

**Construction Specification for the
Geopolymer Spin Cast Rehabilitation of
Sanitary and Storm Sewers**

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TS 472.01**SCOPE**

This specification covers the requirements for the designing, supplying and installing a geopolymer to structurally rehabilitate existing sanitary and storm sewers and channels. The geopolymer liner shall be spin cast or hand sprayed to various pipe surfaces including: brick, concrete, corrugated metal, clay tile, and various other compatible materials.

The Work shall include the following; repairing jagged edges or deformities to the existing structure, filling cavities around the existing structure with pea gravel, flowable backfill, grout, or invert repair mortar, rights of entry, maintenance and removal of temporary fence, removing debris and foreign material from the existing structure, cleaning the existing structure, preparation of a work plan, providing design calculations, presence of the manufacturer's representative, testing and any corrective actions.

TS 472.02**REFERENCES**

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

City of Toronto Standard Specifications

TS 4.02	Construction Specification for Sewer Bypass Flow Pumping for Trunk Sewers
TS 409	Specification for Closed-Circuit Television Inspection of Pipelines
TS 411	Specification for Sewer and Maintenance Hole Cleaning

American Society for Testing and Materials

C31/C31M	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C33	Standard Specification for Concrete Aggregates
C39/C39M	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C42/C42M	Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C78/C78M	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C109/C109M	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
C114	Standard Test Methods for Chemical Analysis of Hydraulic Cement
C157	Modified Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete
C172	Standard Practice for Sampling Freshly Mixed Concrete
C267	Standard Test methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacing and Polymer Concretes
C403	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C469/C469M	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
C496/C496M	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
C642	Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

C666	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C801	Standard Test Method for Time of Setting of Hydraulic Cement Mortar by Modified Vicat Needle
C882/C882M	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
C1090/C1090M	Standard Test Method for Measuring Changes in Height of Cylindrical Specimens of Hydraulic-Cement Grout
C1138	Standard Test Method for Abrasion Resistance of Concrete (Underwater Method)
C1202	Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
F1216-16	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube

American Concrete Institute (ACI)

ACI 305R-99	Hot Weather Concreting
ACI 306R-88	Cold Weather Concreting

TS 472.03 DEFINITIONS

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

CCTV Survey means the closed-circuit televised inspection of sewers using closed circuit television.

Engineer means the licensed individual or firm responsible for the design of the works or their designate and registered with the Professional Engineers of Ontario.

MECP means the Ministry of the Environment, Conservation and Parks

NASSCO means the standards developed by the National Association of Sewer Service Companies for sewer inspection.

OHSA means the Occupational Health and Safety Act

PACP means the Pipeline Assessment Certification Program

SCGP means Spin Cast Geopolymer Pipe

Sewer Section means the length of pipe connecting two maintenance holes.

SSD means to Saturated Surface-Dry which relates to condition of an aggregate particle or other porous solid when the permeable voids are filled with water, but the exposed surfaces are dry.

XRF means X-Ray Fluorescence, a non-destructive technique used to determine the elemental composition of the geo spray polymer material.

TS 472.04**DESIGN AND SUBMISSION REQUIREMENTS****TS 472.04.01****Detailed Design and Shop Drawings Submittals**

Submit detailed design of geopolymer spray lining after field verification of pipe dimensions, pipe depth, water table, and other design parameter confirmation and shall be in accordance with the ASTM F1216-07a Appendix X1, Design Considerations for the fully deteriorated pipe condition and design parameters in the Table 1 below. The design and calculations must be prepared by an Engineer and shall comply with the requirements listed herein.

If after V1 and V2 actual field conditions are found to be different (e.g. dimensions of pipe, depth of sewer) than provided/suggested in the contract, the design shall be adjusted to actual field conditions. The adjusted design may result in a thicker liner to be installed. Any additional cost involved shall be determined according to the provisional adjustment items for additional liner thickness and if provisional items for additional liner thickness are not included in the tender, then shall be negotiated with the Contract Administrator.

In addition to other submittal requirements found herein, the Contractor is required to submit:

- 1) The design calculations for the wall thickness. Design calculations and drawings substantiating the geopolymer liner thickness shall be prepared by an Engineer with experience in the design of sewer pipe or sewer pipe linings. Submittals with drawings and computations without the Licensed Structural Engineer seal, signature and date shall be immediately rejected without any review.
- 2) Method to verify applied thickness during installation.
- 3) Field measurement of cured liner thickness.
- 4) Site specific health and safety plan.
- 5) Confined spaces safety plan.
- 6) Manufacturers' product data for reinforcing fabric and installation instruction.
- 7) Plastic indicator tabs.
- 8) The new liner test results to verify 28-day compressive strength in accordance with ASTM C39 and Modulus of Elasticity in accordance with ASTM C469/469M.
- 9) The X-Ray Fluorescence (XRF) analysis report as per ASTM C114 for the proposed geopolymer material.
- 10) Sewer Drying Plan submission.
- 11) Temporary Sewer Bypass Plan according to TS 4.02.
- 12) Work plan.

TS 472.04.02 Liner Design

The thickness of the liner and steel reinforcement (where required) shall be calculated and designed based on the requirements stated in these specifications.

Submit liner thickness calculations, prepared by an Engineer to the Contract Administrator for review. Liner thickness calculations shall be based on the following minimum design criteria identified in Table 1.

