Specification, Installation Practices, QC/QA and Warranty Information

Structurally Independent SIPP Linings for Pressure Pipe for Diameters 6 in. through 12 ft.

Contents

SPECIFICATION, INSTALLATION PRACTICES, QC/QA AND WARRANTY INFORMATION

1. General Information

This section specifies the materials and robotic applications of a polymeric lining system for pressure pipes intended to form Spray In Place Pipe (SIPP) to provide a structurally independent liner. SIPP Technology encompasses many different market sectors such as municipal, industrial, as well as, governmental. The work related to this section shall include pipe cleaning, surface preparation, a closed-circuit television (CCTV) inspection, and the robotic application of the polymeric lining systems on all the pipe interior surfaces as described herein. If there are conflicts between this section and the instruction from the lining material manufacturer, more stringent document will be used to enforce the work. Conflicts between this section, instructions from the lining material manufacturer, and other sections of the specification shall be immediately brought to the attention of the owner or his representative. The owner or his representative shall make the final determination or interpretation of the specification.

2. Reference Standards

The publications listed below form a part of this specification to the extent referenced. The publications are referred in the text for basic designation purpose only. the latest edition on the date of advertisement for bids shall be used.

ASTM C1557 Standard Test Method for Tensile Strength and Young's Modulus of Fibers
ASTM D149 Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
ASTM D543 Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
ASTM D570 Standard Test Method for Water Absorption of Plastics
ASTM D638 Standard Test Method for Tensile Properties of Plastics
ASTM D6943 Practice for Immersion Testing of Industrial Protective Coatings and Linings
ASTM D732 Standard Test Method for Shear Strength of Plastics by Punch Tool
ASTM D790 Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D870 Practice for Testing Water Resistance of Coatings Using Water Immersion
ASTM D883 Standard Terminology Relating to Plastics
ASTM D1599 Standard Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
ASTM D1600 Standard Terminology for Abbreviated Terms Relating to Plastics
ASTM D2240 Standard Test Method for Rubber Property—Durometer Hardness
ASTM D2990 Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics
ASTM D2992 Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings
ASTM D3039/D3039M Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D3517 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe
ASTM D4060 Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D4541 Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM D6289 Standard Test Method for Measuring Shrinkage from Mold Dimensions of Molded Thermosetting Plastics
ASTM D7791 Standard Test Method for Uniaxial Fatigue Properties of Plastics
ASTM E289 Standard Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry
ASTM F412 Standard Terminology Relating to Plastic Piping Systems

ASTM F1216 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
ASTM F3182 Standard Practice for the Application of Spray-Applied Polymeric Liners Inside Pipelines for Potable Water
ASTM G14 Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
AWWA C222 Polyurethane coatings for the Interior and Exterior of Steel Water Pipe and Fittings
AWWA C620 Spray-Applied In-Place Epoxy Lining of Water Pipelines, 3 In. (75 mm) and Larger
ANSI/AWWA C602 Standard for Cement-Mortar Lining of Water Pipelines in Place – 4 in (100 mm) and Larger
AWWA C651 Disinfecting Water Mains
AWWA M28 Rehabilitation of Water Mains, Third Edition
NSF/ANSI 14 Plastic Piping System Components and Related Materials
NSF/ANSI 61 Drinking Water System Components – Health Effects
NSF/ANSI 372 Drinking Water System Components – Lead Content
SSPC-PA 1 Shop, Field, and Maintenance Painting of Steel
SSPC-PA 2 Measurement of Dry Coating Thickness with Magnetic Gages
Performance Pipe Technical Note 813-TN PE Pressure Water Piping Systems Mechanical Restraint and Poisson Effects"
NACE SP-0188 Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates

QUALIFICATIONS

Since the pipeline rehabilitation/reconstruction products are intended to have a 50-year design life, and in order to minimize the Owner's risk, only proven products with substantial successful installations and experience will be approved. In order for the SIPP product and installation contractor to be deemed commercially acceptable and approved for this project, they must meet the following criteria:

3. Materials

3.1 Pipe and fittings, including both new pipe and existing pipe at connection point, shall be lined using a 100% solid polymer composed of two components with a minimum film thickness in accordance with the included calculus (see Attachment A).

3.2 The lining material shall consist of a thermosetting polymer, specifically designed for the use in pipeline applications.

3.3 The lining material shall have low viscosities that enable the pumping of the material components to a robotic application device.

3.4 The lining material shall be able to generate a high-build, slump-resistant lining.

3.5 The lining material must be able to be applied over a wide range of temperatures (32°F

to 120 °F).

3.6 The lining material must be moisture tolerant to produce a hard, smooth lining with excellent water & chemical resistance and long-term durability.

3.7 The lining material shall be able to achieve required liner thickness while completely encapsulating all pipe welds, rivets, joints and edges.

3.8 The lining material shall have an initial rapid cure time (gel time) or thixotropic nature necessary to arrest sagging, dripping, or puddling of the lining material.

3.9 At 75 ℉, the cure time of the lining material to be tack free shall not exceed 10 minutes, and normal immersion use shall not exceed 24 hours.

3.10 No primers are required for the lining material to achieve proper performance.

3.11 The lining material shall contain no volatile organic compounds (VOC) or solvents.

The lining material to be used on the interior of the pipe and fittings shall meet all of the material properties shown in Table 1 below as determined by third party accredited, independent laboratory.

3.12 laboratory testing report in accordance with ASTM or AWWA procedures as cited.

3.13 All lining materials within the lining system shall be produced and supplied by the same manufacturer.

3.14 Lining system components shall have a shelf life of no less than one year in sealed containers.

3.15 The two components shall be supplied in two distinct colors, when mixed together in the proper ratio, the mixed material shall produce a third distinct color.

3.16 Acceptable products for field-applied lining systems, or equal to SippSteel Composite SIPP Lining by SippTech.

Table 1: Required lining material properties per ASTM Standards

i.	**Flexural Modulus (ASTM D790)**	• 350,000 psi minimum
ii.	**Tensile Strength (ASTM D638) D3039/D3039M**	• 7,000 psi minimum
iii.	**Elongation (ASTM D638)**	• 20% maximum
iv.	**Hardness (ASTM D2240)**	• 60 Shore D minimum
v.	**Adhesion to Steel (ASTM D4541)**	• 1,200 psi minimum
vi.	**Water Absorption (ASTM D570)**	• 2% maximum
vii.	**Cathodic Disbondment (ASTM G95)**	• 12 mm maximum
viii.	**Dielectric Strength (ASTM D149)**	• 250 V/mil minimum
ix.	**Chemical Resistance (ASTM D543)**	• < 5% change in mass • 10% H_2SO_4, 30% NaCl, 30%NaOH, #2 Diesel Fuel • maximum and <5% change in length or width maximum • No blistering, cracking, softening, or other forms of deterioration (other than changes in color or staining)
x.	**Abrasion Resistance (ASTM D4060)**	• 50 mg loss maximum
xi.	**Impact Resistance (ASTM G14)**	• 75 in-lbs minimum
xii.	**Long-Term Tensile & Flexural Strength (ASTM D2990)**	• 1,000 hours ~ 10,000 hours
xiii.	**Material shrinkage in curing process (ASTM D6289)**	• 1% maximum
xiv.	**Shear Strength of Polymer Matrix Composite Materials (ASTM D732)**	• 5,000 psi minimum

xv.	**Tension-Tension Fatigue of Polymer Matrix Composite Materials (ASTM D7791)**	• Tensile strength of control specimens for Procedure 5,000 psi
xvi.	**Short-Time Hydraulic Pressure of Composite Lining System (ASTM D 1599)**	• 600 psi for at least 60 seconds
xvii.	**Field Leak Testing of Composite Lining System (ASTM F2164)**	• pressurized liquid to test for leaks

4. <u>Lining Equipment</u>

4.1 Lining equipment used to apply the lining material shall be suitable for the intended work and meet the requirements of the lining material manufacturer.

4.2 Lining equipment used for application of lining shall be suitable to store, heat, move, and mix the lining material and function in accordance with the lining manufacturer's instructions for use.

4.3 Lining Equipment shall be capable of providing necessary heat, flow and pressure required for installation conditions.

4.4 Lining equipment heat sources shall be equipped with suitable monitors to gauge temperatures of lining material components.

4.5 Lining equipment shall be capable of mixing components so that the material mix ratio is achieved at the material casting assembly, (application head, spinner, spinning cone etc.) meets the requirements of the lining material manufacturer.

4.6 Lining equipment shall be capable of autonomous axial centering of the material casting assembly (application head, spinner, spinner cone, etc.) to assure uniform lining thickness.

