Designation: ~~F3508 – 21~~ F3508 – 21a

Standard Guide for In-Situ Pipeline ~~Re-Construction~~Renovation As ~~Coupled~~ Dual-Wall Composite Pipeline by Push/Pull Installation of Compressed-Fit Shape-Memory-Polymer Tubular (SMPT)[1]

This standard is issued under the fixed designation F3508; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide describes the ~~the~~ specification and re-construction of in-situ pipelines and conduits 2 in. to 63 in. (50 mm to 1600 mm) diameter) by the pulled-in-place installation, into an existing conduit, of circular, radially reduced, Shape-Memory-Polymer Tubular (SMPT) that after installation, re-expands (by "memory") to press against the ID of the host pipe, thus coupling the interior pipe, by friction fit, as reinforcement to the host pipe. The added SMPT pipe wall restores leak tightness and adds its strength to the host pipe (Dual-Wall Composite-Pipe). It becomes a continuous compressed-fit dual-wall pipeline. Depending upon the SMPT compound used, the re-constructed pipelines or conduits are suitable for pressure and nonpressure pipeline applications such as process piping, raw and treated water transmission, water pipe systems, forced-mains, industrial and oil-patch gathering and transmission pipelines, sanitary sewers, storm sewers, and culverts.

NOTE 1— This standard guide covers circular SMPT tubulars which are radially reduced by mechanical means at the time of installation. This guide does not address "liners" that at the time of manufacture are deformed (folded) into U-shape, C-shape, H-shape, or other such configurations. This guide refers to dual-wall meaning two layers of pipe co-joined in the field, which is different from dual-wall factory-made co-extruded pipe or corrugated pipe. This guide does not provide a complete design basis covering the many variables required for design and construction of this field fabricated product; the advice of professional contractors and/or registered professional engineers may be incorporated as an adjunct to this guide.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

NOTE 2—There are no ISO standards covering the primary subject matter of this guide.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This test method is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.67 on Trenchless Plastic Pipeline Technology.

Current edition approved ~~Aug. 1, 2021~~Nov. 1, 2021. Published ~~August 2021~~December 2021. Originally approved in 2021. Last previous edition approved in 2021 as F3508–21. DOI: ~~10.1520/F3508–21~~10.1520/F3508–21A

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D638 Test Method for Tensile Properties of Plastics
D1238 Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer
D1598 Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
D1599 Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
D1600 Terminology for Abbreviated Terms Relating to Plastics
D2290 Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe
D2412 Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
D2513 Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings
D2837 Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
D3035 Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D3350 Specification for Polyethylene Plastics Pipe and Fittings Materials
D4066 Classification System for Nylon Injection and Extrusion Materials (PA)
D4101 Classification System and Basis for Specification for Polypropylene Injection and Extrusion Materials
F412 Terminology Relating to Plastic Piping Systems
F714 Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter
F1417 Practice for Installation Acceptance of Plastic Non-pressure Sewer Lines Using Low-Pressure Air
F1606 Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner
F2164 Practice for Field Leak Testing of Polyethylene (PE) and Crosslinked Polyethylene (PEX) Pressure Piping Systems Using Hydrostatic Pressure
F2389 Specification for Pressure-rated Polypropylene (PP) Piping Systems
F2620 Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings
F2619/F2619M Specification for High-Density Polyethylene (PE) Line Pipe
F2785 Specification for Polyamide 12 Gas Pressure Pipe, Tubing, and Fittings
F2786 Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Gaseous Testing Media Under Pressure (Pneumatic Leak Testing)
F2945 Specification for Polyamide 11 Gas Pressure Pipe, Tubing, and Fittings
F3183 Practice for Guided Side Bend Evaluation of Polyethylene Pipe Butt Fusion Joint

2.2 *AWWA Standard:*[3]

AWWA C651 Disinfecting Water Mains
AWWA C906 Polyethylene Pressure Pipe and Fittings, 4-in. through 65-in. (110mm – 1650 mm) for Waterworks

