SPECIFICATION FOR SPRAY-IN-PLACE CEMENTITIOUS LINER (SIPCL) FOR THE REHABILITATION OF CSP/CMP AND RCP SEWERS AND CULVERTS

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TS 4.15: V27062022

TS 4.15.01 SCOPE

This specification is for the Sprayed-in-Place Cementitious Lining of sewers and drainage culverts in the City of Toronto. Hereinafter a Sprayed-in-Place Cementitious Lining (or Liner) is referred to as an SIPCL. SIPCLs include cementitious materials commonly called Geopolymers. The sewers may include sanitary sewers, storm sewers and combined sewers. This specification is limited to applications of SIPCL as follows:

- For existing circular pipelines not less than 1200 mm in inside diameter and with existing ovality not exceeding 15%
- For existing non-circular pipelines with a minimum dimension in any direction of not less than 1200 mm and which have not deformed by more than 15% from their original dimensions.
- For existing pipelines that are either corrugated steel/metal pipe (CSP/CMP) or reinforced concrete pipe (RCP).
- For cover over the top of the existing pipeline of not less than 0.9 m when the pipeline is, or will be, subject to a surface vehicle live load.

When completed in place inside the existing pipeline, the SIPCL shall:

- Fully resist all the applicable external loads
- Fully prevent infiltration and exfiltration.
- Fully resist the corrosive and erosive effects of normal municipal sewage flow
- Fully resist H2S gas induced microbial corrosion when required in the Special Provisions of Contract
- Achieve all the requirements in this specification.

Within this specification the term sewer section refers to a MH-MH section of the existing pipeline or for a culvert refers to MH equivalent access points. Within this specification the term SIPCL means Sprayed-in-Place Cementitious Liner or Lining.

The Work shall include performing the following operations: notification of public, CCTV inspections, determining pipeline and liner dimensions, design of liners, field determination of any changes to design parameters for liners and any corresponding revised designs, flow control and bypass pumping, cleaning and preparation of the pipelines to be lined, infiltration and moisture control, service connection investigation and related work, installation and curing of the SIPCL, reinstatement of sewer service connections, fabricating and testing of SIPCL installation samples, return of the lined pipeline to regular service plus any other work required for and incidental to the foregoing.

The work involved requires special equipment to be handled, operated and monitored by persons experienced in all phases of the Work.

TS 4.15.02 LINING OBJECTIVES

The SIPCL shall accomplish the following objectives throughout the design life of the rehabilitation.

- Prevent infiltration of ground water into the lined pipeline.
- Prevent exfiltration of flow out of the lined pipeline.
- Provide structural performance against external load in accordance with requirements herein.
- Provided the required structural performance against external load without any cracking of the liner.
- Prevent corrosion or erosion occurring in the rehabilitated pipeline.
- Prevent root intrusion into the lined pipeline.
- Provide a continuous rehabilitation over the full length of the pipeline (or pipeline section) without any annular space, gaps, joining or structural discontinuities.
- Provide flow capacity in accordance to the requirements herein.

TS 4.15.03 INFORMATION TO BE REVIEWED PRIOR TO BID SUBMISSION

For bidding purposes where the pipeline sections or zones for lining have been identified in the procurement documents, all bidders shall review the City's CCTV inspection video records of these sections prior to submission of their Bid. Arrangements for viewing these records shall be made according to the instructions in the procurement documents. Upon viewing, the prospective bidder shall fill out and sign the *CCTV Review Sign Up Sheet.*

If CCTV inspection is not available for the sections or zones for lining, alternate procedures will be described in the Special Provisions of Contract.

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. Permission to enter the City's sewer or culvert system for inspection purposes shall be obtained from the Contract Administrator.

TS 4.15.04 INFORMATION TO BE SUBMITTED WITH BID

The following shall be submitted with the Bid for review by the Contract Administrator. Based on review, the Contract Administrator has the right to decide whether submittals are acceptable to the Contract Administrator including whether a submittal provides the substantiation requested.

Further information to be submitted may be required elsewhere in the Contract Procurement Documents other than in TS 4.15 herein.

Submit with Bid:

1) The name of a professional engineer licensed in the province of Ontario who will provide the SIPCL engineering designs required according to the liner design requirements in TS 4.15 herein. The professional engineer shall be authorized to perform such work by Professional Engineers Ontario (PEO).

2) SIPCL designs for all pipeline sections or zones identified for lining in the procurement documents. Where different sections or zones have identical design criteria, one design may be submitted that applies to all the sections or zones with identical design criteria and this shall be noted on the design. The liner design shall be according to TS 4.15 herein. The designs shall bear the seal and signature of the engineer identified in 1) above.

3) For each design submitted, as per 2) above, submit a corresponding comparative flow analysis demonstrating that the lined pipeline section or zone will provide the required flow capacity as specified in the Special Provisions of Contract.

4) A signed letter from the bidder confirming that lining material, design and installation procedure to be used for this project meet all requirements of the Contract Procurement Documents including TS 4.15.

5) A signed letter from the lining material supplier confirming that the material to be used for this project meets all the requirements of the Contract Procurement Documents including TS 4.15.

6) Material specifications and structural details of the proposed liner in sufficient detail to enable confirmation by the Contract Administrator that the SIPCL proposed will meet the design and performance requirements in TS 4.15 herein. Include the SIPCL material manufacturer, material type(s) and manufacturer's identification number(s).

7) Third party test reports for the proposed SIPCL that support the physical properties proposed by the Contractor, including the properties used in design. Include third party test reports for: Flexural strength by ASTM C78; Modulus of Elasticity by ASTM C469; Compressive Strength (28-day) by ASTM C39 as well as test reports for any other liner material properties that are used in the design(s).

8) Third party test reports for the proposed SIPCL substantiating that the liner is fully resistant to chemical degradation or corrosion from normal municipal sewage. Testing shall be in accordance with ASTM C-267, DIN 19573 or equivalent.

9) When required in the Special Provisions of Contract, third party test reports for the proposed SIPCL substantiating that the liner is fully resistant of H2S gas induced microbial corrosion.

10) If any materials proposed by the Contractor are subject to long-term creep in the context of the lining application, submit substantiation for the long-term values of the properties to be used in design.

11) A cured sample of the proposed SIPCL that is representative of the liner to be installed on the Contract. The sample shall have the following approximate dimensions: Thickness 25 mm; Width 200 mm; Length 200 mm.

12) A complete list of equipment including CCTV equipment, host pipe cleaning and preparation equipment, SIPCL application equipment and other necessary major items to be dedicated to the work. The list of equipment shall specify type, manufacture and quantity of equipment.

13) A summary of the Contractor's proposed the SIPCL lining procedure. The summary shall include, along with other information, the following:

- Temperature limits (both upper and lower) for the application of the SIPCL including as recommended by the SIPCL material supplier.

- Temperature limits inside of host pipe (both upper and lower) for cure of the SIPCL including as recommended by the SIPCL material supplier.

- Maximum and minimum time between applications of succeeding layers required to build-up the liner thickness.

- Surface treatment required when maximum time between applying succeeding layers has been exceeded.

- Surface moisture limits and surface dampness limits for application of the material to the existing pipeline.

The Contract Administrator has the right to accept or reject the material proposed by the Contractor. Such acceptance or rejection will be based on analysis of the material and/or subsequent information obtained from the Contractor that, in the opinion of the Contract Administrator, demonstrates that the material does not conform to the material accepted for Award of Contract or does not conform to the Contract requirements.

TS 4.15.05 NOTIFICATION TO PUBLIC

Prior to commencement of any Work on the Contract, the Contractor shall deliver written notices to all parties directly affected by the work (such as residents or businesses) a minimum of 7 Days to a maximum of 14 Days prior to any work commencing at the affected location. The Contractor must schedule the works accordingly. Such written notices shall consist of letters supplied by both the Contract Administrator and the Contractor and both must be delivered at the same time.

From time to time during the Contract other notices, such as the *Service Interruption Notice*, shall be distributed by the Contractor when required due to specific aspects of the work directly affecting specific parties.

Contractor's notices shall be typed on the Contractor's letterhead and clearly indicate both daytime and after hours local contact telephone numbers. Telephone numbers shall be either local area code or toll free numbers. No work will be allowed to commence without such notices. Any Contractor's written notice shall be submitted to the Contract Administrator for approval prior to notice delivery.

When and where applicable the Contractor shall be responsible for notifying the homeowners to limit their sewer use, including the use of any mechanical devices, for example sump or ejector pumps from discharging to the sewer service, in a manner that may adversely affect the lining process.

The Contractor shall provide the Contract Administrator with a copy of such notice for approval.

TS 4.15.06 SITE INVESTIGATION

Before commencing any construction work at a site the Contractor shall investigate each site to determine the existing site conditions and identify any obstructions or any other problem that may affect the completion of the proposed works. No additional payment shall be made on account of difficulties to complete the works because the Contractor failed to investigate the site prior to commencement of the work.

TS 4.15.07 EXISTING VIDEO INSPECTION RECORDS AND DRAWINGS

The Contract Administrator shall provide the Contractor with a list of pipeline sections and/or zones for the SIPCL lining along with the City's available CCTV inspections, inspection reports and sewer map drawings for the sections. This information will be provided either in full at the start of the contract or alternately on an incremental monthly basis during the contract. The method of provision, either in full or incrementally, will depend on the structure of the specific procurement document including the structure of schedule of unit prices and quantities.

The Contractor shall review the inspection information and drawings prior to undertaking any work in the pipeline sections.

TS 4.15.08 WEATHER CONDITIONS FOR FLOW CONTROL

It is the Contractor's responsibility to review Environment Canada weather forecasts prior to commencement of pipeline preparation and lining operations to ensure anticipated weather conditions (i.e. rainfall, snow melt) do not result in situations that will:

- Exceed the Contractor's flow control capacity
- Cause basement flooding due to flow obstructions caused by the lining process
- Negatively effect the installation of the SIPCL

Where the anticipated weather conditions are such that they have the potential to cause problems, commencement of construction that requires flow control shall be delayed until favourable weather is forecast.

This applies to all pipeline sections and zones to be lined.

TS 4.15.09 FLOW CONTROL AND BYPASS

When interruption of sewer line flows is necessary to properly conduct the work including such as for CCTV inspection and lining operations, acceptable methods of flow control shall be provided. In situations where flow control exceeds the standard flow allowed for in this specification (defined below) and includes bypass pumping, flow control for these situations shall be according to TS 4.01 – *Construction Specification for Temporary Sewer Bypass System.*

The Contractor is to make all necessary arrangements with the owners of each building. The Contractor shall contact all affected property owners or tenants or both to co-ordinate the repair work to the sewer and minimize any impact on residents or businesses or both.

During the inspection and rehabilitation, sewer flows in the pipeline section being lined shall be shut off in order to enable proper inspection of the pipe, including the invert and for the SIPCL installation. After the work is completed, flows shall be restored to normal. Excess sewage flows shall be transported through a closed, leak tight pipeline or by tank trucks to the nearest or most economical disposal area.

On all liner installation dates when flow control is executed by bypass pumping, the Contractor must maintain on site both a primary and stand-by bypass pump and pump power supply. Sufficient power supply and hoses must be on site in order to allow the pump to discharge into the next downstream sewer section. The stand-by bypass pump and power supply shall be of an equal or better capability than the highest capacity primary bypass pump and power supply. No bypass pumps or related equipment shall be disconnected or removed from the sewer or job site until after all service connections have been reinstated and the Contractor has recorded the post-installation video.

All bypass pumping shall be in place and operation prior to the final pre-installation inspection. All bypass pumping capacities and configurations must be approved by the Contract Administrator prior to the actual liner installation date.

All bypass pumps and related equipment must be silenced equipment or contained within an acceptable sound reduction structure.

Standard Flow Control

The Contractor shall provide for all flow control bypass capacity up to and including 150 mm pump configurations where a 150 mm pump shall have a minimum capacity of 4540 L/min (1200 usgpm), which shall be the Standard Flow Control and included in all unit rates.

The Contractor shall be responsible for determining the required flow control or bypass capacity for the work. Where the Contractor determines that the required flow control/bypass requires capacity exceeds the Standard Flow Control, the Contractor shall advise the Contract Administrator of the requirement and any additional cost for the higher flow control/bypass capacity. The Contract Administrator shall provide further instruction to the Contractor as needed including, as required, negotiation of additional payment for the bypass capacities exceeding the Standard Flow Control.

Sufficient Capacity for Flow Control

No flow control or bypass pumping shall be employed that has insufficient capacity to maintain flow in the sewer system. It is the Contractor's responsibility to employ and maintain flow control of sufficient capacity. No work requiring flow control shall proceed until flow control arrangement is in place that provides sufficient flow control capacity including for situations that exceed the Standard Flow Control.

TS 4.15.10 CCTV INSPECTIONS AND REPORTS

CCTV inspections for V1, V2 and V3 assessments shall meet the following requirements:

CCTV Equipment

The cameras and transmission cables utilized under this contract shall produce colour recordings and the recording equipment utilized shall produce MPEG-1 or MPEG-2; one MPEG file per sewer section inspection.

The CCTV camera used the inspections shall be colour, pan, tilt and zoom view type capable of radial rotation of 360°, lateral rotation of 270°, and of producing a continuous picture resolution of not less than 400 lines at the periphery of the picture. Picture resolutions shall, at the discretion of the Contract Administrator, be confirmed using a RS Resolution Chart—Retina Type.

The cameras shall be equipped with a self-contained, adjustable, directed light source compatible with the lens angle and dispersed to create even distribution of the light around the pipe perimeter without the loss of contrast, flare out of picture or shadowing.