Table 1: Geopolymer design requirements

Parameter	Requirement
Design Method	The thickness of the geopolymer liner furnished shall be designed by the Contractor and shall not be less than the thickness designated in these Specifications. The calculations for this project shall be based on the fully deteriorated condition.
Design Life	50 years
Safety Factor	2.0
Ovality	3% or the actual ovality of the sewer section, whichever is greater. For noncircular and irregular shape sewer, the calculation shall take in to consideration any additional consideration due to noncircular shape.
External Hydrostatic Pressure	Corresponding to ground water table maximum 1.2 m below ground surface or actual ground water table if geotechnical report suggests ground water can be found at less shallow depth than 1.2 m.
External Earth Load	Based on 2.0 m over top of pipe or the actual height of cover that exists at the liner location, whichever is greater. If the ground cover height varies by more than 0.5 m from one end to other, use the highest ground cover for that maintenance hole to maintenance hole section. Calculations for the thickness of the geopolymer liner shall be furnished by the Contractor shall include allowances for deflection, shrink-back, stiffness, ring bending and buckling, and shall have sufficient water tightness, and structural strength to support all dead loads, live loads, and groundwater load.
Live Load	AASHTO HS-20 or the actual live load that exists at the liner location, whichever is greater (e.g. For railway crossing use E-80 live load)
Soil Weight	18.85 KN/m ³ (1922 Kg/m ³)
Soil Modulus	6.89 MPa
SCGP Liner Flexural Modulus used for design	See Table 2 for minimum geopolymer liner material requirements.
SCGP Liner Flexural Strength used for design	See Table 2 for minimum geopolymer liner material requirements.

The minimum liner thickness that must be achieved within the host pipe shall be calculated using the distributed beam load over a partial ring model. This design model is applicable for circular, elliptical, egg shaped and arch sewer shapes. The liner thickness shall consider a 50-year design for the specified applied loads and calculated using the following equation:

$$t = \sqrt{\frac{0.0744 (Q_T) r^2 N}{S_f c}}$$

Where:

t = Minimum liner thickness, mm

QT = Total external load as calculated from ASTM F1216-16 for fully deteriorated cases for soil and hydraulic loads with the addition or appropriate live load standards as specified, kPa

r = Radius of the crown of the pipe, mm

N = Safety Factor (see Table 1 requirements)

Sf = The Flexural Strength (or Modulus of Rupture), kPa

c = Ovality Reduction Factor as defined in ASTM F1216-16

The minimum liner thickness, independent of design, shall be 25 mm for all pipes with an internal diameter of less than 1350 mm for structural applications.

The minimum liner thickness, independent of design, shall be 38 mm for all pipes with an internal diameter of 1350 mm or greater for structural applications.

TS 472.05 MATERIALS

The geopolymer liner material shall be a micro-fiber reinforced ultra-dense geopolymer. This material shall provide a high strength fiber reinforced mortar specifically designed for ease of mechanical pumping, spraying and spin casting. The geopolymer lining material shall have a minimum of 70% pozzolanic material from the following SiO₂, MgO, Al₂O₃, Fe₂O₃ and be verified by third party certified X-ray Fluorescence (XRF) testing.

The dry geopolymer shall be premixed and packaged by the manufacturer. Only water shall be added to the premixed packages. The addition of admixtures/additives is not acceptable.

The geopolymer liner material shall conform to the minimum requirements listed in Table 2.

Table 2: Minimum geopolymer liner material requirements

Property	Test method	1 Day	28 Days
compressive strength	ASTM C39	17,000 kPa	55,000 kPa
flexural strength	ASTM C78	5,100 kPa	8,900 kPa
tensile strength	ASTM C496	n/a	5,500 kPa
shrinkage	ASTM C1090	n/a	0% at 65% RH
modulus of elasticity	ASTM C469	20,500 MPa	34,400 MPa
bond strength	ASTM C882 Type II	6,100 kPa	17,000 kPa
rapid chloride ion permeability	ASTM C1202	n/a	very low; below 1000 Coulombs
freeze thaw durability	ASTM C882 Type II	zero loss at 300 cycles	
set time	ASTM C807	initial set: < 75 min final set: < 120 min	
abrasion resistance	ASTM C1138	5 Cylinders 28 Day: < 3% loss	

¹ Particle size of maximum aggregate of 2.38 mm based on 100% of material (except fibers) passing the No.8 Sieve.

Additional materials including chemical grouts and hydraulic cements necessary to stop infiltration and create a surface for the geopolymer lining be applied as may be necessary.

Specific materials must be compatible with the geopolymer lining and the City reserves the right to require preapproval of such materials.

The lining shall be compatible with the thermal and chemical conditions of the existing sewer structures. Surface temperatures will range from -7°C to 38°C and pH may range as low as 1.0.

TS 472.06 EQUIPMENT

The work consists of spray applying or centrifugally spin-casting the specified geopolymer liner material to the inside of an existing sewer. The necessary equipment and application methods to apply the liner materials shall be only as approved by the material manufacturer. Material shall be mixed in accordance with manufacturer's specifications to proper consistency, then the materials shall be pumped through a material plaster hose for delivery to the selected application device.

The mortar delivery hose shall be coupled to a high-speed rotating applicator device.

The rotating casting applicator shall then be positioned within the center, or positioned higher inside the pipe, as required by the diameter the pipe.

The spin cast nozzle must be cable of bidirectional operation.

The high-speed rotating applicator shall then be initialized and pumping of the material shall commence. As the material begins to be centrifugally cast evenly around the interior of the sewer, the rotating applicator head shall uniformly travel back and forth at or near the center point of the pipe at a controlled frequency conducive to providing a uniform material thickness to the pipe walls.