2.3 *NSF/ANSI Standards:*[4]

Standard No. 61 for DrinkingWater Systems Components—Health Effects

2.4 *NACE Standards:*[5]

SP0102 Cleaning and Inspection of Pressure Pipelines

2.5 *API Standards:*[6]

API 15LE Specification for Polyethylene Line Pipe

2.6 *Other Standards:*

PPI TR-4 HDB/SDB/PDB/MRS Listed Materials, PPI Listing of Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe[7]
APWA Uniform Color Code[8]
NASSCO Recommended Specifications for Sewer Collection System Rehabilitation.[9]
ISO 8501 Preparation Cleaning of Metallic Substrates[10]

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
[3] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.
[4] Available from NSF International, P.O. Box 130140, 789 N. Dixboro Rd., Ann Arbor, MI 48105, http://www.nsf.org.
[5] Available from NACE International (NACE), 15835 Park Ten Pl., Houston, TX 77084, http://www.nace.org.
[6] Available from American Petroleum Institute (API), 200 Massachusetts Avenue, NW Suite 1100 Washington, DC 20001-5571, http://www.api.org.
[7] Available from Plastics Pipe Institute (PPI), 105 Decker Court, Suite 825, Irving, TX 75062, http://www.plasticpipe.org.
[8] Available from the American Public Works Association (APWA) https://www.apwa.net/
[9] Available from NASSCO 5285 Westview Drive, Suite 202, Frederick, MD 21703 info@nassco.org
[10] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

3. Terminology

3.1 Thermoplastic definitions are in accordance with Terminology F412, and abbreviations are in accordance with Terminology D1600.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *compressed fit*—the dimensional ~~interference fit~~frictional fit, or interference fit, between the in-situ host pipe and internal SMPT, resulting in a compressive strain between the ID of the host pipe and the OD of the SMPT, ~~which compressive strain results in mechanical coupling or bonding the two layers together, becoming a~~ resulting in a conjoining held together by friction, forming the composite pipe structure.

3.2.1.1 *Discussion*—

The interlaminar stress is mathematically estimated from the measured differential strain, the layer thicknesses, each cylindrical layer's Modulus of Elasticity, Poisson's Ratio.

3.2.2 *composite pipe*—~~A fluid-containing long cylindrical structure, capable of sustaining internal pressure and/or external pressure, without radial leakage, being formed of at least two layers of same or differing materials, with each layer exerting a degree of mutual radial interfacial pressure (compression-fit) between the tubular layers.~~Pipe consisting of two or more different materials arranged with specific functional purpose to serve as pipe. **F412**

3.2.3 *hydrostatic design basis and hydrostatic design stress*—the hydrostatic design stress, HDS, is determined by multiplying the hydrostatic design basis, HDB, by a design factor, DF that has a value less than 1.0.

3.2.3.1 *Discussion*—

Refer to Test Method D2837.

3.2.4 *relationship between dimension ratio, hydrostatic design stress, and pressure rating, for thermoplastic tubulars*—

$$P = \frac{2*S}{DR - 1}$$

where:

S	=	hydrostatic design stress, HDS, for water at 73 °F (23 °C), psi (or kPa or MPa),
P	=	pressure rating, PR, psi (or kPa or MPa),
DO	=	outside diameter, in. (or mm),
t	=	minimum wall thickness, in. (or mm),
$DR = DO/t$	=	dimension ratio

3.2.5 *shape memory polymer tubular (SMPT)*—A specified diameter, ductile, plastic pipe extruded from a thermoplastic polymer with a high degree of rubber-like elastic properties (memory reversion characteristics), suitable for temporary radial diameter reduction, such that the mechanical deformation is recoverable back to a very high proportion of the original shape.

3.2.5.1 *Discussion*—

Shape memory polymers (SMPs) are polymers which can be deformed into a temporary shape and then return to the original shape, when triggered by an external stimulus. Depending upon the deformation process, the external stimulus may be removal of axial tensile load, imposition of heat internal to the SMPT, application of pressure interior to the SMPT, or a combination there-of.

