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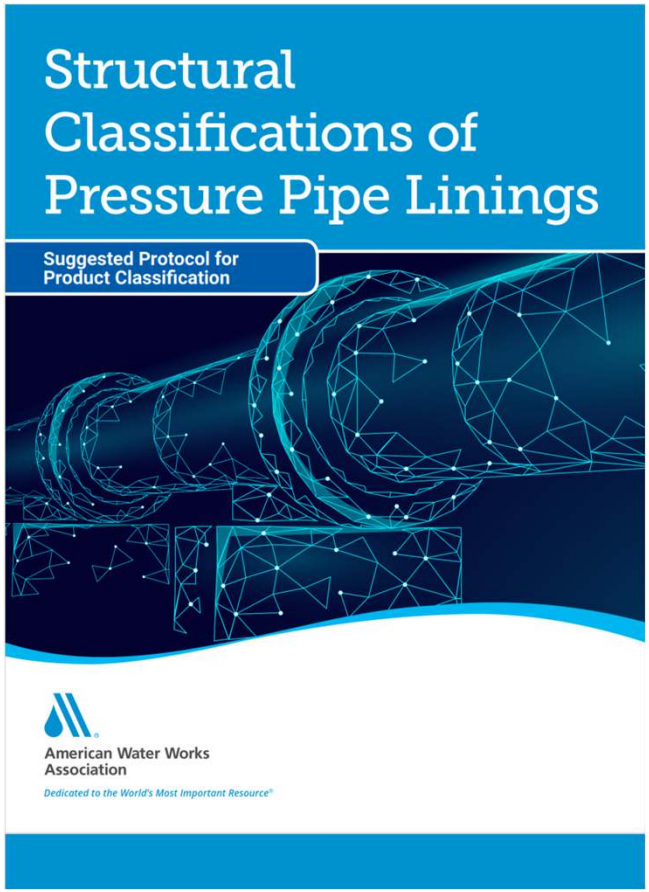
PRESSURE PIPE REHABILITATION – SPECIFICATIONS AND DESIGN

Presented By
Norman E. “Ed” Kampbell
NASSCO

Published in 2019 by the AWWA the Structural Classifications of Pressure Pipe Linings is the best reference an engineer has at present to determine the proper application of CIPP in a pressure pipe application…

Additionally, the following AWWA MOPs should be in your reference library…

M77 – Condition Assessment of Water Mains
M28 – Rehabilitation of Water Mains
M45 – Fiberglass Pipe Design



Alignment of Lining Application Requirements with an Owner's Design Objectives

- The host pipe description (material, year of manufacture, diameter, wall thickness, pressure class, joint type, etc.), horizontal/vertical alignment, the major deficiencies and deterioration mechanisms intended to be addressed and general chemistry of the fluid to be conveyed
- All relevant internal pressures to be resisted by the lining system including MAP, MAOP, occasional surge (if applicable), vacuum pressures (if applicable), and the intended magnitude and duration of the test pressure.
- All relevant external loads to be resisted by the lining system including the load duration where relevant (e.g., earth and groundwater with design duration if not intended to be long-term loading; and live loads – implied short-term duration unless otherwise noted).

Structural Classifications of Liners

- Class I Linings are non-structural systems used to protect the inner surface of the host pipe from corrosion or maintain water quality
- Typical design objectives
  - To protect host pipe from internal corrosion and the formation of future corrosion
  - Relies on the host pipe to provide all internal and external load resistance
- Typical product considerations
  - Un-bonded and bonded lining products such as CML or PL, respectively
  - Chemical resistance to the fluid being conveyed and adequate stiffness or adhesion to the host pipe to remain intact when pressurized and dewatered
  - PL should be free of holidays and blisters

Structural Classification of Liners

- Class II and III Linings are both interactive and semi-structural systems. Class II adhere to the pipe wall while Class III linings may or may not be adhered to the host pipe.
- Typical design objectives
  - To protect host pipe from internal corrosion and future corrosion
  - To prevent any leakage occurring from the host pipe at pinholes, holes, and faulty joints
  - To accommodate future external deterioration by providing sufficient hole spanning capability to meet future conditions.
- Typical product considerations
  - All CFLs (CIPP, deformed and compression fit linings), SL, PL, and CFRP
  - Demonstrated chemical resistance
  - Adequate structural properties based on type testing
  - Adequate means to resist all hydrostatic and, if specified, vacuum loads based on reliable adhesion for Class II products or inherent ring stiffness for Class III products

Structural Classification of Liners

- Class IV liners have long-term hoop strength evaluated independently of the host pipe equal to or greater than the MAOP of the host pipe
- Typical design objectives
  - Provide corrosion protection (same as Class I, II, and III)
  - Prevent any leakage from occurring (same as Class II and Class III)
  - To accommodate further external deterioration by providing sufficient reinforcement to resist hoop stress failure of the host pipe
- Typical product considerations
  - Currently CFL and SL
  - Demonstrated resistance to the fluid being conveyed
  - Adequate structural properties based on type tests that when modified by the appropriate Material Resistance Factor meet the long-term design objectives for all specified loads (internal and external) for the intended design life.

