Track IX: Pressure Pipe Rehabilitation Testing and Design

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Fort Worth, TX

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Pressure pipeline rehabilitation technologies are designed to accommodate a wide range of host pipe materials, conditions and applications

- Potable water
- Raw water
- Sewer force mains
- Industrial settings

Lining systems can be grouped into one of the following processes:

- Cement mortar lining (CML)
- Spray-on polymer lining (PL)
- Cured-in-place pipe lining (CIPP)
- Close-fit lining (CFL)
- Sliplining (SL)
- Carbon fiber reinforced pipe (CFRP)

Structural classifications of linings loosely defined in AWWA M28, *Rehabilitation of Water Mains* – Appendix A

- No design guidance given

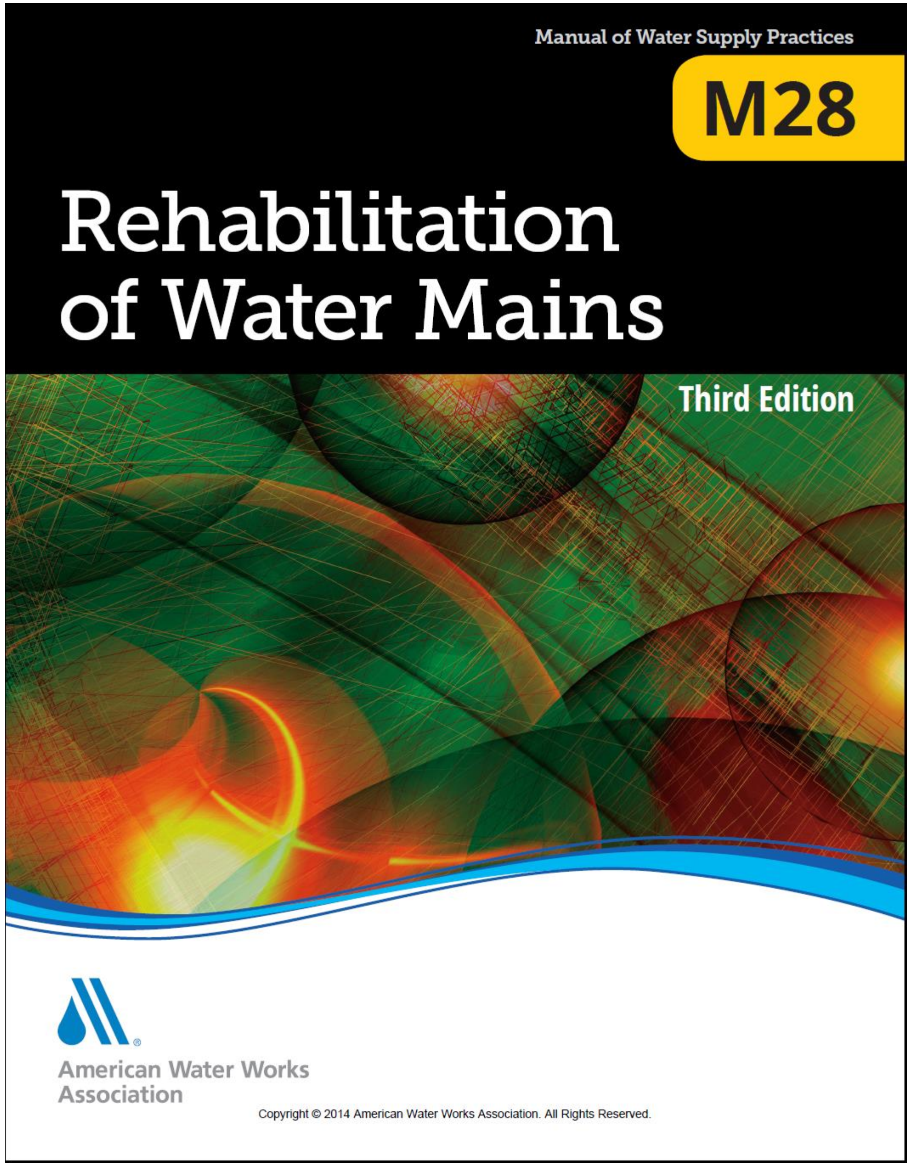
Class IV Linings

Class IV linings, termed fully structural or structurally independent, possess the following characteristics:

1. A long-term (50-year) internal burst strength, when tested independently from the host pipe, equal to or greater than the MAOP of the pipe to be rehabilitated
2. The ability to survive any dynamic loading or other short-term effects associated with sudden failure of the host pipe due to internal pressure loads

Class IV linings are sometimes considered to be equivalent to replacement pipe, although such linings may not be designed to meet the same requirements for external buckling or longitudinal/bending strength as the original pipe. Also, they may be of smaller internal diameters. Class IV linings can, of course, be used in circumstances similar to those for Class II and III, but their use is essential for host pipes suffering from generalized external corrosion where the mode of failure has been, or is likely to be, catastrophic longitudinal cracking.

Some available renovation technologies can offer both Class II and III and Class IV linings, while a given lining system may be rated as Class IV for MAOP levels up to a threshold value and Class II and III for higher pressures.

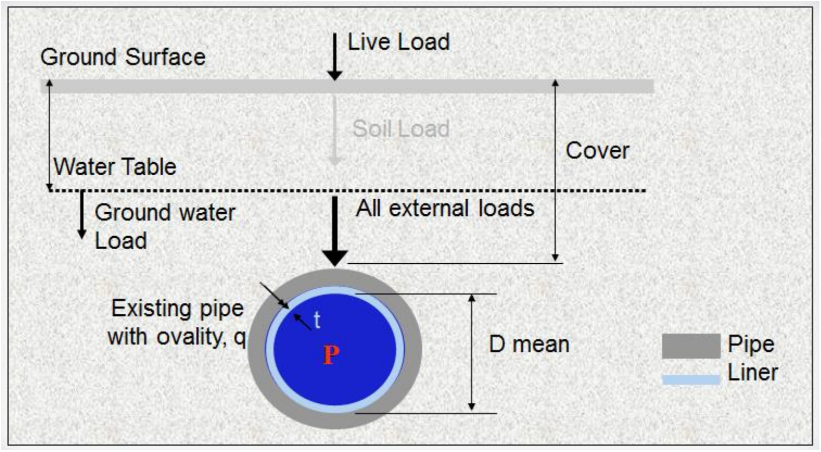


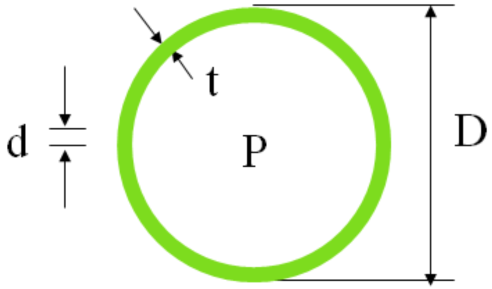
Pressure Pipe Lining Design Methodology

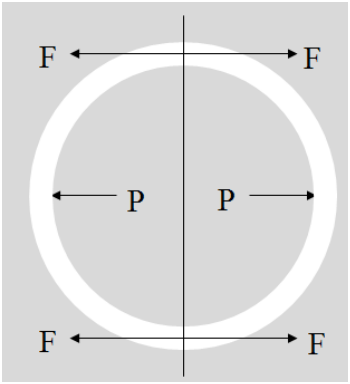
- ASTM F1216 first introduced in 1989
- To date, most pressure liners in North America have used Appendix X1 of ASTM F1216 as the design basis for liners
- With provisions for gravity and pressure pipe loading applications, it provides a design approach for un-bonded, close-fit liners with checks for:
  - **Gravity flow pipelines**
    - Buckling due to hydrostatic loads limited by stiffness (modified Timoshenko)
    - Hydrostatic loads limited by flexural strength
    - Buckling loads due to earth/live loads (modified from Luscher)
  - **Pressure pipe**
    - Hole spanning (interactive design)
    - Full hoop stress (independent design)
  - Standard has a minimum stiffness requirement (Equation X.1.4)

ASTM INTERNATIONAL **Designation: F1216 – 16**

**Standard Practice for
Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube[1,2]**







ASTM F1216, Appendix X1

AWWA M28 Class III?