4. Significance, Classification, Designation, and Use

4.1 This guide is for use by pipeline system designers and component specifiers, regulatory agencies, owners, and inspection organizations who are involved in the improvement of pipelines or conduits through installation of compressed-fit, reduced-diameter Shape Memory Polymer Tubulars (SMPT) pulled-in-place through an existing pipeline or conduit and secondarily allowed to recover to the ID of the host conduit, while exerting radial pressure between the two, to form the compressed-fit dual-wall pipeline. As with any guide, modifications to the guide may be required for specific project conditions, provided such modifications are agreeable between Contractor and Owner, or the Owner's representative.

4.2 *Desirable Mechanical Characteristics of the SMPT Compressed*—Fit Composite Pipe are specified by its 15-digit cell-classification. Table 1 outlines the pipe macro-parameters of the composite pipe structure, and optional levels of performance. Fig. 1 and Eq 1-3 provide a means of evaluating the hoop-stress in each of the dual pipe walls, based on an interior flow-stream

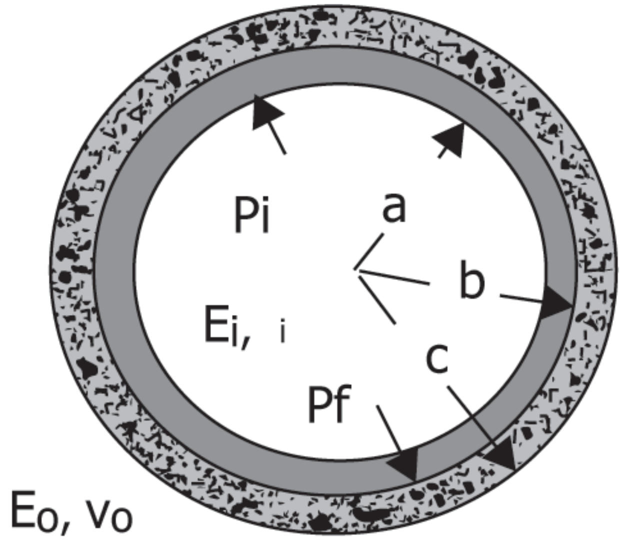

FIG. 1 Dual Wall Composite ~~Pipe :~~ Pipe: Compressed-Fit

pressure, the material modulus, and the contribution of each wall thickness. The evaluated hoop-stress can be compared to the material's long term allowable hydrostatic design stress (HDS), to assure performance and longevity within the stress-limits of each layer's material.

4.2.1 When subjected to internal pressure, both pipe-walls strain the same, with each pipewall resisting the pressure load in proportion to its combined thickness, Young's Modulus of Elasticity, and Poisson's Ratio. The Hoop-Stress (σ_h) in each layer is proportional to the applied pressure and each layer's Thickness and Modulus (stiffness). The hoop-stress, σ_h, in each internal and external pipe-wall can be calculated from these mathematical strain equations:[11]

$$p_f = \frac{2p_i}{\left\{E_i\,(R_i^2 - 1)\left[\frac{1}{E_i}\left(\frac{R_i^2+1}{R_i^2-1} - \nu_i\right) + \frac{1}{E_o}\left(\frac{R_o^2+1}{R_o^2-1} - \nu_o\right)\right]\right\}} \quad (1)$$

When the composite pipe is subjected to internal pressure, p_i , a radial interfacial pressure, p_f, is generated, and, from which the maximum hoop stress within each pipe-wall can be calculated.

$$\sigma_{hi} = \frac{p_f}{(R_o^2 - 1)}\left(1 + \frac{b^2}{r^2}\right) - \frac{p_f R_o^2}{R_i^2 - 1}\left(1 + \frac{a^2}{r^2}\right) \quad (2)$$

$$\sigma_{ho} = \frac{p_f}{(R_o^2 - 1)}\left(1 + \frac{c^2}{r^2}\right) \quad (3)$$

where:

R_i = b/a,
R_o = c/b, as the R-ratios of the respective radii,
a = the radius to the ID of the inner cylinder,
b = the radius to the interfacial boundary,
c = the radius to the OD of the composite pipe

4.2.2 In both general equations, r designates the radial coordinate of points through each pipe-wall thickness. Eq 1 and Eq 2 calculate the effective long-term hoop-stress in each pipe-wall of the composite pipe structure subjected to internal pressure. Setting $\boldsymbol{r = a}$ in Eq 1 and setting $\boldsymbol{r = b}$ in Eq 2 gives the maximum hoop-stress in each of internal and external pipe-walls, respectively. V_i, V_o are the inner and outer cylinder's Poisson's Ratio of each pipe-wall's material. E_i,E_o are the respective pipe-wall's Modulus of Elasticity

5. Materials

5.1 *General*—This guide is agnostic regarding the SMPT material used, such that this Guide includes all amorphous,

[11] www.faculty.fairfield.edu/wdornfeld/ME311/PresCylinderHam.pdf

TABLE 1 Classification and Designation Specification for Shape Memory Polymer Composite Pipe (with SMPT Example, below)

Class I	Class II	Class III	Class IV	Class V	Class VI
Loose-Fit	**Neutral Fit**	**Neutral Fit**	**Compression Fit**	**Compressed Fit**	**Compressed Fit**
Insertion	Insertion	Insertion	Insertion	Insertion	Insertion
Mono-Layer Pipe	Bi-layer	Bi-layer	Bi-layer	Bi-layer	Bi-layer
Gravity-Flow or Pressure	Gravity Flow	Pressure	Gravity Flow	Pressure	Pressure
Unconstrained	Unbonded	Unbonded	Mech. Bonded	Mech. Bonded	Mech.Bonded
Example Specification >> Material: PE4710, Nylon, PVDF, etc ..				PED3542C1111211 PE(4710)	PED3521C1121211 PE(4710)
1. Design Life - years					
A: 0-25					
B: 26-50					
C: 50-100					
D: > 100				D	D
2. Fit					
1: Loose					
2: Neutral					
3: Compression				3	3
3. % Compression					
1: 0%					
2: 1% - 2%					
3: 2% -3%					
4: 3 %-4%					
5: > 5%				5	5
4. Diff. Press. Multiplier					
1 : 1.0					
2: 2 to 5					2
3: 6 to 10					
4: > 10				4	
5. Pressure Confinement					
1: Inner layer Only					1
2: Bi-layer together				2	
6. Axial Friction Constraint					
A: None					
B: Some					
C: High				C	C
7. Corrosion Barrier					
1: YES				1	1
2: NO					
8. Bridges Holes and Gaps at MAOP					
1: YES				1	1
2: NO					
9. Composite WPR. > Inner Layer WPR Only					
1: YES				1	
2: NO					2
10. Inner Layer Survives Outer layer Rupture					
1: YES				1	1
2: NO					
11.Harsh Curing Chemicals Required					
1: YES					
2: NO				2	2
12. Earthquake Resistant					
1: Yes				1	1
2: NO					
13. Addresses Internal and External Loads					
1: YES				1	1
2: NO					

semi-crystalline, and crystalline thermo-plastic materials, elastically deformable at its workable temperatures. The thermoplastic pipe selected for each project installation shall be submitted for approval by the owner, to include a data sheet with material propertied determined in accordance with at least these standards: Test Methods D638, D1238, D1598, D1599, D2837, D2290, D2412, Specification D3350 (PE), and Classifications D4066 (PA), D4101 (PP). The interior thermoplastic pipe may be made from selected thermoplastic material into pipes conforming to standard or custom diameters permitted by the following pipe standards: Specifications F714, D2513, F2619/F2619M, F2785, F2945, F2389, API 15LE, or other pipe standard as agreeable between owner and engineer or contractor. For purpose of an example, semicrystalline, PPI TR-4 listed, pipe-grade Polyethylene, specifically PE4710, can be deformed while in the temperature range of 0 °F (-17 °) to 180 °F (82 °C). The example PE4710 polyethylene compound used to make the SMPT is specified in accordance with Specification D3350 cell- classification PE445574C-CC2, or higher. Alternate SMPT material specifications (PP, PA, PC, PTFE) using ASTM Standards, are acceptable when agreeable between contractor and owner. When required by the regulatory authority having jurisdiction, SMPT intended for contact with potable water shall have been evaluated, tested, and certified for conformance with NSF/ANSI Standard No. 61 by certifying organization acceptable to the authority having jurisdiction.

