

**SPECIFICATION FOR SPRAY-IN-PLACE THERMOSET PLASTIC FLEXIBLE  
LINING (SIP-TPFL) FOR SEWERS, STORMS AND CULVERTS****TABLE OF CONTENTS**

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## **Appendices**

A1: Service Connection Statement

A2: Design Method C1 for SIP-TPFL in Circular Host Pipe

A3: Guidelines for FEA Design Method for SIP-TPFL

TS 4.14: V20042022

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#### **TS 4.14.01      SCOPE**

This specification is for Sprayed-in-Place Thermoset Plastic Flexible Lining of sewers and drainage culverts in the City of Toronto. Hereinafter a Sprayed-in-Place Thermoset Plastic Flexible Lining (or Liner) is referred to as an SIP-TPFL. The sewers may include sanitary sewers, storm sewers and combined sewers. This specification is limited to applications of SIP-TPFL 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 SIP-TPFL 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 H<sub>2</sub>S gas induced microbial corrosion when required in the Special Provisions of Contract
- Achieve all the requirements in this specification.

SIP-TPFL, when completed in place inside the existing pipeline, shall have the capacity to deflect up to 15% under external load without cracking, distress or deterioration occurring in the lining wall. This specification does not apply to the cementitious geopolymer liners or similar liners that do not have the capability to deflect up to 15% without cracking.

Within this specification the term sewer section refers to a MH-MH section of the existing pipeline and in the context a culvert refers to MH equivalent access points. SIP-TPF means Sprayed-in-Place Thermoset Plastic Flexible. SIP-TPFL means Sprayed-in-Place Thermoset Plastic Flexible Lining (or Liner).

The Work shall include performing the following operations: notification of public, CCTV inspections, determining sewer 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 sewers to be lined, service connection investigation and related work, installation and curing of the SIP-TPFL liners, reinstatement of sewer service connections, making and testing of SIP-TPFL installation samples, return of the lined sewer to regular service plus any other work required for and incidental to the foregoing.

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

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#### **TS 4.14.02 LINING OBJECTIVES**

The SIP-TPFL 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.
- 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 gaps, joining or structural discontinuities
- Provide flow capacity in accordance with the requirements herein

#### **TS 4.14.03 INFORMATION TO BE REVIEWED PRIOR TO BID SUBMISSION**

For bidding purposes where the sewer sections for rehabilitation have been identified in the tender or RFP documents, all bidders shall review the City CCTV inspection records of these sections prior to submission of their Bid. Arrangements for viewing these records shall be made according to the instructions in the contract 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 that further inspection is required 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 system for inspection purposes shall be obtained from the Contract Administrator.

#### **TS 4.14.04 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 4.14 herein.

Submit with Bid:

- 1) The name of a professional engineer licensed in the province of Ontario who will provide the SIP-TPFL liner engineering designs required according to the liner design requirements in TS 4.14 herein. The professional engineer shall be authorized to perform such work by Professional Engineers Ontario (PEO).

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- 2) SIP-TPF liner designs for all pipeline sections or zones identified 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 4.14 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 lining material, design and installation procedure to be used for this project meets all requirements of the Contract Procurement Documents including TS 4.14.
  - 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 4.14.
  - 6) Material specifications and structural details of the proposed sewer liner in sufficient detail to enable confirmation by the Contract Administrator that the SIP-TPFL proposed will meet the design and performance requirements in TS 4.14 herein. Include the SIP-TPFL material manufacturer, material type(s) and manufacturer's identification number(s).
  - 7) A complete list of equipment including CCTV cameras, robotic spray equipment, robotic service connection cutters (if to be used), reamers and other necessary major items to be dedicated to the work. The list of equipment shall specify type, manufacture and quantity of equipment.
  - 8) Third party test reports for the proposed SIP-TPFL liner that support the physical properties (short-term values and long-term design values) used in design. Include third party ASTM D790 test report(s) for flexural modulus and flexural strength.
  - 9) Third party test reports for the proposed SIP-TPFL substantiating that the liner is fully resistant to chemical degradation or corrosion from normal municipal sewage.
  - 10) When required in the Special Provisions of Contract, third party test reports for the proposed SIP-TPFL substantiating that the liner is fully resistant of H<sub>2</sub>S gas induced microbial corrosion.
  - 11) Third party testing demonstrating the proposed SIP-TPFL liner has the capability to deflect up to 15% without cracking or exhibiting any other wall distress or deterioration. Include third party ASTM D2412 test report. The testing shall be done on a minimum 900 mm diameter full cylindrical sample with a maximum DR of 36. For a 900 mm sample, DR 36 corresponds with a wall thickness of 25 mm.
  - 12) A cured sample of the proposed SIP-TPFL liner that has been prepared by using the same methodology that will be used to apply the SIP-TPFL conduit(s) to be lined on the contract. The sample shall have the following minimum dimensions. Thickness 25 mm; Width 200 mm; Length 200 mm.
  - 13) A sample of digital spray data log from the spray robot application system that will be used for Quality Assurance/Quality Control (QA/QC) purposes by the Contract Administrator along with a table identifying acceptable ranges for each parameter as per spray lining manufacturer.
  - 14) A summary of the Contractor's proposed SIP-TPFL liner procedure including required minimum environmental conditions (i.e., ambient temperature, substrate temperature, relative humidity,

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dewpoint spread, and substrate condition). The summary shall also include, along with other information, the following:

