatures recommended by the manufacturer.

Materials shall be stacked as recommended by the manufacturer.

468.05.06 Handling of Materials

Geopolymer liner materials shall be handled according to their safety data sheets (SDS) and in such a manner as to prevent damage to the product or finishes.

468.06 EQUIPMENT

468.06.01 Spray-Applying Equipment for Geopolymer Liner

The work consists of hand spray application or centrifugally spin-casting the specified geopolymer liner material to the inside of the host pipet. The necessary equipment and application methods to apply the liner materials shall be only as approved by the manufacturer. Material shall be mixed in accordance with manufacturer's specifications and pumped to the appropriate application device.

Prior to proceeding with the lining, a letter from the manufacturer shall be submitted to the Contract Administrator indicating that the applicator's plans, means, methods and application calibrated equipment satisfy the requirement for application of the lining. Copies of the plans, means, methods and description of application equipment shall be attached to the letter for information purposes.

468.07 CONSTRUCTION

468.07.01 Site Preparation

Site preparation shall be according to OPSS 490.

468.07.02 Preservation and Protection of Existing Facilities

Preservation and protection of existing facilities shall be according to OPSS 491.

468.07.03 Dewatering

When required, flow diversion, unwatering/dewatering, shall be installed to fulfill the Contract requirements. Dewatering when required shall be according to OPSS 517.

The Environment Canada weather forecast shall be monitored prior to commencement of lining operations. Where the anticipated weather conditions are such that anticipated host pipe/box culvert flows may exceed the installed bypass pumping capacity or may cause potential site flooding, commencement of construction shall be delayed until favourable weather is forecast.

468.07.04 Temporary Protection Systems

The construction of all protection systems shall be according to OPSS 539.

468.07.05 Cleaning of Host Pipe

Host pipe cleaning shall be according to OPSS 411.

468.07.06 Preparation and Pre-Lining Repairs

Prior to the geopolymer liner installation, the host pipe shall be inspected using visual observations or when specified CCTV/zoom camera where personnel entry is impracticable. CCTV inspection shall be according to OPSS 409.

Any open joints and voids shall be sealed with the geopolymer liner material prior to the lining of the host pipe. If additional repair procedures are required to restore the host pipe for lining, for example invert reconstruction, a repair plan shall be submitted to the Contract Administrator prior to proceeding.

All active infiltration prior to application of the geopolymer liner material and ensure that the host pipe is sufficiently dewatered as per the manufacturer's instructions.
Additional materials including quick setting mortars, chemical grouts and hydraulic cements necessary to stop infiltration and create a surface for the geopolymer liner to be applied to may be necessary and shall be in accordance with the relevant specifications. All products used to stop active infiltration shall be approved by the Contract Administrator and used in accordance with manufacture's recommendations.

Temporarily plug all drop inlets or laterals to prevent mortar from entering the inlets.

The diameter, profile, length and all other dimensions of all host pipes to be rehabilitated shall be accurately measure for planning all construction activities and choosing appropriate equipment.

All surfaces shall be inspected by the Contract Administrator during and after preparation and before the repair material is applied.

468.07.07 Preparation of Geopolymer Liner Material

The geopolymer liner material shall be mixed in a high shear mixer to the required water cement ratio, as recommended by the manufacturer.

Mixing water temperatures shall be determined before blending operations begin. The mixing water temperature shall be recorded in the daily activity log at multiple times throughout the Day during the installation process.

Water temperature shall be maintained at a consistent temperature of 27 ºC or lower.

468.07.08 Prior to Application of Geopolymer Liner

At the completion of the cleaning, surface repair and infiltration stoppage operations of host pipe to be lined and a minimum of 2 Business Days prior to the planned commencement of the application of liner, MTO form PH-CC-701, Request to Proceed shall be submitted to the Contract Administrator.

The MTO form PH-CC-701, Request to Proceed shall be accompanied by a signed letter by the manufacturer stating that the culvert surface preparation has been completed in accordance with the manufacturer's requirements and to their satisfaction, and that the host pipe is ready for the spray applying of the geopolymer liner.