The camera shall be self-propelled. The mounting of the camera shall be adjustable such that the central axis of the camera lies at a point equidistant between the invert and overt of the pipe during inspection of the sewer. In the case of egg shaped sewers, the camera lens must be positioned vertically above the invert at a height two thirds of the vertical dimension of the sewer. In all instances, when transporting the camera through the sewer the camera lens must be positioned on, and looking along the central axis of the sewer.

The equipment and cables utilized shall be capable of inspecting a minimum sewer length of 150 m, without reversal.

Pipeline Conditions for CCTV Inspections

The sewer section under inspection shall be sufficiently dry so that any remaining water does not obscure any part of the interior of the sewer during the CCTV inspection. Where required, flow control shall be used to accomplish this clear viewing of the sewer.

The camera shall provide sufficient light and proper focus to enable clear viewing of the pipe surface at all locations.

The sewer section under inspection shall be free of any fog or vapour that obscures the view. Where required ventilation or other provision shall be used to eliminate such fog or vapour.

The inspection speed shall allow proper analysis of the sewer condition. The maximum camera travel speed shall be 5 m/minute.

When required for a specific inspection, the CCTV camera shall stop and view each service connection clearly and completely for at least five seconds.

Each individual CCTV inspection shall be continuous over the sewer section.

Notice to City of Inspections

The Contractor shall provide 48 hours notice prior to a required CCTV inspection in order that, if required, the Contract Administrator can arrange to be present for the CCTV inspection.

CCTV Screen Information

A sewer information screen in the format indicated in the attachments shall be displayed for a minimum of 10 seconds at the start of all inspections. Inspection of the sewer shall not proceed while the information screen is being displayed. Upon commencement of, and throughout the inspection, the following information shall be continuously displayed on-screen and captured on the recording: start and ending maintenance hole numbers, street name, continuous chainage, and feature/defect coding as per the National Association of Sewer Companies (NASSCO) Pipeline Assessment and Certification Program (PACP), in accordance with most current version of PACP Reference Manual.

Sewer Condition, Defect Coding and Inspection Reports

When required, CCTV Inspections must be carried out in accordance with National Association of Sewer Companies (NASSCO) Pipeline Assessment and Certification Program (PACP). The cost of providing the above requirement shall be included in the CCTV inspection or lining items. As part of this requirement, the following must be applied:

The sewer inspection reports shall be in the format identified in attachments, as adopted from the most current version of the PACP Reference Manual. The report shall identify the chainage and defect code for all defects and construction features as established from the classification definitions. Alternative classification systems will not be accepted. Defect coding may not be required for all CCTV inspections. See individual CCTV inspection sections in this specification.

The Contractor shall submit inspection reports and videos to the Contract Administrator in a timely manner using portable hard drives. The final submission that includes all videos (i.e. V1, V2, V3 and post deficiencies inspection) shall be also submitted two copies on portable hard drives. The City will no longer accept CD/DVD media for sewer lining contracts.

The cost of hard drives or uploading shall be included in the sewer lining items.

CCTV Inspection Video Player Requirements

CCTV inspection video files shall play properly and completely on commonly used video file playing software applications. The video files must play properly and completely on correctly configured, up to date versions of Microsoft Windows Media Player, VideoLAN VLC Player and Apple QuickTime Player. Video files that do not play properly and completely on all these three players, in either Windows OS versions or Mac OS versions, will be rejected. The Contractor is advised that playback problems often can be traced back to the software or equipment that was used to generate the MPEG files. Playback problems may also be traced back methodologies employed for writing files to the storage media or for uploading to remote servers.

Inspection Reports

Each CCTV inspection submitted shall be accompanied by an electronic format sewer inspection report in PDF file format that is generated from the sewer.dat file. The reports shall be in the format required by the City. The PDF reports shall be included on the approved media or uploaded along with the video file and sewer.dat 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.

TS 4.15.11 CCTV TRUCK UNITS

Proper seating accommodation must be provided by the Contractor to enable two people, in addition to the operator, to clearly view the screen of the on-site monitor, which displays the inspection work in the main line sewer or sewer service as such work proceeds. No equipment utilized within the sewer shall be allowed to be stored in the viewing area.

The Contractor will equip the inspection units and crew supervisor with a cellular telephone utilizing province of Ontario telephone numbers and will provide the Contract Administrator with the cellular telephone numbers.

Each inspection unit shall be equipped with all fans or blowers or both necessary to remove any fog that may be present in the sewers during inspection.

TS 4.15.12 PRELIMINARY CCTV INSPECTION – V1

The Contractor shall make a preliminary CCTV inspection—called the V1—of the pipeline section before undertaking any work required for 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.

De-watering of the sewer shall be sufficient for V1 inspection purposes and sewer flow control shall be done where the sewer is not sufficiently clear for V1 inspection purposes.

Sewer defect coding is: Not required for the V1.

The V1 CCTV inspections shall be submitted to the Contract Administrator according to the requirements of TS 4.15 herein.

TS 4.15.13 FIELD MEASUREMENT OF EXISTING PIPELINES

The Contractor shall measure the dimension parameters of the pipeline section or zone to be lined. The measurements taken shall be suitable for proper sizing of the liner(s) to be installed and for verifying that liner design is correct for actual field conditions. Refer to requirements for the SIPCL in TS 4.15.22 through 4.15.25. Where field determined parameters identify a changed condition versus the conditions for bid, this may necessitate a revised liner design (Changed Condition Design). Where a Changed Condition Design is required this shall be paid for under the relevant contract item.

The Contractor shall not rely on dimensions provided by the City. Measurements shall be provided to the Contract Administrator on request.

TS 4.15.14 SERVICE CONNECTION STATEMENT

The Contractor shall record details of all service connections on a pipeline section on a S*ervice 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 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.

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

For a sample of the *Service Connection Statement* form, see Appendix A1.

TS 4.15.15 PIPELINE CLEANING AND PREPARATION FOR LINING

The sewer section to be lined shall be cleaned to remove all foreign materials prior to lining by means of a controlled hydro pressure sewer cleaner. Precautions shall be taken to ensure that no flooding of public or private property occurs during any phase of the cleaning and any reaming operations. Satisfactory precautions shall be taken to protect the sewer lines from damage that might be inflicted by the use of cleaning and preparation equipment.

All sludge, dirt, sand, rocks, grease and other solid or semi-solid material shall be cleaned from the sewer. Resulting debris from the cleaning operations shall be removed at the downstream MH of the pipeline section being cleaned. Passing material to other MH to section(s) shall not be permitted. The Contractor shall also install an effective screen (or equivalent device) in the downstream maintenance hole in order to catch any material, including cut outs from service connection openings, which might migrate downstream. Such material from the maintenance hole shall be removed and properly disposed.

Where the V1 or sewer cleaning operations indicate the presence of deposits, roots, protrusions or other foreign materials in the sewer that are resistant to sewer cleaning operations, these shall be removed by sewer reaming cutting or grinding.

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 will be responsible for the complete removal and disposal off site, of all foreign materials flushed, scraped, or cut out of the existing pipeline. Flushing and abandoning of debris in pipelines is not permitted.

The Contractor shall submit its MOE license with the Bid.

Prior to commencement of the Contract, the Contractor shall notify the Contract Administrator of the disposal site(s). The Contractor shall also provide the Contract Administrator with documentation, such as weigh scale tickets, attached to all relevant invoices, indicating discharge quantities, pertinent dates and discharge location(s).

Infiltration and Moisture Control: Refer to Section TS 4.15.18

TS 4.15.16 PIPELINE REAMING, CUTTING AND GRINDING

The pipeline section to be lined shall be reamed to remove deposits and protrusions using an approved reaming method. Deposits and protrusions can include calcite build up, roots and protruding service connections. An acceptable CCTV camera must monitor reaming operations.

Where calcite and similar deposits are hard and firmly attached to the existing pipeline, full removal is not required as long as the remaining calcite does not reduce the existing pipeline inside diameter by more than specified below under Reaming Tolerances and the remaining calcite is not an impediment to the application of the SIPCL.

Reaming Tolerances

All protrusions, deposits, build-ups and other foreign material in the pipeline section shall be removed such that the internal cross section of the pipeline pipe is not reduced by more than 20 mm by any material remaining after reaming. Any such remaining material must hard and firmly attached to the pipeline wall.

Protruding Service Connections

Service connections that protrude into the pipeline section beyond the thickness of the liner shall be cut or ground back prior to reaming of the pipeline with any type of reaming device that may damage the service connection. Protruding service connections shall be cut back sufficiently to preclude damage from reaming operations and the extent of the protrusion left in place must not interfere with the installation or long-term performance of the SIPCL liner. Cut back protruding service connections shall be smooth and even with no jagged edges. If the service lateral piping or service connection is damaged or broken by the Contractor, then the Contractor shall repair the damage by using excavation if necessary. The Contractor shall submit for approval, the proposed method of repair and reinstatement for damaged drain piping or service connections.

Precaution to Prevent Damage to the Pipeline Section

The Contractor shall plan and execute the reaming operation to prevent damage to the pipeline section and any service connections in the pipeline section. Proper precautions shall be taken by the Contractor to ensure that the reaming operation does not cut into the pipeline itself, to ensure that the reaming tools do not become jammed in the pipeline and that any areas of the pipeline that are structurally unsound are not further damaged. Any extraction of reaming tools or other equipment, including extraction by excavation, is the responsibility of the Contractor.

TS 4.15.17 FILLING OF VOIDS

Voids Identified for Filling in the Contract

The Contractor shall fill voids through the pipe wall, behind the pipe wall or around the pipe wall outside of the pipe as specified for filling in the Contract Documents. Void filling shall ensure structural integrity of the lined pipeline and prevent bridging of void spaces by the liner. It shall also ensure there is adequate contact surface available for SIPCL. The Contractor shall submit for the approval of the Contract Administrator a detailed method statement outlining the procedures and materials to be used in filling the voids. The method statement shall correspond with requirements that may be specified for void filling such as in the contract documents.

Voids Requiring Filling Not Identified in the Contract

If, during the course of the work such as during the V1, cleaning and preparation or V2, the Contactor identifies voids that require filling to ensure the structural integrity of the liner and to prevent bridging of voids by the liner, the Contractor shall advise the Contract Administrator of these voids, including any voids created by cleaning and preparation work by the Contractor. Where the filling of such voids is required by the Contract Administrator, the Contractor shall submit a detailed method statement outlining the procedures and materials to be used in filling the voids. Where the Contract Administrator requires filling of the voids, the cost shall be negotiated. However, this provision shall not apply to any voids created as a result of the Contractor’s work unless, and at the discretion of the Contract Administrator, the creation of such voids was an unavoidable repercussion of the work.

TS 4.15.18 INFILTRATION AND MOISTURE CONTROL FOR LINING INSTALLATION

For the duration of lining installation within the pipeline there shall be no running or standing water in the pipeline and no infiltration of water into the pipeline. Moisture on the inside surface of the pipeline, or within the wall of the pipeline shall be limited to dampness only.

The Contractor shall take the necessary measures to make sure that infiltration and standing water is eliminated and surface moisture (including surface dampness) is controlled within product application requirements. These measures shall include (where necessary): Stopping infiltration by grouting, prevention of all flow into the pipeline by damming or blocking inlets or bypass pumping, clearing of all standing and ponded water by pigging or swabbing or other means and, where necessary, plugging all incoming lateral connections.

No lining shall take place when the pipeline is wet or moist beyond surface dampness.

When grouting is used to stop infiltration, the Contractor shall employ measures to prevent the buildup of condensation on the interior pipe wall surface and thus prevent any dripping or wetness that might be misinterpreted as infiltration or, alternatively may hide actual infiltration. Such measures can include environmental control within the pipe suitable to stop condensation on the interior surface of the pipeline.

A grouting progress report must be submitted on a daily basis at the end of each working day. The daily progress report shall include the installation of number of grout ports, grouting ports' chainage/clock positions, ports injected and amount of grout injected.

The cost of moisture control shall be included in cleaning, preparation and lining items.

The cost of infiltration control shall be as per applicable pay item.

TS 4.15.19 POST CLEANING AND PREPARATION CCTV INSPECTION – V2

After completion of the cleaning and preparation of the pipeline section including all reaming, cutting, grinding, void filling and infiltration/moisture control, a CCTV inspection—called the V2—of the full length of the pipeline section shall be done. The V2 shall be according to the requirements of TS 4.15 herein.

The V2 complete with all reports shall be provided to the Contract Administrator at least 2 Days prior to lining for the Contract Administrator's approval of the cleaning and preparation.

Lining shall not commence until approval of the cleaning and preparation has been provided by the Contract Administrator to the Contractor.

Sewer defect coding is: Not required for the V2.

In the event that, after the V2, a deficiency in the cleaning and preparation (and specifically including moisture control) is identified that requires correction, the V2 shall be redone after the correction has been done and the redone V2 submitted to the Contract Administrator.

Submission of the V2 and/or the Contract Administrator's approval of cleaning and preparation do not remove the Contractor's responsibility for the cleaning and preparation of the pipeline in accordance with the requirements of TS 4.15 herein.

TS 4.15.20 MATERIALS AND STANDARDS

General

The SIPCL shall be suitable for application to the full perimeter and area of the interior wall surface of the pipeline or conduit by an application process that can include direct hand spraying, spin casting or other centrifugal methods. Allowed exception to spraying shall be made for surface preparation and on the terminations of the liner in the maintenance holes (or other termination structures) and other zones where hand trowel application (or similar method) is acceptable.

The SIPCL material shall be a cementitious material (including cementitious material designated as a geopolymer) that meets the requirements of TS 4.15. When applied in multiple sequential passes by the application equipment, the layers must bond to each other in a manner that the resulting thickness shall be a continuous, fully homogenous and monolithic element without any structural weakness at the interfaces where successive layers have been applied to build up the required liner thickness.