- How environmental conditions are measured and recorded on daily basis (i.e., sensors and meters on robotic spray equipment or independent from spray equipment) for Quality Assurance/Quality Control (QA/QC) purposes by the Contract Administrator.
  - Temperature limits (both upper and lower) for the application of the SIP-TPFL including as recommended by the SIP-TPFL material supplier.
  - Temperature limits inside of host pipe (both upper and lower) for cure of the SIP-TPFL including as recommended by the SIP-TPFL material supplier.
  - Maximum and minimum time between applications of succeeding layers required to build up the required thickness.
  - Surface treatment required when maximum time between applying succeeding layers has been exceeded.
  - Surface moisture/dampness limits for application of the material to the existing pipeline.
- 15) A complete list of Contractor spray lining training and certification (all spray liner applicators and robotic operators shall hold current certification through the lining material supplier approved training program (i.e., robotic equipment certification, operator training and certification, sample preparation, quality control procedures, etc.). Certification shall be renewed at intervals not greater than two (2) years. Certification for all personnel shall always be available on site during installation.)

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 4.14.05      NOTIFICATION TO PUBLIC**

Prior to commencement of any Work on the Contract, the Contractor shall deliver written notices to all affected parties a minimum of 7 Days to a maximum of 14 Days prior to any work commencing at each 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.

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.

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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 4.14.06 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 4.14.07 EXISTING VIDEO INSPECTION RECORDS AND DRAWINGS**

The Contract Administrator shall provide the Contractor with a list of sewer sections for the SIP-TPFL 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 contract tender 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 sewer sections.

#### **TS 4.14.08 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:

- Exceed the Contractor's flow control capacity
- Cause potential basement flooding such as blocked laterals due to the liner
- Negatively effect the installation of the SIP-TPFL

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

This applies to all pipeline sections to be lined.

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#### **TS 4.14.09 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 SIP-TPFL 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 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.



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## **TS 4.14.10 CCTV INSPECTIONS AND REPORTS**

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

### **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.

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### **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 PACP Reference Manual – Version 6.0.1 – November 2010, as per attachments attached.

### **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 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 can often 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.

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#### **TS 4.14.11 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 4.14.12 PRELIMINARY CCTV INSPECTION – V1**

The Contractor shall make a preliminary CCTV inspection—called the V1—of the sewer section before undertaking any work required for the SIP-TPFL lining of the section. The purpose of 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 4.14 herein.

#### **TS 4.14.13 FIELD MEASUREMENT OF PIPELINES**

The Contractor shall measure the internal diameters (or dimensions) of the sewer sections to be lined and the length of the sections to be lined. The measurements taken shall be suitable for proper sizing of the liner(s) to be installed. Refer to requirements for the SIP-TPFL in TS 4.14 herein.

The Contractor shall measure the 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 design requirements for the SIP-TPFL in TS 4.14.22 through TS 4.14.24. 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.

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

#### **TS 4.14.14 SERVICE CONNECTION STATEMENT**

The Contractor shall record details of all service connections on a sewer section on a *Service Connection Statement* form. The form shall be fully completed identifying all service connections on the sewer section to be lined prior to installation of the liner. The 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 A.

#### **TS 4.14.15 PIPELINE CLEANING AND PREPARATION FOR LINING**

The sewer section to be lined shall be cleaned to remove 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 using cleaning 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 a screen in the downstream maintenance hole 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 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 debris in main sewers or sewer laterals 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 Section TS 4.14.18

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#### **TS 4.14.16 PIPELINE REAMING, CUTTING AND GRINDING**

The sewer 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 is 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 SIP-TPFL.

##### **Reaming Tolerances**

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

##### **Protruding Service Connections**

Service connections that protrude into the sewer section shall be cut or ground back prior to reaming of the sewer 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 SIP-TPFL 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.

##### **Precautions to Prevent Damage to the Sewer Section**

The Contractor shall plan and execute the reaming operation to prevent damage to the sewer section and any service connections in the sewer section. Proper precautions shall be taken by the Contractor to ensure that the reaming operation does not cut into the sewer itself, to ensure that the reaming tools do not become jammed in the sewer and that any areas of the sewer 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 4.14.17 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 sewer and prevent bridging by the liner. It shall also ensure there is adequate contact surface available for spray lining material to be applied. 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's Sewer Section Lining Summary Table.

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### **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 Contractor identifies voids that require filling to ensure the structural integrity of the liner and to prevent bridging by the liner, the Contractor shall advise the Contract Administrator of these voids. 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 4.14.18 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 absolutely no infiltration of water into the pipeline. Moisture on the inside surface of the pipeline shall be limited to surface dampness only.

The Contractor shall take the necessary measures to make sure that infiltration and moisture is controlled. These measures shall include (where necessary): Stopping infiltration by grouting, prevention of all flow into the pipeline by damming or blocking inlets, clearing of all standing and ponded water by pigging or swabbing and 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 4.14.19 POST CLEANING AND PREPARATION CCTV INSPECTION – V2**

After completion of the cleaning and preparation of the sewer section including all reaming, cutting, grinding, void filling and infiltration/moisture control, a CCTV inspection—called the V2—of the full length of the sewer section shall be done. The V2 shall be according to the requirements of TS 4.14 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.

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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 4.14 herein.

#### **TS 4.14.20      ENVIROMENTAL CONDITIONS FOR LINER APPLICATION**

The spray lining material Technical Data Sheets (TDS), Specifications, and project-specific Method Statements and Application Procedures shall define the minimum environmental conditions required for proper spray application and liner performance.