5.2 *Tubular Dimensions and Dimension Ratio*—The SMPT shall be made in accordance with pipe standards agreeable between Contractor and Project Owner / Project Engineer. As an example, using Polyethylene SMPT, the project's PE4710 tubular shall be made in accordance with the specifications, dimensions, and requirements of Specification F714, or, Specification D3035, or, Specification F2619/F2619M, or Specification D2513, or AWWA C906, or API-15LE. The SMPT may be ordered as standard outside diameters and standard dimension ratios, or, as custom outside diameters and dimension ratios, as permitted by the pipe standards.

5.3 *SMPT Pipeline Construction*—Prior to on-site construction of the composite dual-wall pipeline, the 'long' SMPT pipeline shall be assembled from 'short' tube segments using thermoplastic heat fusion practice. Most Thermoplastics heat-fusion practices are published in ASTM Standards. As an example, for Polyethylene material, the specified heat fusion practice is Practice F2620.

NOTE 3—(Heat fusion Standards for Polyamid and Polypropyene pipes are in development.) The exterior butt-fusion bead shall be trimmed flush to the OD of the SMPT, in accordance with the trim-tool and pipe manufacturer recommendations. The heat butt-fusion jointing process shall be evaluated by reverse bend testing, or, in accordance with the procedures of Practice F3183 for thicker wall pipe.

5.4 *Design Performance*—It is beyond the scope of this guide to list or specify the numerous design parameters or performance characteristics for polymeric SMPT pipes that are important determinants of physical performance over the life of an installation; for example, moduli (flexural, creep), ductility, life span, hole and gap spanning, abrasion resistance, etc. It shall be the contractor's responsibility to provide such independently-verified data to the owner's representative when requested.

6. Installation

6.1 *Interior Pipe*—shall be installed in accordance with the contractor's recommended procedures. using the means and methods specified by the contractor. Typically, the SMPT is pulled through a mechanical diameter reduction die of custom configuration. The pulling means is typically by means of hydraulically drawn linkages or wenched continuous wire-rope of sufficient strength. All interior pipe installation shall be completed by manufacturer-approved, certified installers, using manufacturer-approved, specialty equipment following written procedures. For each installation length, the installer shall calculate the maximum pulling force to be used to pull the liner through the host pipe for the overall length; such records shall be maintained with the Project QA files.

6.2 *Preparatory Planning*—Comprehensive planning is required before the commencement of SMPT installation operations. The following list of considerations is provided to the owner/contractor for guidance and is not exhaustive:

(1) Review and analysis of system architecture, surface and subsurface information,
(2) zoning restrictions and regulations,
(3) safety and health concerns and requirements,
(4) access and egress considerations,
(5) customer care planning,
(6) environmental concerns (weather, waste disposal),
(7) flow bypass requirements and arrangements,
(8) traffic control,
(9) availability of water and provisions for alternative supplies,
(10) discussions and meetings with other utilities, highway authorities and fire services, disinfection regulations and operations,
(11) permitted hours for lining operations, and

(12) bylaws/regulations affecting SMPT construction operations.