Groundwater pressure
Hole spanning

X1.3.1 *Partially Deteriorated Pressure Condition*—A CIPP installed in an existing underground pipe is designed to support external hydrostatic loads due to groundwater as well as withstand the internal pressure in spanning across any holes in the original pipe wall. The results of Eq X1.1 are compared to those from Eq X1.6 or Eq X1.7, as directed by Eq X1.5, and the largest of the thicknesses is selected. In an above-ground design condition, the CIPP is designed to withstand the internal pressure only by using Eq X1.5-X1.7 as applicable.

X1.3.2 *Fully Deteriorated Pressure Pipe Condition*—A CIPP to be installed in an underground condition is designed to withstand all external loads and the full internal pressure. The design thicknesses are calculated from Eq X1.1, Eq X1.3, Eq X1.4, and Eq X1.7, and the largest thickness is selected. If the pipe is above ground, the CIPP is designed to withstand internal pressure only by using Eq X1.7.

External loads
Pipe stiffness
Internal pressure

AWWA M28 Class IV?

AWWA M28 Class II-IV?

Vacuum

X1.4 *Negative Pressure*—Where the pipe is subject to a vacuum, the CIPP should be designed as a gravity pipe with the external hydrostatic pressure increased by an amount equal to the negative pressure.

Pressure Pipe Lining Design Methodology

- ***ASTM F1216 has it all, you say?***
  Why do we need more?
- Design methods need to reasonably match the products that they are intended for
  - It's seldom a perfect fit
  - But you need to match the design method to the products
- While F1216 has served the industry well, its evolution was based on:
  - Un-bonded liners
  - Non-reinforced tubes, or at least ***Isotropic liner material*** behavior
  - Compromises, consensus, and many other things that are a reality of standards
    - Minimum stiffness for flexibility for a close fit liner doesn't make sense

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

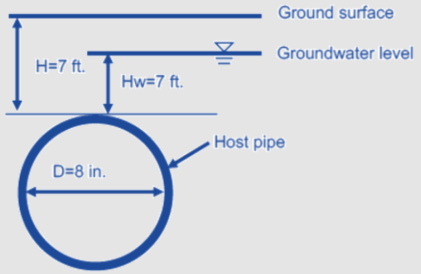
$P_w = \gamma_w(H_w + D/12)/144$

$$t_1 = \frac{D}{\left(\left[\frac{2 \cdot K \cdot E_L \cdot C}{(1-\upsilon^2) \cdot N \cdot (P_w + P_V)} \right]^{1/3} \right) + 1}$$ ASTM F1216, Equation X1.1

$$1.5 \cdot \frac{q}{100} \cdot \left(1 + \frac{q}{100}\right) \cdot DR^2 - 0.5 \cdot \left(1 + \frac{q}{100}\right) \cdot DR - \frac{\sigma_L}{P \cdot N} = 0$$ ASTM F1216, Equation X1.2

- If $P_w = 0$, default DR = 100

Quadratic factors for Eq. X1.2 used to solve for DR_2 and t_2:	a = 0.07875 b = -0.525 c = -688.714146



- From live load calculations

$R_w = 1 - 0.33(H_w/H)$ (min. value = 0.67)

$q_t = 0.433H_w + \delta_s HR_w/144 + W_s$

$B' = 1/(1+4e^{-0.065H})$

$$t = \left[\frac{(q_t \cdot N)^2 \cdot D^3 \cdot 12}{32 \cdot R_w \cdot B' \cdot M_{sn} \cdot E_L \cdot C} \right]^{1/3}$$ ASTM F1216, Equation X1.3