Verification of these parameters during installation including ambient temperature, substrate temperature, relative humidity, dewpoint spread, and substrate condition is mandatory to ensure the product performs as designed.

All environmental conditions shall be recorded in a consistent unit of measure.

- Ambient Temperature & Humidity: Exact conditions must be recorded using approved meters and sensors installed on the robotic spray system or independent from spray equipment.
- Dewpoint Spread: Must be verified on-site with timestamped photos. A minimum difference of 3°C is required between substrate temperature and dewpoint to prevent condensation.
- Moisture Content & pH: Timestamped photos of meter readings provide indisputable proof that the substrate was at acceptable moisture levels and chemically neutral prior to application.

Failure to apply the liner within the specified environmental limits is considered a non-compliant application as it results in improper curing, poor adhesion, or premature failure.

By recording and checking these parameters during installation, compliance with the spray lining manufacturer's requirements and long-term performance of the liner can be verified and validated.

Failure to provide complete and accurate records of the environmental conditions recorded at the time of application will be considered as a deficiency.

Where the successful application of a specific SIP-TPFL 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.

In submission with procurement document the Contactor shall have provided the application temperature limits. 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 require clarification or revision, no liner shall be applied.

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## **TS 4.14.21 MATERIALS. EQUIPMENT AND STANDARDS**

### **General**

The SIP-TPFL shall be suitable for application to the full perimeter and area of the interior wall surface of a pipeline of conduit by a direct mix at the pressurized spray head process. Spin casting or other centrifugal methods of spray application shall not be used.

The liner spraying shall be executed robotically with CCTV video recording of the lining process. The CCTV recording that shall be submitted to the Contract Administrator upon request. Allowed exception to robotic spraying shall be made for surface preparation and on the terminations of the liner in the maintenance holes (or other termination structures) where manual spraying is acceptable.

Manual spray application will not be permitted unless authorized in writing by the Contract Administrator and meets the spray lining material manufacturer guidelines.

The SIP-TPFL material shall be a polyurethane, a polyurea, a combination of both or other thermoset plastic material that meets the requirements of TS 4.14. When applied in multiple passes by robotic spray-on application equipment, the layers must bond to each other in a manner that the resulting thickness shall be constant and be 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 in-place SIP-TPFL shall be capable of withstanding up to 15% deflection under external load without cracking or exhibiting other evidence of distress or failure.

The material shall be 100% solids with zero VOC.

The performance of the in-place SIP-TPFL shall meet and achieve all the requirements and objectives in TS 4.14.01 and TS 4.14.02.

### **Spray Robot Application System**

The robotic application system shall provide digital records of travel speed, spray head distance, and ambient environmental conditions for each pass of the spray application.

### **Spray Robot Digital Data Log & Environmental Condition Records**

The spray robot shall be capable of producing automated digital logs for all plural-component spray application equipment.

The Contractor shall maintain a digital chain of custody log for all samples, test results, and data files.

Data logs shall include continuous records of component pressures, hose and material temperatures, and A/B ratio throughout all spray operation. Logs shall be submitted in native electronic format (CSV or XML) together with a summary PDF.

Each file shall be uniquely identified using the following naming convention:

- Project\_Location\_Date\_SampleID. All records shall be provided to the Contract Administrator in searchable electronic format (PDF plus native data files).

Data shall be stored in a secure repository accessible to the City until the Contract Completion Date.



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The data log packages shall also include, at a minimum, the following for QA/QC verification purposes by the Contract Administrator:

- environmental condition records
- substrate preparation data
- spray equipment logs
- fabricated samples
- timestamped photographic and video evidence of all on-site and in-field testing activities. All photographic records shall clearly indicate date, time, and test location. Environmental conditions shall be recorded in a consistent unit of measure.

The logs shall be cross-referenced to the daily inspection report, photographic and video evidence, and the specific culvert or pipeline section being lined. All records shall be retained until the Contract Completion Date.

#### **Verification of Spray Robot Digital Data Log & Environmental Condition Records**

Prior to continuation of spray operations on any subsequent work day, the Contractor shall submit a data log package, including environmental conditions records, to the Contract Administrator for review and approval on daily basis.

Failure to provide complete and accurate daily data log package with environmental conditions records at the time of application will be considered as a deficiency.

Where the daily data log package demonstrates that all parameters are proper, complete and in accordance with contract requirements, the spray lining operation may take place at the Contractor's option prior to review and approval by the Contract Administrator of the submitted daily data log package.

When the Contractor opts to continue with the spray lining operation before the review and approval by the Contract Administrator, the Contractor accepts complete responsibility that the spray lining has carried out in accordance with the Contract requirements. In the case that the Contract Administrator finds that the daily data log package does not meet the contract requirements, the Contractor shall rectify any deficiencies to the satisfaction of the Contract Administrator, whether or not the lining has already been installed.

#### **Calibration and Traceability of Field Instruments**

All field instruments, including hygrometers, infrared thermometers, thickness gauges, and spark testers, shall have current calibration certificates traceable to current applicable standards. Calibration certificates shall be valid within twelve (12) months of the date of use.

The Contractor shall submit copies of all calibration certificates at the pre-construction meeting and maintain copies on site for inspection throughout the duration of the Contract.

#### **Corrosion Resistance**

Chemical resistance of the completed in-place liner shall meet the chemical resistance requirements in ASTM F1216-16 (including appendix X2) and ASTM D5813.

