Ongoing Evolution of Pressure Pipe Rehabilitation






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Overview

- A brief history of water mains and rehabilitation
- Relining Technologies and M28
- AWWA White Paper ***"Structural Classifications of Lining Systems - Suggested Protocol for Structural Product Classification"***
  - Problem Definitions
  - Functional Objectives of Pressure Pipe Linings (Watertightness)
  - Testing to Meet Design Objectives
- There's a lot going on out there…
  - New and Developing AWWA Standards

A brief history of mostly iron water mains (and rehab)

1664 – 1st Pit cast iron in Versailles, France

1804 – 1st NA CI install Philadelphia, PA

The Age of Iron Pipe

1600

1700

1800

1900

2000

1652 - Boston, MA – hollowed out logs

1834 – 1st NA CI Foundry Millville, NJ

1903 – 1st AWWA Standard for pit CI
1922 – Centrifugal casting method invented (thinner wall pipe)
1937 – 1st rubber gaskets not a very good joint)
1939 –1st AWWA Standard for Centrifugally CI
1948 – DI Invented
1950's – Lead and galvanized iron house connections to copper
1957 – 1st push-on joint rubber gasket (lead fades away)
1965 – 1st AWWA DI Standard
1970's – Widespread use of internal linings in CI and DI pipe in manufacturing

Most vulnerable iron inventories
~ 1953 forward
- Stopped by some with corrosion protection
- Corrosion protection not practiced by many to this day

A brief history of pressure rehab

1900 1925 1950 1975 2000

Man-entry CML -1905 Australia

CML in New Jersey- 1934

1940's – Sliplining in NA

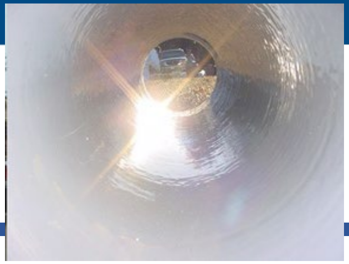
1955 – 1st NA HDPE

PL – Epoxy (UK) 1970

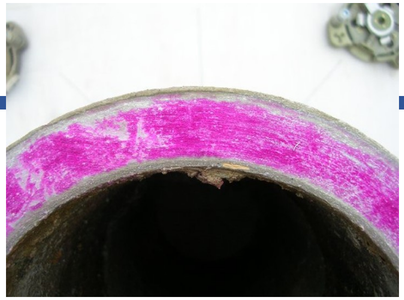
Gravity CIPP - 1971

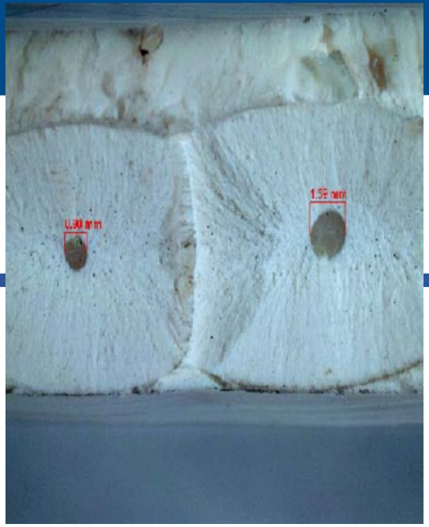
1990's –HDPE and PVC as CFL

Fully Structural CIPP - 1998



PL –PU in NA 2002





AC Pipe Invented -1913

JM AC Pipe In NA -1930

SS-P-351 1940

AWWA C400 1953 - AC

AWWA C900 PVC

Rise of Thermoplastics

1900

1925

1950

1975

2000

1st PVC pipes in Germany -1936-40

1955 – 1st NA HDPE

ASTM Series PVC ~ mid to late 60's

Early 80's – 1st HDPE with HDS

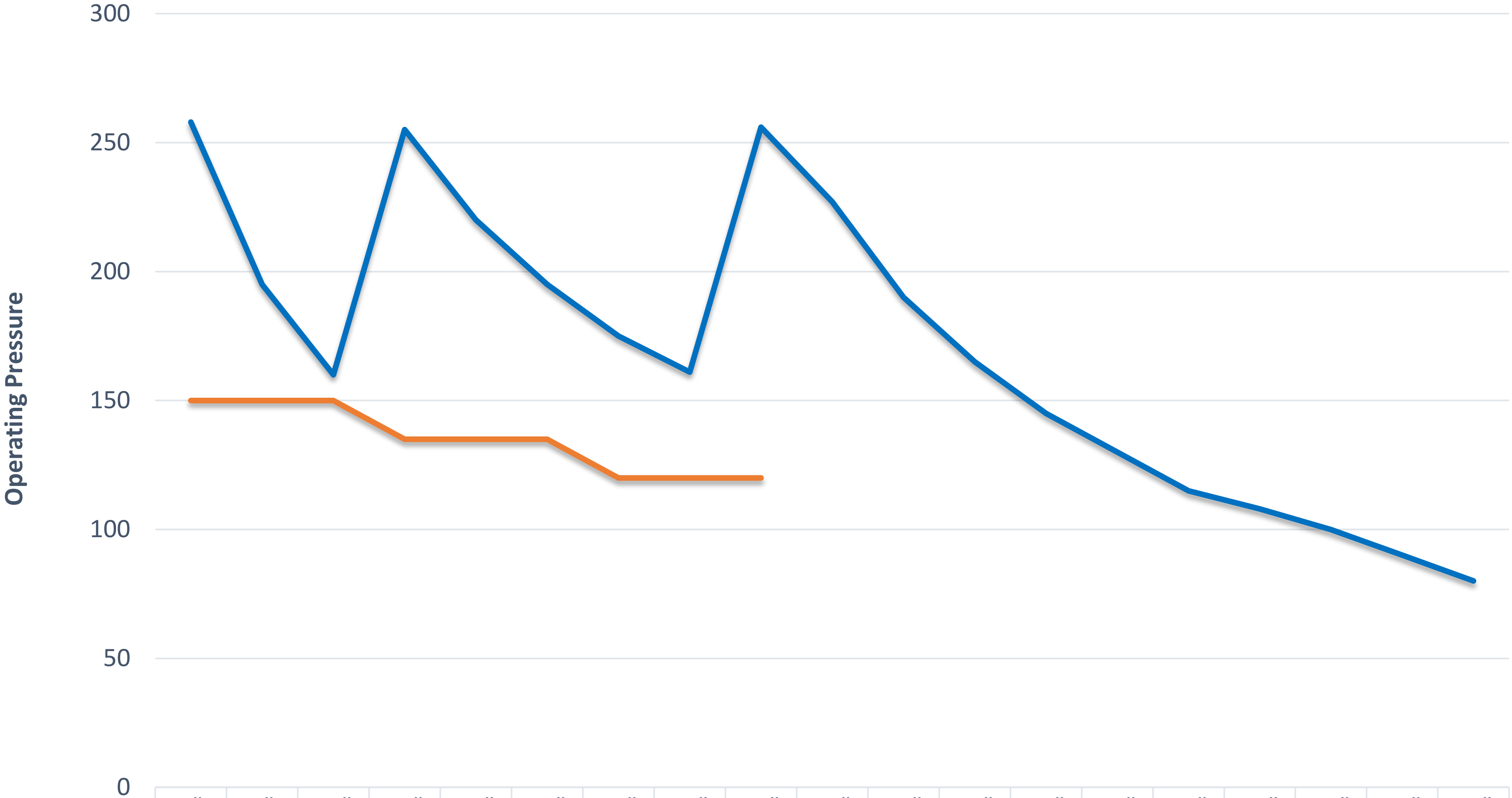
4710 HDPE in NA ~ 2008

A brief history of everything else – what rehab technologies will work on these materials?

Class IV CIPP Liner Material Advancements

Composite Tube Materials

- Advancements in Fiberglass
- Increased Technical Envelope



	6"	8"	10"	12"	14"	16"	18"	20"	24"	30"	36"	42"	48"	54"	60"	66"	72"	84"	96"
Glass	258	195	160	255	220	195	175	161	256	227	190	165	145	130	115	108	100	90	80
Woven	150	150	150	135	135	135	120	120	120										

AWWA M28

- Problem definitions
- Technology overview
- Matching problems to technology
- Planning and delivery considerations
    - Logistical Considerations (maintaining service and communications issues)
    - Overall Programing
- Common approaches to pipe prep for lining technologies
- Qualitative overview of Structural Lining

This is not just a North American Issue

- In ISO 11295, subcommittee TC138/SC8 'Rehabilitation of pipeline systems' has published structural classifications for pressure pipe liners which are closely aligned with those of AWWA Manual M28
  - Class D (non-structural) through Class A (fully structural) as opposed to Class I through IV
  - Similar qualitative measures
- In NA, the AWWA sub-committee on *'Structural Classifications of Lining Systems'* has produced a ***Suggested Protocol for Structural Product Classification***
- While much is the same there are subtle differences in definitions, terminology, and technical approach

Liner characteristics	Class A	Class B	Class C	Class D
Can survive internally or externally induced (burst, bending or shear) failure of host pipe	✓	—	—	—
Long-term pressure rating ⩾ maximum allowable operating pressure (MAOP)	✓	—	—	—
Inherent ring stiffness[a]	✓	✓	—[b]	—[b]
Long-term hole and gap spanning at MAOP	✓	✓[c]	✓	—
Provides internal barrier layer[d]	✓	✓	✓	✓

[a] The minimum requirement is for the liner to be self-supporting when pipe is depressurized.

[b] The liner relies on adhesion to the host pipe to be self-supporting when depressurized.

[c] The liner becomes sufficiently close-fit for radial transfer of internal pressure stress to the host pipe, either during installation or within a short period from initial application of operating pressure.