$t = D/(E/0.093 \cdot 12)^{1/3}$ ASTM F1216, Equation X1.4

$t_{pr} = D/([(D/d)^2 \cdot (5.33 \cdot \sigma_L/PN)]^{1/2} + 1)$ ASTM F1216, Equation X1.6

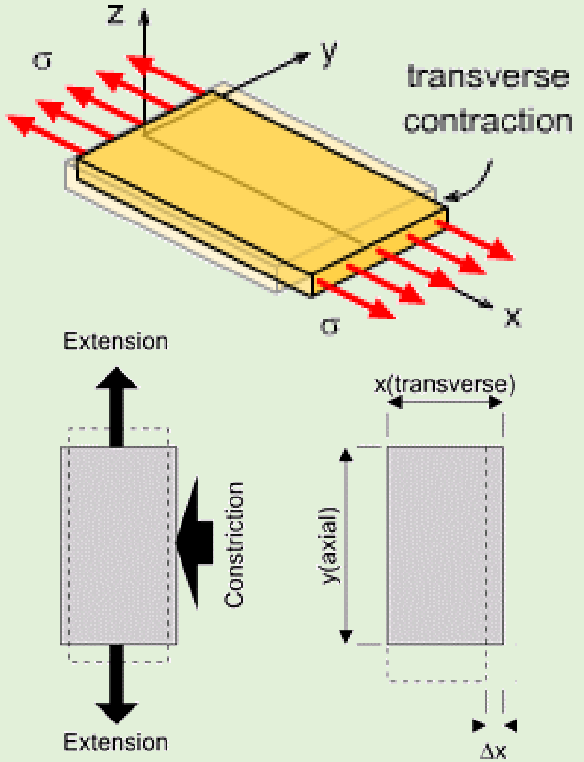
- If $d/D > 1.83 \cdot (t_{pr}/D)^{1/2}$ liner is in ring tension or hoop stress and fully deteriorated pressure pipe condition applies (Equation X1.7) ASTM F1216 Equation X1.5

$t_{pr2} = D/((2 \cdot \sigma_{TL}/PN) + 2)$ ASTM F1216, Equation X1.7

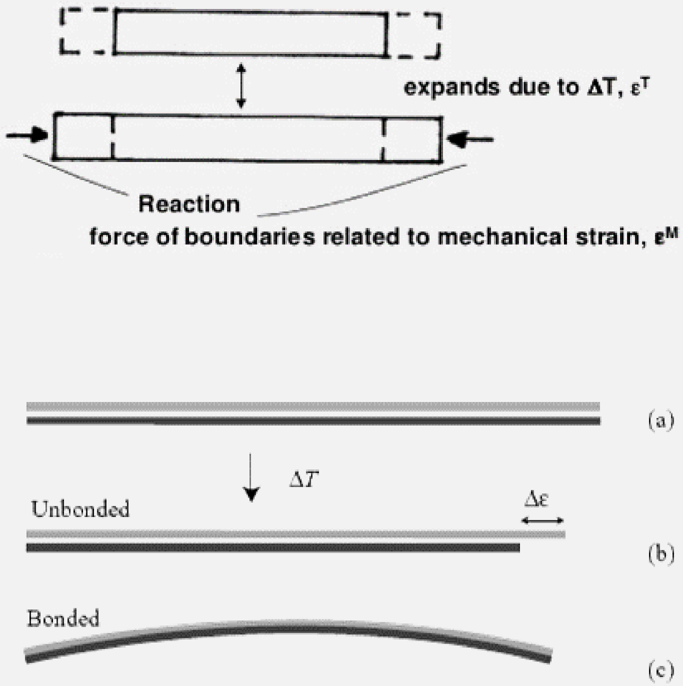
- Use this equation for all above ground pressure pipe applications