Table 1: ***General Structural Classifications Objectives***

Lining System Characteristic	Non-Structural	Semi-Structural (Interactive)		Fully Structural
	Internal coating	Hole span	Hole span + ring stiffness	Structural resistance for all specified loads (internal & external)
	Class I	**Class II**	**Class III**	**Class IV**
Internal corrosion protection	✓	✓	✓	✓
Long-term adhesion to the host pipe	See Note 1 Below	✓	See Note 2 Below	See Note 2 Below
Hole span at MAOP		✓	✓	✓
Inherent ring stiffness (hydrostatic pressure or vacuum loads only)	See Note 1 Below	See Note 1 Below	✓	✓
Water tightness (positive connection to service taps and sealed at termination points or other discontinuities)		✓	✓	✓
Inherent ring stiffness (all static and dynamic external, hydrostatic, and vacuum loads)				✓
Pressure rating of lining ≥ MAOP of host pipe				✓
Lining survives anticipated host pipe failures				✓

1 The owner/engineer must specify whether vacuum loads exist. This is addressed through reliable adhesion to the host pipe, which is a characteristic of all Class II and some Class I linings, or inherent ring stiffness.
2 For Class III and IV linings, adhesion is not required to develop ring stiffness. However, it may be necessary to achieve a watertight seal (for example, at services and lining terminations). There are also situations where adhesion is not desirable, such as applications with broad temperature swings and in Class IV linings where the host pipe is anticipated to experience brittle failure modes.

Table 2: *Type Testing*

Note: In order for a lining technology to be categorized under a specific Structural Classification, one or more test methods listed for each property must be documented and all applicable acceptance criteria met.

	Property	Technology	Test Method(s)	Acceptance Criteria
Class I	Potable Water Certification	All	N (r	
	Material Properties	CML	A (s	
	Lining Thickness	All		
	System Hydraulics	All		
	Adhesion	Some Class I	A si A (c	
Class III	All Class I & II attributes PLUS:			
	Adhesion	Some Class III	Per Class I, as required	Per Class I, as required
	Ring Stiffness	All Class III-IV	Any or all of: ASTM D2412; DIN EN 1228; ISO 7685 (initial ring stiffness)	Per owner/engineer requirements
			Any or all of: ASTM D2990 (flexural creep, hoop direction); DIN EN 761; ISO 7684 with ISO 10468 (flexural creep, full ring)	For full ring tests, samples must be round, reflect the finished quality and geometry of the installed product, and tested independently of the host pipe
Class II	All Class I attributes PLUS:			
	Adhesion	All Class II	Per Class I	Per Class I
	Hole Span @ MAOP	All Class II	Any or all of: ASTM D790; ISO 178; ISO 11296-4, Annex B (initial flexural properties, 3-pt bending)	Test values = short-term flexural properties
				For anisotropic materials, flexural properties should be obtained in the hoop and axial directions
			Any or all of: ASTM D2990; ISO 899-2; ISO 11296-4, Annex C & D (flexural creep)	Test values = long-term flexural properties
	Water Tightness	All Class II	Supporting test data from end seal and fittings manufacturers, as applicable	End seals, service connections, hot taps and fittings: Pressure Rating ≥ MAOP
				Demonstration test(s) by the manufacturer as directed by the owner/engineer
	Hydrostatic Integrity at Services	All Class II		Demonstration test(s) by the manufacturer as directed by the owner/engineer
Class IV	All Class I, II & III attributes PLUS:			
	Adhesion	Some Class IV	Per Class I, as required	Per Class I, as required
	Resists all internal and external pressures	All Class IV	Any or all of: ASTM D638; ASTM D3039; ASTM D2290; ISO 8521; ISO 8513 (initial tensile properties)	Test values = short-term tensile properties
				For anisotropic materials, tensile properties should be obtained in the hoop and axial directions
				For full ring tests, test samples must be round, reflect the finished quality and geometry of the installed product, and tested independently of the host pipe
			ASTM D2990 and/or ISO 899-1 (tensile creep)	Determination of long-term (50-yr) retention of tensile properties
		All Class IV	ASTM D1599 (short-term burst testing)	Test samples must be round, reflect the geometry of the installed product, and tested independently of the host pipe
				Test value/PRF = estimated pressure rating (straight alignment). Generally, PRF ≥ 4 but lower PRF values are permissible when documented testing, as outlined herein, has established the acceptability of a lower short-term to long-term strength ratio. Further product specific de-rating may be recommended when geometric anomalies compromise hoop integrity, or when lining through bends and offsets
		CIPP	ASTM F2994, ASTM F1216 or ASTM F1743 (CIPP impregnation)	Demonstration test: Insure proper resin mixing ratio and CIPP saturation rate; vacuum impregnation under controlled conditions; data logging of impregnation process
		CFRP[3]	ASTM D6641	Compressive strength; AWWA C305, Sec. 3
			ASTM D7616	Shear strength; AWWA C305, Sec. 3
		SL (FRP) CIPP[4]	ASTM D2992 or ISO 7509 with ISO 10928 (regression analysis)	HDB or ISO test results may be used as a comparative measure vs short-term burst and long-term tensile creep results
		SL (HDPE)	ASTM D2837 or PPI TR-3	HDB
			ASTM D3350	Material cell classification
			ANSI/AWWA C906	Dimensions and tolerances, bend back or elongation at break, ring tensile or short-term burst, carbon black/UV inhibitor, melt flow index, density, thermal stability
		SL (PVC)	ASTM D2837	HDB from multiple stress-rupture tests from <1 hour to >10,000 hours
			ANSI/AWWA C900 or PPI TR-2	HDB + 1000-hour pressure test; burst test; flattening test