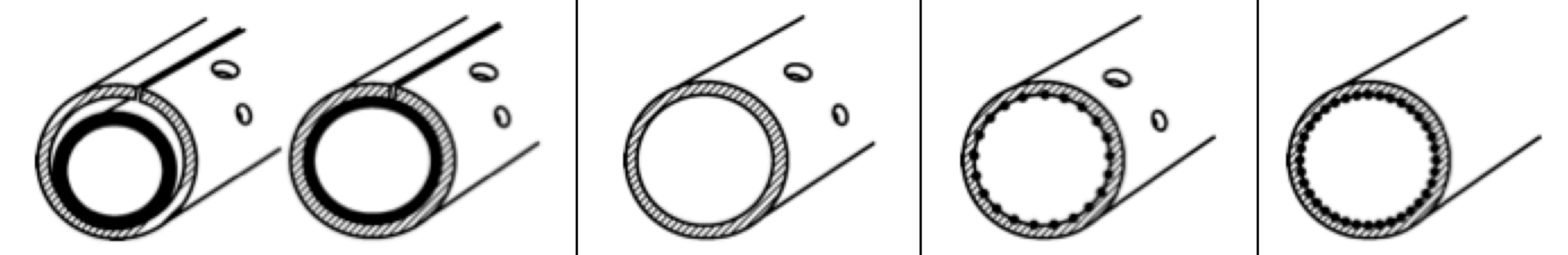
[d] The liner serves as barrier to the corrosion, abrasion and/or tuberculation/scaling of the host pipe and to the contamination of the pipe contents by the host pipe; it also generally reduces surface roughness for improved flow capacity.

ISO Structural Classifications

LINER CHARACTERISTICS	NON-STRUCTURAL	SEMI-STRUCTURAL		FULLY STRUCTURAL
	CLASS I	CLASS II	CLASS III	CLASS IV
INTERNAL CORROSION BARRIER	YES	YES	YES	YES
BRIDGES HOLES/GAPS AT PIPE OPERATING PRESSURE	NO	YES	YES	YES
INHERENT RING STIFFNESS	NO (depends on adhesion)	NO (depends on adhesion)	YES*	YES*
LONG-TERM INDEPENDENT PRESSURE RATING ≥ PIPE OPERATING PRESSURE	NO	NO	NO	YES
SURVIVES "BURST" FAILURE OF HOST PIPE	NO	NO	NO	YES

AWWA Structural Classifications

ISO's Journey from Qualitative to Quantitative taught us some subtle lessons

ISO Class A	Class B	Class C	Class D
Independent	Interactive		
			
loose-fit close-fit	inherent ring stiffness	relies on adhesion	relies on adhesion
Fully structural	Semi-structural		Non-structural
AWWA Class IV	Class III	Class II	Class I

- Important: the full ISO defined terms *independent pressure pipe liner* and *interactive pressure pipe liner* refer to action of the liner in resisting ***internal pressure*** only.
- Structural action of a flexible liner in resisting ***external loads*** is always interactive: enhanced by restraint of host pipe and/or dependent on support from surrounding soil.

Where we are ? – Structural Classification Objectives

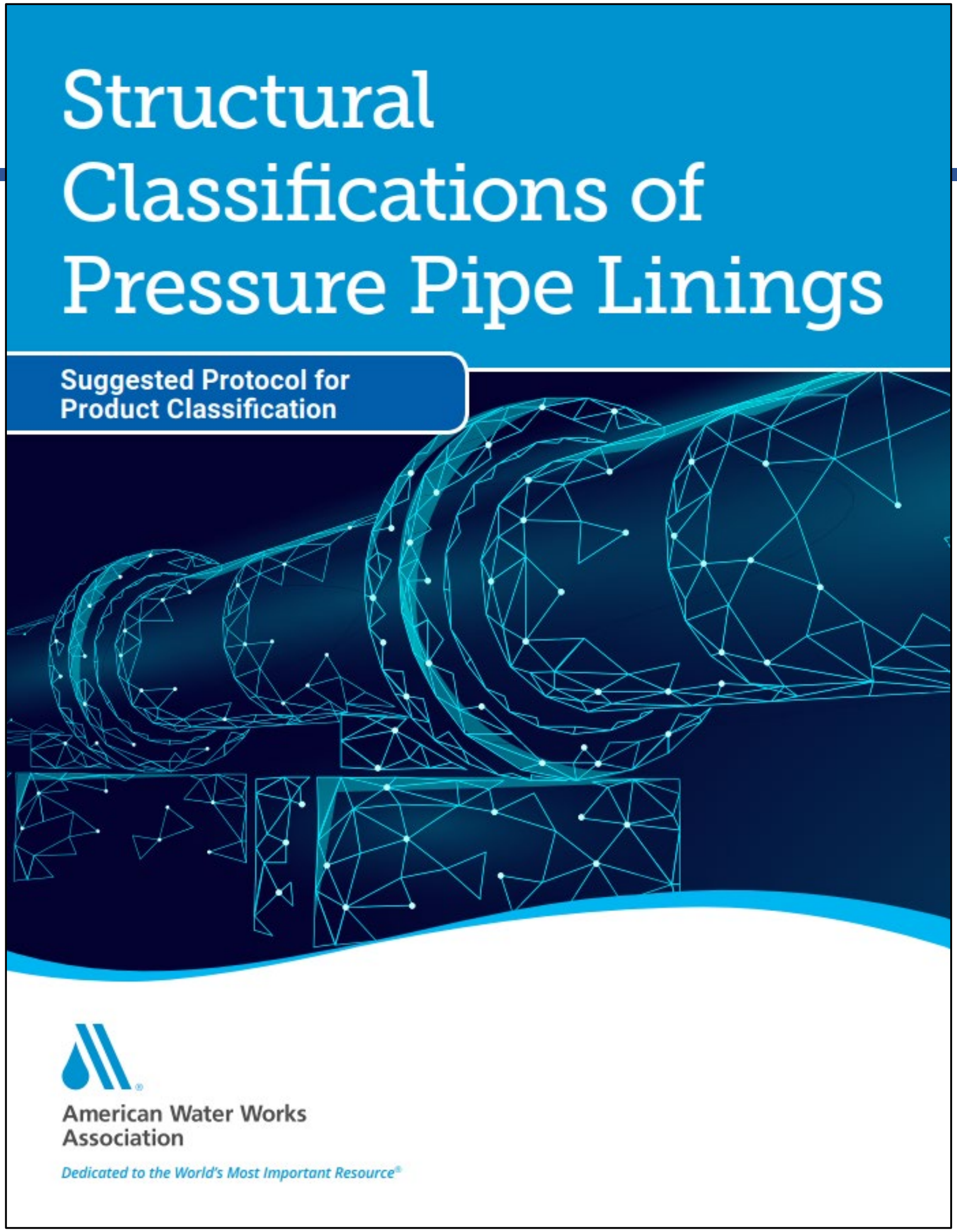
Table 1: General Structural Classifications Objectives

Liner Characteristics	Non-Structural	Semi-Structural (Interactive)		Fully Structural
	Internal Coating	*Hole and gap span*	*Hole and gap span + ring stiffness*	*Structural Resistance for all specified loads (internal & external)*
	Class I	Class II	Class III	Class IV
Internal corrosion protection	✔	✔	✔	✔
Reliable adhesion to the host pipe	See Note 1 Below	✔	See Note 2 Below	See Note 2 Below
Hole and gap span at MAOP		✔	✔	✔
Inherent ring stiffness (hydrostatic pressure or vacuum loads only)	See Note 1 Below	See Note 1 Below	✔	✔
Positive connection to service taps and sealed at other discontinuities (water tightness)			✔	✔
Inherent ring stiffness (all 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, where services are reinstated robotically. There are also situations where adhesion is not desirable, such as above ground applications with broad temperature swings.

- Structural Classification of Linings – Suggested Protocol for Product Classification
  - Takes qualitative concepts to a quantitative format
  - Provides guidance on design and product selection for all lining products
  - Provides illustrative examples of sound engineering judgement to go beyond current design code



Some Practical Aspects of the AWWA Structural Classifications Framework

- **Alignment of Lining Application Requirements with an Owner's Design Objectives**
  - When is a Class IV (or any other Class) liner really a Class IV liner???
  - Need to match products to Owner's Design Objectives
  - Owner's design objectives many be similar but often vary considerably

- **How Do We Do This?**

A. *Problem Definition Statements* – The Owner/Engineer needs to quantify failure applied loads and design condition

B. *Type Tests* – the products need quantifiable measures of short and long term mechanical/chemical resistance properties