The performance of the in-place SIPCL shall meet and achieve all the requirements and objectives in TS 4.15.01 and TS 4.15.02

Corrosion Resistance

The SIPCL shall be fully resistant to degradation due to chemical or corrosive effects of municipal sewage. Refer to substantiation required with bid in TS 4.15.04

H2S Gas Induced Microbial Corrosion Resistance

When required in the Special Provisions of Contract, the SIPCL shall be fully resistant to H2S gas induced microbial corrosion. The Special Provisions of Contract will identify when full resistance to H2S gas induced microbial corrosion is required. Where the Special Provisions of Contract identify that this is a requirement for the SIPCL, the submissions with tender shall have included third party test reports, acceptable to the Contract Administrator, that substantiate the liner's resistance to H2S gas induced microbial corrosion.

Erosion Resistance

The in-place liner shall be suitable for the transport flow of municipal sewage and shall not degrade or erode when transporting municipal sewage at flow velocities normal for municipal sewer pipelines.

Properties

The in-place liner shall have the following minimum properties:

Flexural Strength: 5.5 MPa by ASTM C78 test method
Modulus of Elasticity: 15,000 MPa by ASTM C469
Compressive Strength: 55.0 MPa by ASTM C39 (28 day)

Structural Wall Thickness: Per the applicable liner design accepted by the Contract Administrator.

The wall thickness design for the liner may use properties greater than the minimums above in which case test results from liner samples shall meet the greater values used in design.

The in-place liner shall meet or exceed the material properties used in the design.

Materials Substitution

Where, in the course of work, the Contractor has reason to use equivalent materials that differ from the original proposed materials, either in general or for a specific installation, proposed alternate materials shall meet the above minimum properties and all performance requirements outlined in TS 4.15 and require the approval of the Contract Administrator prior to use.

TS 4.15.21 FLOW CAPACITY AND LINER INTERIOR SURFACE FINISH

The lined pipeline's internal size and flow characteristics shall provide a relative flow capacity versus the existing pipeline meeting or exceeding the percentage requirement specified in the Special Provisions of Contract. For determination of the relative flow capacity, the existing pipeline shall be assumed to have a Manning n of 0.016 for a concrete pipeline and a Manning n of 0.024 for a CMP/CSP host pipe.

In CMP/CSP pipe the Contractor may, at the Contractor's discretion, opt to level out the flow surface of the lined pipeline by completely filling the corrugations with SIPCL so that the lined surface extends smoothly along the pipeline without corrugations in the interior surface of the liner. This option does not waive the requirement that the liner thickness over the CMP/CSP interior peaks shall meet the requirements for liner thickness.

The liner's surface finish shall be generally smooth and uniform throughout the length of the lined pipeline. The liner interior surface finish shall be free of ridges, high spots, hollows, valleys or depressions except in CMP/CSP where such ridges and hollows may be a reflection of CMP/CSP corrugations (assuming the Contractor has not opted to completely fill the corrugations with the SIPCL).

There shall be no irregularities that may result in ponding or flow damming unless such irregularities are a reflection of the host pipe surface. This exception does not apply if irregularities in the interior surface grade of the host pipe are due to host pipe cleaning and preparation that does not conform to the Contract requirements.

The liner interior shall provide for a continuous and uniform grade (slope) for gravity flow except in the case that the grade of the liner is a reflection of the grade of the host pipe. This exception does not apply if irregularities in the interior surface grade of the host pipe are due to host pipe cleaning and preparation that does not conform to the Contract requirements.

Exception to Liner Interior Surface Finish and Flow Requirements

Exception to the above requirements will occur when the Contractor has been directed by the Contract Administrator to install liner in part of or all of the pipeline in which there are geometric characteristics that will prevent the liner from achieving the liner interior surface finish and flow requirements prescribed above.

TS 4.15.22 DESIGN OF SIPCL

The SIPCL wall thickness shall be determined by the Contractor in accordance with the requirements herein.

The Contractor shall make the required engineered designs for each pipeline section or zone to be lined and submit the designs to the Contract Administrator for acceptance. Where different sections or zones have identical design criteria, one design may be submitted that applies to all the sections or zones with identical design criteria and the applicable sections or zones shall be noted on the design. Each design shall be stamped by a Professional Engineer licensed and authorized to perform such work by Professional Engineers Ontario (PEO).

The Contract Administrator reserves the right to reject the design if, in the Contract Administrator's opinion, it is not in accordance with the requirements herein. The Contract Administrator has the right to request clarification and supporting information in regard to the Contractor's proposed design method and results. The Contractor shall provide the requested clarification and supporting information.

During the course of the work field conditions may be identified that require revised design(s). A revised design shall be in accordance with the requirements herein except for changes in design parameters to accommodate field conditions, such as existing pipe size, depth, ovality and live load situation. Refer TS 4.15.24.

No lining shall be installed without a design accepted by the Contract Administrator.

Design for Circular CSP/CMP Pipe

For circular CSP/CMP (corrugated steel pipe/corrugated metal pipe) the design shall be by either the method identified in Appendix 2 (A2 design method) or shall be by finite element analysis design (FEAD). For FEAD refer to TS 4.15.23.

Design for Circular Reinforced Concrete Pipe

For circular reinforced concrete pipe (RCP) the design shall be by finite element analysis design (FEAD). For FEAD refer to TS 4.15.23.

Design for Non-Circular Pipe

For non-circular pipe, such as egg, oval, elliptical, rectangular and other non-round shapes, the design shall be by finite element analysis design (FEAD). For FEAD refer to TS 4.15.23.

Design Parameters

The design parameters given in Table 1 below shall be used for all designs (circular, non-circular, CSP/CMP, RCP) except for designs by A2 design method. For A2 design method, Appendix 2 has a table of design parameters specific to the A2 design method.

Table 1. Design Parameters

Parameter	Requirement	Notes
Design Life	50 years	
Safety Factor	≥ 2.0	
Existing Pipe Dimensions	Based on the actual field determined dimension. Where field determined dimension is not available (such as at time of bid) use nominal dimension.	
Ovality	For circular RCP 2% or the ovality determined in the field, whichever is greater. For circular CMP/CSP 4% or the ovality determined in the field, whichever is greater.	
External Hydrostatic Pressure	Except for surface water drainage culverts, a hydrostatic pressure corresponding with the greater of: 1) Ground water table at 1.4 m below ground surface, 2) A water head of 1.5 m over invert or 3) A water head of 0.2 m over top of pipe. For surface water drainage culverts hydrostatic pressure corresponding with 0.75 m of water head over the top of the culvert.	
External Earth Load	Based on 2 meters cover over top of the existing pipe or a cover over top of the existing pipe equal to 2.5 times the existing pipe inside diameter, whichever yields the greater cover. The foregoing applies unless full cover loading is specified in the Special Provisions of Contract in which case the external earth load shall be based on 2 m cover over top of the existing pipe or the actual cover, whichever is greater.	
Live Load	CHBDC CL-625-ONT or a vehicle loading determined in the field, whichever is greater. Live load shall be based on the actual cover over the top of the existing pipe, which may differ from the cover used for External Earth Load.	
Soil Weight	18.85 KN/m3 (1922 Kg/m3)	
Soil Modulus	6.9 MPa	
Liner Properties	The value of any liner property used in design shall be the value that will be routinely and reliably obtained in tests of samples from/for the installed liners.	

Live Load

The CHBDC CL-625-ONT live load shall be determined using the ACPA DD1M live load calculation method using the actual height of cover over top of the existing host pipe. Should the Contractor propose to use a different method for determining the CHBDC CL-625-ONT live load, the different method must be acceptable to the Contract Administrator.

Partially Deteriorated Design When Needed for Liner Installation Purposes

In certain situations, such as active infiltration (refer TS 4.14.27), a partially deteriorated design for the SIPCL may be required for installation purposes. Such a design is for the Contractor's own purposes and there is no requirement to submit such a design to the Contract Administrator, unless specifically requested by the Contract Administrator.

TS 4.15.23 DESIGN BY FINITE ELEMENT ANALYSIS METHOD

Design by finite element analysis method is hereafter referred to as FEAD (finite element analysis design). The following requirements apply to FEAD. Refer to Appendix A3 for additional information and guidance.

The Contract Administrator has the right to accept, reject or request clarification in regard to the Contractor's proposed design method. Among other considerations, the Contract Administrator will assess whether liner performance under bending or deflection should be or has been addressed in the design method.

Location(s) Requiring Design(s)

An FEAD is required for the location along the host pipeline that has the most onerous performance requirements for the liner (location of maximum external loading effect). Where the Contractor proposes to use more than one liner thickness corresponding to pipeline locations in the host pipeline with different external loading effects (different performance requirements for the liner), an FEAD shall be provided for each proposed thickness and each design shall identify the pipeline zone(s) to which it applies. The FEAD is not required to address the complete length of the host pipeline.

Host Pipe Condition State

The host pipe shall be considered to be in fully deteriorated condition, meaning that for SIPCL design the host pipe shall not provide any load bearing contribution to the liner's capacity to resist external load.

External Loads

The design shall use the theoretical hydrostatic and earth cover loads due to the specified design conditions in TS 4.15.22 Table 1. Vertical earth load applied to the liner shall use the load derived from the prism load method based on the depth at which the load is being applied to the liner. Where a horizontal earth load is applied in the liner design it shall be ≤ 40% of the vertical load at the same depth. Vertical live load (surface vehicle) load applied to the liner shall be as specified in TS 4.15.22 Table 1. Where a horizontal live load is applied in the liner design it shall be ≤ 20% of the vertical live load. Hydrostatic load due to ground water, when applied to the liner, shall be based on the water table location specified.

Safety Factor

The FEAD shall use a safety factor ≥ 2.0

SIPCL Deflection Limit

The design shall assure that, under the specified design loading, the maximum change in height or width of the liner shall not exceed the allowed limit given below, called the Deflection Limit (DL).

Deflection Limit, DL: 0.25%. Refer Note A below.

For a circular host pipe this means that the liner design shall limit the increase or decrease of any outside diameter of the liner to a change not exceeding (DL) x (design input diameter). For example for a liner with 1200 mm design input diameter, the design shall limit the change in diameter to not more than 3 mm (i.e. maximum of 1203 mm and/or minimum of 1197 mm in diameter). In a typical situation, this means that, for the required design load, the design shall limit the vertical deflection to not more than 3 mm or a deflected vertical diameter of not less than 1197 mm for a 1200 mm design input diameter.

For a non-circular pipe, such as egg shapes, ellipses, ovals, box shapes, horseshoe shapes and other non-circular shape, this means that the liner design shall limit the increase or decrease of any outside vertical or horizontal cross section length to a change not exceeding (DL) x (the design cross section length). For example for an egg shape liner with a design height of 1500 mm and a design width of 1200 mm, the design shall limit the change in height to not more than 3.75 mm and the change in width to not more 3 mm.

Note A: Use of Higher or Lower Deflection Limit

A higher DL shall be allowed where independent 3rd party testing substantiates that the specific product will not crack at the higher DL. Where the design uses a DL greater than 0.25%, independent 3rd party testing shall be submitted with the design that substantiates the higher DL. If the 3rd party testing demonstrates that the liner will crack at DL lower than specified above, the allowed DL shall be reduced. The testing must be applicable to the thickness yielded by the design and the sample tested must have a thickness within plus or minus 15% of the thickness yielded by the design. For example a deflection test on a 10 mm thick sample is not applicable to a design yielding a 50 mm thickness. The Contract Administrator has the right to accept or reject the testing findings based on reasonable findings by the Contract Administrator regarding the 3rd party testing and/or testing report. For TS 4.15 purposes a crack is defined as follows. The liner will be considered to have cracked when either of the following crack dimensions is exceeded: Crack Depth: 15% of the liner wall thickness. Crack Width: 0.5 mm.

Results of FEAD

The FEAD including its report shall clearly show that:

- The values of all liner material properties used in the FEAD
- The loads on the liner input into the FEAD
- Safety factors, including the minimum safety factor, and their locations around the perimeter of the liner
- Deflections, including the maximum deflection, and their locations around the perimeter of the liner
- The constitutive model used is representative of the brittleness/ductility of the completed liner material.
- The Failure Theory used is appropriate for the completed liner material properties and material behaviour.

The FEAD including its report shall be of sufficient detail, clarity and transparency to allow the Contract Administrator to determine whether the FEAD and corresponding liner thickness are acceptable to the Contract Administrator.

FEAD Methodology Guidance

The FEAD methodology shall conform to the guidance in Appendix A3.

TS 4.15.24 LINER DESIGN AND THICKNESS TO BE CORRECT FOR FIELD CONDITIONS

Changed Condition(s) Design

The Contractor shall check and determine that the actual field conditions for any liner installation correspond with the conditions used for the liner design for that installation. The field conditions to be checked for the existing pipe shall include outside and inside dimensions, deepest cover, live load situation and, where applicable, ovality. Where the existing liner design (such as the design submitted with procurement document (bid) or a later time) is not appropriate for the field conditions, the Contractor shall make a revised liner design (changed condition design) and the liner installed shall meet the requirements of the revised design.

Other than the changed conditions, all other parameters of the previous shall apply to the revised design. The revised liner design shall be submitted to the Contract Administrator for acceptance. The revised (or changed condition liner design) shall be stamped by a Professional Engineer (per TS 4.15.22) and submitted to the Contract Administrator for acceptance.

The changed condition liner design shall be paid under the relevant contract item.