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## **H2S Gas Induced Microbial Corrosion Resistance**

When required in the Special Provisions of Contract, the SIP-TPFL 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 SIP-TPFL, the submissions with tender shall have included third party test reports, acceptable to the CA, 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: 55 MPa (7,977 psi) by ASTM D790 test method  
Flexural Modulus: 1,724 MPa (250,045 psi) by ASTM D790 test method  
Hardness: 70 Shore D

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

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

The in-place liner shall meet or exceed the short-term properties and long-term material properties used in the design.

## **Manufacturer's Certificate of Analysis (COA)**

For each batch or lot of liner material supplied for the project the Contractor shall provide to the Contract Administrator a Certificate of Analysis (COA), directly from the manufacturer. This certificate must comply with the manufacturers published Technical Data Sheet and include the following:

1. Product Manufacturer's Name and Location
2. Product Name & Identification Number or Code
3. Product Batch Number
4. Date of Manufacture
5. Date of Expiry
6. Batch Physical Properties for Elongation, Gel Time, Tensile, Viscosity and Color

Refer also to TS 4.14.28 Liner Materials Sampling, Testing and Conformance.

## **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 4.14 and require the approval of the Contract Administrator prior to use.

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#### **TS 4.14.22 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 SIP-TPFL 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 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 SIP-TPFL).

There shall be no irregularities that may result in ponding or flow damming unless such irregularities reflect 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 reflects 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 4.14.23 DESIGN OF SIP-TPFL**

##### **General**

The SIP-TPFL 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).

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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 4.14.24.

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

### **Design for Circular Pipe**

For circular pipe the design shall be by either the method identified in Appendix A2 (Design Method C1) or shall be by finite element analysis design (FEAD). For FEAD refer to TS 4.14.23.

### **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 4.14.23.

### **Design Parameters**

The design parameters given in Table 1 below shall be used for all designs (circular and non-circular) except for designs using the C1 design method for circular host pipe. For C1 design method, Appendix A2 has a table of design parameters specific to the C1 design method.

**Table 1. Design Parameters** (v200422)

<b>Parameter</b>	<b>Requirement</b>	<b>Notes</b>
Design Life	50 years	
Safety Factor	$\geq 2.0$	
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.	

Parameter	Requirement	Notes
External Earth Load	<p>Based on 2 m 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.</p> <p>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.</p>	
Live Load	<p>CHBDC CL-625-ONT or a vehicle loading determined in the field, whichever is greater.</p> <p>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.</p>	
Soil Weight	18.85 KN/m <sup>3</sup> (1922 Kg/m <sup>3</sup> )	
Soil Modulus	6.9 MPa	
Liner Properties Short-term Test	The short-term test 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.	
Liner Properties Long-term Design	<p>The liner properties used for long-term design for the design life shall be the amount of the short-term test properties retained for the long-term design life. The retention factor shall be based on long-term testing (such as ASTM D2990). The long-term testing shall determine the retention factor, which shall account for the long-term creep behaviour of the liner material under the appropriate stress and stress duration conditions.</p> <p>The short-term test property to be used as the starting value for determining the design life property value to be used in the design shall be the short-term test property that is routinely and reliably obtained in tests of actual installed liners. The design shall identify the short-term test values and long-term design values. A required minimum short-term test property values may be specified in this specification or in applicable standards.</p> <p>Independent third party testing in accordance with ASTM D790 (or equivalent) is required to substantiate the short-term test properties used. Independent third party testing in accordance with ASTM D2990 (or equivalent) is required to substantiate the retention factor used for long-term design.</p> <p>When long-term testing to establish the long-term design retention factor is not available, a maximum retention factor of 50% shall be used.</p>	

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## **Short-term Test Properties as Starting Points for Long-term Design Values**

The short-term test values of liner properties used in design as the starting values from which the long-term design values are derived shall be short-term test values that will be reliably and repeatedly obtained in the installed liners as substantiated by testing samples from installed liners. The starting short-term test values shall be identified in the liner design.

### **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 SIP-TPFL 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 4.14.24 DESIGN BY FINITE ELEMENT ANALYSIS METHOD**

### **General**

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 SIP-TPFL design the host pipe shall not provide any load bearing contribution to the liner's capacity to resist external load.

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## External Loads

The design shall use the theoretical hydrostatic and earth cover loads due to the specified design conditions in TS 4.14.22 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  $\leq 40\%$  of the vertical load at the same depth. Vertical live load (surface vehicle) load applied to the liner shall be as specified in TS 4.14.22 Table 1. Where a horizontal live load is applied in the liner design it shall be  $\leq 20\%$  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  $\geq 2.0$

## SIP-TPFL 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: 3%

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 36 mm (i.e. maximum of 1236 mm and/or minimum of 1164 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 36 mm or a deflected vertical diameter of not less than 1164 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 45 mm and the change in width to not more 36 mm.

## Results of FEAD

The FEAD including its report shall clearly show:

- 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.

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- 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 4.14.25 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 4.14.22) 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 SIP-TPFL 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 4.14.26 DESIGN THICKNESS VERSUS INSTALLED LINER THICKNESS**

Unless otherwise specified in the contract documents, the thickness determined by the latest liner design accepted by the CA 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.



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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 4.14.35.

## **TS 4.14.27      INSTALLATION OF SIP-TPFL**

### **Installation Procedure**

All liner installations shall be completed using robotic spray application equipment to ensure consistent spray quality, even thickness, and real-time monitoring of application parameters.