TS 472.07 CONSTRUCTION

SCGP lining can only commence upon:

- 1) Field verification and confirmation of actual field conditions, submission of detailed designs, shop drawings and other submittals as listed herein this specification from the Contractor and, review and acceptance of the detailed designs, shop drawings and submittals by the Contract Administrator.
- 2) Installation and operation of flow control as specified in the Contract Documents and as per the approved flow control plan. It is the Contractor's responsibility to employ flow control and no work requiring flow control shall proceed until the Contractor demonstrates that the flow control or bypass pumping capacity meets the requirement stipulated in the contract.
- 3) Installation of exhaust fans with odour control for work in sanitary and combined sewers.

TS 472.07.01 Pipe Cleaning

All internal debris shall be removed from the original pipeline. Gravity pipes shall be cleaned with hydraulically powered equipment, high-velocity jet cleaners, or mechanically powered equipment sufficient to remove all laitance and loose material and flush debris from the structure.

If pipe diameters allow for manned entry, the use of high-pressure washers delivering a minimum of 24,000 kPa may be utilized. The use of higher-pressure washers may be required to achieve the desired surface condition. Mechanical cleaning methods may be required.

The surface of the pipe to be lined shall be capable of directly receiving the lining material. The surface of calcite deposits shall be roughened by sand-blasting or grinding to produce a surface to which the liner can bond. Calcite ridges shall be removed to a level such that the minimum liner thickness or reinforcement cover can be obtained.

When grease and oil are present within the pipe, warm water and/or an approved detergent may be added to during high pressure cleaning water. Debris, warm water and water with detergent shall be removed carefully and shall not reach the water course. All materials resulting from the cleaning of the pipe shall be removed prior to application of the geopolymer lining.

All loose or defective concrete, brick, or grout, shall be removed to provide an even surface prior to application of the geopolymer lining material.

All materials resulting from the cleaning of the pipe shall be removed prior to application of the geopolymer lining material.

All defective concrete, brick, or grout shall be removed and the sewer and repair the localized defect to provide a smooth surface for to apply the geopolymer lining material.

The floor and interior walls of the pipe 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.

TS 472.07.01.01 *Obstruction Removal*

The Contractor shall clear the existing structure of all obstructions such as, but not limited to, solids, dropped joints, roots, protruding laterals, or collapsed pipes that will prevent SCGP liner installation. All other foreign materials shall be removed from the existing structure and disposed of in accordance with MECP guidelines. Drop inlets and taps shall be cut back to be flush with the existing structure. If inspection reveals an obstruction that cannot be removed by conventional sewer cleaning equipment, the Contractor may make a point repair excavation to remove or repair the obstruction.

TS 472.07.01.02 *CCTV Inspections and Reports*

CCTV inspections for V1, V2 and V3 assessments shall be according to TS 409.

Inspection Reports

Each CCTV inspection submitted shall be accompanied by an electronic format sewer inspection report in PDF file format. The reports shall be in the format required by the City. The PDF reports shall be included on the USB storage media along with the video file.

Prior to the regular contract required submissions of CCTV inspections/reports, the Contractor shall submit a trial inspection report in PDF format for approval by the Contract Administrator.

CCTV Inspection Submission

When a required CCTV inspection has been completed, it shall be submitted to the Contract Administrator on a properly identified portable hard drive or other media approved by the Contract Administrator. The submission for a sewer shall include the video file and the PDF report file and NASSCO PACP access database.

The portable hard drive may include CCTV inspections for more than one sewer service. In this case, the DVD shall be properly organized with each CCTV inspection submission in its own folder. Such folders shall be clearly and properly identified in regard to the sewer service to which it pertains by the street number corresponding to the sewer service inspected.

The reports shall be in a format that will enable direct down loading of the data into a data management system.

TS 472.07.02 Preliminary CCTV Inspection – V1

The Contractor shall make a preliminary CCTV inspection—called the V1—of the sewer section before undertaking any work required for the CPPP lining of the section. The purpose of the V1 is to determine and record the initial condition of the sewer section and to determine if a significant changed condition exists versus the CCTV inspection provided to the Contractor by the Contract Administrator. Significant changed condition means a condition that will prevent lining of the section, require an unexpected excavated repair before lining, require a change in the liner design resulting in an increased liner thickness to deal with the changed condition or any other situation, which in the Contract Administrator's opinion, is a significant changed condition.

Where a significant changed condition is encountered, the Contractor shall immediately inform the Contract Administrator.

In making the V1, the Contractor shall employ only such preliminary cleaning that is necessary to obtain a CCTV inspection sufficient to record the initial condition including a count and condition of service connections.

The V1 shall be conducted during minimal flow or low sewer flow period when the flow is below 5 to 7 o'clock position. Otherwise sewer bypass operation is required to lower the flow at no additional cost to the City.

Sewer defect coding is required for V1 if the sewer inspection data was not provided to the Contractor by the City, and if the CCTV inspection data provided by the City is more than 2 years old from the date of V1 inspection

The V1 CCTV inspections shall be submitted to the Contract Administrator.

The Contractor shall be responsible for confirming the following design parameters as part of the V1 inspection:

- a) Sewer diameter
- b) Depth to invert (of pipe to be lined)
- c) Preliminary Pipe ovality assessment (final confirmation of ovality during V2)
- d) Live load condition (e.g. pipe under train tracks)
- e) Number, size, location and clock position of sewer services and connections.

The Contractor shall provide the Contract Administrator with a record log of all verified field conditions prior to the ordering and installation of any liners. The log shall also include any further deterioration, higher ovality than design calculations, and additional repair required when compared to CCTV data provided by the City. This log will be used to determine the need for special designs and increased liner thickness. Should the Contractor order or install a liner without confirmed field conditions and such conditions are found to have required a liner thickness increase, no payment shall be made for the installed liner.