C. *Acceptance Tests* – How we measure in the field that we met the design objectives

Structural Classifications of Pressure Pipe Linings

Suggested Protocol for Product Classification

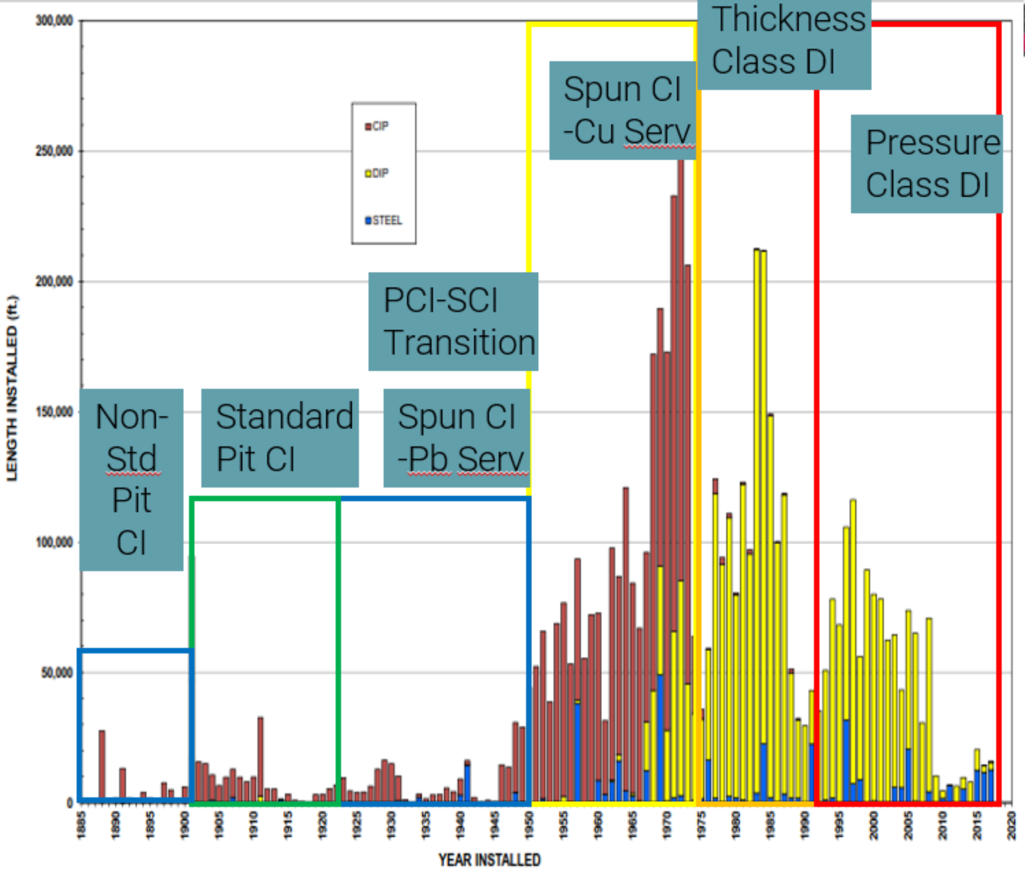
AWWA Committee Report

Table of Contents

Problem Definition Statements

Define the objectives of the lining project in terms of a problem statement and specific design requirements including a summary of:

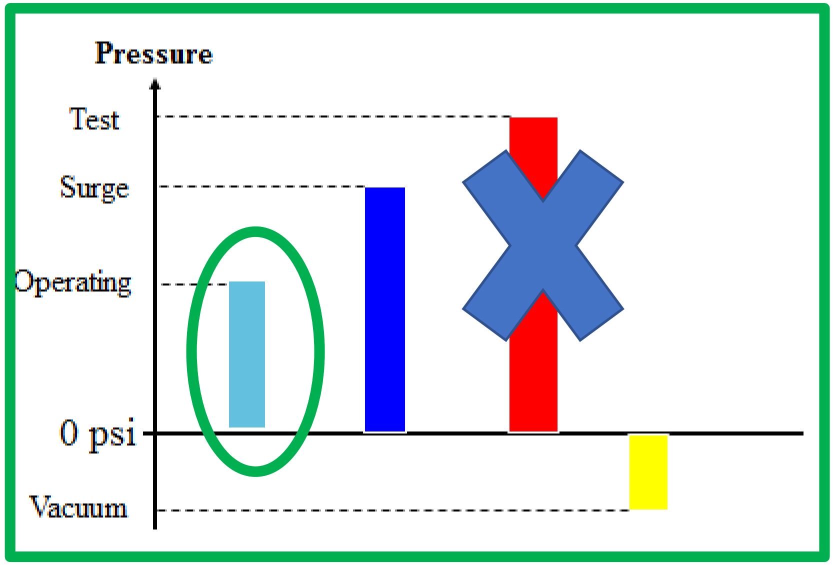
1. The host pipe description
   - (material, year of manufacture, diameter, wall thickness, pressure class, joint type, etc.),
   - horizontal/vertical alignment,
   - the major deficiencies and deterioration mechanisms intended to be addressed and
   - general chemistry of the fluid to be conveyed.



Problem Definition Statements

Define the objectives of the lining project in terms of a problem statement and specific design requirements including a summary of:

2. All relevant internal pressures to be resisted by the lining system, including
   - Maximum applied pressure (MAP),
   - Maximum applied operating pressure) MAOP,
   - Occasional surge and recurrent surge (if applicable),
   - Vacuum pressures (if applicable) and
   - The intended magnitude and duration of the test pressure.



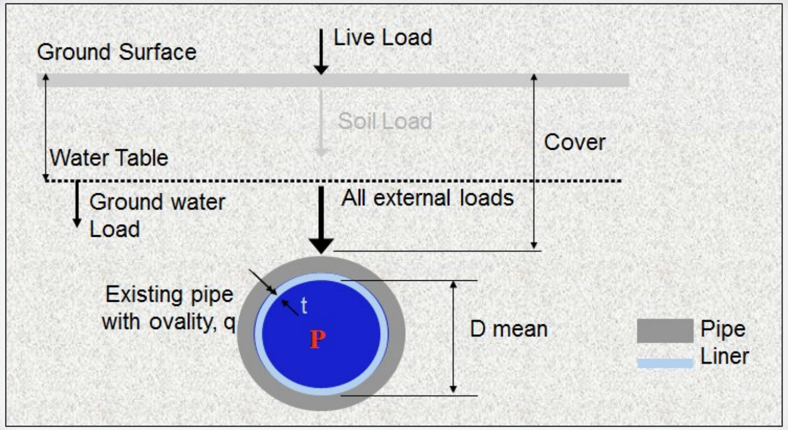
It's a leakage test not a structural test. Run it as one.

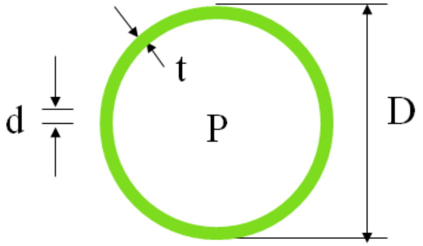
Determine structural adequacy through mechanical property review

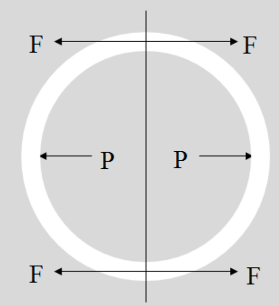
Problem Definition Statements

Define the objectives of the lining project in terms of a problem statement and specific design requirements including a summary of:

3. All relevant external loads to be resisted by the lining system including
   - the load duration
   - Relevant loads
     - Earth and groundwater loads with design duration if not intended to be long-term loading; and
     - Live loads – implied short-term duration unless otherwise stated).







CFRP Design Approach

- Consider degradation level of host pipe
- Stand-alone versus composite design (with inner core)
- Use LRFD

Circumferential Design

Limit State	Loads
CFRP Rupture	Internal pressure + External gravity loads
Buckling	External loads - Groundwater + Vacuum
Debonding	Empty pipe under external loads

Longitudinal Design

Limit State	Loads
CFRP Rupture	Internal pressure (Thrust, Poisson) + Temperature
Debonding	Internal pressure (Thrust, Poisson) + Temperature
Buckling	Temperature

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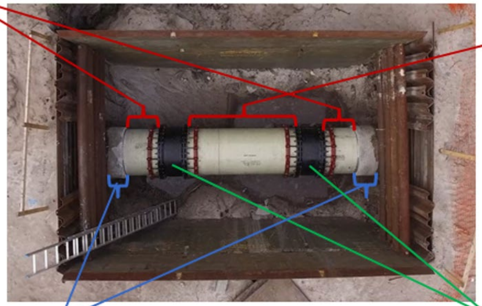
Problem Definition Statements

Define the objectives of the lining project in terms of a problem statement and specific design requirements including a summary of:

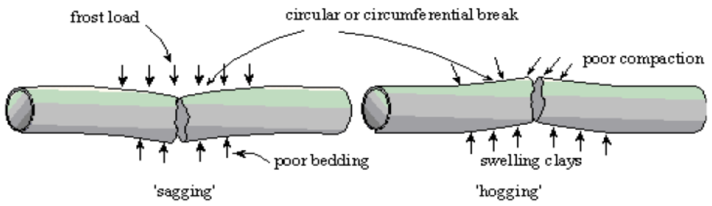
4. Practical design considerations to meet functional requirements of the lining system such as
   - The requirement to reinstate water services in a manner that does not compromise the overall hydrostatic integrity of the system.
   - Overall hydrostatic integrity requirements at closure, for example
   - Ability on to repair the lined pipe
   - Ability to tap the rehabilitated pipe in the future



Problem Definition Statements

Define the objectives of the lining project in terms of a problem statement and specific design requirements including a summary of:

5. The nature of the failure mode of the host pipe to be considered in design
   - Particularly important in instances where a Class IV Structural Classification is desired.
   - Brittle circumferential failures versus pitting corrosion
   - Burst, bending and shear requirements



Taking Qualitative Concepts to Quantitative Measures

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 categori… test methods listed for each property must be docu…

	Property	Technology	Test M…
Class I	Potable Water Certification	All	NSF/ANSI … (potable w…
	Material Properties	CML	ASTM C14… (slump test…
	Lining Thickness	All	
	System Hydraulics	All	
	Adhesion	Some Class I	ASTM D45… substrate) ASTM D72… (concrete s…
	All Class I attributes PLUS:		
Class II	Adhesion	All Class II	Per Class I…
	Hole Span @ MAOP	All Class II	Any or all o… D790; ISO 11296-4, A… B (initial fle… properties, bending)
			Any or all o… D2990; ISC… ISO 11296-… & D (flexura…
	Water Tightness	All Class II	Supporting… from end s… fittings ma… as applicab…
	Hydrostatic Integrity at Services	All Class II	