Changed Conditions Liner Thickness

Where a SIPCL design previously accepted by the Contract Administrator is found needing adjustment due to determined actual field design parameters (changed conditions), the Contractor shall advise the Contract Administrator within 48 hours and wait for the Contract Administrator's instructions. Where the accepted revised design results in a thicker liner to be installed, any additional cost involved shall be paid in accordance with the applicable Contract Item and if there is no applicable item, then shall be negotiated with the Contract Administrator. An additional payment shall not be made if the originally accepted design was in error due to the Contractor using incorrect parameters versus parameters provided to the Contractor (such as provided in the tender or bid documents).

No liner shall be installed that does not meet the requirements for actual field conditions, including required liner thickness for actual field conditions.

TS 4.15.25 DESIGN THICKNESS VERSUS INSTALLED LINER THICKNESS

Unless otherwise specified in the contract documents, the thickness determined by the latest liner design accepted by the Contract Administrator shall be the required structural thickness of the in-place completed liner. Measurements of the actual installed liner wall thickness shall not include the thickness of any non-structural components.

The thickness of the installed liner is defined as the thickness perpendicular to the cleaned and prepared surface of the existing pipeline pre-lining. That is, at any location in the lined pipeline the perpendicular liner thickness over the pipeline surface at that location must equal or exceed (subject to limit below) the design thickness accepted by the Contract Administrator.

The liner wall thickness shall not exceed 1.25 times the required thickness with the exceptions that: 1) In CSP/CMP pipe where the corrugation valleys have been filled (at the option of the contractor), the 1.25 factor shall apply to thickness over the corrugation peaks and 2) where blemishes, depressions or other surface non-uniformities have been filled in with liner material.

When actual liner thickness or liner properties appear to be deficient, design reconciliation based on test result values may be permitted at the discretion of the Contract Administrator. Such reconciliation may or may not resolve the deficiency. Refer to design reconciliation procedure in TS 4.15.34.

TS 4.15.26 WEATHER CONDITIONS FOR LINER APPLICATION TEMPERATURE

Where the successful application of a specific SIPCL is temperature dependent, such as minimum and maximum allowed temperatures for application and cure of the liner on to the inside of the host pipe, it is the Contractor's responsibility to review Environment Canada weather forecasts to make sure that temperatures for liner application are within allowable limits and will remain within the temperature limits during the application including any curing time required. No liner shall be installed when the temperature is outside of minimum and/or maximum allowed temperature for application.

In submission with procurement document the Contactor shall have provided the application temperature limits including the limits recommended by the SIPCL material supplier. When in the opinion of the Contract Administrator, the temperature limits will not be met no liner shall be applied.

When in the opinion of the Contract Administrator the application temperature limits provided in the Contractor's submission with procurement document (or at a later date) require clarification or revision no liner shall be applied.

TS 4.15.27 INSTALLATION OF SIPCL

Installation Procedure

The actual installation procedure shall be according to the submission with the Bid. Any proposed deviation from the submitted procedure shall be submitted, with explanation, to the Contract Administrator for approval and the submission shall include the approval of the lining manufacturer or senior licensor.

The mix proportions to be used and the mixing procedure is the responsibility of the Contractor. The Contractor shall use the mix proportions and mixing procedure that correspond with the required physical properties and performance of the in-place SIPCL.

The Contractor shall ensure that all required equipment including as required by the Contract is on site and in satisfactory working order prior to commencing the installation of any lining installation.

The Contractor shall ensure that the existing host pipeline is completely free of infiltration, has no standing water and has limited moisture (surface dampness only). The Contractor shall ensure that, when multiple sequential spray passes of the SIPCL are required to build up the required thickness, there is no surface contamination (including standing water) on the material applied in the previous SIPCL pass.

Back-Up Spray Robot On Site for SIPCL

Depending on the Contract's requirement, a back-up spray robot for the SIPCL may be required. Refer to the Special Provisions of Contract for when this back-up robot is required.

Temperature Control

The Contractor shall control the temperature in the pipe so that the application temperature and curing temperature are maintained within the required range. Both auxiliary heating and cooling may be required dependent on ambient outside temperatures and pipeline configuration. Pipelines that are outfalls will require a significant level of temperature control when outside ambient temperatures are low.

If required, temperature control shall be maintained through to the completion of the liner cure, which may be a significantly longer period of time than for the application of the liner to the wall of the pipeline.

Time Between Successive Liner Spray Passes

The spray application of the SIPCL shall consist of continuous passes of the spray head (or equivalent device) with each pass applying a thickness of the liner on top of the preceding pass until the required thickness has been applied. There shall be no contamination of the preceding pass surface before the succeeding pass, where contamination means any dirt, dust, debris or standing water that will negatively impact the bonding of the succeeding layer to the preceding layer of SIPCL material. Where the surface has become contaminated (for any reason), the succeeding pass shall not take place until the surface contamination has been eliminated.

Where a delay is encountered between successive passes and the re-coat window for the specific product (as recommended by the product supplier) has been exceeded, the next pass shall not take place until the surface has been properly prepared to accept the next pass.

Installation in Corrugated Pipe (CSP/CMP)

The corrugations in CSP/CMP require full coverage to the required liner thickness. Where automatic robot (or hand) spraying will (or may) result in incomplete coverage or shadowing at corrugations, the Contractor shall employ further means to assure the required coverage throughout the corrugations is achieved. Further means may require hand lay-up of the lining material. Refer to TS 4.15.22 to TS 4.15.25 for determining thickness requirements.

Installation Step Thickness (Controlled by Minimum Thickness to Temporarily Achieve Partially Deteriorated Design Thickness)

In situations where stopping infiltration for sufficient time for the application of the required fully deteriorated design thickness is difficult or impossible, the following two-step solution is acceptable.

- Step 1 is the application of sufficient liner thickness to resist groundwater pressure (i.e. partially deteriorated design thickness).

- Step 2 is applying the remaining thickness to bring the SIPCL to the required fully deteriorated design thickness.

Where this approach is used, it is necessary that the Contractor shall determine the thickness to resist the ground water pressure, the partially deteriorated design thickness.

Odour Control When Required

In the case that a disturbing odour is generated by the application of the SIPCL the Contractor shall provide notice to the affected residents indicating possible odour resulting from pipeline lining and curing process. The notice shall indicate to the residents what to expect and typical procedures to alleviate odour and include advising residents to ensure all plumbing drain traps are full of water.

The Contractor is responsible to respond, investigate and act immediately on any odour complaint that may occur. Actions to be taken by the Contractor to alleviate an odour problem within a property shall include:

- Seeking permission to enter the property;
- Filling of any dry traps;
- Preventing air flow from any traps which to do not function properly: will not water seal;
- Ventilating the property via open window and doors;
- Ventilating the property with fans/blowers; and
- Other actions that are useful in alleviating the odour problem.

The Contractor shall provide adequate pipeline ventilation and odour mitigation during the pipeline lining process. The following steps shall be taken:

<u>Exhaust Fans for Pipeline When Required:</u> When required to control odour two maintenance hole exhaust fans with a minimum capacity of 2100 cfm each shall be used to exhaust air from the pipeline via maintenance holes. One fan shall be located at an adjacent maintenance hole immediately downstream of the pipeline section being lined. The second fan shall be employed at the tail end maintenance holes as soon as access for the fan is available following removal of the liner tail. If the second fan cannot be readily employed at the tail end maintenance hole, it shall be employed at the closest possible adjacent maintenance hole that will permit air to be exhausted from the pipeline being lined. In the event that odour control becomes a problem, the Contractor shall provide additional exhaust ventilation of the pipeline to alleviate odour.

Installation to Include Making of Liner Test Samples

As part of the installation, the Contractor shall make the required test samples. Refer TS 4.15.28.

TS 4.15.28 SIPCL INSTALLATION SAMPLES AND TESTING

Samples of SIPCL

The Contractor shall fabricate and provide samples of the SIPCL that are representative of the installed liner. The samples shall be of suitable sizes and configurations for the required testing methods. The samples shall be made using the same material (including mix proportions) as used for the liner installed in the pipeline being liner. All samples shall be clearly and indelibly identified with Contract number, asset ID, location, size of the pipeline being lined, date sample made and whether start sample or finish sample. Samples shall include:

<u>Samples for Flexural Strength Testing</u>

Two samples required per lined pipeline section. One fabricated with materials used close to the start of the lining installation and the other fabricated with materials used close to the end of the lining installation. Testing shall be in accordance with ASTM C78.

<u>Samples for Modulus of Elasticity Testing</u>

Two samples required per lined pipeline section. One fabricated with materials used close to the start of the lining installation and the other fabricated with materials used close to the end of the lining installation. Testing shall be in accordance with ASTM C469.

<u>Samples for Compressive Strength Testing</u>

One set of samples required for each working day of spray-on liner installation. Testing shall be in accordance with ASTM C39 or ASTM C109.

Other Samples for Testing When Required

Where a design accepted by the Contract Administrator uses SIPCL material properties other than, or in addition to, flexural strength, modulus of elasticity and compressive strength, the Contractor shall fabricate and provide samples for testing these additional properties. The samples shall be representative of the installed liner and be of a suitable size and configuration for the required testing procedures.

These additional samples may include samples for testing of:

Samples for Tensile Strength Testing

Two samples required per lined pipeline section. Testing shall be in accordance with ASTM C307

Sample Audit Trail and Chain of Custody

The Contractor shall have a verifiable process for documenting the chain of custody of all samples so that the Contract Administrator can verify the origin and history of all the samples tested.

Testing of Liner Samples

The Contractor shall provide for the testing and inspection of samples of liner at an independent testing agency. The testing agency shall be subject to the acceptance of the Contract Administrator. The Contractor shall authorize the testing agency to forward all test reports to the Contract Administrator and communicate with the Contract Administrator concerning the testing and results. The Contractor shall provide for delivery of the samples to the testing agency.

The test results will determine whether the required values for the properties have been met. The required value shall be the value used in the SIPCL design accepted by the Contract Administrator or a minimum requirement in TS 4.15.20, whichever is greater.

Visual Inspection of Samples

All samples shall be inspected visually by the test agency to confirm that the liner wall is homogeneous and monolithic. Specifically there shall be no sign of an interface characteristic between thicknesses layers applied laid by passes of the spray on application that would or could compromise the structural performance of the liner over the design life. While it is understood that this is a qualitative judgment rather than a quantitative judgment, any inspection finding suggesting that the wall is not homogeneous and is not monolithic will require further discussion and may result in the Contract Administrator deeming the liner/lining unacceptable.

TS 4.15.29 SERVICE CONNECTION REINSTATEMENT

Any service connection incoming to the existing pipeline shall be reinstated into the lined pipeline unless the Contract Administrator has directed otherwise. Reinstatements shall be made immediately on completion of the lining so that that service is restored with minimal delay to the affected property.

In the making of the V2 CCTV inspection, the Contractor shall have recorded the quantity, locations and positions of all the service connections.

Although the installation of the SIPCL may not have completely blocked off the existing service connection, however it may have reduced the opening size due to spray into the service connection. In which case any excess material limiting the size of the service connection pipe shall be removed.

Reinstatement of the service connections shall be carried out according to the approved method statement. All live service connections shall be reopened to their full diameter, and the interface with the liner made leak tight.

Immediately following any SIPCL installation that covers a live service connection the Contractor must open each service connection to a minimum of 75 per cent within 18 hours. All service connections must be opened completely by no later than 48 hours after any temporary reduction of service size by lining.

When live in use service connections are to be covered or blocked off, the Contractor must provide a 48-hour *Service Disruption Notice* to all affected parties. Such notice must be typed on the Contractor's letterhead and clearly indicate both daytime and after hours local contact telephone numbers. The Contractor must schedule the liner installation accordingly. No service disruption will be allowed without such 48-hour notification. In the event that the Contractor is unable to install the liner on the date stated in the *Service Disruption Notice* the Contractor must immediately provide written notification of the change of date including the new date for the liner installation. After the service connection has been reinstated the Contractor must provide written notification to all affected parties that their service connection is again in service. The notification format must be submitted to the Contract Administrator for approval prior to the commencement of work on this Contract.

The 48-hour *Service Disruption Notice* shall contemplate providing residents, upon request of the resident, the supply of a clean, properly functioning portable chemical toilet for the entire time that such resident’s service connection is blocked at the pipeline. Such toilets shall be delivered prior to any service connections being blocked in the pipeline and shall be promptly retrieved by the Contractor upon service connection reinstatement.

The Contractor shall maintain a detailed record of the time at which the reinstatement of each service connection is completed and this record shall be entered on the *Service Connection Statement*.

TS 4.15.30 LINER WALL THICKNESS VERIFICATION

Liner wall thickness means the structural wall thickness of the completed in-place SIPCL and this thickness shall not include any layers or thickness that do not add to the liner’s structural resistance to external loads. On completion the in-place liner shall meet or exceed (subject to limit specified in TS 4.15.25) the required liner wall thickness. The required liner thickness shall be the greater of:

(1) The wall thickness determined by the latest SIPCL design accepted by the Contract Administrator.

(2) A minimum thickness as may be specified in the Contract documents.

The Contractor shall verify the in-place lining thickness using one of the following methods.

Thickness Measurement by Depth Studs/Gauges

A pattern of depth studs shall be attached to the interior wall of the existing host pipe perpendicular to the wall surface. The length of the studs projecting from the wall surface shall be equal to the required thickness of the liner. The pattern shall consist of 3 lengthwise rows of studs with one row along the crown of the pipe one row along each side of the host pipe at the vertical midpoint of the pipe.

The studs shall be placed a maximum of 3 m apart and shall be staggered row to row, such that opposing sidewall stud is offset by 1.5 m to the stud on the opposite side.

For CMP/CSP host pipe the stud locations shall include the interior peaks of the corrugations.

The length of the studs may be uniformly longer than the required liner thickness providing that it shall be clearly evident when the thickness of the liner has reached the required thickness. When these longer studs are used, the remaining projecting length beyond the thickness of the liner shall be removed to reasonably flush with the liner surface.