4.7 Lining equipment used to pressurize and pump the lining material shall be equipped with flow meters and pressure gauges capable of monitoring the individual components to ensure mixing of components within manufacturer's recommended tolerances for the specified mix ratio.

4.8 Lining equipment flow meters and pressure monitors shall provide a continuous record of the information:

1) Volume and flow of material to the material casting assembly,

2) Pressure in both component hose lines.

4.9 Lining or ancillary equipment shall be capable of filling or applying thin adhesive membrane over all cracks, perforations and other discontinuities in the pipe prior to lining.

4.10 Lining equipment shall be capable of applying low Poisson's ratio closed cell elastomer as the initial bonding layer and high tensile rigid layer of the composite lining.

4.11 Lining equipment shall be capable of incorporating a reinforcing filament or fabric into the composite lining concurrently with the rigid liner installation process.

4.12 Lining equipment shall be capable of self-propulsion.

4.13 Ancillary equipment shall be capable of self-propulsion.

4.14 Umbilical or tether equipment shall be capable of self-propulsion

4.15 Lining equipment shall be capable of highly accurate and consistent material dispersion in any diameter of pipe.

4.16 Lining equipment shall be capable of autonomous articulation of material casting assembly, (application head, spinner, spinner cone) to assure axial centerline of material dispersion during all lining processes.

4.17 Lining equipment shall be capable of real time lining thickness measurement at no less than four (4) points circumferentially on the liner surface with no less than 85 degrees separating any measurement point.

4.18 Lining equipment shall be capable of traversing and lining through short radius ninety-degree (90°) pipe bends for the pipe diameter being lined.

4.19 Lining or ancillary equipment shall be capable of autonomously cleaning and sanitizing umbilical's/tethers prior to entry into the pipe for potable water applications.

4.20 Lining equipment shall be capable of lining pipe without the removal of valves.

4.21 Lining equipment shall be capable of real time, onboard video monitoring and recording of the lining process.

4.22 Lining equipment shall be capable of recording all lining video with time/date stamp.

4.23 Lining equipment shall be capable of reporting and documenting locational, thickness and lining material processing data during lining operation.

5. <u>SUBMITTALS</u>

5.1 Product Data

Shall submit manufacturer's technical datasheet and SDS sheet.

Shall submit test results from accredited third-party certification organizations for all required material tests per Attachment A for the completion of liner thickness calculus. All Attachment A calculus inputs shall match all testing data provided by third-party certification organizations.

5.2 Lining Applicator

Contractor shall submit notarized letter stating that the contractor (or personnel in the employ of the contractor for a minimum of one year), has greater than five (5) years' experience in performing SIPP applications on underground and elevated pipelines. Documents included with this letter shall identify the size and length of pipeline projects, references, and contact information.

Contractor shall submit notarized letter from the lining material manufacturer stating that the contractor is

1) an approved/certified contractor by the manufacture for the lining material being applied,
2) has completed all training in the use of manufacturer-approved spray equipment.

6. <u>Construction Requirements</u>

6.1 Quality Control & Quality Assurance

6.1.1 Contractor shall provide a NACE and or SSPC and manufacturer certified lining inspector for QA/QC to be reviewed and approved by the owner or his representative. The QC/QA Lining Inspector will verify the overall lining was performed in the field per the requirements of this specification.

6.1.2 The QC/QA Lining Inspector shall review and certify that all tests results specified in the contract document are met Contractor shall repair any damaged lining per manufacturers repair procedures that result from the QC/QA testing at no additional cost to the owner.

6.1.3 All pipe cleaning, surface preparation, and lining activities shall be inspected by the QA/QC Lining Inspector and approved by the owner or his representative. The lining applicator shall also notify the designated owner representative sufficiently in advance so as to be present during the following activities to witness the operations on site:

1) The completion of pipe cleaning,
2) The completion of surface preparation,
3) Dry film thickness measurements,
4) During any lining repair.

6.1.4 The QC/QA Lining Inspector shall perform visual, CCTV inspections and dry film thickness measurements. The QC/QA Lining Inspector shall submit daily reports to the designated owner representative for records. Reports shall include the following information as included but not limited to:

1) Environmental conditions prior to liner application, including surface temperature, ambient air temperature, relative humidity and dew point;
2) Observations of pipe cleaning and surface preparation;
3) Temperature and Flow (gpm) of lining material during lining operations, and;
4) Dry film thickness measurements.

CCTV color recording of the pipe line before and after cleaning to be approved by the owner or his representative, prior to the lining process.

6.1.5 Contractor shall touch up any areas, where QC/QA lining inspection was performed, to the satisfaction of the QC/QA Lining Inspector, and reviewed and approved by the owner or his representative.

6.1.6 Contractor shall prepare samples of the lining material on pieces of steel, either salvaged from the removal of steel pipe from the existing pipeline or from material procured by the lining applicator, in a manner consistent with the application technique being used. The curing of samples shall be done in a like environment in which the pipe lining will be cured. The samples for bond strength, mechanical properties, porosity (holidays) and liner thickness tested, by accredited, independent laboratory, the test results will be reviewed and approved by the owner or his representative.

6.2 Delivery, Storage, and Handling of Material

6.2.1 The lining material shall be delivered to the project site in unopened, sealed containers and labeled with the manufacturer's identification and printed instructions for use.

6.2.2 Care shall be taken during transportation, handling, and installation of lining material and safety procedures shall be maintained in accordance with SDS.

6.2.3 Lining material shall be stored in original sealed containers in a dry environment at a temperature specified by the material manufacturer.

6.3 Pipe Cleaning—The lining applicator shall perform a mechanical cleaning with a device specifically manufactured for the purpose of cleaning the pipe of the same diameter of the pipe to be lined to the requirements of the lining system to be applied. This includes the removal of corrosion by-products; chemicals or other deposits; loose or deteriorated remains of old lining material; and oils, grease, and accumulations of water, dirt, and debris.

Several lining techniques are available for removing corrosion, debris and encrustation and preparing the existing pipe:

1) Power Boring,
2) Drag Scraping,

3) Air Scouring,
4) High Pressure Water Jetting,
5) Abrasive Pigging,
6) Sponge Blasting,
7) Venturi Media Blasting.

6.4 Foam Swabbing— After the cleaning process, the pipe shall be smooth, clean of loose material and free from standing water. If applicable, drying with foam swabs and or ventilating pipe with dry compressed air are acceptable methods.

6.5 Leaking Valves—The presence of substantial amounts of water suggests leaking valves. Due to age and condition, the lining applicator shall prepare plan to stop water from leaking valves, to be reviewed and approved by the owner or his representative

6.6 Pre-Lining Inspection— The lining applicator shall inspect the cleaned pipe throughout the length to be lined with CCTV system. The lining applicator shall disinfect all parts of the equipment before insertion into the water mains. The CCTV system camera shall be specifically designed and constructed for pipe inspection. The camera should provide the flexibility in examining pipe details, especially joints and service connections extending into the pipe. The lighting system shall be capable of lighting the full periphery of the pipe. The camera shall provide a color picture.

The interior surfaces of the pipe shall be clean and stop the leak to a drip-tight condition water before the lining material is applied. Service connections shall be carefully inspected to ensure that there is no debris blocking any service taps and there is no inflow of water into the pipe. If any services are leaking, appropriate steps shall be taken to stop the leak to a drip-tight condition. The method to be used shall be reviewed and approved by the owner or his representative A video recording shall be made of the entire inspection and submitted to the for review and approved by the owner or his representative prior to lining. If the initial video inspection reveals significant issues and resolution is not clear, the CCTV inspection may be repeated.

6.7 Spray Lining

6.7.1 The lining applicator shall follow the manufacturer recommendations on dehumidifying and or heating the pipe, if any. The manufacturer's recommendations for both minimum and maximum application temperatures, both ambient air temperature and surface temperature, for applying the lining material shall be followed.

6.7.2 Once pipe temperature has been checked, the lining rig is fully prepared and checked for operation and correctly heated, the lining material is at the correct temperature and any dehumidification equipment recommended by the manufacturer to facilitate the application has been put in place, lining can begin.

Only equipment that has been approved by the lining material manufacturer and reviewed and approved by the owner or his representative to apply the lining material to the interior surface of the pipe shall be used.