	Property	Technology	Te…
Class IV	All Class I, II & III attributes PLUS:		
	Adhesion	Some Class IV	Per Cla…
	Resists all internal and external pressures	All Class IV	Any or… D638; … ASTM … 8521; I… tensile…
			ASTM … and/or … (tensile…
		All Class IV	ASTM … term b…
		CIPP	ASTM F1216 (CIPP i…
		CFRP³	ASTM …
			ASTM …
		SL (FRP) CIPP⁴	ASTM … ISO 75…
			ISO 10… analysi…
		SL (HDPE)	ASTM … or PPI…
			ASTM …
			ANSI/A…
		SL (PVC)	ASTM …
			ANSI/A… or PPI…

3 AWWA C305 applies to CFRP used for the renewa… implemented at the discretion of the owner/enginee…
4 HDB testing is difficult to execute for CIPP and ma… long-term performance. If available, HDB test resul… measure vs short-term burst and long-term tensile …

Table 3: *Acceptance Testing*

Note: In order for a lining technology to be categori… test methods listed for each property must be docu…

	Property	Technology	Test M…
Class I	Drinking Water System Components – Health Effects	All	Bacteriolo…
	Material Properties	CML, PL	Compress…
	Lining Thickness	CML, PL	Physical measurem…
	Adhesion	Some Class I	Surface pr… and dryne…
			Visual and … inspection
			ASTM D45… substrate)
			ASTM D72… (concrete …
	All Class I attributes PLUS:		
Class II	Adhesion	All Class II	Per Class I…
	Hole Span @ MAOP	All Class II	ASTM D79… or ISO 112… Annex B (i… flexural pro… axial direc…
	Water Tightness	All Class II	ASTM F12… 8.3 (press… 2 times M… MAOP + 5… bar), which… or ISO 112… 7 (pressure… 1.5 times M…
	All Class I & II attributes PLUS:		
Class III	Adhesion	Some Class III	Per Class I…
	Ring Stiffness	All Class III	ASTM D79… or ISO 112… Annex B (i… flexural pro… hoop direc…

	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.

Some challenging issues

- It's a short list of a pretty long list but we'll focus on a couple of testing issues and one of design
  - ***Functional Requirements***
    - *Hydrostatic integrity*
      - *At service connections*
      - *At closures*
    - *Surviving failure of the host pipe (to bond or not to bond)*
  - ***Long term testing***
    - Hydrostatic strength (hoop direction)
    - Flexural strength (in all directions)
  - ***Design***
    - Having relevant design methods for radically different products
  - ***Acceptance Tests***
    - Carrying out meaningful tests post installation to reasonably confirm design intent has been achieved

An Emphasis on Watertightness

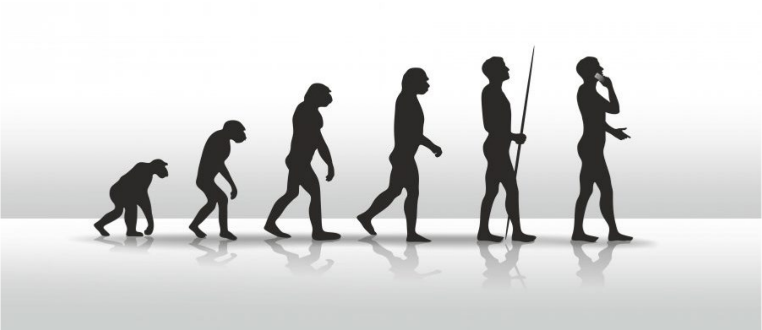
- **Advancements in technology and best practices have renewed focus on watertightness**
  - Advancements and long-term expectations are evolving, influencing approach to end connections
  - Innovation in robotics, as well as long-term standards & expectations are evolving for service connections
  - Focus shifting to watertightness from a long-term perspective

Watertightness – End Connections

Adhesive

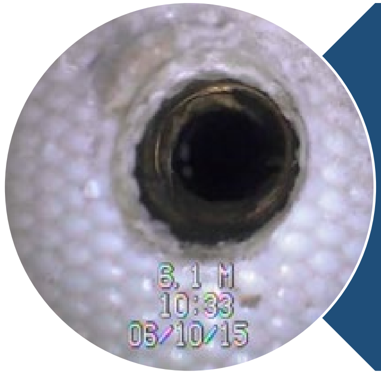
Mechanical

The Evolution of CIPP Closure

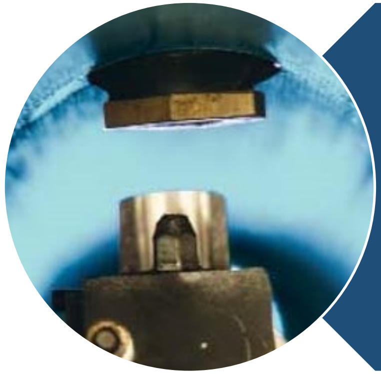


Adhesion to host	Mechanical end seal	Hymax connection	Spool-piece connection

Watertightness – Service Connections



Adhesive

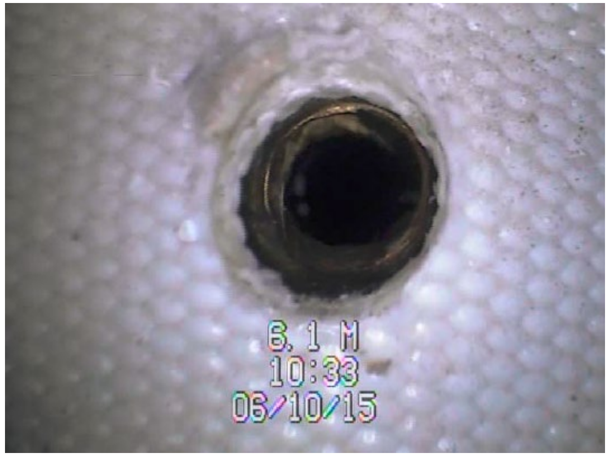


Mechanical

Historical Service Reinstatement Options

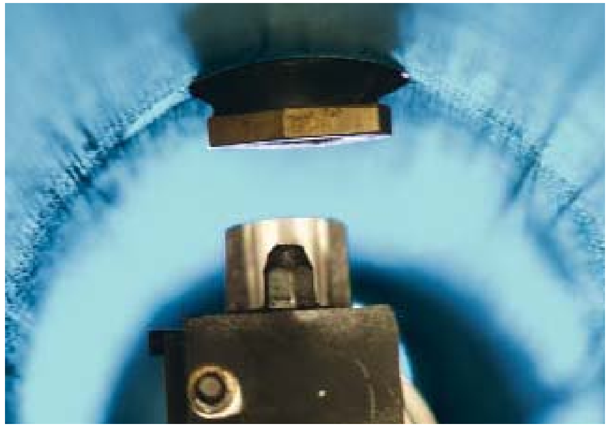
Adhesive reconnections (Relies on host pipe for watertightness)

- Plug and drill method whereby liner adheres to host pipe and service corporation



Excavated mechanical reconnections

- Involves open-cut excavation and installation of new mechanical connections at each service.

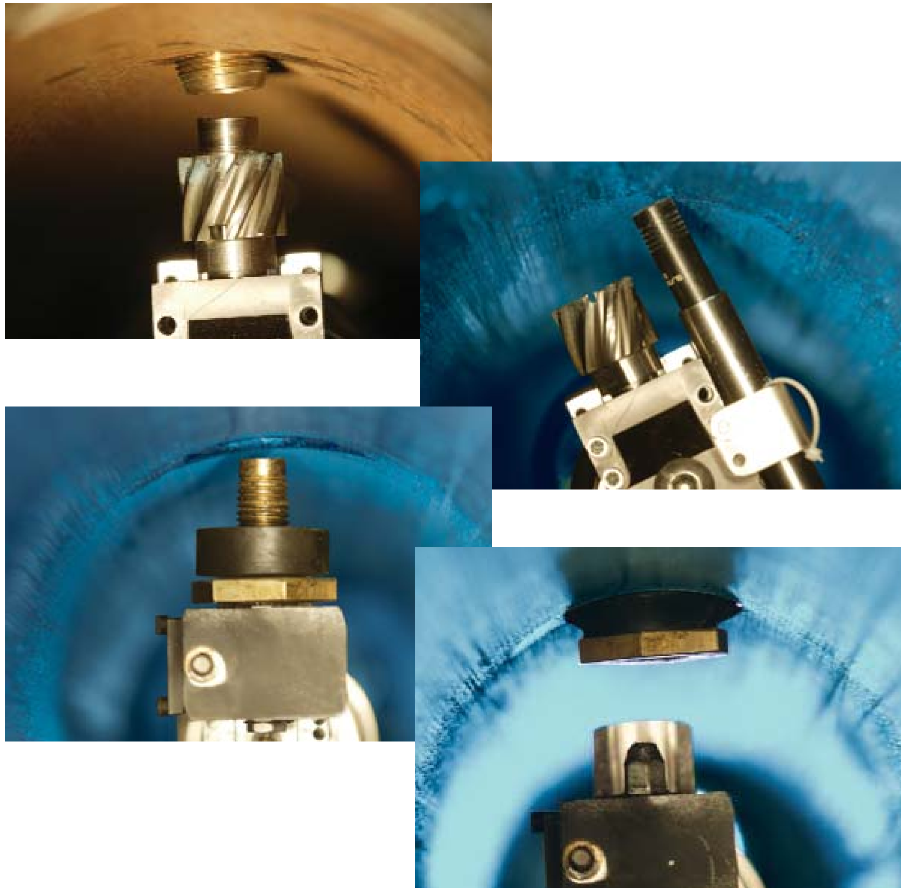


Robotic mechanical reconnection

- Robotic installation of a mechanical fitting to provide a watertight internal connection

Old Robotics

- Reverse thread of protruding services
- Plug existing services
- Locate & Drill at connection (post lining)
- Install mechanical fitting



- Highly inefficient:
  - One at a time
  - Miles traveled for each segment
- Success rate – just ok
- Limited to direct taps 1” and smaller
- Expensive