When the stud length is equal to the required liner thickness, the required liner thickness will have been achieved when the end of the stud projecting from the host pipeline is flush with or below the liner.

When the stud length is greater than the required thickness of the liner, the required liner thickness will have been achieved either when a gauge mark on the stud is flush with or below the surface of the liner or when the remaining projection of the stud beyond the surface of the liner relative to the uniform overall length of the stud indicates that the required liner thickness has been achieved.

The Contractor shall advise the Contract Administrator of the stud length being used.

A Method Proposed by the Contractor and Acceptable to the Contract Administrator

The Contractor may propose to the Contract Administrator a different method for verifying in-place liner thickness. At the discretion of the Contract Administrator the proposed method may be accepted or rejected.

TS 4.15.31 LINER PHYSICAL PROPERTIES VERIFICATION

Required In-Place Physical Properties for SIPCL

The completed in place SIPCL wall properties shall meet or exceed the required properties. The required liner properties shall be the greater of:

1. The liner properties used in the latest liner design accepted by the Contract Administrator.

2. Any minimum liner properties required by this specification. Refer TS 4.15.20.

The in-place physical properties shall be determined by testing of liner samples from the installation. The samples shall be representative of the installed liner.

In the situation where properties may not meet requirements, refer TS 4.15.34 for potential reconciliation.

Liner Wall to Be Homogeneous and Monolithic

The wall of the SIPCL shall be homogeneous and monolithic throughout. There shall be no visible layering or other signs of interface between material layers applied by subsequent passes of the spray-on application that would or could compromise the structural performance of the liner over its design life. All samples shall be inspected to verify that the liner wall is homogenous and monolithic. Evidence from the sample inspections that the liner wall is not homogeneous and monolithic will be a basis for deeming that the liner is deficient.

Additional Samples & Testing When Required by Contract Administrator

When the Contract Administrator has reason to believe that additional sampling and testing is required to verify liner properties this shall be provided by the Contractor. When testing shows that the sampling meets requirements, the additional sampling and testing shall be paid under the applicable tender item or if no item is applicable the payment amount shall be negotiated. No payment shall be made if test results do not meet requirements.

TS 4.15.32 REQUIRED FIT AND FINISH PARAMETERS FOR SIPCL

The in place and completed SIPCL shall meet or exceed the following parameters in Table 2 below.

Table 2: Required Liner Fit and Finish Requirements

Continuity of Liner	The finished liner shall be continuous over the entire length of the liner installation from MH to MH (or inlet to outlet) without any breaks, cracks or separations.
Liner Fit to Existing Pipeline	The outside surface of the finished liner shall be in contact with the inside surface of the existing pipeline. There shall be no annular space. The inside surface of the existing pipeline is the surface after the pipeline has been cleaned and prepared for lining in accordance with the cleaning and preparation requirements.
Liner Shape	The liner shape will be as defined by liner fit to existing pipeline line. In general the liner shape shall conform to the shape of the existing pipeline line inside surface after its cleaning and preparation in accordance with requirements with the exception that for corrugated existing host pipelines, the liner is not required to mirror the corrugations in regard to the liner's interior flow surface.
Liner Wall	The liner wall shall be free of any interior bulges, ribs, ripples, or other irregularities except where any irregularity results from fitting the shape of the host pipeline after cleaning and preparation. The wall of the liner shall be free of any voids, cavities or bubbles. The liner wall material shall be homogeneous.
Liner Surface	The interior surface of the liner shall be free of any bumps, protrusions or irregularities that will be an impediment to flow. The interior surface shall provide for a post-lining flow capacity of not less than the required flow capacity. Refer to TS 4.15.21.
Liner Terminations	The ends of the finished liner shall be neat and smooth
Service Connection Reinstatements	Reinstatements shall be clean and without ragged edges or discontinuities. The inside size of the service pipe shall not be reduced more than 5% by liner spray reaching up into the service connection pipe.

TS 4.15.33 CCTV INSPECTION OF COMPLETED REHABILITATION – V3

After completion of all work in the lining of the pipeline section including reinstatement of service connections and maintenance hole benching, a CCTV inspection—called the V3—of the full length of the pipeline 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 4.15 herein. The Contract Administrator will review the V3 as part of its approval process for the lined pipeline.

In the event that, after the V3, a deficiency in the lined pipeline section is identified that requires repair or remediation, the V3 shall be redone after the repairs or remedial action have taken place and the redone V3 submitted to the Contract Administrator.

The V3 shall be coded in accordance with requirements in TS 4.15.10.

TS 4.15.34 LINER THICKNESS/PROPERTY DEFICIENCIES AND DESIGN RECONCILIATION

When liner wall thickness and/or sample test result properties are deficient compared to the requirements, a design reconciliation based on test results for liner properties shall be permitted subject to exception below. Such design reconciliation may or may not resolve the deficiency.

Design reconciliation determines a revised required thickness by substituting the actual as-tested properties for the original design properties in the latest applicable design accepted by the Contract Administrator while all other parameters remain the same. Where the in-place liner thickness meets or exceeds the reconciled design thickness (revised required thickness), the liner shall not be deemed deficient based on properties or thickness. The Contractor shall provide the design reconciliation. Any design reconciliation and the results from it are subject to the acceptance of the Contract Administrator.

Exception to Design Reconciliation: Design reconciliation is not permitted when any liner material property or the liner wall thickness is below the minimum requirements in this specification, Refer to TS 4.15.20 and in the contract procurement documents.

TS 4.15.35 DEFICIENCIES

A deficiency will exist when the work or the results of the work is/are not according to Contract Documents including TS 4.15 herein. Deficiencies include (but are not limited to) liners that do not meet the required physical properties, liners that do not meet the required thickness and liners that do not meet the fit and finish requirements. Further, when the SIPCL does not achieve the performance capabilities set out in TS 4.15.01 and does not achieve the lining objectives set out in TS 4.15.02 it shall be deemed deficient.

When the Contractor is aware of any deficiencies in the Work or in the results of the work, the Contractor shall advise the Contract Administrator of these deficiencies within 48-hours including situations where the deficiency has already been rectified.

Where deficiencies have been identified, either by the Contract Administrator or the Contractor, the Contractor shall resolve, correct or rectify the deficiencies to the satisfaction of the Contract Administrator. Depending on the nature of the deficiency, the Contract Administrator may request that the Contractor provide the Contract Administrator with a method statement, subject to the Contract Administrator's approval, for the repair of the deficiency.

Where in the Contract Administrator's opinion, there is no repair or correction that is satisfactory, the Contract Administrator may require removal of the deficiency and replacement with a non-deficient lining (either in whole of in part) or require an alternate resolution at the discretion of the Contract Administrator.

TS 4.15.36 PAYMENT

Payment at the Contract Price shall be full compensation for all labour, Equipment and Material to do the Work.

APPENDIXES

A1: Service Connection Statement
A2: Design Method A2 for SIPCL in Circular CSP/CMP Including Design Example
A3: Guidelines for FEA Design Method for SIPCL

APPENDIX A1 for TS 4.15

SERVICE CONNECTION STATEMENT (SCS) – TORONTO CONTRACT NO. ______________________________

Sewer Section (MH-MH) ____________________

Date: __________________________ Page # _____ of ______

Street Name	Contractor's Name	Distance Between M.H. (camera)	Sewer Dia. (mm)	From M.H. #	To M.H. #	Camera Direction	Total # of S/C	Total # of Live S/C

S/C Address	Live (yes/no)	Visible Plug (yes/no)	Camera Distance from M.H. # …………………	Clock Position	S/C Size	S/C Material	S/C (P//F/R)*	S/C Open (yes/no)	S/C Open (Date)	S/C Open (Time)	Comments

* P (protruding), F (flushed with the main sewer line), R (recessed)

APPENDIX A2, TS 4.15
Design Method A2 for Circular CSP/CMP Including Design Example
Full resistance to Crown Cracking using Non-Composite Behaviour by the method illustrated in Appendix A2.

The method is drawn from the principles presented in ASCE Pipelines 2019 paper: Design of Sprayed Liners within Corrugated Steel Pipes, Ian Moore, Ph.D., P.Eng., M.ASCE. Non-composite design is used due to the inherent difficulties in determining the present and future condition of the existing pipeline. The paper's LRFD Earth Load, Live Load and Resistance Factors are not used and are replaced by a conventional safety factor.

A) OVERVIEW OF DESIGN STEPS
B) DESIGN EXAMPLE, DESIGN INPUTS
C) DESIGN EXAMPLE CALCULATIONS

Appendices
Table A2.1 for Design Parameters Applicable to Design Method A2
Table A2.2 for Nominal Outside Diameters of CSP/CMP when actuals are not available
Table A2.3 for values of CHBDC CL-625-ONT truck live load in kN/m for CSP/CMP

Continued on page 2.

A) OVERVIEW OF DESIGN STEPS

1. Determine Mcracking, the crown cracking moment for liner with correction for existing pipe ovality

By ASCE Paper equation 2, adjusted for ovality of the existing pipe,

$M_{cracking} = [(\sigma_L \times t^2) / 6] \times C$ See calculation 1 below

Where C = Ovaity Correction Factor

2. Determine Fcracking, the vertical force on the crown to produce Mcracking

By ASCE Paper Equation 1 adjusted for YL = 1, YE = 1 & Ø = 1 because a tradional safety factor is used instead of LRFD factors.

$M_{crown} = (F_L/BF_L + F_E/BF_E) \times MAF \times (D/2\pi)$	Earth and Live Load case	
$M_{crown} = F_v \times MAF \times (D/2\pi)$	General case. Fv is vertical force per unit length on crown	
then **$M_{cracking} = F_{cracking} \times MAF \times (D/2\pi)$**	Crown cracking case	
and **$F_{cracking} = M_{cracking} / [MAF \times (D/2\pi)]$**	See Calculation 2 below.	D = (ODliner + IDliner)/2

3. Determine Factual, the actual vertical force on crown of existing pipe due to earth and live load adjusted for bedding factors

$F_{actual} = F_E/BF_E + F_L/BF_L$ See Calculation 3 below

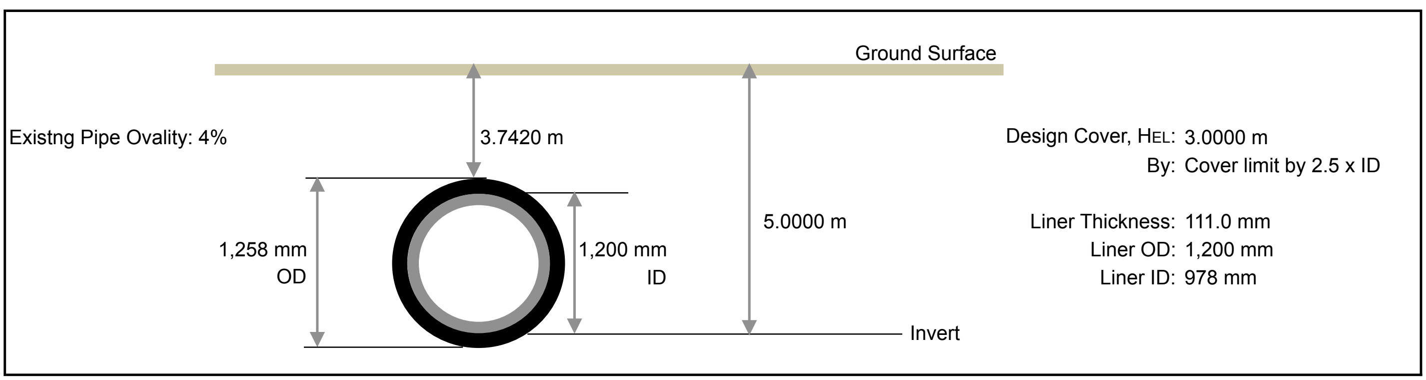
4. Determine Safety Factor N

$N = F_{cracking} / F_{actual}$ See Calculation 4 below

Adjust proposed thickness until N ≥ N required

B) DESIGN EXAMPLE, DESIGN INPUTS

Input	**Symbol**	**Typical Units**	**Required Units**	Required Units are the units needed for the equations
Existing Host Pipe OD	OD	**1,258 mm**	1.2580 m	
Existing Host Pipe ID = OD liner	ID, OD Liner	**1,200 mm**	1.2000 m	
Exsting Pipe Ovality	Δ	**4%**	4%	> 0 for Rise < Span; < 0 for Rise > Span
Depth to Invert	INV	**5.00 m**	5.00 m	
Min Cover for Earth Load Design	Hemin	**2.00 m**	2.00 m	
Soil Unit Weight	γ	**18.85 kN/m3**	18.85 kN/m3	
Soil Modulus	Es	**7.00 MPa**	7,000 kN/m2	
Soil Poisson's Ratio	nus	**0.40**	0.40	
Vertical Arching Factor	VAF	**1.40**	1.40	
Earth Load Bedding Factor	BF_E	**1.70**	1.70	
Live Load Bedding Factor	BF_L	**1.10**	1.10	
Moment Arching Factor Minimum	MAF	**0.30**	0.30	
Liner Flexural Strength	σ_L	**10.500 MPa**	10,500 kN/m2	
Liner Flexural Modulus	E_L	**26,000 MPa**	26,000,000 kN/m2	
Liner Poisson's Ratio	nu	**0.20**	0.20	
Required Safety Factor	N Req'd	**≥ 2.0000**	≥ 2.0000	
Proposed Liner Thickness	t	**111.0 mm**	0.1110 m	**Gives N = 2.0185** OK. N is ≥ Req'd N