6.7.3 The lining shall be applied in single or multiple passes using an application device connected to a lining rig through an umbilical or tether. It shall be the lining manufacturer’s responsibility to establish limitations, reviewed and approved by the owner and his representative on each lining application, including thickness of application per pass, lining material curing time, and instructions or limitations for multiple-layer lining and any re-linings. In potable water applications, the lining applicator shall disinfect all parts of the equipment and umbilical before insertion into the pipe based on AWWA C602 standard. Also, the umbilical shall be encapsulated with impermeable cover like polyurethane.

The applicator shall complete all manufacturer-mandated quality control checks and records for the rig and lining material. Once the rig and material are fully prepared, and the pipe has been approved to ensure free passage of the lining application head, the umbilical shall be winched or self-propelled fully through the pipe.

6.7.4 Before the lining material is applied, the lining applicator shall demonstrate that the equipment is functioning properly by circulation of the lining material components in the equipment. Temperature of the components and weight ratio of the pumped lining material shall be verified (by weight or volume) to be within the manufacturer's tolerances. After pulling the umbilical through the length of pipe to be lined and attaching the lining head, the lining applicator shall "spin-up" the lining head to its operating rotation speed and sample the mixed lining material for the uniform color expected of thoroughly mixed components. Material dispersed from the lining apparatus during the demonstration shall not be applied to the pipe wall. Instead, a sacrificial surface define shall be placed within the pipe which shall receive any material dispersed from the lining apparatus during the demonstration. After inspection, this sacrificial surface shall be removed from the pipe.

6.7.5 The rigid lining material shall not bond directly to the host pipe. A low Poisson's ratio, closed cell porous materials shall be applied to the host pipe as the initial bonding layer of the composite lining system. Field samples shall be tested by accreted laboratory for tensile adhesion to the pipe wall in accordance with Test Method ASTM D4541. For the composite system, field samples of the inter-coat bonding between the elastomer layer and the rigid layer shall be also tested for tensile adhesion in accordance with ASTM D4541. Test results shall be submitted to the owner or his representative for review and approval, within minimum of a week prior to the start of the lining operation.

6.7.6 A reinforcement filament or fabric shall be wound in a unidirectional or bi-directional helical orientation onto the elastomer layer before applying the rigid layer of the composite. The filament or fabric shall be bonded to is adhered to the elastomer layer and the rigid lining material shall be immediately applied over and encapsulate the filament or fabric. The rigid lining material shall bond to the elastomer layer and filament layers to create the finished composite lining system.

6.7.7 Once lining operations commences, the lining contractor shall operate the lining apparatus continuously in each run by using the computer-controlled accumulator reel on the lining rig and speed-synchronization and self-propulsion devices, such as tracks, wheels or belts on both the umbilical/tether and the lining device to pull application head back through the pipe. Any maintenance stoppages shall not exceed the recoat time published by the lining manufacturer. This requirement may be modified if the lining applicator submits to the owner or his representative, for review and approval, methods and details to prevent "cold joints" and ensure that the lining is continuous at all locations. Wherever there is a condition which, in the opinion of the owner or his representative, may endanger the consistency of the lining application, the lining applicator shall operate the lining process with a full crew for 24 hours a day, including weekends and holidays, without intermission until those conditions no longer jeopardize the consistency of the lining application.

6.7.8 The manufacturer's instructions, shall be followed to assure that the application head and umbilical traverse in a synchronized fluid motion during the entire application process.

6.7.9 The applicator shall monitor the lining device throughout the lining process via on-board cameras. On-board cameras shall be utilized to monitor all material casting assembly (application head, spinner, spinner cone) and filament/fabric winder functionalities. If a serious fault is suspected, by the owner representative and the applicator the process shall be aborted and all the lining equipment must be removed from the pipe.

6.7.10 Once the lining is completed, a dip card or test spool shall be used to sample resin cure and shall be kept by the applicator as a permanent record. Immediately after lining, the applicator will review the lining printout in accordance with the manufacturer's procedures and provide a copy to the owner's representative. The cure period shall commence only when the lining device has been removed out of the pipe completely.

6.7.11 If difficulties with the lining operation are encountered or there is a significant change in the rate of progress, notify the owner's representative immediately. Within twenty-four hours of the difficulty, the contractor shall provide a written report to the owner's representative describing the details of the difficulty and the actions that were taken or are proposed to be taken to deal with the difficulty. Where lining operations may cease due to the malfunction of the lining apparatus, the lining applicator shall be prepared to prevent discontinuities in the lining or the formation of "cold joints" by having sufficient spare parts or a second lining apparatus at the project site to continue lining operations without a delay lasting beyond recoat time published by the lining manufacturer.

6.7.12 The contractor shall receive no additional compensation for any expenses resulting from the failure of the lining device or ancillary equipment to apply the lining material due to the malfunction of the lining apparatus. Contractor shall take every precaution to prevent a delay lasting beyond the recoat time published by the lining manufacturer.

6.7.13 Should a "cold joint" form or the lining not be continuous at any point during lining operations, the lining applicator shall repair the defect following recommendations from the lining material manufacturer. Manufacturer guidelines must prescribe all additional lining preparation necessary if a repair is required and another material coat is to be applied after the lining materials recoat window has been exceeded. The Contractor shall receive no additional compensation for the preparation of "cold joints".

6.7.14 Post-Lining Inspection—The lining applicator shall inspect the lined pipe throughout the entire length after the lining material has cured with CCTV equipment as described above. The lining applicator shall limit bacteriological contamination from the CCTV equipment. The interior surfaces of the pipe must be completely covered by the lining material without evidence of poor mixing or excessive ringing. Particular attention must be paid to inspect the service connections to ensure that there is no evidence of blockage. A standard video recording shall be made of the entire inspection and turned over to the engineer at the end of the project.

6.7.15 Return to Service—Upon completion of the work, debris, and containers of lining materials, cleaners, and other items shall be removed from the site and disposed of by the lining applicator in accordance with local, state, and federal requirements.

7 <u>Execution – Purchaser</u>

7.1 Purchaser shall assist the contractor to secure a heated storage area for all contractor temperature sensitive materials when the ambient atmospheric air temperature is below 65 ℉ at any time during a 24-hour period.

7.2 Purchaser shall assist the contractor to secure a sufficient lay down area and parking nearby unit for ancillary equipment.

7.3 Purchaser shall provide contractor with unencumbered accesses to expose the pipeline to be lined or remove sections of the pipeline at the locations identified by contractor to provide access for lining operations.

7.4 Purchaser shall assist the contractor to secure an unencumbered location near all accesses to the pipe for equipment, material and personal staging.

7.5 Purchaser will provide contractor with a pipe that will not be subjected to any additional work by other contractors and or purchaser personnel that would impede and or delay contractor’s scope during the duration of the project.

8 <u>Execution - Contractor</u>

8.1 Contractor shall apply lining material in accordance with the requirements of this section, the lining material application instructions provided by the lining material manufacturer, and the field technical support instructions from the QC/ QA Lining Inspector.

8.2 All safety procedures established by local, state, and federal agencies regarding job safety, which include confined space access requirements, shall be strictly adhered to by contractor. Contractor shall provide full time HSE personnel for the duration of the project.

8.3 No work shall be performed when the weather is not suitable or proper storage conditions are not in place for the lining operation, as determined by the QC/ QA Lining Inspector.

8.4 Contractor shall submit a schedule of lining operations to the owner's representative at least thirty (30) days in advance of the start of work.

8.5 The pipe shall be cleaned before application of lining material. Contractor shall be responsible to ensure cleaning and surface preparation has been achieved for the lining process to the satisfaction of the QC/QA Lining Inspector and the owner' representatives.

8.6 Contractor shall perform a mechanical cleaning with devices specifically manufactured for the purpose of proper surface preparation of the pipe in accordance with the requirements of the lining system to be applied. This includes the removal of corrosion by-products; chemicals or other deposits; loose or deteriorated remains of old lining material; oils, grease, and accumulations of any water, dirt; and debris that is a direct result of the cleaning and or surface preparation process.

8.7 Contractor shall perform but not be limited to abrasive blasting per NACE/SSPC specifications and more specifically to minimum meet or exceed SSPC SP6/NACE 3 Commercial Blast specifications. Contractor shall ensure that all areas around service laterals or other branch connections are clean and have a minimum of 2 mils of mechanical profile to assure bonding at service or branch interface with host pipe.

8.8 The interior surfaces of the pipe must be clean and free of excessive or standing water before the lining material is applied. Service connections must be carefully inspected to ensure that there is no debris blocking any service taps and there is no inflow of water into the pipe. If any services are leaking, appropriate operations must be taken to stop the leak to a drip-tight condition. A video recording shall be made of the entire inspection and submitted to the designated purchaser representative prior to lining.