The application of geopolymer liner shall not proceed until MTO form PH-CC-702, Notice to Proceed has been received from the Contract Administrator.

468.07.09 Application of Geopolymer Liner

The work consists of hand spray application or centrifugally spin-casting the specified geopolymer liner material to the interior surface of the host pipe after it has been properly prepared and cleaned. The necessary equipment and application methods to apply the geopolymer liner material shall be only as approved by the material manufacturer.

Spraying shall be performed by starting at the pipe-end project location and progressing towards the entrance of the host pipe.

The geopolymer liner material shall be applied to a damp surface, with no flowing water.

In the case of host pipe being corrugated steel pipe (CSP), the surface shall be dry and the final surface appearance shall be minimum thickness following the host pipe profile.

If desired, the geopolymer liner may be troweled following the spray application. Initial troweling shall be in an upward motion, to compress the material and solidify the host pipe's wall. Precautions shall be taken not to over-trowel. Only a wood float or Magnesium (Mg) float shall be utilized.

Multiple sets of placing equipment (spin casting units, sprayers etc.) shall be available onsite to address any application issues that arise during the geopolymer liner process.

468.07.10 Curing of Geopolymer Liner

Manufacturer's recommended schedule shall be followed in curing of the geopolymer liner. The material shall be allowed to cure for a minimum of 6 hours and until the material has reached the final set condition, whichever is longer, prior to the release of bypass or flow through the host pipe that would contact the liner. The geopolymer liner shall be sufficiently cured to not be damaged by water. Any surface water diversion/dewatering requirements must remain active until curing and post-construction inspection is complete.

Refer to ACI PRC-306 Guide to Cold Weather Concreting. The geopolymer liner shall not be placed when the ambient temperature is less than 7 ºC or when the temperature is anticipated to fall below 7 ºC within 48 hours of placement, without written permission from the manufacturer. If the ambient temperature goes below 7 ºC after application of the geopolymer, proper heating recommended by the manufacturer shall be applied to keep the material and substrate warm.

Refer to ACI PRC-305 Guide to Hot Weather Concreting**.** The geopolymer liner material shall not be applied when ambient and surface temperatures are 35 ºC and above. Chilled water may be added to the mix material as recommended by the manufacturer. The substrate shall be saturated surface dry (SSD) before application of the geopolymer begins. Proper curing recommended by the manufacturer is always required and is particularly important in hot weather.

The geopolymer liner material shall be cured in a moist and moderate climate. When dry and/or hot conditions are present, the use of a wind barrier and fogging spray shall be required.

The use of calcium chloride as a settling and hardening accelerator is not permitted.

468.07.11 Lining the Host Pipe Ends

Termination of the geopolymer liner at the ends of the host pipe shall be completed by hand, applying the geopolymer material to the bevelled ends and outer surface of the host pipe.

468.07.12 Manufacturer's Certificate of Conformance

Upon completion of the geopolymer liner work and restoring of flow water of the host pipe and prior to the start of the work on other host pipes, a Certificate of Conformance signed by the manufacturer's Engineer shall be submitted to the Contract Administrator. The Certificate of Conformance shall state that the installed liner materials and construction have been done according to the manufacturer's requirements and to their satisfaction and as per Contract Documents. The certificate shall state MTO contract number, the structure site number, the name of the structure and the date of lining work completion.

468.07.13 Supervision

The project Superintendent shall have received adequate training from the technology supplier and shall have a minimum of 3 years demonstrated experience on projects with similar scope and complexity.

468.07.14 Environmental Protection and Contingency

Environmental protection requirements and mitigation measures shall be according to the Contract Documents with the following additions:

a) Install containment measures to prevent the escape of grout from the host pipe undergoing geopolymer liner procedure.

b) Reinstate water flow no sooner than 24 hr after installation of the geopolymer liner and as per the manufacturer's recommended schedule.

c) Capture and properly dispose-off the rinse/first flush water until pH levels are confirmed to be at or below a pH level of 9.

468.07.15 Electrical Equipment, Fixtures and Systems

Electrical equipment shall be suitably insulated for noise reduction. Noise produced by electrical equipment must comply with local municipal noise by-laws.