Longitudinal Design

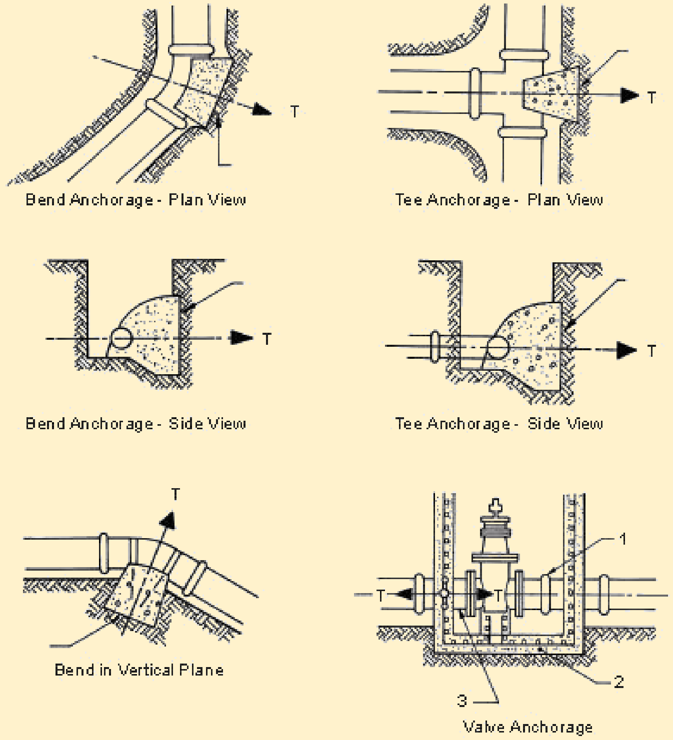
Poisson's Effect

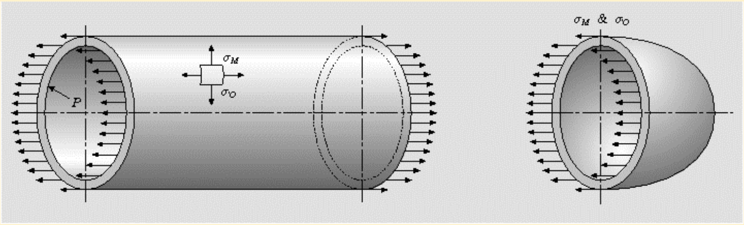


Temperature Effects



Thrust Restraint





Alternative design methods:

- *ASME PCC-2, Repair of Pressure Equipment and Piping*
- Case N-589 of ASME Boiler and Pressure Vessel Code, Class 3 Non-Metallic Cured-In-Place Piping, Section XI, Division I
- *ASME B31.1, Power Piping, ASME Code for Pressure Piping, B31*
- AWWA “Structural Classifications of Linings” (white paper w/2019 target publication date)
- *AWWA C305-18, CRFP Renewal and Strengthening of Prestressed Concrete Cylinder Pipe (PCCP)*

Design Check	ASTM F1216	ASME PCC-2	ASME N-589	ASME B31.1	AWWA SCL	AWWA C305
Hoop Direction						
Working Pressure	•	•		•	•	•
Transient Pressure		•	•	•	•	•
Vacuum Pressure		•	•	•	•	•
Live loads	•	•	•	•	•	•
Soil loads	•	•	•	•	•	•
Ovality	•		•	•	•	•
Deflection Limits				•		•
Combined Loading				•		•
Longitudinal Direction						
Poisson’s Effect			•	•	•	•
Temperature Effect		•	•	•	•	•
Thrust Effect		•		•	•	•
Design Method *	**ASD**	**ASD**	**ASD**	**ASD**	**ASD**	**LRFD**
* ASD = allowable strength design; LRFD = load & resistance factor design						