8.9 Contractor shall inspect the cleaned pipe throughout the length to be lined with a CCTV system. The CCTV system camera shall be specifically designed and constructed for pipe inspection. The camera should provide the flexibility in examining pipe details, especially joints and service connections extending into the pipe. The lighting system shall be capable of lighting the full periphery of the pipe. The camera shall provide a color picture.

8.10 Contractor shall follow the manufacturer recommendations on dehumidifying and heating the pipe, if any. The manufacturer’s recommendations for both minimum and maximum application temperatures, both ambient air temperature and surface temperature for applying the lining material shall be followed.

8.11 Only equipment that has been inspected and certified by the manufacturer shall be approved to apply the lining material to the interior surface of the pipe.

8.12 Before the lining material is applied, contractor shall demonstrate that the equipment is functioning properly by recirculating the lining material components in the equipment.

8.13 All linings shall meet or exceed the requirements of ASTM F17.69 (See Attachment A) and meet or exceed the contract thickness as required by the calculus included in this specification.

8.14 Upon completion of the lining process contractor will install stainless steel compression bands on all liner terminations except for service or other branch lateral connections. This installation process is outlined in segments of Attachment B–Band Installation.

8.15 After the lining material has cured, the contractor’s QC/QA inspector along with the owner's representative shall inspect the lined pipe throughout the entire length with CCTV equipment as described above. The interior surfaces of the pipe must be completely covered by the lining material at the specified thickness without evidence of poor mixing or ringing. Particular attention must be paid to inspect the service connections to ensure that there is no annulus at discontinuity and there is no evidence of blockage. A standard video recording shall be made of the entire inspection and turned over to the owner's representative.

8.16 Upon completion of the work, debris, containers of lining materials, cleaners, and the other items used during lining shall be removed from the site and disposed by the lining applicator in accordance with local, state, and federal requirements.

9 Lining Faults and Repair/Over Lining

Lining faults will not be tolerated by this specification. The following lining faults may be observed after application of the lining material. In each case, the fault must be corrected.

9.1 **Blisters**—Blisters or bubbling, round, raised sections of hardened lining material usually occur where there is graphitization on pipe walls. However, not every instance of graphitization causes blisters; the formation of blisters could be caused by a number of factors acting either individually or in combination. Other factors include poor cleaning, excess moisture, raised water and ambient temperature, and overheating of material and the lining equipment. Such faults, if isolated, may be cosmetic in nature and do not create a long-term weakening of the lining. In most instances, the structural integrity of the lining is not compromised and no remedial action is necessary.

9.2 **Uncured lining**—Careful CCTV inspection should reveal any sections of uncured lining, which are inevitably caused by a malfunction of the lining machine or manual application equipment. The uncured material must be removed from the pipe and the section relined. Only sections of pipe lined with hardened, fully cured lining material shall be returned to service.

9.3 **Ringing**—Ringing is the lining defect where ring or ridge protrusions appear on the interior lining wall. Ringing can be caused by jerky winches however typically is the result of the non-fluid movement of the umbilical and lining device inside the host pipe. This non-fluid movement is due to the friction between umbilical/application head and pipe wall.

For structurally independent linings, ringing is to be considered as a serious lining fault. Ringing will increase pipeline pressure drop therefore reducing the pipes hydraulic capacity. Due to change in surface geometry and variance in lining thickness, ridges create areas of localized stress on the liner system from internal pressure and fatigue the material. Ringing lends to a very high probability that the liner system will not meet structurally independent system pressure rating requirements over cracks, perforations and other discontinuities. Ringing shall not be tolerated by the purchaser.

To assure ringing does not occur, lining systems shall maintain both consistent fluid speed and movement during the entire lining process with self-propulsion of both the umbilical and lining device.

9.4 **Non-Uniform thickness**—The most prevalent causation of inconsistent thickness, exclusive of the above described ringing effect, is the material casting assembly (application head, spinner, spinner cone) inability to consistently maintain axial centerline in the pipe.

The deviation of a lining device’s material casting assembly from pipe centerline during the lining process affords high potential that the lining’s thickness and uniformity will not meet contract and/or computational requirements of this standard. The application of linings with uniform thickness is critical. Lining thickness variations (as with ringing) will create localized areas of stress resulting in liner fatigue and support a high probability for liner failure.

The absence of the mechanical functionality to assure axial centering to apply the criticality of achieving consistent liner thickness is highly exacerbated when lining through bends and should not be attempted for structurally independent lining systems unless the application head is capable of autonomous centering or it has other proven mechanical centering functionalities.

9.5 **Incomplete lining—**Skips in the lining may be caused by machine malfunction. Incomplete lining shall be repaired to the satisfaction of the owner or his representative. If the incomplete lining cannot be repaired the liner will be rejected

9.6 **Annulus—**All thermosetting polymeric resin systems experience radial shrinkage which creates an annulus. The annular space created between the host pipe and the liner system can allow pressurized fluid infiltrate behind the liner at pipe discontinuities if not properly sealed. This infiltration can result in equalized pressure on both sides of the liner; rendering the liner system insignificant. Any annulus at services, liner terminations and other discontinuities between rigid lining and host pipe shall be repaired to the satisfaction of the owner or his representative.

9.7 **Adhesion**—The rigid lining material should not bond directly to the host pipe as the rigid lining material fails during host pipe failure events. If the rigid liner is directly adhered to the pipe wall, once fractures or remarkable deformations happen on the pipe, the deformations and strains on the pipe will be transferred onto the rigid lining via the adhesion bonding, causing the lining material to crack, fracture or tear. A closed cell porous elastomer with low Poisson's ratio shall be applied as the initial bonding layer of a composite system. This type of system eliminates the potential for hydraulic failure from unsealed or unbonded liner material and resulting annulus at discontinuities in host pipe, as well as, mitigating the strain applied on the rigid liner during the curing process or during a host pipe failure event. Rigid layer adhesion directly to the host pipe shall not be tolerated by the purchaser unless third party test data and the resulting calculus certifies that the lining material at contract thickness will withstand all host pipe failure events.

9.8 **Slump/Puddling**—Slump is usually caused by applying excessive thickness of lining material to the pipe surface or overheating of the components. Puddling is caused by slumping of the lining material due to gravity forcing the lining material to flow down the sides of the pipe into the pipe invert prior to cure. Puddling can cause reduced hydraulic capacity, increased localized stress, liner fatigue and liner failure. Puddling should not be tolerated by the purchaser.

9.9 **Water damage—**Water damage is usually caused by lining through undetected standing water or water flow running along the invert during the lining material application and curing. Depending on the length of the fault and the length of the section being lined, the lining applicator shall submit process to remedy the situation, for review and approval of the owner or his representative. The owner or his representative may require lengths of pipe to be relined with new material.

9.10 **Pinholes—**Through wall pinholes shall not be tolerated by the purchaser. Any defective or damaged areas of the lining shall be relined, repaired, and/or over lined by contractor. The relining, repair, or over lining shall be performed as recommended by the lining material manufacturer. Any relining, repair, or over lining shall be re-inspected for dry film thickness and holidays before final acceptance by the QA/QC Lining Inspector and owner's representative. Wall pinholes shall be tested for lining leakage in accordance with ASTM D4541.

9.11 **Over lining**—If it is determined by the purchaser that it is necessary to apply an over lining to address minor blemishes or minor faults, the first coat of lining material must be completely tack free before the second coat is applied as recommended in the manufacturer's guidelines. Manufacturer guidelines must also prescribe a maximum curing time, relining window and additional preparation needed if an over lining coat is required.

10 Recording documentation

The Contractor is required to record the location and size of all pipe lines rehabilitated as well as the location and size of all service connections. Once completed with each post-installation inspection, the Contractor is required to mark up the drawings with accurate locations of all pipe lines and service connections. Prior to each pay estimate the Contractor must review the current record drawings with the City's Project Manager. Providing inaccurate or incomplete record information is reason for withholding of progress payments. A final set of record documents shall be submitted by the Contractor, for As-Built purposes, prior to processing final payment.