Table 3: *Acceptance Testing*

Note: In order for a lining technology to be categorized under a specific Structural Classification, one or more test methods listed for each property must be documented and all applicable acceptance criteria met

	Property	Technology	Test Method(s)	Acceptance Criteria
Class I	Drinking Water System Components – Health Effects	All	Bacteriological testing	AWWA C651
	Material Properties	CML, PL	Compressive strength	CML: AWWA C602, Section 5.1.2
				PL: ASTM F3182, Section 6
	Lining Thickness	CML, PL	Physical measurements	CML: ANSI/AWWA C602, Table 1
				PL: ASTM F3182, Section 8.2
	Adhesion	Some Class I	Surface preparation and dryness	Surface preparation methods shall be confirmed by the owner/ engineer before proceeding with the lining installation process.
				PL: ASTM F3182, Section 8.3
			Visual and CCTV inspection	No visual leaks at ends or at services
				ISO 11297-1:2013, Section 9.8
				PL: ASTM F3182, Section 7.9
			ASTM D4541 (metal substrate)	Test values ≥ design value
				PL: ASTM F3182, Section 8.3
			ASTM D7234 (concrete substrate)	Test values ≥ design value
Class II	All Class I attributes PLUS:			
	Adhesion	All Class II	Per Class I	Per Class I
	Hole Span @ MAOP	All Class II	ASTM D790 and/ or ISO 11296-4, Annex B (initial flexural properties, axial direction)	Test values ≥ design submittal If these criteria are not met, design compliance shall be verified using actual test values
	Water Tightness	All Class II	ASTM F1216, Section 8.3 (pressure test): 2 times MAOP or MAOP + 50 psi (3.4 bar), whichever is less,	Minimum 1-hour duration once system is stabilized; leakage allowance = 20 gal/inch diameter/mile/day (1.86 L/mm diameter/km/day)
			or ISO 11297-4, Table 7 (pressure test): 1.5 times MAOP	15 minute test duration with no leakage per ISO 7432 or ISO 8533, as applicable
Class III	All Class I & II attributes PLUS:			
	Adhesion	Some Class III	Per Class I, as required	Per Class I, as required
				CIPP: ASTM F1216, Section 8.7; tight fit, full saturation
				CFRP: AWWA C305, Section 4.5[5]
	Ring Stiffness	All Class III	ASTM D790 and/ or ISO 11296-4, Annex B (initial flexural properties, hoop direction)	For anisotropic materials, flexural properties should be obtained in the hoop direction
				Test values ≥ design submittal