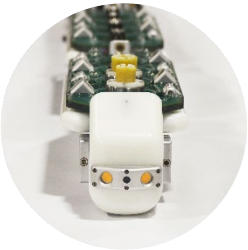
Need for updated and improved methods…

Next Generation Internal Mechanical Reinstatements

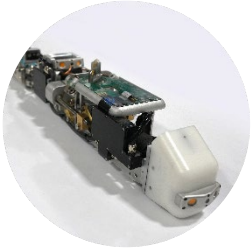
Measurement probe
Consists of laser sensors and inspection camera

Mechanical fittings
Utilizes a patented push-in-place "Corpbite" system that maximizes pull-out force

Self-locating plug
Installed prior to lining to prevent resin migration



Cartridge loading system
Holds up to 8 plugs/mechanical fittings to maximize production



Drilling tool
Detects exact location of plug prior to drilling

Interface software
Provides operator with easy-to-use interface for reinstating connections

Robotic Equipment – Measurement Probe

Consists of laser sensors and inspection camera

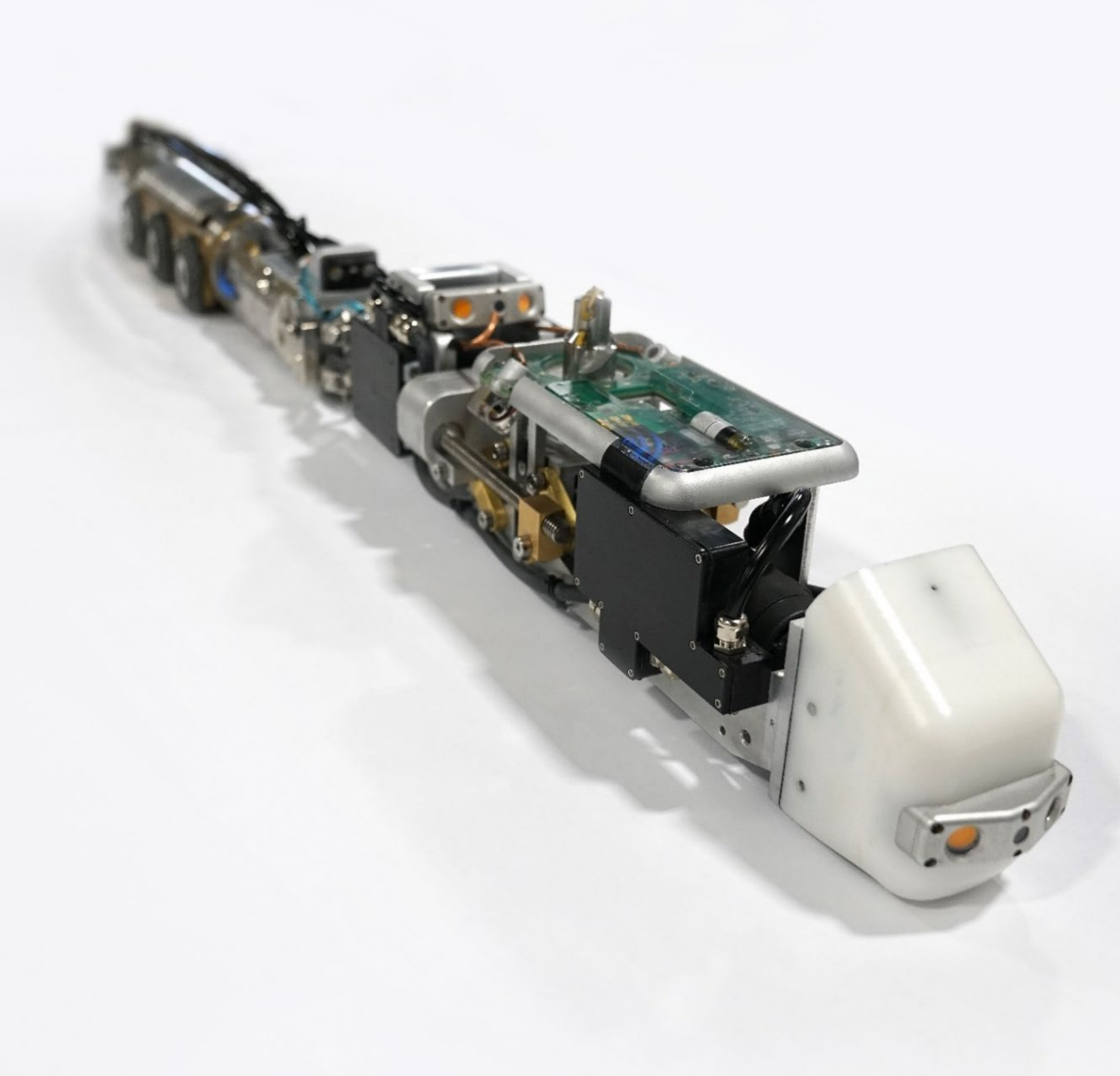
- Laser identifies corporation diameter and alignment to the host pipe
- Camera mounted on the probe validates the current position of the corporation valve

Service Relocation Device – Plug

Installed prior to lining

- Prevents resin migration during cure
- Magnetic array embedded into the rim of the device enables precise relocating after lining

Robotic Equipment – Drilling Tool



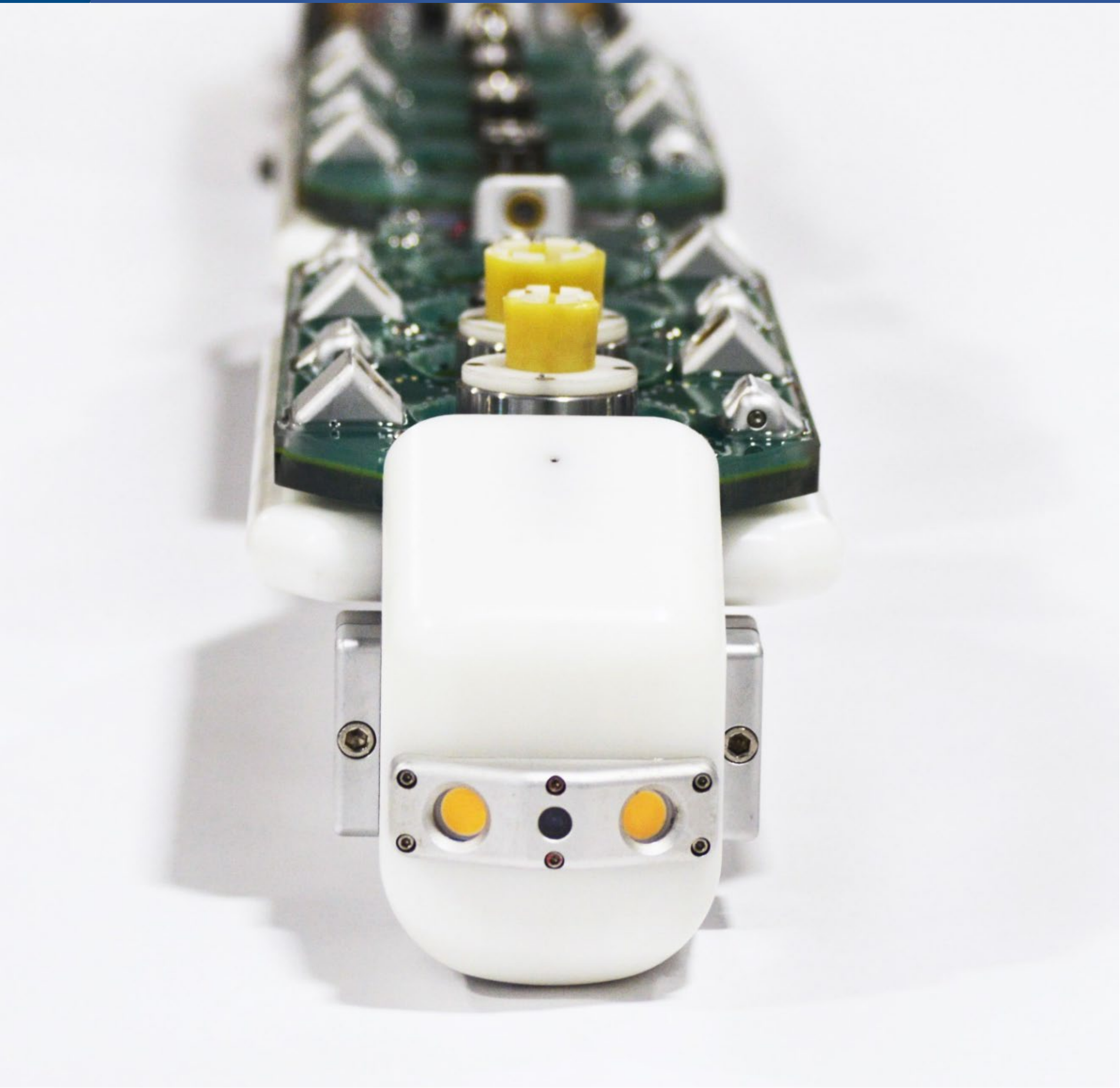
Contains cameras, lights and lasers to assist operator with alignment as well as sensors to detect exact location of plug prior to drilling