6.3 *Flow Bypass*—Whenever the continuance of the water supply or sewage removal is required for customers connected to the pipeline under construction, the bypass system shall be designed, installed, and tested to meet the requirements of the contract documents and local health regulations. The bypass system shall receive the approval of the owner and local health officer prior to the commencement of construction operations. The bypass system shall be monitored and maintained for the full duration of construction operations. The bypass system must remain in service until the lined main has been fully returned to service. If bypassing of the host-pipe's flow is required around the sections of pipe designated for renewal, the bypass shall be made by isolating the line at a point upstream of the pipe to be renewed and pumping the flow to a downstream point or adjacent system. The pump and bypass lines shall be of adequate capacity and size to handle the flow. Services within this reach will be temporarily out-of-service, unless a temporary service-line header is installed until the renewed pipeline is ready for re-connection.

6.4 *Pipeline Access:*

6.4.1 The main to be lined is isolated by closing all relevant supply valves and accessed at planned locations above ground or by localized removal of the surface pavement or concrete where the main is buried below ground.

6.4.2 For buried pipe-mains, pits are then excavated, followed by the cutting and removal of a section of pipeline, and draining the host pipe prior to cleaning. Access is preferably completed at a valve, bend, fitting, or other location wherever an excavation is needed for cleaning and lining operations. Piping components such as air valves, flow meters, butterfly valves, and pressure reducing valves should (are generally) be removed prior to cleaning, and then replaced after SMPT installation.

6.4.3 Access pits are typically drained/dried for safety and health (personnel and contamination) and are suitably covered or barricaded when not in use. Care shall be taken by the applicator to erect proper barricades and signage around these excavations to prevent accidents or injuries.

6.5 *Cleaning and Pre-Inspection*—Pressure Pipelines and Gravity Flow Pipelines:

6.5.1 *Safety*—Prior to entering access areas, such as manholes, and performing inspection or cleaning operations, an evaluation of the atmosphere to determine the presence of toxic or flammable vapors or lack of oxygen must be undertaken in accordance with local, state, or federal safety regulations.

6.5.2 *Cleaning of Pipeline*—The quality of host pipe cleaning and preparation is paramount. Cleaning is very important for the removal of all point loads that can either tear the liner or add future stress concentrations. Any cleaning and preparation method used shall clean and prepare the pipe in order to meet the performance requirements of this section. The cleaning method chosen shall achieve the removal of all foreign material on the pipe wall and around service connections, including sediment, corrosion, biofilm and graphite. When viewed without magnification, the cleaned, prepared surface shall be free of all visible contamination prior to coating. The pipeline shall also be dried and left free of visible moisture (free standing water) in both the pipe and the pipe joints prior to lining. The cleaning technology chosen shall consider and take precautions to minimize potential damage to service connections, appurtenances and the host pipe. All cleaning residue and contamination shall be disposed of in accordance with the owner's stipulations.

6.5.3 *Pressure Pipe*—All internal debris including rust, sand or sludge, and tuberculation, or chemical contamination shall be removed from the original pipeline, typically accomplished by pressure-fluid driven scrapping or swabbing pigs. High pressure water-jet, abrasive blasting, ice blasting, and other mechanical or chemical means are relevant to remove imperfections that could damage the SMPT during pull / push installation, or that could chemically affect the SMPT after installation. NACE Standard SP0102 provides guidance for cleaning and inspection of pressure pipe. Alternately, pressure pipelines shall be cleaned with cable attached devices or fluid propelled devices, as standard industry best practice. ISO 8501 and SSPC/NACE also offer guidance for metallic host pipeline.

6.5.4 *Non-Pressure Pipe*—These pipes shall be cleaned man-hole to manhole, with hydraulically powered equipment, high-velocity jet cleaners, or mechanically powered equipment in accordance with NASSCO Recommended Specifications for Sewer Collection System Rehabilitation.

6.6 *Inspection of Pipelines*—Prior to SMPT Installation, inspection of pipelines shall be performed by experienced personnel trained in locating breaks, obstacles, and service connections by closed-circuit television or man entry, where possible. The closed-circuit television (CCTV) inspection of the cleaned pipe must be carried out prior to SMPT installation to verify the quality