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 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 sewer lateral rehabilitation.

The Contractor shall ensure that the existing host pipeline is completely free of all water and infiltration and has limited moisture (surface dampness only) that will not negatively affect the SIP-TPFL during its application onto the existing host pipeline. The Contractor shall ensure that, when several sequential spray passes of the SIP-TPFL are required to build up the required thickness, there is no surface contamination or moisture built up on the material applied in the previous SIP-TPFL pass.

Liner terminations shall be in key cuts in the concrete of the maintenance hole (or other termination structure) approximately 5 mm wide by 5 mm deep.

### **Application Parameters and Thickness Limitations**

The Contractor shall comply with the following application parameters to prevent excessive exotherm, thermal cracking, adhesion failure, and premature deterioration of the liner system.

Any exceedance of these limits shall be deemed non-compliant and subject to rejection, removal, and reinstallation at the Contractor's expense.

The Contractor shall advise the Contract Administrator and the spray lining manufacturer in writing in advanced if these parameters cannot be met or are not recommended by the manufacture.

- **Layer Thickness per Pass**
  - A target application thickness of 0.5 mm to 1.0 mm per pass is recommended to achieve uniform finish and minimize surface irregularities.

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- **Cumulative Build Limit**
    - The liner shall not exceed a cumulative build thickness of 240 mils (6 mm) without verification of surface temperature.
    - Exceeding this limit without verification may result in uncontrolled exothermic heat retention.
  - **Liner Surface Temperature Control**
    - At no time shall liner surface temperature exceed 185°F (85°C).
    - If this limit is reached or exceeded, spray application shall be suspended until temperatures show a consistent decreasing trend and have cooled below 185°F (85°C).
  - **Base Layer Cooling**
    - Prior to application of subsequent layers, the previous layer shall be permitted to cool to 120°F (49°C).
  - **Interval Between Layers**
    - Overcoating shall be permitted once the previous layer has cooled below 120°F (49°C).
    - Where the interval between successive passes exceeds 24 hours, an appropriate approved primer by the spray lining manufacturer shall be applied before additional liner material is installed.
  - **Substrate Condition**
    - The substrate shall be dry and free of unsealed voids prior to application.
    - Where residual moisture or dampness is present, an approved pure polyurea by the spray lining manufacturer shall be applied as a moisture barrier prior to installation of spray liner.
  - **Compliance Verification**
    - All temperature, thickness, and environmental compliance checks shall be documented through Graco Reactor digital logs, robotic application system data, and timestamped photographic evidence of field readings.
    - Any exceedance of the above limits shall be deemed non-compliant and subject to rejection, removal, and reinstallation at the Contractor's expense.

#### **Back-Up Spray Robot On Site for SIP-TPFL**

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

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## **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 SIP-TPFL shall consist of continuous passes of the spray head 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 moisture that will negatively impact the bonding of the succeeding layer to the preceding layer of SIP-TPFL material. Where the surface has become contaminated (for any reason), the succeeding pass shall not take place until the surface has been cleaned and dried (where required).

Where a delay is encountered between successive passes that exceeds 12 hours, the next pass shall not take place until the surface is cleaned, dried and primed with the required primer for the SIP-TPFL. In its submissions the Contractor shall identify the required primer to use in this situation.

## **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 4.14.22 to TS 4.14.25 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 SIP-TPFL 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 SIP-TPFL the Contractor shall provide notice to the affected residents indicating possible odour resulting from sewer 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.

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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 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 sewer ventilation and odour mitigation during the sewer lining process. The following steps shall be taken:

Exhaust Fans for Sewer When Required: 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 sewer via maintenance holes. One fan shall be located at an adjacent maintenance hole immediately downstream of the sewer 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 sewer being lined. In the event that odour control becomes a problem, the Contractor shall provide additional exhaust ventilation of the sewer 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 4.14.28.

### **TS 4.14.28 LINER MATERIALS SAMPLING, TESTING AND CONFORMANCE**

As required in TS 4.14.20, the Contractor shall have provided the Contract Administrator with Certificates of Analysis (COA) for each batch or lot of product delivered for the project.

At the discretion and direction of the Contract Administrator, the Contractor shall take liquid draw down samples from any batch delivered and provide them to the manufacturer to perform an FTIR (Fourier Transformed Infrared Spectroscopy) to confirm the chemical fingerprint of the batch provided matches the samples taken. The Contractor shall permit and facilitate the Contract Administrator to witness the taking of samples. The samples shall be clearly labelled as to their origin and sampling date.

The Contractor shall authorize the manufacturer to communicate directly with the Contract Administrator regarding this sampling testing and conformance. The Contractor shall authorize the manufacturer to send the conformance testing results directly to the Contract Administrator.

Failure of any sample to match to the relevant FTIR documentation for the sample shall be considered a deficiency. Refer TS 4.14.36.

### **TS 4.14.29 SIP-TPFL INSTALLATION SAMPLES AND TESTING**

Samples of the SIP-TPFL shall include flat plate samples and full cylindrical samples. Plate samples shall be tested for flexural strength and flexural modulus (ASTM D-790). Cylindrical samples shall be tested for deflection capacity.