Drills plug out post-lining

Service Connection Hardware – Mechanical Fitting

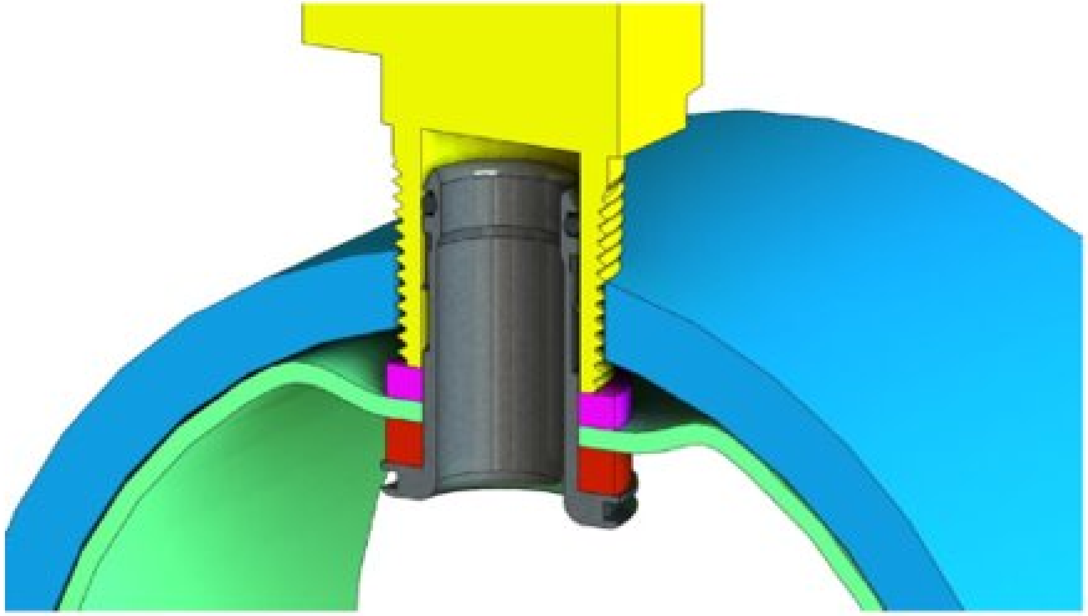
- Manufactured utilizing specialized stainless steel materials and gaskets that are capable of withstanding long-term exposure
- Utilizes a patented push-in-place "Corpbite" system that maximizes the pull-out force of the device while maintaining the low force required for installation

Robotic Equipment – Fitting and Plug Installation Tool

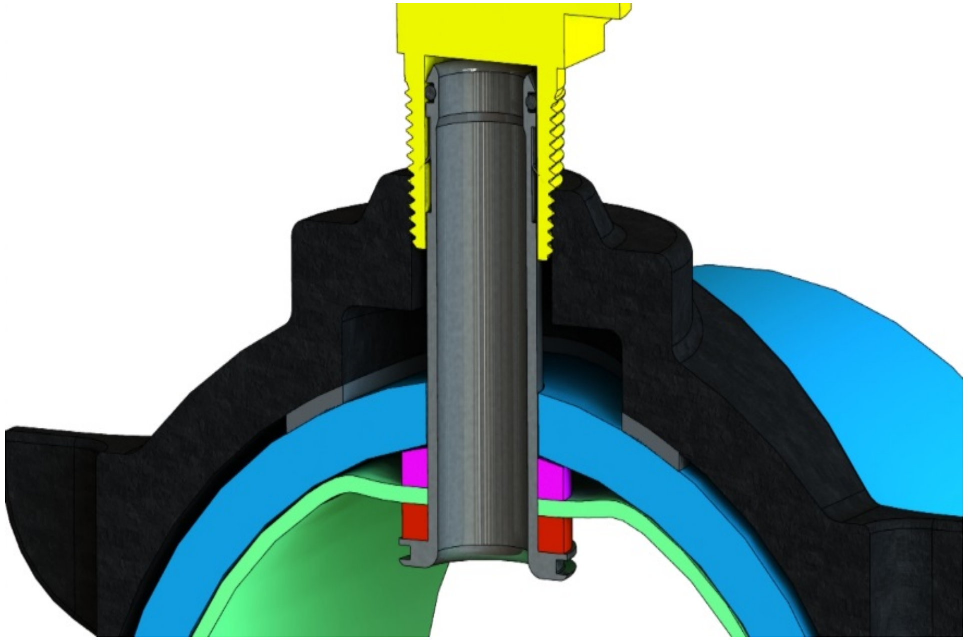


- Cartridge system holds up to 8 plugs/mechanical fittings in order to maximize production
- Each cartridge silo includes laser alignment tools and cameras for precise installation

Completed Watertight System



Direct tapped service

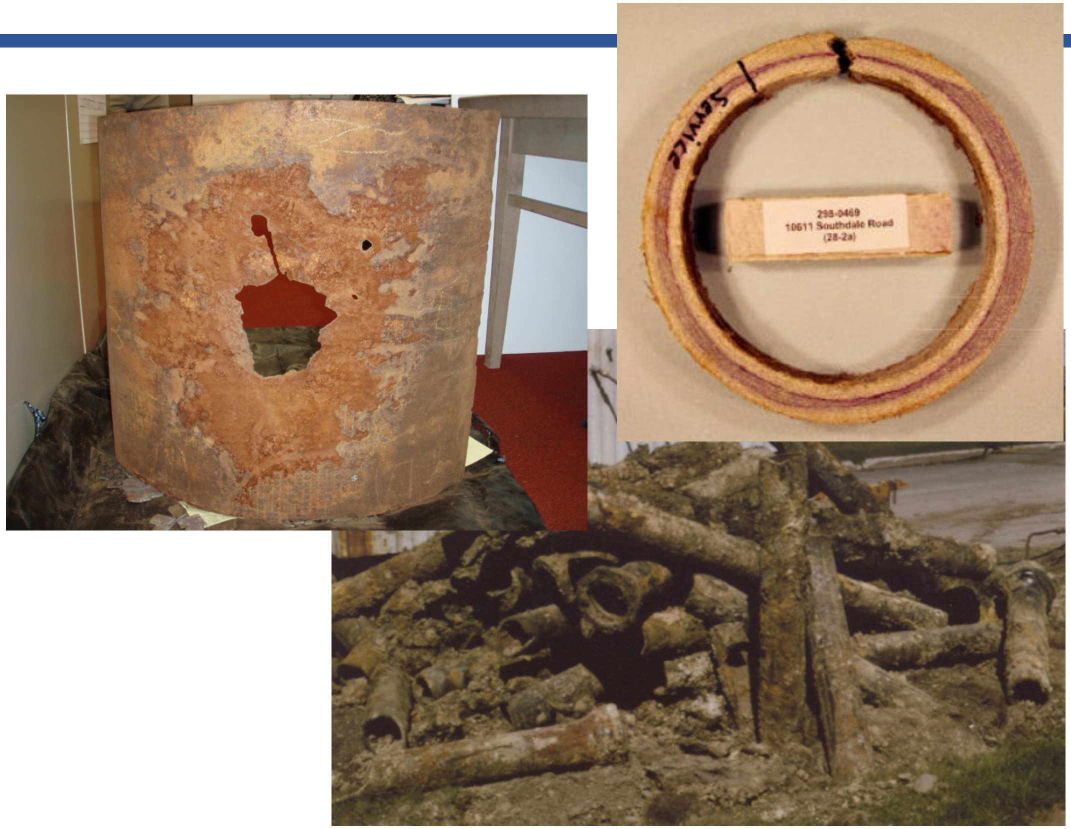


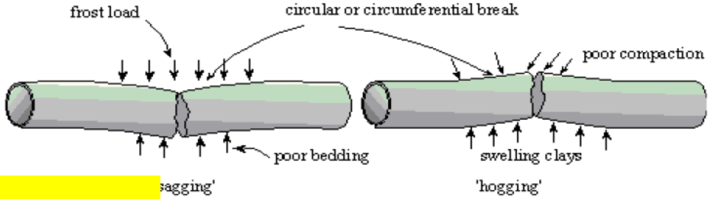
Saddle tapped service

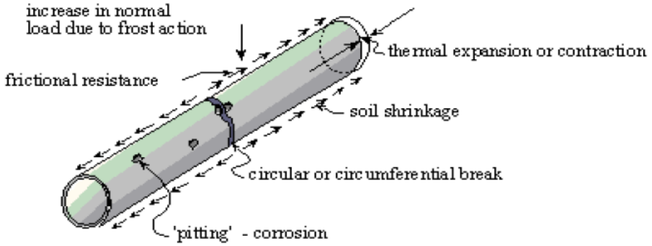
Completed Watertight System

Surviving failure of the host pipe – to bond or not to bond?

- Class IV liners are complex because the liners needs to survive a failure of the host pipe
- Excessive bond to the host pipe does not bode well in pipes that exhibit brittle fracture modes lined with brittle materials
- How does your host pipe fail? In brittle failure modes
  - Should I put in a pre-liner to preclude bond?
  - How do I reinstate services?



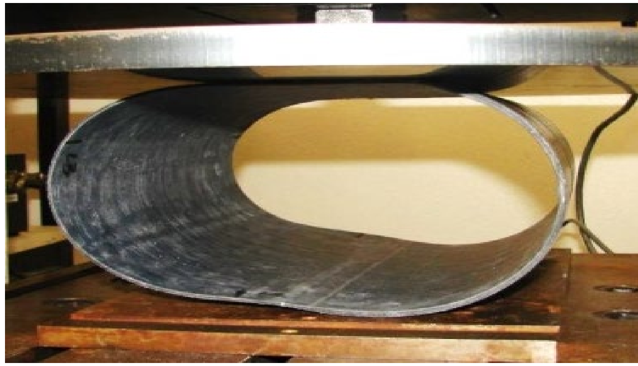




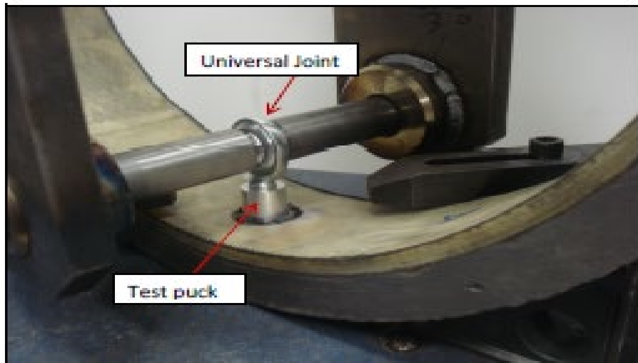
Typical CI Failure 3rd party drivers

Where we are? – testing objectives

- ISO's product testing standards ISO 11297-4/ 11298-4 (CIPP for pressure sewers and WM's) brought a number of practical implications of current liner structural classifications into sharper focus.
- We face the same practical issues:
  - Design, test approaches, pending long term test results and
    - *the demand to keep working while working to achieve consensus on a number of complex issues for a wide variety of products….*



- Core objectives for both committees:
  - Common, objective and verifiable criteria based on sound engineering principles
  - Assessing ***"fitness for purpose"*** of Pressure lining products for different clearly defined applications.