	Property	Technology	Test Method(s)	Acceptance Criteria
Class IV	All Class I, II & III attributes PLUS:			
	Adhesion	Some Class IV	Per Class I, as required	Per Class I-III, as required
	Resists all internal and external pressures	CIPP	ASTM F2994 or ASTM F1216 (CIPP impregnation)	Verify compliance during CIPP impregnation process
			Visual and CCTV inspection	Confirm fit and finish. Geometric anomalies compromising the lining system's hoop integrity shall be verified through type testing and reflected in design. Isolated circumferential fins or imperfections from lining through vertical or horizontal misalignment, offset(s) or directional change(s) shall be documented and reviewed with the owner/engineer for design compliance
			Any or all of: ASTM D638; ASTM D3039; ASTM D2290; ISO 8513; ISO 8521 (tensile properties, hoop direction)	For anisotropic materials, tensile properties should be obtained in the hoop direction
				Test values ≥ design submittal
			Wall thickness measurements: Restrained samples: ASTM F1216, Section 8.6; Measurements per ASTM D3567	Average of eight (8) measurements around circumference; not less than 87.5% of design thickness at any point (excluding coating). Although hoop tensile strength (force/unit area) is an important parameter for reinforced CIPP laminates, hoop load capacity (force/unit width) is equally or even more important. Laminate thickness can vary without changing the amount of reinforcing fibers used. As an example, the thickness may increase by adding felt material to increase the external load-resisting capacity. In this example, as the thickness increases, the tensile strength (psi) decreases. However, the hoop load capacity (lb/ in.) remains the same or may slightly increase. Thus, although the hoop tensile strength decreases, the internal pressure load capacity of the CIPP remains the same or slightly increases. In this context, hoop load capacity, not wall thickness or resulting tensile strength, is a measure of pressure pipe structural performance.
				Flat plate sampling methods per ASTM F1216, Section 8.1.2 may be used in lieu of restrained samples in accordance with manufacturer's recommendations and as directed by the owner and/or engineer.
		SL (HDPE)	AWWA M55 or ASTM F2164	Hydrostatic leak test
		SL (FRP)	AWWA M45	Hydrostatic leak test
		SL (PVC)	AWWA C605	Hydrostatic leak test

5 AWWA C305 applies to CFRP used for the renewal and strengthening of PCCP. Alternative acceptance criteria may be established at the discretion of the owner/engineer for applications involving different host pipe materials.

Table 4: ***Current Typical Design Approaches***

	Property	Technology	Design Procedure(s)	Design Criteria
Class I	Potable Water Certification	All	NSF/ANSI-61	Product certification (all system components)
	Material Properties	CML	ANSI/AWWA C602, Sec. 4.4	Mortar mix design
	Lining Thickness	CML	ANSI/AWWA C602, Sec. 4.4.5	Minimum lining thickness
	Adhesion	All	Project specific	Surface preparation and dryness requirements to be submitted by the manufacturer and/or contractor Adhesion strength ≥ negative pressures, thermal stresses, and shear stresses where relevant (Equations 1a and 1b)
		PL	ASTM F3182	
	System Hydraulics	All	AWWA M45, Ch. 4	Minimum C value and pipe inside diameter required after lining to maintain or increase hydraulic capacity
		CML	AWWA C602	
		PL	AWWA C620	
Class II	All Class I design requirements PLUS:			
	Adhesion	All Class II	Per Class I	Per Class I
	Hole span @ MAOP	All Class II	ASTM F1216, Equation X1.6 (as directed by X1.5)	All holes should be supported, or per manufacturer's guidelines
				If Eq X1.5 can't be satisfied, Eq X1.7 applies (reverts to Class IV design)
	Water tightness	All Class II	See Table 3	See Table 3

	Property	Technology	Design Procedure(s)	Design Criteria
Class III	All Class I & II design requirements PLUS:			
	Adhesion	Some Class III	Per Class I, as required	Per Class I, as required
	Ring stiffness	All Class III	ASTM F1216, Equation X1.1 (vacuum and hydrostatic pressure)	For vacuum, use short-term flexural properties
				For external hydrostatic pressures due to groundwater, short-term flexural properties, higher retention values or a lower design safety factor should be considered in design, unless the pressure pipe is expected to be out of service for an extended period or routinely operates under gravity conditions. External pressures should control lining design only when absolutely necessary.
		SL (FRP)	AWWA M45, Equation 5-17 (in accordance with ASTM D2412) or AWWA M45, Equation 5-18	Per owner and/or engineer guidelines
			AWWA M45, Eq. 5-24a (wall buckling)	Allowable buckling pressure > Total external pressure
		SL (PVC)	AWWA M23	Per owner and/or engineer guidelines
		SL (HDPE)	AWWA M55	Per owner and/or engineer guidelines
		CFRP[6]	AWWA C305, Section 2	Wall buckling (LRFD) – vacuum and hydrostatic pressure
	Thermal effects	Some Class III	PPI Handbook of PE Pipe, Chapter 6, Equations 4-1 and 4-2	Lining systems that do not demonstrate reliable adhesion to the host pipe should be properly anchored or designed to accommodate axial movement due to temperature fluctuations