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## Flat Plate Samples

Contractor shall provide a plate type sample, fabricated at site, made by applying the SIP-TPFL material onto a flat plate. Plate samples shall be made by spraying the liner materials on to a flat plate using the same materials to be used in the pipe. The plate samples shall be representative of the lining installed in the pipeline. ~~A release agent shall be used to allow for easy separation of the sample from the plate.~~

All flat samples shall be linked to specific batch or lot number of liner material supplied for the project with a full chain of custody. A release agent which does not adversely affect the liner material properties shall be used for plate fabrication to ensure proper separation. Fabrication shall be carried out by disconnecting the robotic hose and reconnecting to a manual spray gun ("hot swap") solely for the purpose of preparing the sample; purging shall be undertaken to ensure on-ratio, temperature-compliant material. The sample shall be created at the start of the material application to the host pipe i.e. immediately prior to pipe application.

Each flat plate sample shall be prepared at a nominal thickness of 12.7 mm (0.5") and cured for fourteen (14) days, including eighty-eight (88) hours of conditioning at 25°C. Samples shall be cut into five (5) test specimens of approximately 0.5" × 0.6" × 10" saw-cut using diamond blades for ASTM D-790 testing. All sample cuts shall be carried out by an independent accredited testing laboratory approved by the Contract Administrator.

All environmental conditions shall be recorded for the plate sample as per the application requirements in this specification.

The Contractor shall arrange for the Contract Administrator to receive the test results directly from the test agency and shall provide the test agency with the Contractor's permission to communicate directly with the Contract Administrator.

The samples shall be clearly and indelibly identified with Contract number, location, size of the pipeline being lined, date and whether the start sample or the finish sample.

For each pipeline segment installation, flat samples shall be made in the following manner:

- One immediately before the start of lining the pipeline (start sample)
- One immediately after completion of the last spray pass in the pipeline (finish sample)
- One for every 5 days of spraying operation (intermediate samples)

## Full Cylindrical Samples

For each pipeline being lined the Contractor shall make a full cylindrical sample in an appropriate cylindrical form. The form shall be a close approximation of the size of the pipeline and the thickness applied the same as the required liner thickness in the pipeline. Prior to making a sample the Contractor shall consult with the third party testing agency to determine the length of the sample that the testing agency will require for the testing by ASTM D2412.

For pipeline sizes greater than 1200 mm diameter, a 1200 mm diameter form shall be used and the thickness of the cylindrical sample shall result in the same DR as the DR of required thickness liner in the pipeline. (DR = Dimension Ratio = t/OD). For example, a 50 mm thick liner in an 1800 mm pipeline results in a liner DR of  $1800/50 = 36$ . Therefore the 1200 mm cylindrical sample thickness would be  $1200/36 = 33$  mm.

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For non-circular pipelines, the cylindrical sample form diameter shall be the average of the height and width of the non-circular pipeline to a maximum 1200 mm diameter cylindrical sample. For sample cylindrical form diameters up to 1200 mm the sample thickness shall be the same thickness as required in the pipeline. Where the average of the pipeline height and width is greater than 1200 mm, a 1200 mm diameter form shall be used and the sample thickness shall be based on an equivalent DR, where the DR of the non-circular pipeline shall be considered to be the average of the height and width divided by the required liner thickness.

Cylindrical samples may be fabricated in a location off site if the conditions of spraying are similar to the on-site conditions and the identical material is sprayed into the cylindrical sample. The Contractor shall provide the Contract Administrator with 5 days advance notice of the fabrication so that the Contract Administrator can attend the fabrication.

The samples shall be clearly and indelibly identified with Contract number, location, size of the pipeline being lined, date and location where the sample was made.

The Contractor shall have the samples tested at a testing agency approved by the Contract Administrator and shall arrange for the Contract Administrator to receive the test results directly from the test agency and shall provide the test agency with the Contractor's permission to communicate directly with the Contract Administrator.

#### **Core Sample from Wall of Installed Liner**

When in the opinion of the Contract Administrator a further sample from the actual installed liner is required to clarify information obtained from other samplings, a core sample shall be extracted from the installed liner within the conduit that was lined. The core sample shall be 75 -100 mm in diameter or, if cut from the mouth of the lined conduit, 75-100 mm wide by 75-100 mm long. The depth of the sample shall be at least 90% of the wall thickness of the installed liner. When and where a core sample is extracted, the liner shall be repaired using a suitable method.

#### **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 - General**

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

#### **Testing of Flat Plate Samples**

Flat plate samples of installed liner shall be tested for flexural modulus and flexural strength as per ASTM D790 and thickness as per ASTM D5813-04(2008). The provision of testing service shall allow for the obtaining of test reports within 10 days of delivery of the sample to the testing agency.

The Contractor shall provide for the testing agency to forward test reports by email to the Contract Administrator.

The Contractor shall provide the test agency with the design parameters for the liner corresponding with the sample as follows:

- Flexural Strength Short-term test used in design

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- Flexural Modulus Short-term test used in design
  - Required Liner Thickness determined by design

These values shall have been identified in the Contractor's liner design. The testing agency's report shall reference these values as the specified values.

The test results will determine whether the required physical properties and required thickness have been met. However in regard to thickness, the Contract Administrator reserves the right to have the actual installed thickness verified by field measurement, either at the accessible ends of the liner or by a sample removed from the liner itself or by drilling into the liner to determine the thickness.

### **Testing of Full Cylindrical Samples**

Full cylindrical samples shall be tested as per ASTM D2412, Standard Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading. A full report shall be provided including photographs and video recording of the test. The test shall be limited by occurrence of a crack (deflection to be recorded) or when the cylindrical sample has reached 20% deflection. The Contractor shall provide the Contract Administrator with 5 days advance notice of the test so that the Contract Administrator can attend the test.