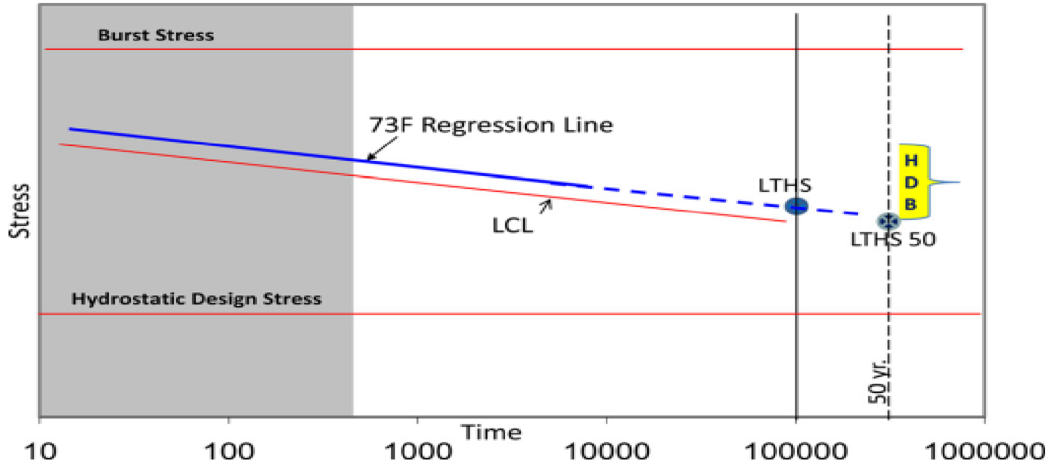


Short to Long term material properties

- Need to understand short and long term response to load (continuous, short term, and cyclic)
- Long term hydrostatic strength
  - ASTM D2990 and/or ISO 899-1 (tensile creep)
  - ASTM D2837/D2992 – HDB Testing
  - ISO 7509/10928 – Long-term failure pressure
- Very limited HDB tests for CIPP and in-field composites to date
  - Cost of testing is very high; As reinforcing scheme changes, product response can change
- If short term response is used as an interim measure use it conservatively
  - ASTM D1599 – Short-Time Hydraulic Pressure
  - ISO 8521 – Determination of the apparent initial circumferential tensile strength
  - NA consensus on appropriate reduction factors ~ 4:1 reduction
  - ISO Standards focus on use of known long term response products only

ASTM D1599/ISO 8521

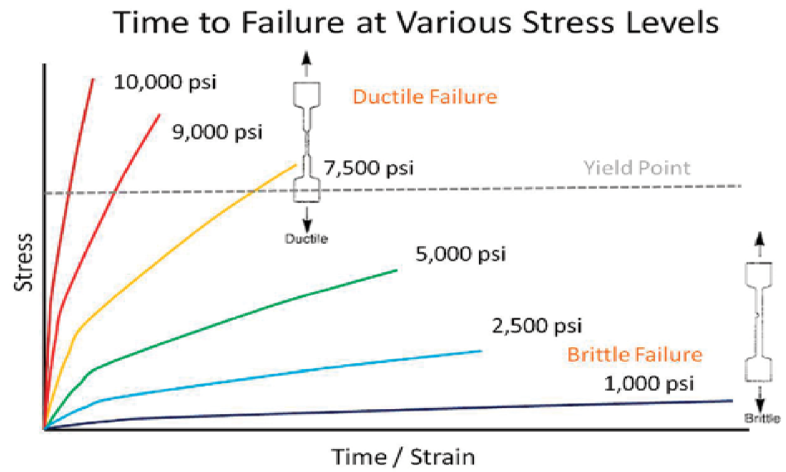
ASTM D2992

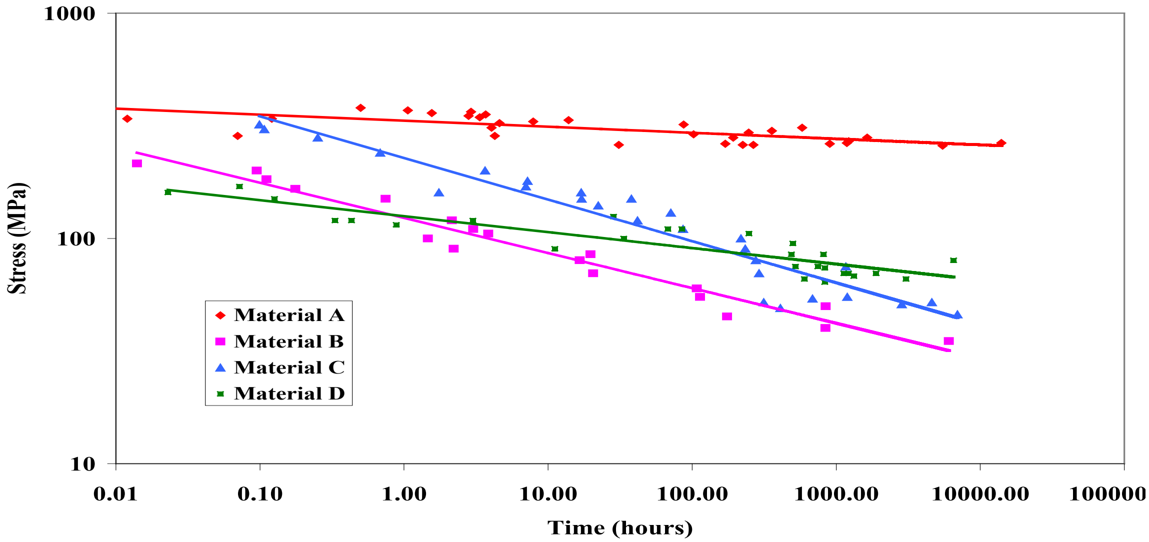


Hydrostatic Design Strength is not the only long term material issue

- Flexural strength diminishes over time at high stress levels
- Very little NA research on time dependent response of flexural strength to continued load application
- Established UK test for long-term flexural strength in dry, wet or acid conditions being adopted in ISO CIPP standards for both non-pressure and pressure applications
- Reduction factors from long-term creep stiffness tests are ***an unreliable guide*** to long-term strength response
  - Need to make better use of ASTM D2990 Tensile Creep Response and other testing regimen's

Understanding Creep Failure of Plastics, Jeffrey Jansen

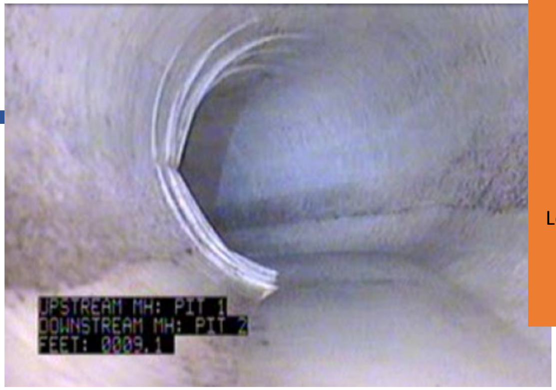




Gumbel & Lowe, No-Dig Berlin 2015, Paper 1-2

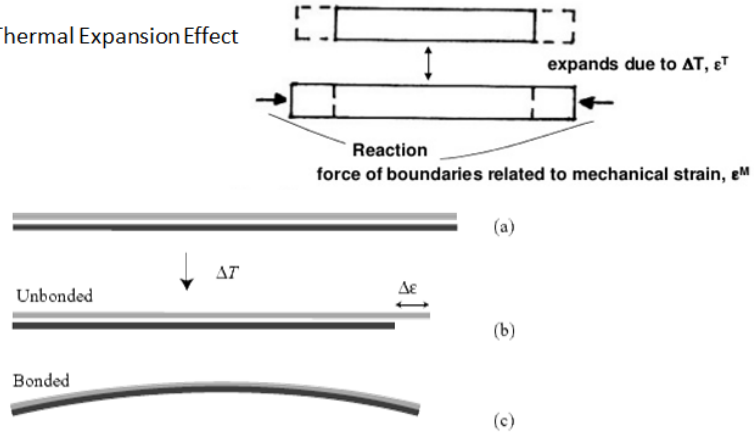
Design to the Product and the Application not an irrelevant standard

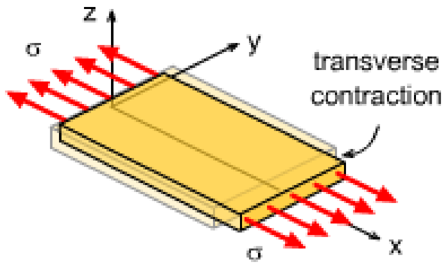
- Design methods need to reasonably match the products that they are intended for
  - It's seldom a perfect fit, but you need to assess the relevance of the design method to the product
- While ASTM F1216 has served the industry well for gravity, its evolution was based on:
  - Looking at flexure in the hoop direction only
  - Non-reinforced tubes - Isotropic as opposed to anisotropic lining material behavior
  - Very low pressure
- Good Guidance for composite materials in AWWA Standard C305 for *CFRP RENEWAL AND STRENGTHENING OF PCCP*
- *All WM rehab design needs to reflect the product and evolve to the problem*