C) DESIGN EXAMPLE CALCULATIONS

Calculation 1. Determine the crown cracking moment for liner

$$M_{cracking} = [(\sigma_L \times t^2) / 6] \times C$$

σ_L	10,500 kN/m2		
t	0.1110 m	Proposed liner thickness from above	
C	0.973	See Calculation 5 below	
$M_{cracking}$	**20.979 kN.m/m**		= [(10500 x (0.111)^2) / 6] x 0.973

Calculation 2. Determine the vertical force on crown to produce the crown cracking moment

Mcracking = Fcracking x MAF x (D/2π)

Fcracking = Mcracking / [MAF x (D/2π)] Where D = (OD liner + ID liner) / 2

Mcracking	20.979 kN.m/m		
MAF	0.9520	See Calculation 6 below	
D	1.0890 m	D = (OD liner + ID liner) / 2. See Calculation 7 below	
Fcracking	**127.14 kN/m**		= (20.979) / [0.952 x (1.089 / 2π)]

Calculation 3. Determine the actual vertical force on crown of existing pipe due to Earth & Live Load Forces

$F_{actual} = F_E/BF_E + F_L/BF_L$ Earth Load Force + Live Load Force

Determine F_E/BF_E

$F_E = VAF \times \gamma \times OD \times H_{EL}$ Where H_{EL} is the height of earth cover for earth load determination

VAF	1.40		
γ	18.85 kN/m3		
OD	1.2580 m	Existing Pipe Outside Diameter	
ID	1.2000 m	Existing Pipe Inside Diameter	
Actual Cover, H1	3.7420 m	Actual earth cover = INV - OD	= 5 - 1.258
Cover Limit, H2	3.0000 m	Cover by 2.5 x ID. Refer TS 4.15.22 Table 1	= 2.5 x 1.2
Minimum of H1 & H2, H3	3.0000 m	H3 = Minimum of H1 & H2	
Minimum Design Cover, Hemin	2.0000 m	Minimum cover for earth load force determination. Refer TS 4.15.22, Table 1	
Design Cover, H_{EL}	3.0000 m	H_{EL} =Maximum of H3 & Hemin	
F_E	99.60 kN/m	$F_E = VAF \times \gamma \times OD \times H_{EL}$	= 1.4 x 18.85 x 1.258 x 3
BF_E	1.70	Bedding factor for earth load	
F_E/BF_E	**58.59 kN/m**	Earth Load Force	= 99.6 / 1.7

Determine F_L/BF_L

INV	5.0000 m		
OD	1.258 m	Outside diameter of existing pipe	
Actual Cover, H1	3.742 m	Height of Cover for Live Load Determination = Actual Full Cover = INV-OD	
F_L	4.84 kN/m	From TS 4.15 Appendix A4/A5 or by calculation	
BF_L	1.10	Bedding factor for live load	
F_L/BF_L	**4.40 kN/m**	Live Load Force	= 4.84 / 1.1

$F_{actual} = F_E/BF_E + F_L/BF_L$ **62.99 kN/m** Total vertical force = Earth Load Force and Live Load Force

Calculation 4. Determine Safety Factor and Compare to Required

N = Fcracking / Factual

Fcracking	127.14 kN/m	
Factual	62.99 kN/m	
N	2.018	= 127.14 / 62.99
Required N	≥ 2.00	
	OK. N is ≥ Req'd N	

Calculation 5 **Determine Ovality Corection Factor, C**

C = (2 - [1 + 2 x (a/b)] / [2 + (a/b)])

Δ	4%	Ovality	Rise < Span	
OD	1,258 mm	OD of host pipe		
DF_V	50.3 mm	Vertical Deflection due to Ovality		= 1258 x 4%
DF_H	50.3 mm	Horizontal Deflection due to Ovality		= 1258 x 4%
VR	1,208 mm	Vertical Rise c/w ovality. OD - DF_V		= 1258 - 50.3
HS	1,308 mm	Horizontal Span c/w ovality. OD + DF_H		= 1258 + 50.3
a	654 mm	1/2 Vertical Rise c/w ovality		= 1208 / 2
b	604 mm	1/2 Horizontal Span c/w ovality		= 1308 / 2
C	**0.973**			= (2 - [1 + 2 x (654 / 604)] / [2 + (654 / 604)]

Calculation 6 **Determine MAF**

Refer ASCE 2019 Paper Equation (3)

MAF = 0.93-0.93*(Sf-1.17)/(Sf+15.5) Munroe et al. (2009)

Where Sf = Ms x [(r^3) / EI)] Where r is mean radius (r = (D-t)/2 and EI is for liner

And Ms = Es x (1-nus) / [(1-2nus)(1+nus)]

Determine Ms = Es x (1-nus) / [(1-2nus)(1+nus)]

Es	7,000 kN/m2	Soil modulus	
nus	0.40	Poisson Soil	
Ms	15,000 kN/m2	1D (constrained) soil modulus	= [7000 x (1 - 0.4)] / [(1 - 2 x 0.4)(1 + 0.4)]

Determine Sf = Ms x [(r^3) / EI]

Ms	15,000 kN/m2	1D (constrained) soil modulus	
OD Liner	1.2000 m	Liner OD	
t	0.1110 m	Liner Thickness	
r	0.5445 m	Mean Radius r = (ODliner - t) / 2	= (1.2 - 0.111) / 2
E_L	26,000,000 kN/m2	E of Liner	
nu	0.20	Liner Poissons Ratio	
I	0.0001187	I of Liner I = t^3 / [12(1-nu^2)]	= (0.111^3) / [12 x (1 - 0.2^2)]
EI	3086.2	EI of Liner	= 26000000 x 0.0001187
Sf	0.785		= 15000 x [(0.5445^3) / 3086.2]

Determine MAF = 0.93-0.93*(Sf-1.17)/(Sf+15.5)

S_f	0.785	Sf of Moore (Hoeg)	
	0.9520	MAF (before minimum applied)	= 0.93 - 0.93 x (0.785 - 1.17) / (0.785 + 15.5)
	0.3000	Minimum Value for MAF	
MAF	**0.9520**	Minimum value applied	= max(0.952, 0.3)

Calculation 7 **Determine D**

Determine D = (OD liner + ID liner) / 2

OD Liner	1.2000 m	OD Liner	
t	0.1110 m	Liner t	
ID Liner	0.9780 m	ID Liner	= 1.2 - (2 x 0.111)
D	**1.0890 m**		= (1.2 + 0.978) / 2

APPENDED TABLES

Table A2.1 for Design Parameters Applicable to Design Method A2

Table A2.2 for Nominal Outside Diameters of CSP/CMP when actuals are not available

Table A2.3 for values of CHBDC CL-625-ONT truck live load in kN/m for CSP/CMP

TABLE A2.1 for APPENDIX A2 for TS 4.15

DESIGN PARAMETERS FOR DESIGN METHOD A2 FOR CIRCULAR CSP/CMP PIPE

Parameter	Sym	Requirement
Design Method		Full resistance to Crown Cracking using Non-Composite Behaviour by the method illustrated in Appendix A2. The method is drawn from the principles presented in ASCE Pipelines 2019 paper: Design of Sprayed Liners within Corrugated Steel Pipes, Ian Moore, Ph.D., P.Eng., M.ASCE. Non-composite design is used due to the inherent difficulties in determining the present and future condition of the existing pipeline. The paper's LRFD Earth Load, Live Load and Resistance Factors are not used and are replaced by a conventional safety factor.
Design Life		50 years
Safety Factor	N	≥ 2.0
Outside Diameter of Existing Pipe	OD	Based on the actual field determined dimension. Where this field determined dimension is not available (such as at time of bid). The outside diameters from Table A2.2.
Liner Outside Diameter	OD L	The outside diameter of the liner shall be assumed to be the inside diameter of existing host pipeline.
Ovality	Δ	4% or the ovality determined in the field, whichever is greater.
External Earth Load	F_E & Hemin	Based on 2 meters cover over top of the existing pipe (Hemin) or a cover over top of the existing pipe equal to 2.5 times the existing pipe inside diameter, whichever yields the greater cover. The foregoing applies unless full cover loading is specified in the Special Provisions in which case the external earth load shall be based on 2 m cover over top of the existing pipe or the actual cover, whichever is greater.
Live Load	F_L	CHBDC CL-625-ONT or a loading determined in the field, whichever is greater. Calculation of live load shall be based on the actual cover over the top of the existing pipe, which may differ from the cover used for External Earth Load. Refer to Table A2.3 for Live load values in kN/m.
Soil Weight	w	18.85 KN/m3 (1922 Kg/m3)
Soil Modulus	Es	7 MPa
Soil Poisson's Ratio	nus	0.40
Vertical Arching Factor	VAF	1.4
Earth Load Bedding Factor	BF-EL	1.7
Live Load Bedding Factor	BF-LL	1.1
Moment Arching Factor	MAF	Based on the calculation or 0.3, whichever is the greater.
Liner Flexural Strength	σ_L	The flexural strength used in the design equations shall be the value that will be routinely and reliably obtained in tests of samples from/for installed liners. For cementitious materials (including cementitious Geopolymers) flexural strength shall be determine by the ASTM C78 or ASTM C293 test method.
Liner Flexural Modulus	E_L	The flexural modulus used in the design equations shall be the value that will be routinely and reliably obtained in tests of samples from/for installed liners. For cementitious materials (including cementitious Geopolymers) flexural strength shall be determine by the ASTM C469.

TABLE A2.2 for Appendix A2 for TS 4.15

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Nominal Outside Diameters for CSP/CMP for A2 Design Method

Deign Method A2 requires using the outside diameter (OD) of the existing pipe.
It is a requirement of TS 4.15 that the Contractor obtain this dimension and use it to update any previous liner design needing updating for a changed OD.

When this dimension is not available (such as at time of bid), the nominal values in the table below shall be used in the liner design.

CSP/CMP Nominal ID Size	**CSP/CMP Nominal OD for Design**
1,200 mm	1,258 mm
1,400 mm	1,458 mm
1,600 mm	1,658 mm
1,800 mm	1,858 mm
2,000 mm	2,058 mm
2,200 mm	2,258 mm
2,400 mm	2,458 mm
2,700 mm	2,758 mm
3,000 mm	3,058 mm
3,300 mm	3,358 mm
3,600 mm	3,658 mm

CSP/CMP: Corrugated Steel Pipe/Corrugated Metal Pipe

Where the required size is not included in the table above, interpolate between sizes shown.

TABLE A2.3 for Appendix A2 for TS 4.15

V280322

CHBDC CL-625-ONT Live Loads for CSP/CMP in kN/m

The existing Pipe ID and Pipe OD given below are nominal values for use when actual field measurement of these parameters are not available, such as for designs with bid. The Contract requires that field measurements be made for existing pipe ID and OD and liner design adjusted accordingly.

Pipe ID mm	Pipe OD mm	Cover m	Live Load kN/m	Pipe ID mm	Pipe OD mm	Cover m	Live Load kN/m
1,200	1,258	1.0 m	25.40 kN/m	1,800	1,858	1.0 m	32.58 kN/m
1,200	1,258	1.5 m	15.65 kN/m	1,800	1,858	1.5 m	20.46 kN/m
1,200	1,258	2.0 m	11.26 kN/m	1,800	1,858	2.0 m	14.94 kN/m
1,200	1,258	2.5 m	8.50 kN/m	1,800	1,858	2.5 m	11.41 kN/m
1,200	1,258	3.0 m	6.65 kN/m	1,800	1,858	3.0 m	9.00 kN/m
1,200	1,258	3.5 m	5.34 kN/m	1,800	1,858	3.5 m	7.29 kN/m
1,200	1,258	4.0 m	4.39 kN/m	1,800	1,858	4.0 m	6.03 kN/m
1,200	1,258	4.5 m	3.67 kN/m	1,800	1,858	4.5 m	5.07 kN/m
1,200	1,258	5.0 m	3.11 kN/m	1,800	1,858	5.0 m	4.32 kN/m
1,200	1,258	6.0 m	2.32 kN/m	1,800	1,858	6.0 m	3.25 kN/m
1,200	1,258	7.0 m	1.80 kN/m	1,800	1,858	7.0 m	2.53 kN/m
1,200	1,258	8.0 m	1.44 kN/m	1,800	1,858	8.0 m	2.03 kN/m
1,200	1,258	9.0 m	1.17 kN/m	1,800	1,858	9.0 m	1.66 kN/m
1,200	1,258	10.0 m	0.98 kN/m	1,800	1,858	10.0 m	1.39 kN/m
1,200	1,258	11.0 m	0.82 kN/m	1,800	1,858	11.0 m	1.18 kN/m
1,200	1,258	12.0 m	0.71 kN/m	1,800	1,858	12.0 m	1.01 kN/m
1,200	1,258	>12 m	0.00 kN/m	1,800	1,858	>12 m	0.00 kN/m
1,400	1,458	1.0 m	28.02 kN/m	2,000	2,058	1.0 m	34.57 kN/m
1,400	1,458	1.5 m	17.39 kN/m	2,000	2,058	1.5 m	21.83 kN/m
1,400	1,458	2.0 m	12.58 kN/m	2,000	2,058	2.0 m	16.00 kN/m
1,400	1,458	2.5 m	9.53 kN/m	2,000	2,058	2.5 m	12.26 kN/m
1,400	1,458	3.0 m	7.48 kN/m	2,000	2,058	3.0 m	9.70 kN/m
1,400	1,458	3.5 m	6.03 kN/m	2,000	2,058	3.5 m	7.87 kN/m
1,400	1,458	4.0 m	4.96 kN/m	2,000	2,058	4.0 m	6.52 kN/m
1,400	1,458	4.5 m	4.16 kN/m	2,000	2,058	4.5 m	5.49 kN/m
1,400	1,458	5.0 m	3.53 kN/m	2,000	2,058	5.0 m	4.69 kN/m
1,400	1,458	6.0 m	2.64 kN/m	2,000	2,058	6.0 m	3.54 kN/m
1,400	1,458	7.0 m	2.05 kN/m	2,000	2,058	7.0 m	2.76 kN/m
1,400	1,458	8.0 m	1.64 kN/m	2,000	2,058	8.0 m	2.22 kN/m
1,400	1,458	9.0 m	1.34 kN/m	2,000	2,058	9.0 m	1.82 kN/m
1,400	1,458	10.0 m	1.12 kN/m	2,000	2,058	10.0 m	1.52 kN/m
1,400	1,458	11.0 m	0.94 kN/m	2,000	2,058	11.0 m	1.29 kN/m
1,400	1,458	12.0 m	0.81 kN/m	2,000	2,058	12.0 m	1.11 kN/m
1,400	1,458	>12 m	0.00 kN/m	2,000	2,058	>12 m	0.00 kN/m
1,600	1,658	1.0 m	30.40 kN/m	2,200	2,258	1.0 m	36.40 kN/m
1,600	1,658	1.5 m	18.98 kN/m	2,200	2,258	1.5 m	23.10 kN/m
1,600	1,658	2.0 m	13.80 kN/m	2,200	2,258	2.0 m	17.00 kN/m
1,600	1,658	2.5 m	10.50 kN/m	2,200	2,258	2.5 m	13.06 kN/m
1,600	1,658	3.0 m	8.26 kN/m	2,200	2,258	3.0 m	10.37 kN/m
1,600	1,658	3.5 m	6.67 kN/m	2,200	2,258	3.5 m	8.43 kN/m
1,600	1,658	4.0 m	5.51 kN/m	2,200	2,258	4.0 m	7.00 kN/m
1,600	1,658	4.5 m	4.62 kN/m	2,200	2,258	4.5 m	5.90 kN/m
1,600	1,658	5.0 m	3.93 kN/m	2,200	2,258	5.0 m	5.05 kN/m
1,600	1,658	6.0 m	2.95 kN/m	2,200	2,258	6.0 m	3.81 kN/m
1,600	1,658	7.0 m	2.30 kN/m	2,200	2,258	7.0 m	2.98 kN/m
1,600	1,658	8.0 m	1.84 kN/m	2,200	2,258	8.0 m	2.40 kN/m
1,600	1,658	9.0 m	1.51 kN/m	2,200	2,258	9.0 m	1.97 kN/m
1,600	1,658	10.0 m	1.25 kN/m	2,200	2,258	10.0 m	1.65 kN/m
1,600	1,658	11.0 m	1.06 kN/m	2,200	2,258	11.0 m	1.40 kN/m
1,600	1,658	12.0 m	0.91 kN/m	2,200	2,258	12.0 m	1.20 kN/m
1,600	1,658	>12 m	0.00 kN/m	2,200	2,258	>12 m	0.00 kN/m