TS 472.07.03 Service Connection Investigation

Where, in the Contract Administrator's opinion or the Contractor's opinion, service investigation is required the Contractor shall carry out the investigation. The service connection investigation when required, shall be completed as part of the V1 and V2 work and payment shall be through provisional items for service connection investigation, or in absence of such provisional item the cost shall be negotiated with the Contractor, whether or not a service investigation is carried out, the Contractor is always required to complete the Service Connection Statement as per base scope.

For a sample of the *Service Connection Statement* form, see Appendix B.

TS 472.07.04 Preparation and Pre-lining Repairs

The Contractor shall seal any open joints and voids with the geopolymer lining material prior to the lining of the pipe. If additional repair procedures are required to restore the existing structure for lining, for example invert reconstruction, the Contractor shall submit a repair plan to the Contract Administrator prior to proceeding.

The Contractor shall seal all active infiltration prior to application of the lining material.

Additional materials including quick setting mortars, chemical grouts and hydraulic cements necessary to stop infiltration and create a surface for the geopolymer lining to be applied to may be necessary and shall be in accordance with these 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 taps to prevent mortar from entering the inlet or tap.

TS 472.07.05 Field Measurement of Sewers and Liner Sizing

The Contractor shall measure the internal diameters of the sewer sections to be lined and the length of the sections to be lined. The measurements taken shall be suitable for proper sizing of the liners to be installed. The Contractor must not rely on dimensions provided by the City. The Contractor shall log all field measurement verification and provide this record log to the Contract Administrator prior to installation of the associated liners.

TS 472.07.06 Service Connection Statement

Where there are service connections, the Contractor shall record details of all service connections on a sewer section on a Service Connection Statement form. The form shall be fully completed identifying all service connections on the sewer section to be lined prior to installation of the liner. The Contractor with assistance from the City shall determine the presence of abandoned service connections within the sewer section to be lined. The form shall be completed as part of the V1 and V2 CCTV inspection work.

The statement shall be updated during service connections reinstatement to show which service connections have been reinstated with date and time of reinstatement and must be verified through V3 CCTV inspection.

The statement shall be provided to the Contract Administrator on request.

For a sample of the *Service Connection Statement* form, see Appendix B.

TS 472.07.07 Preparation of Geopolymer Lining Material

Contractor shall mix geopolymer material in accordance to the Manufacture's recommended water cement ratio. Precision metering of water in a continuous mixing chamber is required to maintain the strict water to material ratio. It is important to maintain the specified water to geopolymer ratio throughout the application process. Uniform water to polymer ratio equates to consistent strength. The ability to closely adjust and monitor the addition of water through the use of a sight tube system is required.

Mixing water temperatures must be determined before blending operations begin. The mixing water temperature must be recorded in the daily operation log at multiple times throughout the day during the installation process. If water temperatures exceed 27°C, then the water shall be chilled to 27°C or lower. The ability to provide mixing water at a consistent temperature is a critical aspect of the mixing and installation process. Industrial electronic chillers are available and shall be of a suitable capacity to provide the proper amount of water and at the required temperature. High temperature applications, those greater than 27°C, require the use of water chillers to maintain the water at the proper temperature.

The geopolymer lining material shall be mixed in a high shear mixer to ensure thorough and uniform mix of water with the material prior to pumping. Begin pumping through an adjustable rotor stator pump for continuous delivery to the appropriate application device.

The mixing operations must be performed so that the minimum of dust is released into the surrounding environment.

This process requires the use of continuous automated mixing and pumping, which eliminates human error and mechanical issues associated with maintaining consistent water/material ratio, mix time, mix speed and dwell time prior to pumping. The automation of dry material feed rate, precise metering of water and pump rate eliminates wet/dry and thick/thin variations resulting in a uniform structure regardless of the pumping distance.

Pumps shall be equipped with multiple sensors that stop the pump if material either runs out or is overflowing.

Multiple spin casting units shall be made available onsite to address any application issues that arise during the lining process.

Multiple spin cast nozzles shall be made available onsite at all times to address any application issues or failure of the nozzle. Multiple nozzles may be required to produce the required depth or finish of the liner surface.

TS 472.07.08 Mixing

Combine all packaged geopolymer liner dry mix with the specified amount of potable water while mixing until proper consistency is obtained, as described by the manufacturer. The mixer must be capable of regulating the amount of water added to the mix on a consistent basis. Mixing water temperatures must be determined before blending operations begin. The mixing water temperature must be recorded in the daily operation log at multiple times throughout the day during the installation process. If water temperatures exceed 27°C, then the water shall be chilled to 27°C or lower. The ability to provide mixing water at a consistent temperature is a critical aspect of the mixing and installation process. Tempering of the material above the manufacturers published limits is not allowed. Continue to agitate the geopolymer liner material to prevent thickening beyond the desired fluidity. The working time shall be as per manufacturer's recommendations.

Application – The geopolymer liner may be spin cast or hand sprayed to the interior surface of the host pipe after it has been properly prepared and cleaned. The geopolymer liner material shall be applied to a damp surface. However, pools of water shall be removed before the start of the application of the geopolymer liner material.

The geopolymer liner material delivery hose shall be coupled to a medium-velocity spray application nozzle. Pumping of the material shall commence and the material shall be atomized by the introduction of air at the nozzle, creating a medium-velocity spray pattern for material application. The temperature of geopolymer in the hoppers shall be around 10°C and rising before pumping begins.

Any person applying the material or operating the pump shall at least have 1 year of experience.