11 Public Information and Notification

All written notices shall be issued on current letterhead or door hanger. Notices will be prepared by the owner's Public Information Officer and provided to the contractor for distribution. All contact with the Public shall be executed in a business professional manner, including adhering to professional standards regarding courtesy, grooming and maintaining visible/legible identification. The Public Information and Notification program shall be at a minimum, require the Contractor to be responsible for contacting each home or business affected by the pipeline rehabilitation/ re-construction and informing them of the work to be done in all of the following ways:

1) Attempt to contact each home and business owner on the day of pre-installation inspection of the pipeline.
2) Written notice shall be delivered to each home or business describing the work, installation date/time, how the construction affects them, and a local telephone number of the Contractor they can call to discuss the project or any problems that may arise (Service Disruption Notice) a minimum of 48 hours in advance of the installation.
3) Personally contacting each home or business owner and provide written notice the day prior to beginning work on the section of pipeline to which they are connected.
4) Personally contacting any home or business owner before and after the service connection has diverted and been reactivated. Provide written notice with the time of reactivation posted on the front door of a residence or business.

12 Clean-up and site restoration

The Contractor shall reinstate all project areas affected by their operations to an equal or better than existing condition upon completion of the SIPP installation. All restoration must be completed prior to submitting that section of SIPP for consideration of payment. Re-grading of rutted areas and re-seeding of disturbed areas is required.

13 Patents

The Contractor and the Contractor's suppliers shall warrant and save harmless the owner against any and all claims, potential litigation involving patent infringement, copyright violations and any loss thereof.

14 Measurements and payment

14.1 Payment for Mobilization

Payment for this item will be a lump sum basis for the entire project divided into three equal payments, the first third of the cost will be included in the first pay estimate, the second third will be included in the second pay estimate, and the third payment will be included in the final pay estimate.

14.2 Payment for Pre-installation Television Inspection, Pipeline Cleaning, and temporary connection of water connection all sizes

14.2.1 Pre-installation cleaning

The measurement for payment of this item will be the actual number of linear feet of pipeline cleaned as measured along the centerline of the pipe line. Only those sections specifically noted in the Contract Documents or authorized by the owner or his representative will be authorized for payment. Contractor shall provide unit pricing for each size diameter pipe.

The unit price bid per linear foot of pipeline cleaning shall include all of the Contractor's costs to perform the work in accordance with the specifications. The price bid shall include: furnishing and setting up of all equipment, labor, and materials necessary to clean the pipeline; removal and disposal, transporting of the sediment for disposal to a landfill, all labor and equipment required to complete this item in accordance with the Contract Documents.

14.2.2 Pre-video inspection

The unit price bid per linear foot of pipe line pre-video inspection shall include all of the Contractor's costs of whatsoever nature. The price bid shall include: furnishing and setting up of all equipment, labor, and materials necessary to clean and perform pre-video inspection of the pipeline, including an explosion-proof television camera, as necessary; recording all information on USB Plug and Play device (flash drive or hard drive) for review by owner; submittal of video in MP4 format and logs in pdf format, both of which must be submitted in accordance to the naming convention required within the applicable details, identifying and reporting structurally deficient pipe sections.

14.3 Payment for temporary connection

Payment for temporary connection of water connection shall be included in the unit price for each diameter of SIPP lining. The work shall include: furnishing and setting up of all equipment, labor, and materials required to temporary connect water services.

14.4 Payment for post installation CCTV inspection

Payment for this item shall be included in the unit price for each diameter of SIPP lining.

14.5 Payment for Laboratory Testing

Laboratory testing will be per test at the discretion and frequency of the owner or his representative samples are required to be taken at all installation sites and collected, labeled, and stored in such a manner as to be easily identified for submittal to a third-party laboratory.

14.6 Payment for Traffic Control

The cost of traffic control relating to installation of SIPP shall be included in the unit price costs of the SIPP Liner, no additional payment shall be considered.

Traffic control plans shall be prepared and approved by the local traffic department's requirements. Traffic control shall include all materials, equipment and labor required to implement the approved traffic control plans for the entire project period.

15 <u>Engineering design calculations</u>

Engineering design calculations shall be in accordance with the Attachment A of this specifications.

These calculations shall be performed and certified by a qualified, licensed Professional Engineer. All calculations shall include data that conforms to the requirements of these specifications. In the event the calculated thickness by the contractor is thinner than those shown in the bid tabulation, the contractor will install the specified thickness shown in the bid tabulation. Proposed manufacturer technology data, including third party test results for physical properties shall be submitted for all SIPP products and all associated technologies to be furnished

16 <u>Warranty</u>

The lining applicator shall provide a two (2) years material and workmanship warranty which starts after the date of substantial completion and as defined below. (See Attachment B)

Contractor and the designated purchaser representative shall perform a warranty inspection within two (2) months prior to the end of the warranty period.

All defective work shall be repaired in strict accordance with this section of the specification and to the satisfaction of the purchasers' representative.

SPECIFICATION, INSTALLATION PRACTICES, QC/QA AND WARRANTY

ATTACHMENT A

DESIGN CONSIDERATIONS

Exhibit - Document based on Spray In Place Pipe (SIPP)–Structurally Interactive and Structurally Independent Linings for Pressure Pipelines, Page 8 to Page 15

APPENDICES – X1

DESIGN CONSIDERATIONS

X1.1 TERMINOLOGY

Filament reinforced lining—The reinforced lining structures with high tensile strength filament, such as carbon fiber and glass fiber, that are used to prevent creep rupture and significantly increase the structure strength and creep resistance along hoop and beam directions. The filament can be continuously wound between the bonding layer and rigid layer of the composite.

X 1.2 THERMAL STRESS EFFECTS

If SIPP lining system does adhere to the host pipe, it should be verified for thermal stresses if to immersed in fluids over 120 °F. SIPP lining systems that are not adhered to the host pipe should be designed to accommodate axial movement due to temperature fluctuations, when applicable:

$$L_C = \alpha \cdot L \cdot \Delta T \tag{X1.1}$$

where: L_C = length change of the lining system, in. (mm),
L = continuous length of the installed lining system, in (mm),
α = coefficient of thermal expansion and contraction in/in/°F (mm/mm/°C) per ASTM E289,
ΔT= temperature fluctuations, °F (°C).

SIPP lining systems demonstrating reliable adhesion to the host pipe or fixed ends of the liner should check for thermal stresses when applied in the working environment with obvious temperature fluctuations. The lining system must have sufficient tensile/compression strength to withstand the thermal stress.

$$\sigma_{TL} \geq \alpha \cdot E_{TL} \cdot \Delta T \tag{X1.2}$$

where: E_{TL} = long-term tensile modulus of elasticity of SIPP under normal working temperature (psi) per ASTM D2990,
σ_{TL} = long-term tensile strength of SIPP at maximum working temperature(psi) per ASTM D2990.

If the working temperature is over 100°F, lining material properties shall be tested under elevated working temperature.

X1.3 STRUCTURALLY INDEPENDENT SIPP LINING

Structurally independent linings need to support external hydrostatic loads due to groundwater, soil, and live load if applicable, as well as, withstand the long-term internal pressure independent of the host pipe. Since the hoop strength of the linings is generally more critical than the axial strength, it is highly recommended to use anisotropic lining material/structure with fiber reinforcement which increases the liners hoop strength and creep-resistance. If fiber filament winding is applied to reinforce the SIPP liner, the liner must have enough wall thickness to withstand the bending and shear stresses caused by the fiber constrains and internal pressure on the liner material.

Additionally, the liner thickness must also be verified to ensure the liner has enough strength to withstand the axial stresses caused by Poisson's ratio effect and thrust load. If the liner is not fixed with uniform support but suspended as beam structures, the liner thickness must also be verified for overcoming the bending stress caused by gravity.

X1.3.1 External Buckling Resistance—The SIPP liner is designed to support the hydraulic loads due to groundwater and/or vacuum pressure, since the soil and live loads can be supported by the host pipe. The groundwater level and vacuum pressure should be determined by the purchaser and the thickness of the SIPP should be sufficient to withstand this the external pressure without collapsing. The following equation may be used to determine the thickness requirement:

$$t_{1a} = \frac{D}{\left(\left[\frac{2 \cdot K \cdot E_L \cdot C}{(1-\upsilon^2) \cdot N \cdot (P_{Water}+P_V)}\right]^{1/3}\right)+1} \quad \text{(X1.3)}$$

where: t_{1a} = minimum liner thickness to resist short-term buckling pressures, in. (mm),

K = enhancement factor (dimensionless),

E= short term flexural modulus of elasticity of SIPP at maximum working temperature (psi),

C = ovality reduction factor (dimensionless) = $\left(\frac{1-q/100}{[1+q/100]^2}\right)^3$,

q = ovality of host pipe (%),

υ = Poisson's ratio of the lining system (dimensionless) per ASTM D638,

P_v = vacuum pressure, psi (Mpa),

P_{water}= external hydrostatic pressure from groundwater, psi (Mpa),

N = design factor of safety.