468.07.16 Quality Control

468.07.16.01 Daily Activity Logs

A daily activity log for each geopolymer liner application shall be completed anytime a work crew is on site. The daily log shall include the following information:

a) List all personnel on site complete with arrival and departure times;

b) Reinforcing prior to spray-on operations, if applicable;

c) Start and end times for application of each spray-on coat and section, including speed of winch and pumping/spraying rate (m^3/minute);

d) Atmospheric conditions at the time of spraying including ambient air temperature and temperature inside the host pipe;

e) Dry powder and mixing water temperature;

f) Operational conditions such as water addition rate and mechanical equipment operations data;

g) Quantity of materials used and area completed including thickness;

h) Total length of the liner installation;

i) Curing/drying time; and

j) Any special conditions are to be noted.

A copy of the daily log shall be submitted to the Contract Administrator within 1 Business Day.

468.07.16.02 Equipment Calibration Reports

All applicable equipment calibrations must be maintained on site by the superintendent and available for inspection upon request by the Owner.

468.07.17 Management of Excess Materials

Management of excess materials shall be according to the Contract Documents.

468.08 QUALITY ASSURANCE

468.08.01 Testing for Compressive Strength

The completed geopolymer liner shall be smooth and free from honeycomb, areas of segregation, cracking, overspray, and debonding.

Liner testing shall be performed on geopolymer liner to verify the mix proportions, observe batching and mixing operations, and to inspect the quality of the in-place material.

All QA sampling and testing of the materials shall be in accordance with applicable ASTM test methods and the manufacturer's specifications and design recommendations to confirm compliance with the requirements specified in the Contract Documents. When casting cylinders, care must be taken to thoroughly mix the sample frequently in the sample container so as the particles are evenly distributed.

Field tests shall be performed by qualified personnel in the presence of the Contract Administrator. The Contractor shall provide equipment, supplies, and the services of one or more employees as necessary to assist in the field control testing.

The Contract Administrator or designated representative shall witness the sampling and administer as specified in the Contract Documents.
The Owner shall conduct compressive strength testing of geopolymer liner in accordance with ASTM C39. The minimum compressive strength at 28 Days shall be 55 MPa. Six 100 mm x 200 mm cylinders shall be collected for each lot. They shall be tested as three at 28 Days, and three samples shall be for Referee testing, if required.

A lot shall be a complete spray pass of the pipe, 18,000 kg or a Day's production, which ever is less.

Individual test result shall be forwarded to the Contractor as they become available.

If the compressive strength of a single test of the installed geopolymer liner is less than 90% as specified in the Contract Documents, the product is considered unacceptable. In addition, if the average of three test results is not more than or equal to the compressive strength as specified in the Contract Documents, the product is considered unacceptable.

468.08.02 Thickness of Geopolymer Liner

The Contractor shall install a minimum of three small depth gauges - stainless steel tabs/self-tapping screws - as a ring on the inner surface of the host pipe at random locations of crown, invert, and sides of the host pipe to verify that the proper thickness of the geopolymer liner is achieved. Tabs/self-tapping screws to be installed on the crest of the corrugation of the CSP. These are positioned to be just below the specified thickness and are left in place when sprayed over. The gauge rings shall be placed a maximum of 2 m apart. The Contract Administrator shall check the thickness of the geopolymer liner at hardened or plastic state at five random locations for each host pipe.

The liner thickness over the CSP interior peaks shall meet the requirements for liner thickness. If the thickness of the installed geopolymer liner anywhere is less than the engineered requirement or minimum according to the geopolymer liner mortar material subsection 468.05.03, the product is considered unacceptable. The Contractor shall remove and repair the geopolymer liner at these five locations.

The Contract Administrator shall continue to check the thickness of the geopolymer liner at hardened or plastic state at a further five random locations for each host pipe until a complete set of five random locations are found to meet Contract requirements. The Contractor shall remove and repair the geopolymer liner at each random five locations that are found to be unacceptable.