The geopolymer liner shall not be applied when ambient and surface temperatures are expected to fall below 4°C or above 32°C within 72 hours of placement, without written permission from the manufacturer.

At a minimum, the following items are required if the Contractor chooses to apply the material below 4°C.

- a) The geopolymer shall be covered, dry and kept above freezing.
- b) All substrates shall be above 4°C.
- c) Air temperature in contact with the material, subsequent new substrate/pipe surface shall be kept above freezing for 72 hours.
- d) Water added to materials shall be above 4°C.
- e) To accelerate the rate of reaction, warm water may be used.
- f) The use of calcium chloride as a settling and hardening accelerator is not allowed.

TS 472.07.09 Thickness Verification

A minimum of three small depth gauges—plastic indicator tabs—shall be attached as a ring around the inner surface of the sewer, one at the crown, and one at each spring line. The depth gauges shall show the thickness as designed or specified. The gauge rings shall be placed a maximum of 6 metres apart. The preset depth gauge guides shall be positioned just below the designed or specified finished geopolymer layer. The gauges will be left in place within the geopolymer layer. These measurements must be written down in a log book which will be submitted to the Contract Administrator.

The Contractor shall be required to apply the approved designed liner thickness. Additional material thickness applied by the Contractor will be at no extra cost to the City. No separate additional payment will be made for any extra material thickness applied above the approved designed liner thickness.

TS 472.07.10 Spin-casting Application of Geopolymer Lining

The existing structure surface shall be saturated surface-dry before application begins. The SCGP liner shall be installed by using a high speed, rotating applicator device as recommended by the manufacturer of the mortar. Mortar mixers, compressors and pumps shall also be of a type recommended by the mortar manufacturer. The mortar shall be mixed and agitated according to the mortar manufacturer's instructions. If recommended by the mortar manufacturer, working time may be extended by mixing the material with cool water or ice-cooled water.

The mortar shall not be applied when ambient or existing structure surface temperatures are 38°C or above or when ambient temperatures are expected to fall below 7°C within 72 hours of placement. Both ambient and existing structure surface temperatures shall be at least 7°C at the time of placement. The SCGP liner shall be protected from freezing.

Water added to materials shall be above 4°C.

To accelerate the rate of reaction, warm water may be used.

The use of calcium chloride as a setting and hardening accelerator is not allowed.

Initialize the high-speed applicator and start pumping of the geo polymer material. As the material begins to be centrifugally cast evenly around the interior of the cavity, the rotating applicator head shall uniformly travel back and forth at or near the center point of the pipe at a controlled frequency conducive to providing a uniform material thickness to the pipe walls.

Install liner according to the manufacturer's installation guidelines. Adjust the applicator retrieval rate to obtain the minimum liner design thickness. Using a wet gage, verify applied thickness at random perimeter locations at least once every 9 metres during the application process. Immediately apply additional material to any areas found to be less than the design thickness.

Controlled multiple passes shall then be made until the specified minimum finished thickness is attained. If the procedure is interrupted for any reason, the operator shall arrest the retrieval of the applicator head until flows are recommenced.

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

Begin at one side of the pipe and retract the spin cast assembly at a monitored uniform rate. Just as important as knowing that a consistent amount of water is being added to the mix, the retrieval rate of the spin head must be measurable and constant. At the beginning of each pipe segment the retraction device shall be calibrated. The calibration process includes setting the digital readout to the desired retrieval rate. Then the retrieval system is laid out and marked to show the distance traveled in two minutes. The rate obtained must be within 5% of the expected speed and can be verified by this process.

The geopolymer liner shall be applied to a specified uniform minimum thickness and can be applied in multiple passes.

Material thickness may be verified at any point with a depth gauge and shall be no less than the minimum thickness specified in TS 472.04.04. If additional material is required at any level, the rotating applicator head shall be placed at the location and application shall recommence until that area meets the required thickness.

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

When the pipe is sufficiently out of round hand spray application of the geopolymer lining maybe necessary, the mortar delivery hose shall be coupled to a medium-velocity spray application nozzle. Pumping of the material shall commence and the material shall be atomized by the introduction of air at the nozzle, creating a medium-velocity spray pattern for material application.

Hand spraying shall be performed by starting at the bottom of the structure and progressing up the wall.

The medium-velocity spray nozzle and the centrifugal spin casting head may be used in conjunction to facilitate uniform application of the material to irregularities in the contour of the pipe walls.

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 pipe wall. Precautions shall be taken not to over-trowel. Only a wood float or Magnesium (Mg) float shall be utilized.

TS 472.07.11 Placement Techniques

Control thickness, method of support, air pressure, and/or water content of geopolymer liner to preclude sagging or sloughing off.

Materials to which geopolymer liner is applied must be saturated with water, but without free water on the surface, to facilitate bond and to reduce the possibility of shrinkage cracking developing from premature loss of mixing water. Normally, surfaces in a sewer are saturated. However, these surfaces shall be dampened if operation of the ventilation system has caused them to dry.

The surface of freshly placed geopolymer liner, to which additional layers of geopolymer liner are to be bonded, shall be broomed or scarified at about the time of its initial set to remove the film of laitance which would inhibit bonding. If the laitance is not removed before the previously applied layer takes its final set, then the surface shall be sand blasted before applying a subsequent layer. Dampen the surface just prior to application of succeeding layers.

Do not allow overspray and rebound to accumulate on the prepared surfaces during geopolymer liner placement. Geopolymer liner placed over accumulations of rebound and overspray will exhibit poor bond and laminations and shall be removed and replaced.