X1.3.2 Internal pressure Resistance & Hole Span— Minimum thickness required to withstand internal pressure in spanning across any holes in the original pipe wall is calculated from Equation X1.4. This generally applies where current holes are detected or future holes are anticipated in the host pipe due to external corrosion. Only holes with circular geometry are considered and the holes with diameter above 1 in (25 mm) should be taped or supported prior to lining, unless otherwise recommended by the lining system manufacturer.

$$t_{2a} = \frac{D}{\left[\left(\frac{D}{d}\right)^2\left(\frac{5.33 \cdot \sigma_L}{P \cdot N}\right)\right]^{\frac{1}{2}}+1} \quad \text{(X1.4)}$$

where: t_{2a} = minimum liner thickness to span holes in the existing pipe wall, in. (mm),

D = mean inside diameter of the host pipe, in. (mm),

d = diameter of hole in the existing pipe wall, in. (mm),

σ_L = long-term flexural strength of SIPP at maximum working temperature per ASTM D2990 (see Note X1.2), psi (Mpa),

P = internal pressure under the maximum allowable pressure, psi (Mpa), MAP, the internal pressure, P is the working pressure, psi (Mpa), Pw. Under the maximum allowable operating pressure, MAOP, the internal pressure, P= (Ps+ Pw)/1.4, Ps is Surge pressure, psi (Mpa),

N = design factor of safety.

NOTE X1.1—The choice of value (from manufacturer's literature) of σ_L will depend on the estimated duration of the internal pressure, P, in relation to the design life of the structure. For example, if the total duration of the load, P, is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value of σ_L will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

Note X1.2—Different physical properties exist due to type and amount of reinforcement. The applicator shall submit design calculations to the owner or his representative for review and approval. Contractor shall submit test results from accredited third-party certification organizations for all required material tests per Appendix X1 for the completion of liner thickness calculus. All Appendix X1 calculus inputs shall match all testing data provided by third-party certification organizations.

X 1.3.4 *External Buckling Resistance*

This design scenario applies when a pressure pipeline is out of service for an extended period of time or when total external pressure is greater than Maximum allowable operating pressure, MAOP.
Calculate total external pressure on pipe:

$$q_t = 0.433 \cdot H_W + \frac{\gamma_S \cdot H \cdot R_W}{144} + W_S \qquad \text{(X1.5)}$$

where: q_t = total external pressure on pipe, psi (Mpa),
γ_S = unit weight of soil overburden, lb/ft^3 (KN/m^3),
H = depth from ground surface to top of pipe, ft (m),
H_W=Height of groundwater, ft (m),
R_w = water buoyancy factor = 1 - 0.33(H_w/H) (≥ 0.67).

If $q_t > P$, use Equation X 1.6 as an additional design check. If $q_t \leq P$, internal pressure controls design as in X1.3.2.

$$t_{1b} = \left[\frac{(q_t \cdot N)^2 \cdot D^3 \cdot 12}{32 \cdot R_W \cdot B' \cdot M_{sn} \cdot E \cdot C}\right]^{\frac{1}{3}} \qquad \text{(X1.6)}$$

where: t_{1b} = minimum liner thickness for overcoming the buckling force, in (mm),
M_{sn} = constrained soil modulus, psi (Mpa),
B' = coefficient of elastic support = $1/(1+4e^{-0.065H})$,
N = design factor of safety,
D= inside diameter of host pipe, in. (mm),
E= short term flexural modulus of elasticity of SIPP at maximum working temperature (psi),
C = ovality reduction factor (dimensionless) = $\left(\frac{1-q/100}{[1+q/100]^2}\right)^3$.

X 1.3.5 *Internal Pressure Resistance*

X 1.3.5.1 *Internal Pressure Resistance without filaments reinforcement*—Maximum allowable operating pressure, MAOP (static pressure, long-term) per ASTM D2990.
For stress basis,

$$t_{2b1} = \frac{D}{\left(\frac{2 \cdot \sigma_{TL}}{P \cdot N}\right) + 1} \qquad \text{(X1.7)}$$

where: t_{2b1} = minimum recommended liner thickness at MAOP without filaments reinforcement, in. (mm),
σ_{TL} = long-term tensile strength of the lining system at maximum working temperature per ASTM D2990, hoop direction, psi (Mpa),

P = internal pressure, psi (Mpa),
N = design factor of safety.

X 1.3.5.2 *Internal Pressure Resistance with filaments reinforcement*— Maximum allowable operating pressure, MAOP (static pressure, long-term) per ASTM C1557 and per ASTM D955.

For stress basis,

$$t_{2b2} = \frac{NPDL_P - 2E_f A_f \varepsilon_{\theta max}}{[2E_L L_P(\varepsilon_{\theta max} + \varepsilon_{\theta S}) + NPL_P]} \quad \text{(X1.8)}$$

where: t_{2b2} = minimum liner thickness at MAOP with filaments reinforcement, in. (mm),
D= inside diameter of host pipe, in. (mm),
P = internal pressure, psi (Mpa),
N = design factor of safety,
L_p= fiber winding pitch distance, in. (mm),
E_f = fiber tensile modulus per ASTM C1557, psi (Mpa),
A_f = fiber cross section area, in^2. (mm^2),
$\varepsilon_{\theta max}$= maximum allowable hoop strain on fiber, per ASTM C1557,
$\varepsilon_{\theta s}$= material shrinkage in curing process per ASTM D955, in/in. (mm/mm).

X 1.3.6 *Bending stress with filaments reinforcement* — If the SIPP lining is combined with filament winding, the lining material between the filament pitches will be under bending moment along radial direction. The minimum material thickness for overcoming the stress caused by bending may be determined by the following equation:

$$t_{3b} = \sqrt{\left(\frac{NP}{2\sigma_L}\right)} L_P \quad \text{(X1.9)}$$

where: t_{3b} = minimum liner thickness at maximum allowable bending stress, in. (mm),
P = internal pressure, psi (Mpa),
N = design factor of safety,
L_p= fiber winding pitch distance, in. (mm),
σ_L = long-term flexural strength of SIPP at maximum working temperature per ASTM D2990, psi (Mpa).

X 1.3.7 *Shearing stress with filaments reinforcement* — If the SIPP lining is combined with filament winding, the shear stress will happen on the lining material which is constrained by fiber filament. The minimum thickness of the lining material for overcoming shear stress can be determined by the following equation:

$$t_{4b} = \frac{\tau_L D - \sqrt{\tau_L{}^2 D^2 - 4\tau_L \varepsilon_{\theta max} E_f A_f}}{\tau_L D} \quad \text{(X1.10)}$$

where: t_{4b} = minimum liner thickness at maximum allowable shear stress, in. (mm),
$\varepsilon_{\theta max}$= maximum allowable hoop strain on fiber, per ASTM C1557,
E_f = fiber tensile modulus per ASTM C1557, psi (Mpa)
A_f = fiber cross section area, in^2. (mm^2),
D= inside diameter of host pipe, in. (mm),

τ_L= long-term shear strength of SIPP at maximum working temperature, psi (Mpa), τ_L= *LR* * τ,
τ = Shear strength of SIPP, initial at maximum working temperature, psi (Mpa), per ASTM D732
LR = Long-term retention of mechanical properties at maximum working temperature (%) per ASTM D2990, *LR*=σ_T/σ_{TL}, σ_T =Tensile strength of SIPP, initial at maximum working temperature, psi (Mpa).

X 1.3.8 *Poisson's Ratio Effect*—As a pipe liner is pressurized, it stretches radially and contracts lengthwise because of the Poisson's ratio effect. Therefore, the internal pressure load on the liner can cause stress along axial direction on the liner material. The minimum lining thickness for withstanding the axial stress shall be determined as:

$$(4\sigma_{TL} + 8\upsilon NP)t_{5b}{}^2 - (8\upsilon NPD + 4D\sigma_{TL})\, t_{5b} + 2\upsilon NPD^2 = 0 \qquad \text{(X1.11)}$$

$$a = (4\sigma_{TL} + 8\upsilon NP)$$

$$b = -(8\upsilon NPD + 4D\sigma_{TL})$$

$$c = 2\upsilon NPD^2$$

$$t_{5b} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

where: t_{5b} = minimum liner thickness as determined by Poisson's effect, in. (mm),
σ_{TL} = long-term tensile strength of SIPP, at maximum working temperature per ASTM D2990, psi (Mpa),
υ = Poisson's ratio of the lining system (dimensionless) per ASTM D638,
N = design factor of safety,
P = internal pressure, psi (Mpa),
D= inside diameter of host pipe, in. (mm).