The test results will determine whether the SIP-TPFL meets the requirement for a minimum 15% deflection without any visible deterioration including cracking, crazing or other indications of failure stress. For example, a 1200 mm diameter cylindrical sample shall ovalize under parallel plate loading to a vertical diameter of 1050 mm, which corresponds with 15% deflection.

### **Visual Inspection of Samples**

Samples shall be inspected 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 4.14.30 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 SIP-TPFL may not have completely blocked off the existing service connection, however it may have reduced the opening size due to spraying 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.

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Immediately following any SIP-TPFL 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 entirely opened by no later than the next day.

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 sewer. Such toilets shall be delivered prior to any service connections being blocked in the sewer 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 4.14.31 LINER WALL THICKNESS VERIFICATION**

Liner wall thickness means the structural wall thickness of the completed in-place SIP-TPFL 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 (within limit below) the required liner wall thickness. The required liner thickness shall be the greater of:

- (1) The wall thickness determined by the SIP-TPFL design accepted by the Contract Administrator (Refer TS 4.14.22, .23, .24 and .25)
- (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.



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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 CA of the stud length being used.

#### **Thickness Measurement by Alternative Methods**

The Contractor may propose to the Contract Administrator a different method for verifying in-place liner thickness such as:

- Installed steel plates for ultrasonic gauge readings, or
- Destructive testing for confirmation of final liner thickness.

Any proposed alternative method shall be subject to the approval of the Contract Administrator.

### **TS 4.14.32 LINER PHYSICAL PROPERTIES VERIFICATION**

#### **Required In-Place Physical Properties for SIP-TPFL**

The completed in place SIP-TPFL 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 4.14.20.

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 4.14.35 for potential reconciliation.

The long-term design performance for the liner properties shall meet or exceed the long-term design performance assumed in the accepted liner design.

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### **Liner Wall to Be Homogeneous and Monolithic**

The wall of the SIP-TPFL 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 4.14.33 REQUIRED FIT AND FINISH PARAMETERS FOR SIP-TPFL**

The in place and completed SIP-TPFL shall meet or exceed the following parameters in Table 2.

**Table 2: Required Liner Fit and Finish Requirements**

<b>Continuity of Liner</b>	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 or separations.
<b>Liner Fit to Existing Sewer</b>	The outside surface of the finished liner shall be in contact with the inside surface of the existing sewer. The inside surface of the existing sewer is the surface after the sewer has been cleaned and prepared for lining in accordance with the cleaning and preparation requirements.
<b>Liner Shape</b>	The liner shape will be as defined by liner fit to existing sewer line. In general the liner shape shall conform to the shape of the existing sewer 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.
<b>Liner Wall</b>	The liner wall shall be free of any interior bulges, ribs, ripples, folds or other irregularities except where any irregularity results from fitting the shape of the sewer 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.
<b>Liner Surface</b>	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 4.14.21.
<b>Liner Terminations</b>	The ends of the finished liner shall be neat and smooth. Terminations at MHs shall be flush or extend slightly beyond the MH wall/sewer interface by only a sufficient extension to allow for any longitudinal shrinkage. Terminations shall be neatly keyed into the MH of other terminating structure.
<b>Service Connection Reinstallments</b>	Reinstallments 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.

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#### **TS 4.14.34 CCTV INSPECTION OF COMPLETED REHABILITATION – V3**

After completion of all work in the lining of the sewer section including reinstatement of service connections and maintenance hole benching, a CCTV inspection—called the V3—of the full length of the sewer section lined shall be done and submitted to the Contract Administrator. The V3 shall be done according to the requirements for CCTV inspection and reports in TS 4.14 herein. The Contract Administrator will review the V3 as part of its approval process for the lined sewer.

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

The V3 shall be coded in accordance with requirements in TS 4.14.10.

#### **TS 4.14.35 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, in the original design, the actual as-tested properties for the original design properties 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 Contract Administrator shall make or otherwise approve any 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 TS 4.14.20), in the procurement documents or in an applicable standard.

#### **TS 4.14.36 DEFICIENCIES**

A deficiency will exist when the work or the results of the work is/are not according to Contract Documents, including TS 4.14 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 SIP-TPFL does not achieve the lining objectives set out in TS 4.14.02 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.

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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 liner or require an alternate resolution at the discretion of the Contract Administrator.

#### **TS 4.14.37      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 C1 for SIP-TPFL in Circular Host Pipe
- A3: Guidelines for FEA Design Method for SIP-TPFL

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)

**TS 4.14, APPENDIX A2****Design Method C1****For SIP-TPFL in Circular Host Pipe**

For circular host pipe the Contractor shall design the SIP-TPFL wall thickness either by design method C1 (as below) or by finite element analysis design (FEAD). For Design Method C1 refer to Table A2-1 below and to TS 4.14.22 for when the C1 design method is acceptable. For FEAD refer to TS 4.14.22.