Fill with sound material corners, cavities, and other areas where rebound cannot escape or be blown free.

Provide a supply of clean, dry air adequate for maintaining sufficient nozzle velocity for the work and, if required, for simultaneous operation of a blow pipe for clearing away rebound.

Do not place geopolymer liner if drying or stiffening of the mix takes place prior to delivery to the nozzle.

Prevent flow across geopolymer liner until it has attained sufficient strength per the manufacturer's recommendations to prevent erosion by the flowing water.

TS 472.07.12 Liner Testing

The completed liner shall be smooth and free from honeycomb and areas of segregation.

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.

Tests shall be performed by quality 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.

Contractor shall employ an independent third party ACI certified testing agency to conduct and report compressive strength testing of the concrete utilized in the rehabilitation.

Testing frequency shall include the first and last day of construction and: (a) the more frequent of once every 18,000 kg of dry geopolymer material or (b) once every other day of application.

At a minimum this shall include compressive strength in accordance with ASTM C39/39M to 55 MPa minimum for the 28-day tests in accordance with Table 3. Test results shall consider the average compression of three samples, with no sample lower than 50 MPa. Additional samples may be held for retesting at 56 days if necessary.

Table 3: Geopolymer testing schedule

Testing	Duration	ASTM Standards	Minimum # tests required
compressive strength testing	7-day	ASTM 39/39M	2
compressive strength testing	28-day	ASTM 39/39M	3
compressive strength testing	56-day	ASTM 39/39M	1

For each cylinder the following information shall be recorded: Water Quantity, Ambient and Mix Temperature, Dry Material Bag number and Batch Number, Location of Material Sampled (such as Station No.)

Samples shall be analyzed by X-Ray fluorescent (XRF) in accordance with ASTM C114 by a third-party independent laboratory for verification of material formulation data as specified herein. The results shall be compared to the XRF testing submitted with the bid. The Contractor shall collect three (3) random 100 g samples of dry powder during the course of the project, as long as at least 56,000 kg of geopolymer material is used, otherwise just collect one (1) sample for testing.

The frequency specified for each test is approximate. If additional tests are necessary, at the option of the Contract Administrator, such tests shall be performed by and at the Contractor's expense.

Indicator tabs can be attached on the structure to verify the proper thickness is achieved. These are positioned to be just below the specified thickness and are left in place when sprayed over.

The Contract Administrator may request the Contractor to remove a test core from the installed liner, at established intervals. This is at the Contractors' expense. The Contractor shall mark the core samples with the date that the liner was installed and the date that the core was removed, and the location taken. When requested by the Contract Administrator, the liner shall be cored at three different clock positions, and the average thickness measured shall be taken as the actual thickness of the liner. If a sample is less than 90% of the specified minimum thickness and or 90% of the 28-day compressive, the liner is considered unacceptable.

In situ core samples shall be taken in the event that the test panels do not meet performance standards as specified. The Contract Administrator shall determine the number and location of the samples to be taken. If the test results indicate that in-place geopolymer liner does not meet the performance standards as specified, geopolymer liner placed in the same shift as the samples shall be rejected. In situ core samples will be tested in the same manner as cores taken during pre-construction testing.

If the thickness or the 28-day compressive strength of the installed spin cast pipe lining is less than 90 percent of the specified values, the product is considered unacceptable. The Contractor shall submit a proposed method of repair or replacement for review and approval by the Contract Administrator. Work required to remedy non-conforming work shall be at no additional cost to the Contract Administrator.

Delamination shall be tested for at a rate of at least once every 2 metres by tapping on the hardened geopolymer liner surface with a small hammer and listening for a hollow sounding response. If delamination is suspected, a core sample shall be taken from that location. If delamination is confirmed by the core sample, that core sample shall not be counted as one of the in-situ core samples required. It shall be the Contractor's responsibility to determine the extent of the delamination to the satisfaction of the Contract Administrator and to remove and replace the rejected section.

If it is determined that the geopolymer liner material did not match the submitted manufacturers claims, the product is considered unacceptable and non-conforming. Submit proof that the geopolymer liner meets or exceeds the requirements of the specification through the use of samples analyzed or retained at the manufacturing facility or submit a method for replacement of the sewer segment liner for review and approval by the Contract Administrator. Work required to remedy non-conforming work shall be at no extra cost to the City.

For all instances, where the geopolymer liner is deemed unacceptable, other than thickness, for compressive strength, as described in this specification section, submit a proposed method of repair or replacement for review and approval by the Contract Administrator. Work required to remedy non-conforming work shall be at no additional cost to the City.

Repair core holes by hand patching with a non-shrink mortar mix of equal or greater strength than the geopolymer liner. Do not fill core holes by shooting or by use of rebound material.

TS 472.07.12.01 *Construction Testing For Manual Installation*

This section is only applicable for manual spraying applications.

Two test panels, at least 0.3 m x 0.3 m, and 50 mm thick shall be made once per shift when geopolymer liner is being placed. The panels shall be shot in the vertical position and the test results will be used to determine the quality of the geopolymer liner placed during that shift.

TS 472.07.13 *Curing of Geopolymer Lining*

Follow manufacturer's recommended cure schedule for the applied geopolymer liner. The material must be allowed to cure a minimum of 2 hours or until the material has reached an initial set condition whichever is longer prior to the release of bypass or flow through the pipe.

Natural curing will be allowed. The surface shall be sprayed with water during the 3 days after placement if operation of the ventilation system causes drying to occur.

Steps shall be taken to ensure the material is cured in a moist and moderate climate. Underground conditions are generally adequate to meet this requirement. The use of a wind barrier and fogging spray may be required during dry and/or hot conditions.