X 1.3.9 *Thrust Load Effect*— If the liner is not fixed at the ends, lining systems will be subjected to thrust load caused by internal pressure, the minimum lining thickness shall be determined as:

$$t_{6b} = \frac{D - \sqrt{\frac{\sigma_{TL} D^2}{NP + \sigma_{TL}}}}{2} \qquad \text{(X1.12)}$$

where: t_{6b} = minimum liner wall thickness for withstanding thrust load, in. (mm),
σ_{TL} = long-term tensile strength of SIPP, at maximum working temperature per ASTM D2990, psi (Mpa),
N = design factor of safety,
P = internal pressure, psi (Mpa),
D= inside diameter of host pipe, in. (mm).

X 1.3.10 *Suspended Pipe Liner*—If the pipe is suspended, bending moments will happen on the suspended lining system between supports due to gravity. The minimum lining thickness for withstanding stress caused by bending moment can be determined as:

$$4(\rho_m - \rho_l)t_{7b}{}^2 + \left(4\rho_l D - 4\rho_m D - \frac{12D^2\sigma_{TL}}{L_{sp}{}^2}\right) t_{7b} + \rho_m D^2 = 0 \qquad \text{(X1.13)}$$

$$a = 4(\rho_m - \rho_l)$$

$$b = \left(4\rho_l D - 4\rho_m D - \frac{12D^2\sigma_{TL}}{L_{sp}{}^2}\right)$$

$$c = \rho_m D^2$$

$$t_{7b} = \frac{-b-\sqrt{b^2-4ac}}{2a}$$

where: t_{7b} = Minimum thickness of the liner for withstanding stress caused by bending moment, in. (mm).
σ_{TL} = long-term tensile strength of SIPP, at maximum working temperature per ASTM D2990, psi (Mpa),
D= inside diameter of host pipe, in. (mm),
ρ_l=liner material density, lb/in^3 (KN/m^3),
ρ_m= conveyed material (liquid or gas) density, lb/in^3 (KN/m^3),
L_{sp}=suspended liner length, ft (m).

X 1.3.11 *Pullout Forces* —Equation X1.14 estimates the minimum pullout forces caused by Poisson's ratio effect on a structurally independent lining system without fixed ends:

$$F_P = \sigma_P \cdot \upsilon \cdot \pi \cdot D^2 \cdot \left[\frac{1}{DR} - \frac{1}{DR^2}\right] \quad \text{(X1.14)}$$

$$\sigma_{zv} = \frac{F_p}{\frac{\pi \cdot D^2}{4\left(1-\left(\frac{(DR-2)}{DR}\right)^2\right)}}$$

where: F_P = pullout force because of the Poisson's ratio effect, lbs (Kg),
σ_P = maximum hoop stress = $\frac{P_P \cdot (DR-1)}{2}$, psi (Mpa),
P_P = maximum internal pressure; greatest of MAOP, MAP and test pressure, psi (Mpa),
D = inside diameter of host pipe, in. (mm),
DR = dimension ratio of lining system = D/t_{min},
t_{min}= minimum structurally independent wall thickness as determined by max(t_{1b},t_{2b},t_{3b},t_{4b},t_{5b},t_{6b},t_{7b}),
$\sigma_{zv=}$ axial stress because of Poisson's effect, psi (Mpa).

X 1.3.12 *Flow Capacity Calculations*

X 1.3.12.1 Uniform pipe flow rate of SIPP in water mains is calculated by the Hazen–Williams Equation with the flow of water with the physical properties of the pipe and the pressure drop caused by friction.

$$V = KCR^{0.63}S^{0.54} \quad \text{(X1.15)}$$

$$Q = V * A$$

where: V = velocity, ft/s (m/s),
A = flow area, ft² (m²),
Q = flow rate, ft³/s (m³/s),

k = conversion factor for the unit system (k = 1.318 for US customary units, k = 0.849 for SI units)
C = roughness coefficient,
R = hydraulic radius, ft (m),
S = slope of the energy line, ft/ft (m/m).

X 1.3.12.2 Uniform pipe flow rate of SIPP in other applications except in water mains is calculated by the Manning's Equation with the flow area and pipe slope.

$$Q = \frac{1.486}{n} A R_H^{2/3} S^{1/2} \quad \text{(X1.16)}$$

where: Q = flow rate, ft^3/s (m^3/s),
A= flow area, ft^2 (m^2),
n = Manning's Roughness Coefficient,
R_H = hydraulic radius, ft (m), R_H = D/4 for pipe flowing full**,**
S = slope of host pipe, ft/ft (m/m).

X 1.3.13 *Service life calculation for material fatigue & aging*—Material fatigue must be considered for structurally independent linings under unsteady working conditions, such as frequent change of internal pressure because of vortex flow, turbulence and cavitation. These factors can be extremely detrimental to a lining system. If the lining will be used in such situations, the lining material manufacturer must provide the S-N curve (Wöhler curve) of material testing data under high-cycle fatigue condition.
Measuring, evaluating or simulating aging of lining materials is important for long-term lining rehabilitation applications. The lining materials must stay stable and not fragile during the service life. Many factors, such as temperature, and exposure to ultraviolet light, visible light, atmospheric components, conveyed chemicals, or humidity, or the combinations of these factors can cause lining material aging. The owner must explain the detailed working condition to the applicator. The applicator needs to make an appropriate and accurate evaluation of the lining material for aging based on the product information from the manufacturer and lining working environment.
If the liner works under unstable loading condition, frequent surge, vacuum, and vortex flow pressure happen on the liner, the fatigue life of the liner shall be determined using Miner's rule as:

$$\sum_{i=1}^{k} \frac{n_i}{N_i} = C \quad \text{(X1.17)}$$

where: k = the number of different stress magnitudes in a spectrum,
n_i= the cycle number of each stress magnitude,
N_i= the number of cycles to failure of a constant reversal per ASTM D7791,
C= constant, it is experimentally found to be between 0.7 and 2.2. Usually for design purposes, C is assumed to be 1.

The determination of stress magnitude will be based on the actual loading conditions and the lining material thickness. The stress magnitude along hoop direction on the lining without filament winding can be obtained by

$$\sigma_{\theta 1} = \frac{P \cdot (D - t)}{2 \cdot t} \quad \text{(X1.18)}$$

where: $\sigma_{\theta 1}$ = the hoop stress on the lining without filament winding, psi (Mpa),
P = internal pressure, psi (Mpa),
D= inside diameter of host pipe, in. (mm),
t= minimum structurally independent wall thickness as determined by max(t_{1b},t_{2b},t_{3b},t_{4b},t_{5b},t_{6b},t_{7b}).

If the lining is reinforced with filament winding, the stress magnitude along hoop direction on the lining can be obtained by

$$\sigma_{\theta 2} = E_{TL}\left[\frac{P(D-t)L_P - 2E_{TL}\cdot t\cdot L_P\cdot \varepsilon_s}{2E_{TL}\cdot t\cdot L_P + 2E_f\cdot A_f} + \frac{P\cdot {L_P}^4}{16D\cdot E_{TL}\cdot t^3}\right] \tag{X1.19}$$

where: E_{TL} = long-term tensile modulus of elasticity of SIPP under normal working temperature (psi) per ASTM D2990,
$\sigma_{\theta 2}$ = the hoop stress on the lining with filament winding, psi (Mpa),
P = internal pressure, psi (Mpa),
D= inside diameter of host pipe, in. (mm),
t= lining wall thickness, in. (mm),
L_p= fiber winding pitch distance, in. (mm),
E_f = fiber tensile modulus per ASTM C1557, psi (Mpa),
A_f = fiber cross section area, in^2. (mm^2),
ε_s = lining material shrink strain.

The stress magnitude of the pipe lining without fixed ends along axial direction shall be determined as

$$\sigma_z = \frac{P\cdot(D-2t)^2}{4Dt-4t^2} \tag{X1.20}$$

where: σ_z = the axial stress on the pipe lining, psi (Mpa),
t= minimum requirement lining wall thickness, in. (mm),
P = internal pressure, psi (Mpa),
D= inside diameter of host pipe, in. (mm).

The stress magnitude of the pipe lining without fixed ends along axial direction shall be determined as shown in X1.3.11.

The total service life can be estimated by:

$$T_s = \sum_{i=1}^{k} n_i t_i \tag{X1.21}$$

where: T_s = the estimated service life of the lining (hr),
n_i = the allowable cycle number of each stress magnitude before failure,
t_i = the time of each cycle of each stress magnitude (hr).