**Table A2-1. Design Parameters for SIP-TPFL in Circular Host Pipe for Design Method C1**

<b>Parameter</b>	<b>Requirement</b>
Design Method C1	SIP-TPFL liners for sewer, storm and culvert shall be designed for wall thickness using the ASTM F1216-07a, Appendix X1, Design Considerations, X1.2 Gravity Pipe. X1.2.2 Fully Deteriorated Gravity Pipe Condition <u>modified as follows</u> :  1. See External Hydrostatic Pressure parameter below. 2. F1216-07a X1 Note X1.2 calling for a maximum DR of 100 is not applicable. 3. F1216-07a Equation X1.4 is not applicable.  Design by appendix X1 from ASTM F1216 versions later than F1216-07a is not permitted.
Design Life	50 years
Safety Factor	2.0 for all equations
External Hydrostatic Pressure	Except for surface water drainage culverts, a hydrostatic pressure corresponding with the greater head 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 m 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 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 the actual live load (such as a railway load) that exists at the liner location, whichever yields the greater live load. Live load shall be based on the actual cover over the top of the host pipe, which can differ from the cover used for External Earth Load.
Ovality	With the exception of CSP/CMP culverts, 2% or the actual ovality of the existing pipe section, whichever is greater. For CSP/CMP culverts, 4% or the ovality of the existing culvert, whichever is greater.
Soil Weight	18.85 KN/m <sup>3</sup> (1922 Kg/m <sup>3</sup> )
Soil Modulus	6.9 MPa

Parameter	Requirement
Flexural Modulus Used in Design Equations	<p>The flexural modulus used in the design equations shall be the amount of the short-term test flexural modulus retained for the long-term design life. The retention factor shall be based on long-term testing (such as ASTM D2990). The long-term testing shall determine the retention factor, which shall account for the long-term creep behaviour of the liner material under the appropriate stress and stress duration conditions.</p> <p>The short-term test flexural modulus to be used as the starting value for determining the flexural modulus to be used in the design equations shall be the short-term test flexural modulus that is routinely and reliably obtained in tests of actual installed liners. The design shall identify the short-term test value and long-term design value. A required minimum short-term test flexural modulus may be specified in this specification or in applicable standards.</p> <p>Independent third party testing in accordance with ASTM D790 (or equivalent) is required to substantiate the short-term test flexural modulus used. Independent third party testing in accordance with ASTM D2990 (or equivalent) is required to substantiate the retention factor used for long-term design.</p> <p>When long-term testing to establish the long-term design retention factor is not available, a maximum retention factor of 50% shall be used.</p>
Flexural Strength Used in Design Equations	<p>The flexural strength used in the design equations shall be the amount of the short-term test flexural strength retained for the long-term design life. The retention factor shall be based on long-term testing (such as ASTM D2990). The long-term testing shall determine the retention factor, which shall account for the long-term creep behaviour of the liner material under the appropriate stress and stress duration conditions.</p> <p>The short-term test flexural strength to be used as the starting value for determining the flexural strength to be used in the design equations shall be the short-term test flexural strength that is routinely and reliably obtained in tests of actual installed liners. The design shall identify the short-term test value and long-term design value. A required minimum short-term test flexural strength may be specified in this specification or in applicable standards.</p> <p>Independent third party testing in accordance with ASTM D790 (or equivalent) is required to substantiate the short-term test flexural strength used. Independent third party testing in accordance with ASTM D2990 (or equivalent) is required to substantiate the retention factor used for long-term design.</p> <p>When long-term testing to establish the long-term design retention factor is not available, a maximum retention factor of 50% shall be used.</p>

### Short-term Test Flexural Modulus and Short-term Test Flexural Strength

The short-term test values of flexural modulus and flexural strength (as per ASTM D790) used as the starting values from which the long-term design values are derived shall be short-term test values that will be reliably and repeatedly obtained in the installed liners as substantiated by testing samples from installed liners. The starting short-term test values shall be identified in the liner design.

### 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.

## APPENDIX A3 for TS 4.14

### Guidelines on Using Finite Element Analysis in Design of Sprayed-on Pipe Liners

#### 1. Introduction.

Finite element analysis can be used to estimate the moment that will develop on a sprayed flexible plastic liners 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 buckling theory, such as TS 468 Design Method C1 for circular host pipes

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**

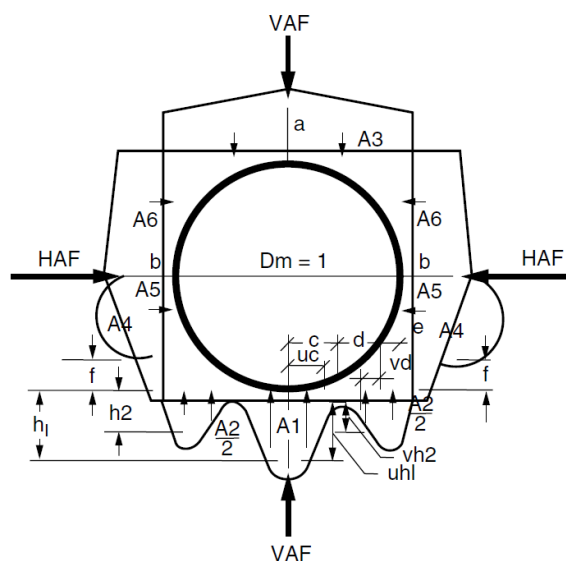
A large number of general purpose finite element programs exist that can be used to undertake either soil-pipe interaction analysis or ring under defined pressure analysis. Examples include PLAXIS and ABAQUS (demonstrated against measurements for culverts responding to vehicle loads by Mai et al., 2014; 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  $h_1$ ,  $h_2$ ,  $uh_1$ ,  $vh_2$ ,  $a$  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  $(0.5-c-e)$ .  
 $h_1$  is calculated as  $(1.5A1) / (c) (1+u)$ .  
 $h_2$  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:

- 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  $\nu$  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.

- 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.

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