CSP/CMP. Corrugated Steel Pipe/Corrugated Metal Pipe
For CHBDC CL-625-ONT determined using the ACPA DD1M method
When actual design cover is not shown, interpolate.

TABLE A2.3 for Appendix A2 for TS 4.15

V280322

CHBDC CL-625-ONT Live Loads for CSP/CMP in kN/m

The existing Pipe ID and Pipe OD given below are nominal values for use when actual field measurement of these parameters are not available, such as for designs with bid. The Contract requires that field measurements be made for existing pipe ID and OD and liner design adjusted accordingly.

Pipe ID mm	Pipe OD mm	Cover m	Live Load kN/m	Pipe ID mm	Pipe OD mm	Cover m	Live Load kN/m
2,400	2,458	1.0 m	38.09 kN/m	3,300	3,358	1.0 m	42.22 kN/m
2,400	2,458	1.5 m	24.28 kN/m	3,300	3,358	1.5 m	28.74 kN/m
2,400	2,458	2.0 m	17.94 kN/m	3,300	3,358	2.0 m	21.52 kN/m
2,400	2,458	2.5 m	13.82 kN/m	3,300	3,358	2.5 m	16.78 kN/m
2,400	2,458	3.0 m	11.00 kN/m	3,300	3,358	3.0 m	13.47 kN/m
2,400	2,458	3.5 m	8.96 kN/m	3,300	3,358	3.5 m	11.07 kN/m
2,400	2,458	4.0 m	7.45 kN/m	3,300	3,358	4.0 m	9.27 kN/m
2,400	2,458	4.5 m	6.29 kN/m	3,300	3,358	4.5 m	7.88 kN/m
2,400	2,458	5.0 m	5.39 kN/m	3,300	3,358	5.0 m	6.78 kN/m
2,400	2,458	6.0 m	4.08 kN/m	3,300	3,358	6.0 m	5.18 kN/m
2,400	2,458	7.0 m	3.20 kN/m	3,300	3,358	7.0 m	4.09 kN/m
2,400	2,458	8.0 m	2.58 kN/m	3,300	3,358	8.0 m	3.31 kN/m
2,400	2,458	9.0 m	2.12 kN/m	3,300	3,358	9.0 m	2.74 kN/m
2,400	2,458	10.0 m	1.77 kN/m	3,300	3,358	10.0 m	2.30 kN/m
2,400	2,458	11.0 m	1.51 kN/m	3,300	3,358	11.0 m	1.96 kN/m
2,400	2,458	12.0 m	1.30 kN/m	3,300	3,358	12.0 m	1.69 kN/m
2,400	2,458	>12 m	0.00 kN/m	3,300	3,358	>12 m	0.00 kN/m
2,700	2,758	1.0 m	40.39 kN/m	3,600	3,658	1.0 m	41.99 kN/m
2,700	2,758	1.5 m	25.91 kN/m	3,600	3,658	1.5 m	29.97 kN/m
2,700	2,758	2.0 m	19.24 kN/m	3,600	3,658	2.0 m	22.53 kN/m
2,700	2,758	2.5 m	14.89 kN/m	3,600	3,658	2.5 m	17.62 kN/m
2,700	2,758	3.0 m	11.88 kN/m	3,600	3,658	3.0 m	14.19 kN/m
2,700	2,758	3.5 m	9.71 kN/m	3,600	3,658	3.5 m	11.69 kN/m
2,700	2,758	4.0 m	8.09 kN/m	3,600	3,658	4.0 m	9.80 kN/m
2,700	2,758	4.5 m	6.85 kN/m	3,600	3,658	4.5 m	8.35 kN/m
2,700	2,758	5.0 m	5.88 kN/m	3,600	3,658	5.0 m	7.20 kN/m
2,700	2,758	6.0 m	4.47 kN/m	3,600	3,658	6.0 m	5.51 kN/m
2,700	2,758	7.0 m	3.51 kN/m	3,600	3,658	7.0 m	4.36 kN/m
2,700	2,758	8.0 m	2.83 kN/m	3,600	3,658	8.0 m	3.54 kN/m
2,700	2,758	9.0 m	2.33 kN/m	3,600	3,658	9.0 m	2.93 kN/m
2,700	2,758	10.0 m	1.96 kN/m	3,600	3,658	10.0 m	2.47 kN/m
2,700	2,758	11.0 m	1.66 kN/m	3,600	3,658	11.0 m	2.11 kN/m
2,700	2,758	12.0 m	1.43 kN/m	3,600	3,658	12.0 m	1.82 kN/m
2,700	2,758	>12 m	0.00 kN/m	3,600	3,658	>12 m	0.00 kN/m
3,000	3,058	1.0 m	42.45 kN/m				
3,000	3,058	1.5 m	27.39 kN/m				
3,000	3,058	2.0 m	20.43 kN/m				
3,000	3,058	2.5 m	15.87 kN/m				
3,000	3,058	3.0 m	12.71 kN/m				
3,000	3,058	3.5 m	10.41 kN/m				
3,000	3,058	4.0 m	8.70 kN/m				
3,000	3,058	4.5 m	7.38 kN/m				
3,000	3,058	5.0 m	6.34 kN/m				
3,000	3,058	6.0 m	4.83 kN/m				
3,000	3,058	7.0 m	3.81 kN/m				
3,000	3,058	8.0 m	3.08 kN/m				
3,000	3,058	9.0 m	2.54 kN/m				
3,000	3,058	10.0 m	2.13 kN/m				
3,000	3,058	11.0 m	1.82 kN/m				
3,000	3,058	12.0 m	1.56 kN/m				
3,000	3,058	>12 m	0.00 kN/m				

CSP/CMP. Corrugated Steel Pipe/Corrugated Metal Pipe

For CHBDC CL-625-ONT determined using the ACPA DD1M method

When actual design cover is not shown, interpolate.

APPENDIX A3, TS 4.15

Guidelines on Using Finite Element Analysis in Design of Sprayed Cementitious Liners

1. Introduction.

Finite element analysis can be used to estimate the moment that will develop on a sprayed cementitious liner as a result of the applied earth loads, vehicle loads and water loading.

This document provides guidance on how to undertake those calculations as an alternative to simplified design methods that utilize rigid or semi-rigid pipe moments (e.g. Moore, 2019).

A number of different procedures are accepted across North America as being effective at estimating the moments that result on a buried sewer pipe or culvert. These include specialist codes developed for analysis of concrete pipes or more general buried pipes, as well as all-purpose finite element programs. While the success of a specific user employing any type of finite element procedure requires careful verification, the choice of a specialist code for buried pipes that is already accepted will facilitate acceptance of the design process.

2. 'Soil-pipe interaction' versus 'Ring under defined pressures' analyses

Finite element analyses for buried pipe problems are generally one of two kinds. While both types of procedures feature explicit modeling of the pipe structure (either including or neglecting the presence of the old pipe), one involves explicit modeling of the surrounding soil, while the other represents the influence of the soil as a set of defined pressure distributions. Each has its advantages and disadvantages, as outlined further below.

Two specialised finite element codes are available that already incorporate modeling approaches that are associated with culvert design procedures as defined in the LRFD Bridge Design Specifications of the American Association of State Highway and Transportation Officials (AASHTO) as outlined in section 4, and these are well accepted across the North American culvert design community. Use of those codes facilitates verification that the numerical methods and modeling choices are suitable, with just a simple requirement that their correct use be demonstrated against a problem with known answer (section 6 below). If general purpose finite element codes are employed, more guidance on the modeling approaches is needed. Guidance on the defined pressures to be used in 'ring under defined pressure' analysis is included in Section 3. Guidance on modeling choices for soil-pipe interaction analysis is provided in section 5 below.

3. Specialist Codes for Assessing Rigid or Other Buried Pipe Systems

The two procedures widely used for assessing expected moments in buried pipes are CANDE and PIPECAR.

CANDE is a program originally developed by Katona et al. (1976) under contract to the Federal Highway Administration, and updated a number of times since through the Transportation Research Board (e.g. Katona et al. 2008). It includes explicit modeling of the pipe, earth loading associated with layer-by-layer placement of the surrounding soil, and two dimensional representations of surface loading (i.e. vehicles). The procedure includes automatic generation of the finite element mesh once the pipe and burial geometries are defined, releasing the analyst from making choices regarding element types, element density (the size of the elements compared to the pipe), and the boundary conditions (definitions of fixities and applied loads). CANDE also includes nonlinear soil models and built-in soil parameters based on simple definitions of soil types and densities. Many studies have been conducted comparing the results of CANDE calculations with measurements for buried pipes (e.g. the study of Mai et al., 2014 examining performance for corrugated steel pipes subjected to surface load). While CANDE is subject to some limitations associated with the use of two dimensional analysis to estimate responses to three dimensional vehicle loads, it otherwise provides effective estimates. Finite element solutions of this kind where the soil and the pipe are modeled explicitly, permit consideration of a range of detailed issues associated with specific projects, including noncircular geometry, nonuniform soil conditions (for example, the native soil and backfill soils).

The buried pipe analysis program SPIDA is similar to CANDE, and was used in the 1990s to carry out design calculations for many different pipe and burial geometries. Using the results of the finite element calculations, Dr Frank Heger developed a series of simplified diagrams to represent the earth pressure distributions around concrete pipes, Figure 1, for soil support conditions of four types (1 being the highest quality, and 4 being the lowest quality). These pressure distributions were subsequently incorporated into the AASHTO design standard for highway culverts (e.g. AASHTO 2017). PIPECAR is a finite element analysis program for a circular ring developed specifically for concrete pipes based on those defined pressure distributions, and so producing design estimates of bending moments based on that AASHTO standard. The primary advantage of ‘defined pressure’ analyses relates to the simplicity of the procedure. However, they are restricted to the four specific burial conditions for concrete pipes considered by Heger as defined in the AASHTO standard.

4. General Purpose Codes

A large number of general purpose finite element programs exist that can be used to undertake either soil-pipe interaction analysis or ring under defined pressure analysis. Examples include PLAXIS and ABAQUS (demonstrated against measurements for culverts responding to vehicle loads by Mai et al., 2014; Elshimi and Moore, 2013; Elshimi et al., 2014). These analyses require more training and expertise than the specialized programs, because they require:

a. Detailed definitions for the soil and structural properties

b. Choices regarding the modeling of interactions across the soil - pipe interface

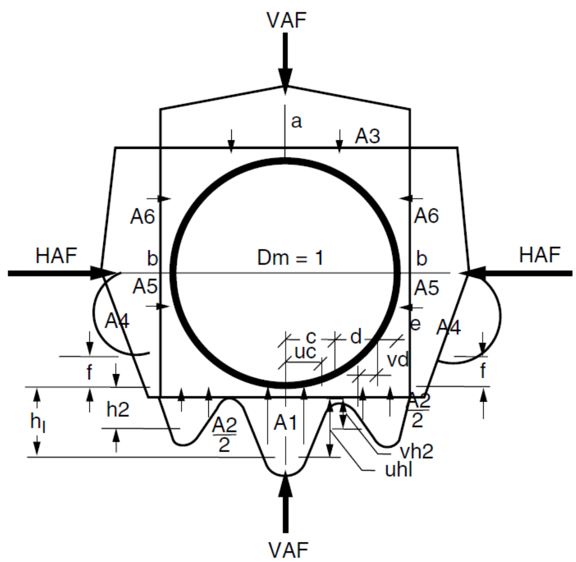
c. Choices about the type of finite element used, and design of the mesh (including mesh density)

d. Choices about how to model earth loads, fluid loads, and surface (i.e. vehicle) loads

e. Familiarity with more complex pre- and post-processors

These more complex codes do however permit consideration of more complex geometries and material conditions (e.g. zones of soil erosion or culvert corrosion if they are known to exist).