The geopolymer liner shall not be placed when the ambient temperature is 3°C and falling or when the temperature is anticipated to fall below 0°C during the next 24 hours, unless specific precautions are employed.

Refer to ACI 305R-99 Hot Weather Concreting. Do not apply geopolymer liner material when ambient and surface temperatures are 35°C and above. Shade the material and prepare the surface to keep it cool. To extend working time, mix the material with chilled water. Be certain the substrate is saturated surface dry (SSD) before application begins. Proper curing is always required and is particularly important in hot weather.

Refer to ACI 306R-88 Cold Weather Concreting. Low-substrate and ambient temperatures slow down the rate of set and strength development. At temperatures below 7°C, warm the material and monitor substrate temperatures. Properly ventilate the area when heating. Protect the new liner from freezing in the first 6 hours after application.

TS 472.07.14 Termination and Sealing at Maintenance Hole Outlets

Termination of the geopolymer liner at the end of a pipe or maintenance hole shall be completed by hand applying the geopolymer liner to the outer surface of the pipe or into the interior of the maintenance hole.

TS 472.07.15 Internal Reconnection of Lateral Services

The Contractor shall reopen the existing active connections after the final geopolymer lining pass. Restored openings shall be neatly and smoothly open and without rough edges. Care must be exercised not to damage the geopolymer lining while reinstating the lateral.

TS 472.07.16 CCTV Inspection of Completed Rehabilitation – V3

After completion of all work in the lining of the sewer section including reinstatement of service connections and maintenance hole benching, a CCTV inspection—called the V3—of the full length of the sewer section lined shall be done and submitted to the Contract Administrator. The V3 shall be done according to the requirements for CCTV inspection and reports in TS 472 herein. The Contract Administrator will review the V3 as part of its approval for payment process for the lined sewer.

In the event that, after the V3, a deficiency in the lined sewer section is identified that requires repair or remediation, the V3 shall be redone after the repairs or remedial action have taken place and submitted to the Contract Administrator. If there are lateral connections, and the Contractor is removing the bypass prior to laterals restoration, two V3s are required. One to inspect the empty sewer pipe with bypass immediately after curing and second for inspecting the laterals during minimal flow period to ensure laterals can be inspected.

TS 472.07.17 Disposal of Materials

In accordance with the requirements of the Environmental Protection Act, R.S.O. 1990, Section 27 and subject to all terms and conditions related to Waste Management, the Contractor shall be responsible for the complete removal and disposal off-site, of all foreign materials flushed, scraped, or cut out of the sewer line. Flushing and abandoning of debris in sewer lines is not permitted.

Before disposing of solids, the Contractor shall decant all liquids into the City designated sanitary sewer main. There shall not be any dumping or decanting into any storm sewers. Decanting of solids into any sewer main is not permitted. The Contractor shall decant liquid only into sanitary or combined sewers greater than 250 mm in diameter clear of debris and with low flow. Filtering devices shall be used during the decanting process to prevent any debris from entering the sewer system. Prior to decanting, the Contractor shall verify the type of flow in the sewer. Should a blockage occur in the sanitary or combined sewer due to decanting, the cost of all sewer backups and cleaning shall be at no extra cost the City.

Prior to commencement of the Contract, the Contractor shall notify the Contract Administrator of the disposal site(s). The Contractor shall provide the Contract Administrator with the following documentation attached to all relevant invoices:

- a) Contract name and No.
- b) Vehicle ID – License Plate Number
- c) Date of disposal
- d) Time of disposal
- e) Net weight of load
- f) Provide log books and scale printouts to the Contract Administrator.

All debris must be decanted prior to disposal. Off-site debris dewatering facilities must meet provincial environmental regulations and requirements. Provide copies of required licenses, permits and relevant documentation required for dewatering facility to the Contract Administrator before starting the Work.

TS 472.07.18 Daily Logs

A daily activity log shall be filled out completely anytime a work crew is on site. This log includes listing the personnel present at the site, when they arrived and when they left the site.

Important spray data includes the times material was applied and under which atmospheric conditions. The ambient air temperature, the dry powder temperature, the mixing water temperature, and the temperature inside the pipe are all recorded on the daily activity report.

The operating conditions are also recorded. These measurements include the water addition rate taken at the meter tube, the retrieval speed of the retraction system and the pump motor speed recorded at the pump. Any special conditions are to be noted in the daily log.

Amount of material used, and work completed will be summarized on the log.

A copy of the daily log for all days of work on the project will be provided in the final quality assurance documentation provided to the Contract Administrator.

TS 472.07.19 Equipment Calibration Reports

All applicable equipment calibrations must be maintained on site by the Contractor available for inspection upon request of the Contract Administrator.

TS 472.07.20 Inspections

Inspections of the lining products and materials may also be made by the Contract Administrator after delivery. The lining products and materials shall be subject to rejection 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. Lining materials rejected after delivery shall be marked for identification and shall be removed from the job at once.

TS 472.08 QUALITY ASSURANCE

TS 472.08.01 Non-conforming Work

If the measured thickness, compressive strength or the compressive modulus of elasticity of the installed pipe lining is less than 90 percent of the specified values, the product is considered unacceptable. Have the Contractor submit a proposed method of repair or replacement for review and approval by the Contract Administrator. Work required to remedy non-conforming work shall be at no additional cost to the City. For liner testing requirements, see clause TS 472.07.12, herein.