X 1.4 SIPP WALL THICKNESS DESIGN SUMMARY

Structurally Independent Application— A SIPP installed in a partially deteriorated or fully deteriorated pipe is designed to withstand all external loads and the full internal pressure. The Eqs. X1.1-1.2 can be used to determine the thermal effects on the lining as discussed above. The maximum thickness result obtained via Eqs. X1.3-1.4 & X1.6-1.12 must be picked as the minimum thickness required for the Structurally Independent lining application. The Eq. X1.13 should be considered to calculate the thickness when the pipe is suspended. The Eq. X1.14 should be applied to calculate the pullout force cause by Poisson's ratio effect. The fatigue life of lining material can be estimated using Eqs. X1.17-1.21.

X 1.5 QUALITY CONTROL CONSIDERATIONS

X1.5.1 *Ringing*—For structurally independent linings, ringing is to be considered as a serious lining fault. Ringing will increase pipeline pressure drop therefore reducing the pipes hydraulic capacity. Due to change in surface geometry and variance in lining thickness, ridges create areas of localized stress on the liner system from internal pressure and fatigue the material. Ringing lends to a very high probability that the liner system will not meet structurally independent system pressure rating requirements over cracks, perforations and other discontinuities.

To assure ringing does not occur, this standard highly recommends the requirement to utilize lining systems that have the ability to maintain both consistent fluid speed and movement during the entire lining process such as self-propulsion of both the umbilical and application head.

X1.5.2 *Non-uniform Thickness*—The deviation of a lining device's material casting assembly (MCA), sometimes referred as spinner or spinning cone, from centerline during the lining process affords high potential that the lining's thickness and uniformity will not meet contract and or computational requirements of this standard. The application of linings with uniform thickness is critical. Lining thickness variations (as with ringing) will create localized areas of stress resulting in liner fatigue and support a high probability for liner failure.

The absence of the mechanical functionality to assure axial centering to apply the criticality of achieving consistent liner thickness is highly exacerbated when lining through bends and should not be attempted for structurally independent lining systems unless the application head is capable of autonomous centering or it has other proven mechanical centering functionalities.

X1.5.3 *Creep*—To prevent creep failure, this standard highly suggests using reinforced lining structures with high tensile strength filament, such as carbon fiber and glass fiber to significantly increase the structure strength and creep resistance along hoop direction. The filament can be continuously wound between the bonding layer and the rigid layer.

SPECIFICATION, INSTALLATION PRACTICES, QC/QA AND WARRANTY

ATTACHMENT B

BAND INSTALLATION PROCEDURE

Band Installation Procedure

1.0 Description

The Internal Joint Seal consists of a rubber seal secured by metal retaining bands and wedges.

2.0 Objective

To properly install the Internal Joint Seal at specified joints needing enhancement. The seals will prevent further degradation of piping joints, will maintain system reliability, and will be installed as a corrective/preventative maintenance measure.

3.0 References

Drawing Seal Assembly Profile.

4.0 Workforce

No less than a two-person team is to execute band installations. The minimum workforce approved for the procedure is 1) trained installer, and 2) outside the pipe, supply and safety support.

The installer is further responsible to have his work plan for the installation reviewed by the HSE supervisor assigned to the project. The HSE supervisor shall confirm compliance with all HSE requirements before installer is approved to proceed with the work.

5.0 Prerequisites

Note: The following prerequisites do not have to be performed in the sequence listed.

This procedure shall be performed while the piping has been removed from service and an adequate safety-tagging boundary has been established and verified.

All vendor supplied tools and equipment are available. All required pressure gauges have been verified by the owner.

All permits have been processed which cover the scope of work to be performed inside the pipe.

All lines have been dewatered and are at atmospheric pressure.

Access to the lines has been provided.

All consumables (i.e. hydraulic oil, lubricants, thread sealers, markers, etc.) have been approved by the owner.

Verify the hydraulic expander has been provided for use in expanding the retaining bands.

Continuous forced air ventilation has been established and is sufficient to maintain the confined space safe for entry.

6.0 Precautions

6.1 The main is to always be cleaned to the point that transportation carts (emergency and work carts) can ride on their wheels without encumbrance due to obstructions or main debris.

6.2 If any unanticipated or unexpected alarm, noise, vibration, odor or excessive leakage is observed, personnel shall immediately exit and remain outside the confined space until the condition is identified and rectified.

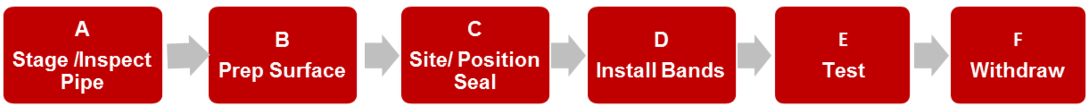
6.3 Rescue Practices

6.3.1 Preparation should be made for emergency rescue situations. In the event of an emergency, under no circumstance should the attendant enter the confined space until help has arrived, and then only with the proper rescue equipment.

6.3.2 Attendants participating in the rescue effort must have received specialized training in confined space rescue techniques. Rescues are to be accomplished using emergency rescue carts or trolleys with a lifeline attached. At no time should the hole man (safety person) exert any pulling force on the anatomy of the person being rescued.

7.0 Procedure

Band Installation Major Process Steps



A. Inspect Pipe

7.1 Perform an inspection of pipe interior. Review all seal installation locations, paying particular attention to those at elbows, to verify that the piping/fitting geometry will allow the Internal Joint Seal installation. Also, confirm that the surface is structurally intact. Report any discrepancies to Engineering for resolution.

B. Prep Surface

7.2 Remove all dirt, scale, and other debris from the pipe walls in areas where the seal is to be installed. These cleaning operations shall be accomplished by hand brushing and scraping, pneumatic wire brushes, and/or oil-free air jet.

7.3 All high/low surface imperfections (i.e. dirt, scale, and other debris) running axially through or part way through the sealing surface must be removed prior to installation of the seal. Any joint gaps or deep imperfections must be properly filled with approved nontoxic joint filler and rendered smooth.

C. Site and Position Seals

7.4 Mark the locations of the lip seals on the pipe ID to clearly define the seal installation positions.

7.5 Lubricate the seal band channel area only. This use of lubricant is to insure even distribution of hydrostatic loading of the seal during band expansion.

7.6 Position the seal parallels to the joint with the pressure test valve located at approximately either the 9 o'clock position or the 3 o'clock position. The seal must be positioned accurately on the joint area. For fully structural (FS) coating, you would center the seal directly at the termination point of the lining.

D. Install Bands

7.7 Install metal radiused shims underneath the wedge area in the seal grooves for each band prior to installing the metal retaining bands in the seal. These shims enable radial loads to be transmitted evenly to the Internal Joint Seal as the bands are expanded.

7.8 Position the retaining bands in seal grooves.

7.8.1 Position the seal expander in line with the retaining band and ensure that the retaining band remains in the grove.

7.8.2 Expand the band using the hydraulic expander, holding pressure for at least two minutes.

7.8.3 Install a radiused locking piece (wedge) in the exposed gap between the expanded band ends. The wedge size shall be selected so as to provide interference fit.

Repeat steps 7.8.1 through 7.8.3 for subsequent bands on the same seal.

Perform a second expansion of each of the retaining bands a minimum of 30 minutes after the first expansion using the same pressure range as the first expansion. Replace wedge piece with larger size if required to provide interference fit.

E. Test / Closeout Process

7.9 Perform a pressure test on the seal sections after a minimum of 30 minutes has elapsed after final fitting of the seal to be tested. A restraining device called a “test band” is to be fitted over the center of the seal. This will prevent excessive ballooning that would otherwise occur during this test.

7.10 Install test band and pressurize to 10 psi through the seal test valve. Apply an approved soap test solution to the seal ends and inspect for leakage.

7.11 If the pressure test indicated leakage, determine cause and repeat steps 7.4 and higher.

7.12 Perform a second test at a lower pressure with the test bands removed.

7.12.1 Remove test bands and pressurize to 5 psig through the seal test valve. Apply an approved soap test solution to the entire surface of the seal. This lower pressure leak test is primarily used to check for seal defects such as seal punctures.

7.12.2 Inspect for leakage. If the pressure test indicates leakage, remove seal and replace with a new seal beginning at step 7.4. Depressurize seal and isolate test port. Using an approved thread sealing compound, install the threaded countersunk hex head completion plug.

F. Withdraw

7.13 Remove all installation hardware, test band, and pressure gauges from the pipe.