AWWA Structural Classifications of Linings (SCL) White Paper

- Developed through AWWA's Structural Classifications Subcommittee
- Established more concrete definitions, design and testing criteria for Class I through IV lining systems
- Each structural classification presented as a sequential building block
- Targeted for publication in 2019
- Content will be included in the next revision of AWWA M28

Liner Characteristics	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 discontinuites)		✔	✔	✔
Inherent ring stiffness (all static and dynamic external, hydrostatic and vacuum loads)				✔
Pressure rating of liner ≥ MAOP of host pipe				✔
Liner survives host pipe failure				✔

[1] The Owner/Engineer must specify whether vacuum loads exist. For Class I and II systems, this is addressed through reliable adhesion to the host pipe, which is a characteristic of all Class II and some Class I linings.

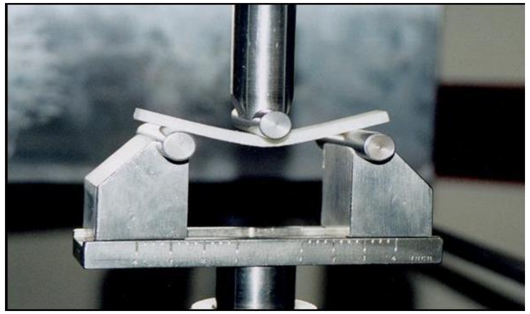
[2] For Class III and IV linings, adhesion is not required to develop ring stiffness. However, it may be necessary to achieve a watertight seal (for example, at services and liner terminations). There are also situations where adhesion is not desirable, such as applications with broad temperature swings and in Class IV linings where the host pipe is anticipated to experience brittle failure modes.

Selection of an appropriate lining system based on design objectives

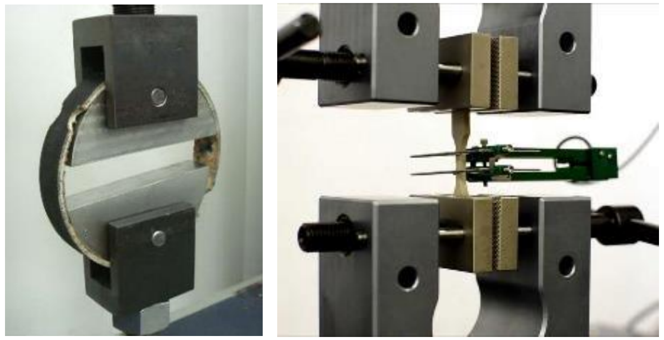
Type Testing

- Provided by the lining system manufacturer
- Confirms material properties and performance used for basis of design
  - Field manufacturing or fabrication of lining system (e.g. CML, PL, CIPP)
- May include:
  - Chemical resistance
  - NSF/ANSI Standard 61 certification
  - Mechanical properties (e.g. tensile, flexural and compressive)
  - Abrasion resistance
  - Adhesion properties
  - Short-term burst pressure
  - HDB testing