468.08.03 Inspection of Materials

Inspections of the geopolymer liner materials may be made by the Contract Administrator after delivery. The geopolymer liner materials shall be subject to rejection by the Contract Administrator at any time on account of failure to meet any of the specification requirements, even though samples may have been accepted as satisfactory at the place of manufacture. geopolymer liner materials rejected after delivery shall be marked for identification and shall be removed from the job site at once.

468.08.04 Inspection After Curing

The completed geopolymer liner shall be smooth, and free from honeycomb, debonding and segregation. The Contract Administrator shall inspect the finished surface after curing. The Contractor shall repair areas with

cracks wider than 0.2 mm. If the geopolymer linear measurement of cracks greater than or equal to 0.2 mm in width per square metre is 2 m or greater, the entire geopolymer liner in the repair area shall be removed and replaced. The Contractor shall replace or repair areas with honeycomb or segregation depending on the severity as decided by the Contract Administrator. The Contractor shall also replace areas of the geopolymer liner where debonding is found.

468.08.05 Closed-Circuit Television (CCTV) Inspection

Installed geopolymer liner shall be inspected using visual observations or specified CCTV/zoom camera where personnel entry is impracticable. CCTV inspection shall be according to OPSS 409.

In the case of repairs required to restore the host pipe for lining, such as joints sealing, invert reconstruction, or additional repairs etc., a post preparation CCTV inspection shall be completed for each host pipe when specified in the Contract Documents.

468.08.06 Non-conforming Work

The Contractor shall be responsible for identifying all non-conforming work. The Contractor shall submit a written proposal for repair or replacement for all non-conforming work identified by either the Contractor or the Contract Administrator.

468.09 MEASUREMENT FOR PAYMENT

468.09.01 Actual Measurement

468.09.01.01 Geopolymer Liner

Measurement for payment shall be the length in meters of geopolymer liner placed, as measured along the centerline of the invert, of the host pipe.

468.09.02 Plan Quantity Measurement

When measurement is by Plan Quantity, such measurement shall be based on the units shown in the clause under Actual Measurement.

468.10 BASIS OF PAYMENT

468.10.01 Geopolymer Liner - Item

Payment at the Contract price for the above tender items shall be full compensation for all labour, Equipment, and Material to do the work.

TABLE 1
Design Parameters for Geopolymer Liner

Parameter	Design Requirement
Structure Condition	Fully Deteriorated
Design Thickness Method	ASTM F1216-09 or Two Way Flat Wall Beam Analysis Assume fully deteriorated condition of the gravity host pipe, box culvert, or associated structures. For non-circular host pipe (such as egg, oval, or other non-round shapes) a design method other than ASTM F1216 X1 shall be used because the F1216 X1 design method is not applicable to host pipes that were not originally circular. The non-circular host pipe design method shall be as specified in the Contract Documents or proposed by the Contractor for approval by the Contract Administrator.
Design Life	50 years
Safety Factor	2.0
Groundwater Depth	Full soil depth, unless otherwise known.
Soil Modulus	6.9 MPa (1000 psi)
Soil Density	20 kN/m^3 (2039 kg/m^3)
External Earth Load	Minimum depth of 3.0 m to top of pipe or the actual height of cover that exists at the liner location, whichever is greater.
Live Load	Canadian Highway Bridge Design Code (CHBDC S6-14 of 166.6 kN).
Ovality	5% or actual existing culvert ovality, whichever is greater
Design Reduction Factor to Determine Design Value for Long Term Flexural Modulus of Elasticity	0.65

TABLE 2
Physical Properties of Geopolymer Liner

Property	Test Method	Minimum Value	
Compressive Strength	ASTM C39	1 Day	17 MPa
		28 Day	55 MPa
	ASTM C78	7 Day	5 MPa
		8 Day	9 MPa
Tensile Strength	ASTM 496	28 Day	6 MPa
Shrinkage	ASTM C1090	28 Day	0% at 65% RH
Modulus of Elasticity	ASTM C469	1 Day	20,000 MPa
		28 Day	35,000 MPa
Bond Strength	ASTM C882 Type II	1 Day	6 MPa
		28 Day	17 MPa
Freeze Thaw Durability	ASTM C666	300 Cycles	100% Zero Loss
Set Time	ASTM C807	Initial	< 75 min
		Final	< 120 min