TS 472.09 MEASUREMENT FOR PAYMENT

TS 472.09.01 Actual Measurement

TS 472.09.01.01 *Lining of Sewer Pipe*

Measurement of geopolymer lining of sewer pipe shall be by length in metres along the horizontal centre line length of the sewer pipe from the nearest edge of upstream maintenance hole to the nearest edge of downstream maintenance hole. Additional liner length may be required due to Contractor's means and methods and is generally cut and removed but payment will be based on installed length only and the Contractor shall provide bid prices accordingly.

TS 472.09.02 Plan Quantity Measurement

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

TS 472.10 BASIS OF PAYMENT

Payment at the Contract Price shall be full compensation for all labour, Equipment and Material to do the Work and shall be as per below:

- 5% of payment for maintenance hole to maintenance hole section upon approval of detailed design by the Contract Administrator.
- 5% after receiving acceptable V1 with the report and the initial service statement report.
- 5% after field verification of dimensions, cleaning, and after receiving acceptable V2 with a report.

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- 5% after installing odour control system.
 - 50% after installing and curing of liner inclusive of actual pressure curve, actual temperature curves showing compliance with anticipated curves.
 - 5% after reinstating, receiving service statement report and acceptable V3 with a report.
 - 25% after testing and final acceptance.

Appendixes

Appendix A: Designer Notes

Appendix B: Service Connection Statement

Appendix 472-A, September 2019 For Use While Designing and Administrating City Contracts

Note: This is a non-mandatory commentary appendix intended to provide information to a designer and contract administrator during the design and construction stage of a contract on the use of this TS specification in a City contract. This appendix does not form part of the standard specification. Actions and considerations discussed in this appendix are for information purposes only and do not supersede an owner's design decisions and methodology.

Notes to Designer:

- 1) *The designer should insert the following text into the tender template in Section 4, Scope of Work*

Information to be Reviewed Prior to Bid Submission

If the sewer sections to be rehabilitated are identified in the Tender Call documents, Bidders shall review the CCTV inspection records, geotechnical and hydrogeological reports and other reports, drawings and data provided with the Tender Call prior to preparing and submission of their Bid. The CCTV inspection records provided with the tender can be a few years old and the Contractor shall acknowledge that the sewer condition may be further deteriorated including more encrustation, more debris, and more corrosion and, prepare the Bid with such consideration.

If, for bidding purposes, the Contractor is of the opinion further inspection is required in order to properly assess the work to be undertaken, the Contractor will be responsible to perform such additional inspection at their own cost. Permission to enter the City's sewer system for inspection purposes during the bidding period shall be obtained through City's Purchasing and Materials Management division.

- 2) *The designer should insert the following text into the tender template in Section 2, Clause 8.1 Mandatory Bid Submission Requirements*

Information to be Submitted with Bid

The following information shall be submitted with the Bid to ensure the Contractor's preliminary design and the Bid prepared based on the design comply with the requirements listed in the Tender Call. This submission is not the design. A separate shop drawing submittal is required after the Contract award, after confirming field conditions and measurements.

Failure to submit this information to the satisfaction of the Contract Administrator can result in disqualification of the Bid.

- 1) The name of the professional engineer licensed in the province of Ontario who will prepare and stamp the SCGP engineering designs required according to the liner design requirements in TS 472. The professional engineer shall be authorized to perform such work by Professional Engineers Ontario (PEO).

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- 2) SCGP design for all sewer sections identified in the Tender Call. The SCGP design shall be according to TS 472.
 - 3) A SCGP liner design example if no sewer sections are identified in the Tender Call: The liner design example shall be submitted according to TS 472. The example designs shall be illustrative of future designs that shall be submitted during the Contract. As sewer sections are identified during the Contract, the designs submitted shall bear the seal and signature of a Profession Engineer licensed in the province of Ontario.
 - 4) Geopolymer manufacturer information, material specifications and, original third party accredited laboratory verification that materials meet:
 - 5) Physical properties specified for design at 24hr and 28 day including ASTM C-39, ASTM C-78, ASTM C-882, and ASTM C-1090.
 - 6) ASTM C-666 for samples cured 28 days and subjected to 300 cycles.
 - 7) A summary of the Contractor's proposed SCGP liner procedure. Include one example of the spray application process including application layers, product mixing, equipment that shall be used, curing time and qualification of staff who will be involved in spraying.
 - 8) A certified original copy of accredited laboratory testing and supporting literature from the manufacturer confirming the performance criteria listed in TS 472, Table 1 are met.
 - 9) X-Ray Fluorescence (XRF) analysis report as per ASTM C114 for the geopolymer material proposed for this Contract
 - 10) Qualifications:
 - a) Submit documentation and verifiable references that the Contractor's proposed geopolymer product has successfully been installed in a minimum 2000 metres of large diameter sewer greater than 900 mm pipes in North America and Europe. The information submitted shall include pipe dimensions, length of installation, size/type of flow control required to perform the Work, description of the actual work performed including installation method, name and telephone number of the pipe owner and date of installation. The stated experience requirements for licensed Contractor or Installer shall be projects which used approved liner manufacturers. All reference experience shall be for the projects completed within North America and Europe.
 - b) The proposed installer performing the lining of the sewer shall be qualified by means of license and training by the approved geopolymer lining manufacturers. The proposed installer shall have demonstrated and verifiable experience of spraying the same geopolymer product for a minimum of 1000 metres length in large diameter pipes greater than 900 mm.
 - 11) Additional materials including chemical grouts and hydraulic cements necessary to stop infiltration and create a surface for the geopolymer lining be applied to may be necessary. Specific materials must be compatible with the geopolymer lining and the City reserves the right to require preapproval of such materials.

Appendix 472-B

Service Connection Statement