Short-Term Testing



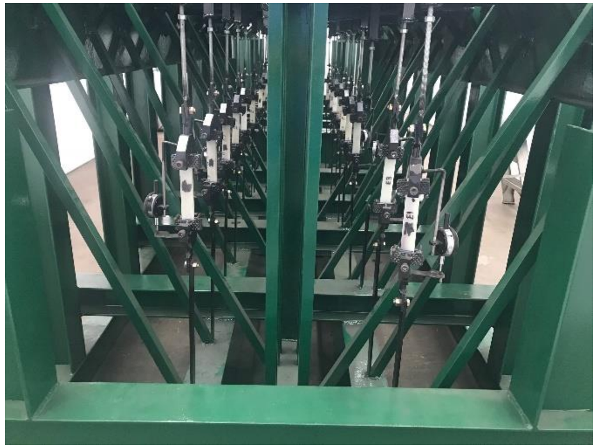
ASTM D790
Flexural

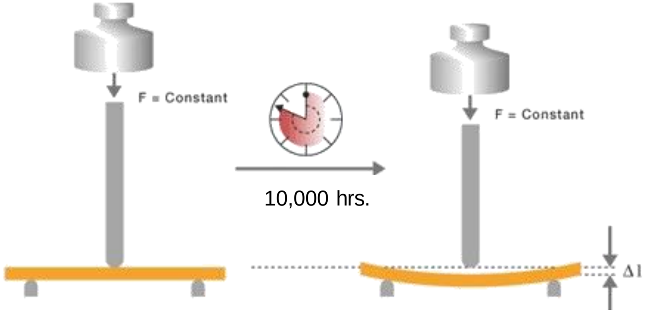


ASTM D2290 *ASTM D638*
Tensile

ASTM D1599
Short-Term Burst

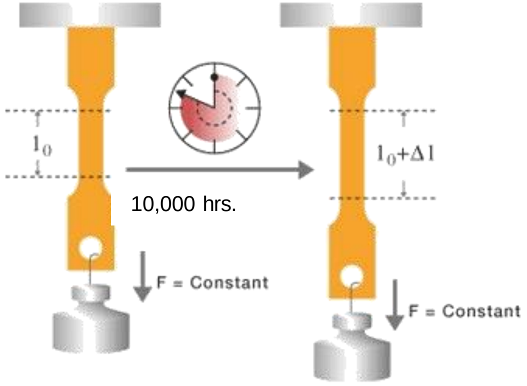
Type Testing (Long-Term)





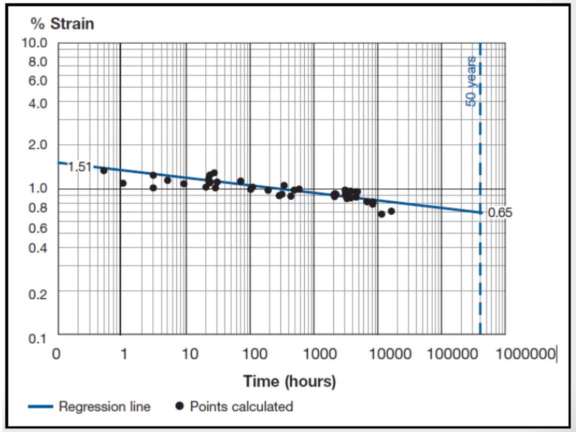
DIN EN 761 *ASTM D2990*

Flexural Creep



ASTM D2990

Tensile Creep



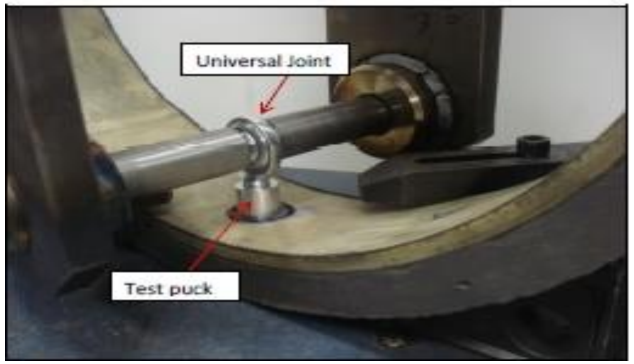
ASTM D2992

Hydrostatic Design Basis (HDB)

Demonstration Testing

Manufacturing

New or Future Connections



Adhesion Testing

Acceptance Testing

- Ensures a quality lining system has been installed
- Confirms contractual requirements and the basis of design are satisfied
- May include:
  - ➢ Measuring applied thickness and consistency of the installed materials
  - ➢ Adhesion testing
  - ➢ Short-term mechanical properties testing from field samples
  - ➢ Hydrostatic leakage (pressure) testing
  - ➢ Visual/CCTV inspection
  - ➢ Bacteriological testing

CCTV Inspection

Fit & Finish

MIAMIBEACH
City of Miami Beach, 1700 Convention Center Drive, Miami Beach, Florida 33139, www.miamibeachfl.gov