Many of these general purpose programs permit three dimensional analysis of vehicle loads, though most design will be conducted using two dimensional finite element analysis based on the plane strain approximation. This involves representing the culvert as having prismatic geometry, great length, and soil properties, structural properties, and loading conditions that do not vary along the pipe (i.e. they are constant along any path parallel to the pipe axis). The limitations of two dimensional analysis for culvert response to vehicle loads have been explained by researchers like Moore and Brachman (1994) and Moore and Taleb (1999).



Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6	a	b	c	e	f	u	v
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17	1.45	0.36	0.20	0.12	0.05	0.85	0.60
4	1.45	0.30	1.45	0.00	1.45	0.00	0.11	0.19	1.45	0.30	0.25	0.00	-	0.90	-

Notes:

1. *VAF and HAF are vertical and horizontal arching factors. These coefficients represent non-dimensional total vertical and horizontal loads on the pipe, respectively. The actual total vertical and horizontal loads are (VAF) X (PL) and (HAF) X (PL), respectively, where PL is the prism load.*
2. *Coefficients A1 through A6 represent the integration of non-dimensional vertical and horizontal components of soil pressure under the indicated portions of the component pressure diagrams (i.e. the area under the component pressure diagrams). The pressures are assumed to vary either parabolically or linearly, as shown, with the non-dimensional magnitudes at governing points represented by h1, h2, uh1, vh2, a and b. Non-dimensional horizontal and vertical dimensions of component pressure regions are defined by c, d, e, vc, vd, and f coefficients.*
3. *d is calculated as (0.5-c-e).*
   h1 is calculated as (1.5A1) / (c) (1+u).
   h2 is calculated as (1.5A2) / [(d) (1+v) + (2e)]

Figure 1. Earth pressure distributions of Heger for buried concrete pipes (see AASHTO, 2017).

5. Requirements for soil-pipe interaction analysis

5.1 Soil properties

Performance limits, such as deflection and moment, are strongly linked to choice of soil moduli. Three alternatives can be used for parameter selection:

- use of values of constrained modulus values tabulated in the AASHTO design standard fitted to either a stress dependent nonlinear elastic modulus function or a modulus function which varies with depth,
- use of standard values, such as the hyperbolic model used in CANDE, or

- use of data derived from laboratory tests; a geotechnical engineer with experience in soil-structure interaction should interpret the results of the soil tests to ensure that properties for design are reasonable and conservative.

Many choices can be made regarding the selection of nonlinear soil properties. The two most common approaches to modeling the nonlinear material response of the soil are nonlinear elasticity (e.g., the hyperbolic model) and elasto-plasticity. Nonlinear elasticity is used widely in North America and is the basis of various public domain and proprietary programs. The model approximates the increases in soil stiffness that occur as confining pressure is increased, and the decreases in stiffness that occur as shear stresses increase.

Many multi-purpose proprietary codes available for use in soil engineering incorporate elasto-plastic constitutive models. These models characterize the fundamental change in soil response that occurs once shear failure has developed. Such modeling is required if bearing capacity and other mechanisms involving soil shear failure are to be successfully predicted. However, at normal service loads, the soil behaviour should not likely include shear failure, and so elastic analysis can be successfully used, provided that the modulus choice is reasonable and conservative.

Soil modulus increases with depth, but reasonable calculations generally result if a uniform modulus is used, where that modulus corresponds to a value under geostatic stress conditions at the depth of the pipe crown (those stresses calculated ignoring the presence of the pipe; these are not the stresses in the soil directly above the crown, which are affected by the soil-pipe interaction).

Culvert design generally ignores the load-spreading performance of the pavement at the ground surface, and so finite element analyses should not feature a layer at the surface to represent the pavement.

5.2 Earth loads

Various approaches can be used to simulate earth loads on a buried structure:

a. Application of geostatic stresses to the soil-pipe system assuming it is already in existence (‘turning on’ gravity to the soil-pipe system), where the sides of the mesh are restrained against lateral movement and the individual soil elements have a defined density; this approach requires careful choice of Poisson ratio for the soil, since an elastic response of the soil will produce a lateral earth pressure coefficient equal to

$$K_0 = \frac{\nu}{1-\nu}$$

Instead of choosing ν in the normal manner (according to the lateral response of a block of elastic material under uniaxial stress), then, it is chosen to give the correct value of K_0,

$$\nu = \frac{K_0}{1+K_0}$$

Once the earth loads are applied, the Poisson ratio can be redefined to the normal value. This approach will produce stresses in the ground that vary with depth.

b. Application of geostatic stress can be undertaken by imposing a vertical stress along the top boundary of the mesh and horizontal stresses to the side boundaries, where those stresses are the vertical and horizontal stresses expected at the level of the springlines of the buried pipe (which are K_0 times the vertical stresses). This approach will not produce any stress variation with depth in the soil, though it will produce stress changes in the vicinity of the pipe associated with soil-pipe interaction. It can be used to simulate deep burial (e.g. Moore, 1988), but is likely to produce poor results when the burial depth is less or equal to twice the size of the pipe span (horizontal distance between springlines) or the pipe rise (the vertical distance between crown and invert).

Finite elements representing the soil should be used until cover over the culvert reaches a depth at least half the culvert span. Above that position, the vertical stress at the top boundary can represent the vertical load equivalent to self-weight of the soil above that position. Modeling the earth placed far above the culvert crown as a vertical pressure effectively ignores the strength and stiffness of the soil, while considering its load, and will generally provide conservative solutions.

c. Some finite element procedures permit definition of initial stresses within elements, based on geostatic stress conditions. This approach neglects the effect of any soil-pipe interaction under earth loading, and will produce stresses in the vicinity of the pipe that are precisely equal to the values as if the pipe were not present (i.e. the pipe was removed and the void left was filled with soil). For flexible pipes, soil-pipe interaction leads to lower vertical stresses above the structure and higher horizontal stresses beside the structure. For rigid pipes, soil-pipe interaction produces higher vertical stresses above the pipe. Not only will these adjustments to geostatic stress for a soil deposit (without the pipe) be missed, but the finite element procedure may define the geostatic stresses as an equilibrium condition, so the pipe does not respond with any deformation, moment or thrust. This approach to defining initial earth pressures is not recommended.
d. The burial process can be simulated by 'placing' (i.e. activating) each layer of elements in turn to represent the placement of soil layers, Katona et al. (1976). This incorporates consideration of the steady increases of soil stiffness as the pipe is buried, due to increasing volume of that soil, which can have a significant impact on how a flexible structure responds and takes up the applied loads. The analysis can also incorporate other aspects of the behaviour, such as progressively increasing soil modulus within each layer of soil as the stresses progressively increase with depth below the ground surface (e.g. Taleb and Moore, 1999) and may also incorporate methods to simulate the effects of compaction (e.g. Katona et al., 1976; Taleb and Moore, 1999; Elshimi and Moore, 2013).

5.3 Fluid pressure loads

Buried pipe analysis is almost always undertaken using 'total stress' analysis rather than 'effective stress' analysis, meaning that the combined effects of soil and water weight are examined together. Analysis featuring explicit treatment of the external fluid loads is challenging, is not normally required, and is beyond the scope of this guideline.

The effect of water pressure inside the pipe can be represented as a stress around the inner surface of the pipe.

5.4 Vehicle loads

Surface loading patterns associated with standard trucks are defined in the Canadian Highway Bridge Design standard, and are three dimensional in nature. Such loads should be considered for structures under roads where there is less than 2.5 m of cover. To consider these loads within a two dimensional finite element analysis first requires conversion from a 3D to a 2D condition. There are various different procedures that are used to make those conversions, with the approach incorporated into CANDE by Katona et al. (1976) is likely the procedure employed most widely in North America, where load spreading to the depth of the crown is calculated using a live load distribution factor of F=1.33.

5.5 Structural modeling

Linear elastic structural modeling is commonly used to predict thrust and moment for comparison with strength. Materially, nonlinear structural response must be modeled if the culvert collapse modes are to be predicted. However, designs can be based on calculations assuming linear elastic structural response.

The structure can be modeled either using solid elements or structural (e.g. thin beam) elements. The use of thin beam elements is generally conservative relative to solid elements, when the structure has high wall thickness. These also provide values of moment, thrust and shear force directly. Solid elements provide stresses at integration points (or sometimes the nodes), and these must be integrated through the thickness to calculate stress resultants like thrust, moment and shear force.

Explicit modeling of corrugated or other profiled geometries cannot be undertaken when using two dimensional analysis. Instead, the pipe can be represented as an equivalent plain material of uniform thickness, by choosing equivalent modulus $\bar{E}$ and equivalent thickness $\bar{t}$ to yield the correct values of circumferential properties per unit length parallel to the pipe axis EA and EI:

$$EA = \bar{E}\bar{t}$$
$$EI = \frac{\bar{E}\bar{t}^3}{12}$$

These should produce deflections and stress resultants reflecting the stiffness characteristics of the profiled structure. However, strains calculated at the extreme fibres will not be correct, since the thickness $\bar{t}$ does not represent the true distance from outer to inner fibre. Strains can be obtained using the thrust and moment, the section properties EA and EI, and the true distances to extreme fibres.

5.6 Soil-pipe interface modeling

The interface between the pipe and the soil may exhibit frictional behaviour, where there are differences in the tangential movements on either side of the interface (i.e. slip). However, for stiff structures slip generally only occurs at the shoulders and haunches, and has modest impacts on the calculated behaviour (Taleb and Moore, 1999). This means that simpler bonded (also known as tied interaction) can generally be used, with little influence on the outcomes.

5.7 Modeling of liner-pipe interaction

Finite element calculations can be undertaken to examine the interaction between the liner and the old pipe, examining the composite behaviour of the two components of the repaired structure (e.g. Jackson et al., 2021).

5.8 Other modeling issues

Mesh design is of key importance if good quality predictions are to be produced using the finite element method. Mesh choice issues to be considered include:

- the number of elements used to model the structure
- the number of nodes used per element (quadratic displacement elements are generally recommended)
- the distance the soil is modeled from the culvert to the mesh boundaries (below and to the sides),
- the size of elements used in the backfill adjacent to the structure, and
- the number of layers represented, for use in modeling progressive soil placement during construction.

The analyst must ensure that the mesh is adequate to provide a reasonable quality numerical result. Techniques to evaluate this include making the mesh progressively finer, and increasing the width until the solution converges to some limiting value. The successful analysis of nonlinear response requires careful integration of the deformations and stresses through the projected load path. Integration effort must be sufficient to provide a reasonable quality numerical result. Again, the solution quality might be evaluated by increasing the effort involved in integrating through the load path until the results for deflections and stresses converge to limiting values.

6. Demonstration that the procedure produces effective results

To demonstrate successful performance of the analysis, the analyst will use the modeling techniques being adopted to study a problem with known solution, and demonstrate that it produces peak bending moments similar to those for the known solution. Solutions that are available include conventional results for the moments that develop in buried concrete pipes responding to earth loads.

7. References

Elshimi, T. and Moore, I.D. 2013. Modeling the effects of backfilling and soil compaction beside shallow buried pipes, Journal of Pipeline Systems Engineering and Management, ASCE, Vol. 4(4), 04013004, 1-7.

Elshimi, T., Brachman, R.W.I. and Moore, I.D. 2014. Effect of truck position and multiple truck loading on response of long-span metal culverts, Canadian Geotechnical Journal, Vol. 51, No. 2, pp. 196-207 doi: 10.1139/cgj-2013-017.

Jackson, R.J., Moore, I.D., and Genikomsou, A.S. 2021. The role of cementitious liners on the structural preservation of overburdened buried concrete pipes, CSCE 2021 Annual Conference, 26-29 May 2021, Paper STR530, 10pp.

Katona, M.G., Smith, J.M., Odello, R.S., and Allgood, J.R., 1976. CANDE: A Modern Approach for the Structural Design and Analysis of Buried Culverts, Federal Highway Administration Report No. FHWA-RD-77-5 (October 1976).

Mai, V.T., Hoult, N.A. and Moore, I.D. 2014. Performance of Two-Dimensional Analysis: Deteriorated Metal Culverts under Surface Live Load, Tunnelling and Underground Space Technology, Vol. 42, pp. 152-160, doi:10.1016/j.tust.2014.02.015.

Mlynarski, M., Katona, M.G., and McGrath, T.J. 2008. Modernize and Upgrade CANDE for Analysis and LRFD Design of Buried Structures, NCHRP REPORT 619, 34pp.

Moore, I.D. and Taleb, B. 1999. Metal culvert response to live loading – Performance of three-dimensional analysis. Transportation Research Record No. 1656, Underground and Other Structural Design Issues. National Research Council, Washington, pp. 37-44.

Taleb, B. and Moore, I.D., 1999. Metal culvert response to earth loading – Performance of two-dimensional analysis. Transportation Research Record No. 1656, Underground and Other Structural Design Issues. National Research Council, Washington, pp. 25-36.