	Property	Technology	Design Procedure(s)	Design Criteria
Class IV	All Class I, II & III design requirements PLUS:			
	Internal pressure resistance	All Class IV	Barlow's equation	Minimum thickness at MAOP and MAP; use long-term tensile properties
			AWWA M45, Equation 5-1[7]	Stress-based HDB
			AWWA M45, Equation 5-2[7]	Strain-based HDB
		SL (FRP), CIPP[8]	AWWA M45, Equation 5-22 and 5-23 (combined loading)	Maximum strain resulting from combined effects of internal pressure and deflection should meet criteria – if applicable (e.g. in the case of SL GRP, where deflection may be a function of design intent)
				Greatest of Class III and IV AWWA M45 design criteria applies
			AWWA M45, Equation 5-4 (surge pressure)	Pressure class should be equal to or greater than the maximum system pressure (working pressure + surge pressure), divided by 1.4. Surge pressure magnitude is highly dependent on hoop elastic modulus and thickness-to-diameter ratio of the lining and host pipe. See AWWA M45, Section 5.7.1.3
		SL (HDPE)	ANSI/AWWA C906 and AWWA M55	Pressure class and design
			ASTM D2837 or PPI TR-3	Hydrostatic Design Basis (HDB) and Hydrostatic Design Stress (HDS)
			ASTM F585	Sliplining installation guide
			ASTM D3350	Material cell classification
		SL (PVC)	ANSI/AWWA C900 and AWWA M23	Pressure class and design
			ASTM D1784	Material cell classification
			ASTM D2837 or PPI TR-2 or PPI TR-3	Hydrostatic Design Basis (HDB) and Hydrostatic Design Stress (HDS)
		CFRP[6]	AWWA C305, Section 2	Wall buckling (LRFD) – working and transient pressures

	Property	Technology	Design Procedure(s)	Design Criteria
Class IV	External pressure resistance	All Class IV	ASTM F1216, Section X1.2.2	Total external pressure on pipe (soil, hydrostatic and surface live load); applies when pipe is out of service for an extended period
		All Class IV	ASTM F1216, Equation X1.3	Applies when total external pressure > MAOP
		CFRP[6]	AWWA C305, Section 2	LRFD – total external loads
	Poisson's effect	All Class IV	Performance Pipe 813-TN	Lining system must resist pullout forces due to Poisson's effect. Maximum internal pressure should be used (greatest of MAP, MAOP and test pressure); see illustrative example, Equation (16)
		CFRP[6]	AWWA C305, Section 2	Longitudinal strain from Poisson's effect
	Thrust restraint	All Class IV	AWWA M45, Chapter 7	Applies to lining systems subjected to hydrostatic or hydrodynamic thrust; prescriptive design per AWWA M45, Chapter 7
		CFRP[6]	AWWA C305, Section 2	Pressure-induced thrust force as calculated from AWWA Manual M9

6 AWWA C305 applies to CFRP utilized for the renewal and strengthening of PCCP. An alternative design approach may be implemented at the discretion of the owner/engineer for applications involving different host pipe materials.
7 HDB testing is difficult to execute for CIPP and may not be indicative of a product's long-term performance. HDB test results may be utilized as a comparative measure vs short-term burst and long-term tensile creep results.
8 For CIPP, this design method may be utilized at the discretion of the owner/ engineer when ASTM D2992 (HDB) test data is available

Specifications … Prescriptive or Performance? ✓

Key items to be included in the project specifications:

- Complete description of the host pipe material and its current condition (Condition Assessment Report)
- Complete description of the current (and future) operating conditions (e.g., MAOP, MAP, etc.)
- All relevant external loads that are required of the liner (dead and live)
- Structural classification of the lining system required
- Acceptable type testing documentation of the lining system being proposed
- Acceptance testing that will be carried out on the project to ensure a quality installation
- Contractor experience qualifications required (commensurate with the size and risks of project)

1. Class of Liner needed
    1. Class I Liner
    2. Class II Liner
    3. Class III Liner
    4. Class IV Liner
2. Design of Liners
    1. Class I and Class II – Adhesion and Hole Spanning
    2. Class III – Inherent Ring Stiffness and Thermal Effects
    3. Class IV – the
        1. Sustained Pressure
        2. Short-term Over Pressure
        3. External Loads
        4. Alignment Modifications
        5. Poisson's Effects
        6. Longitudinal Loads – Thrust