PUBLIC WORKS DEPARTMENT
TEL: 305-673-7080, FAX: 305-673-7028

WATER MAIN/ SERVICES
PRESSURE/ LEAKAGE TEST

Project: SUNSET HARBOUR IMPROVEMENTS - LINING 20" Water Main under Collins Canal
Location: DADE BLVD BETWEEN PURDY AVE & WEST AVE

Date: 8/4/2016 W.O. #: 71766
Crew Supervisor: LANZO
Start Time: 8:30 AM Start Pressure: 100 PSI
End Time: 10:30 AM End Pressure: 98 PSI
Total Test Time: 2HRS Average Pressure: 99 PSI
Pipe Material: D.I.P /LINER Type of joints: PUSH

ALLOWABLE LEAKAGE / AWWA C 600

	Section 1	Section 2	Section 3	Total
S = Length of pipe-Lin. Feet	175	/	/	175
D = Diameter of pipe-inches	20"	/	/	20"
P = Average test pressure (Psi)	99	/	/	99
L = Allowable leak (Gals/Hr.) **= SD √P / 148000**	0.235	/	/	0.235
Total Allowable leak in 2 hours (Oz.)	60.23	/	/	60.23

Amount of water used to maintain test pressure: – Gals. 12 Oz.

TEST RESULTS: **PASSED** ☒ **FAILED** ☐

Remarks: DEO SONNY FROM CMB OPERATIONS WITNESSED PRESSURE TEST.

Approved by: /GERARD HILLS
WITNESS/ Inspector

Engineer

Infrastructure (Utilities) Director

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Hydrostatic Testing

Type and Acceptance Testing Requirements

Lining System	Overall Guidance	Type Tests	Acceptance Tests
CML	AWWA C602	Compressive strength (ASTM C39) Slump Test (ASTM C143)	Compressive strength (ASTM C39) Visual inspection for defects Surface finish - Hazen-Williams Coefficient
PL	AWWA C620 AWWA C210 ASTM F2831 ASTM F3182	Flexural (ASTM D790), Tensile (ASTM D638) Adhesion (ASTM D4541 and ASTM D3359) Sag resistance	Dry film thickness Adhesion Hydrostatic leakage test (ASTM F1216)
CIPP	ASTM D5813 ASTM F1216 ASTM F1743 ASTM F2019	Tensile (ASTM D638 and ASTM D2290) Flexural (ASTM D790) Tensile Creep (ASTM D2990) Burst (ASTM D1599) HDB (ASTM D2992)	Tensile (ASTM D638/D2290) Flexural (ASTM D790) Hydrostatic leakage test (ASTM F1216)
CFL & SL	ASTM F585	AWWA C901/C906 ASTM D3350 AWWA C900/C905 ASTM D1784	Hydrostatic pressure test (ASTM F2164)
CFRP	AWWA C305	Tensile (ASTM D3039) Compressive (ASTM D6641) Shear (ASTM D7616)	Tensile (ASTM D3039) Compressive (ASTM D6641) Shear (ASTM D7616)

Type and Acceptance Test Sampling Requirements Example (CIPP)

Test Method	Diameter Range	Test Results Desired		CIPP Installed Thickness	Minimum Sample Dimensions Required	Total Samples Required
		Hoop Properties	Axial Properties			
Restrained Samples						
ASTM D2290 (Tensile)	Up to 16 in*	x		3-15 mm	18 in long	1
ASTM D638 (Tensile)	All		x			
ASTM D790 (Flexural)	All	x	x			
Plate Samples						
ASTM D638 (Tensile) ASTM D790 (Flexural)	All	x	x	3-6 mm	10 in x 18 in OR 10 in x 10 in	1 2
				7.5-12 mm	13 in x 23 in OR 13 in x 13 in	1 2
				13.5-15 mm	14 in x 25 in OR 14 in x 14 in	1 2

* Dependent on capabilities of third party test lab

Questions?

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