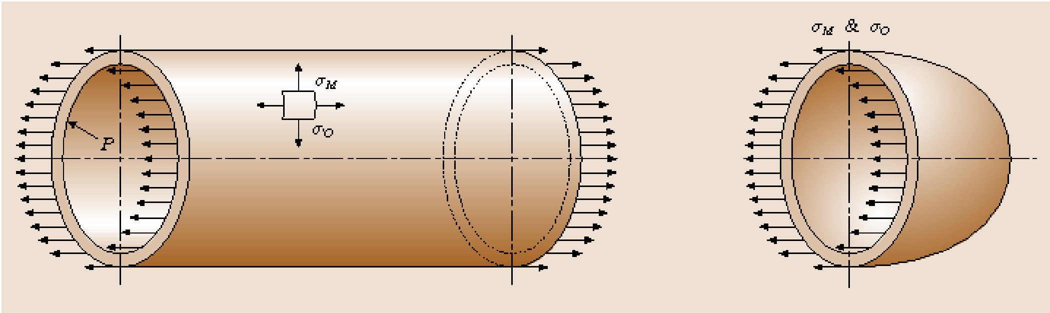


Design Checks	ASTM F1216	AWWA CFRP Draft
Hoop Design		
- Working Pressure	X	X
- Transient Pressure		X
- Groundwater/Vacuum	X	X
- Traffic Loads	X	X
- Soil Loads	X	X
- Ovality	X	X
- Deflection Limits		X
- Combined Loading		X
Longitudinal Design		
- Poisson's Effect		X
- Temperature Effect		X
- Thrust Effect		X

- Thermal Expansion Effect

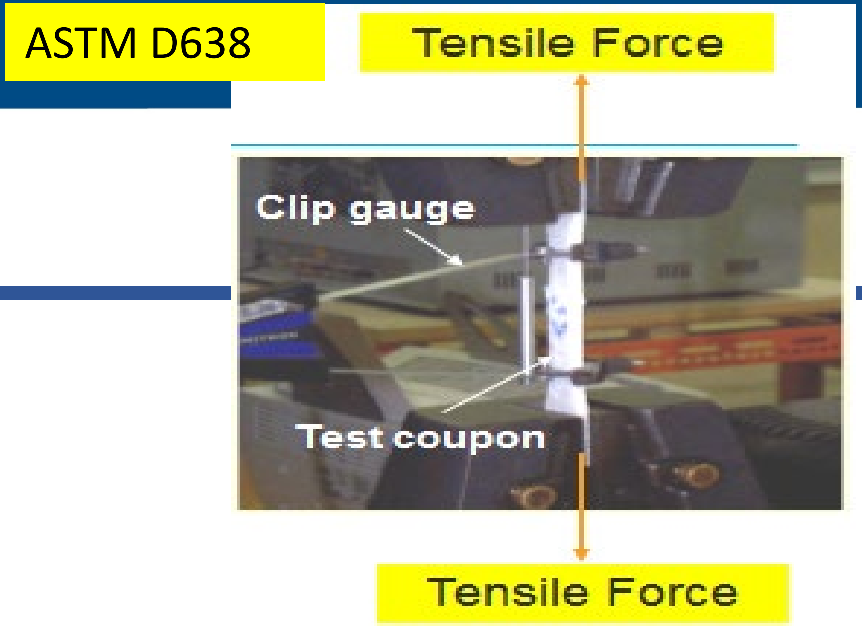


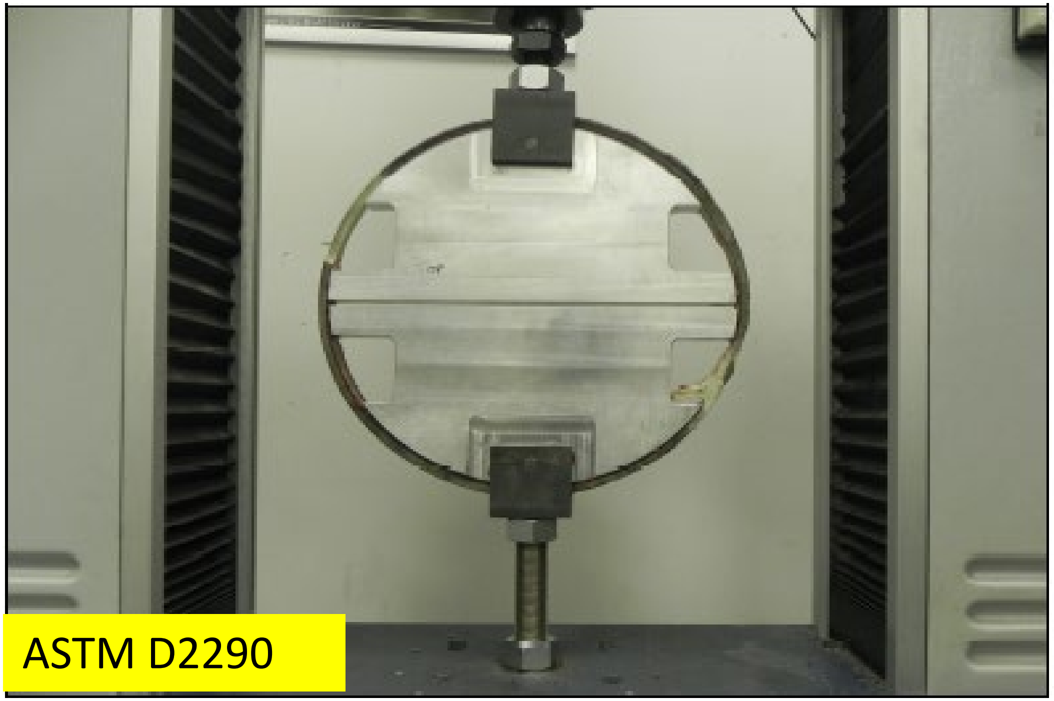




Testing after Installation

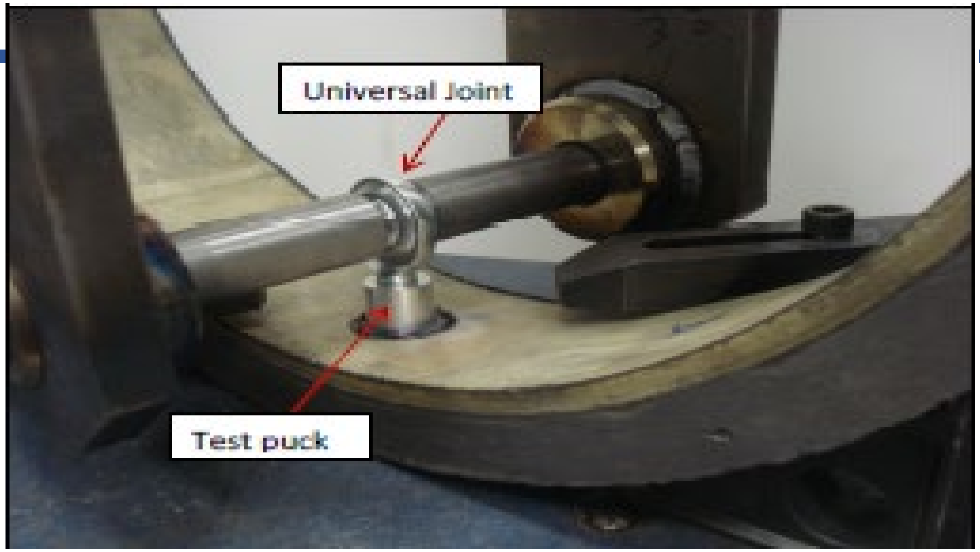
- Testing after installation needs to be related back to the design process
- Carrying out ASTM D638 Strip Tests alone to assess adequacy in the hoop direction can be very misleading
  - Consider ISO 527-4 rationale of Test conditions for isotropic and anisotropic fiber-reinforced plastic composites
  - Use of more direct measurement of hoop stress in an ASTM D2290 test or by the various methods of ISO 8521 referenced by ISO 11297-4 provides greater insight into tensile capacity of the "product", not just a piece of the product

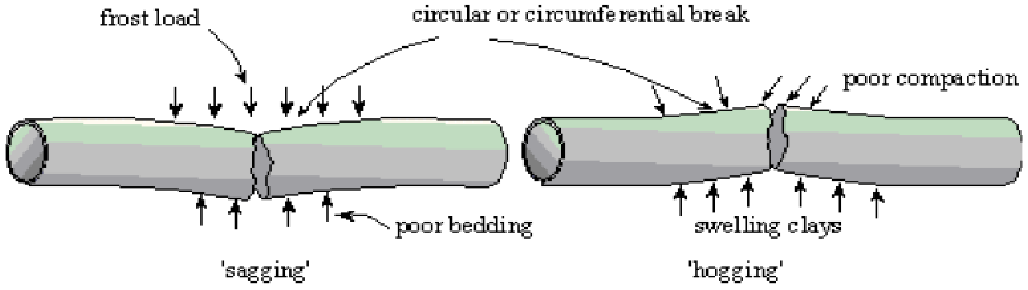




Testing after Installation

- If your structural or functional design requirements require adhesion to the host pipe
  - Employ replicatable visual standards for surface preparation
  - Carry out adhesive testing to confirm it works
    - ASTM D4541/ISO 4624 (metal substrate); ASTM D7234 (concrete substrate)
- Consider the nature of your long term reliance on host pipe in design
  - Functional requirements are for localized bond at service connections
    - Mechanical reinstatement devices preclude this need
  - Comprehensive bond is counterproductive when your host pipe fails in flexure;





If the manufacturing is done in the field; we need to be very structured about Type Testing, Design Acceptance Tests and Process

1. ***Owner's problem definition and technology selection***
2. ***Type testing*** by the product manufacturer
   - Confirm the short and long term mechanical properties
   - Confirm functional objectives (e.g. hydrostatic integrity at service connections)
     - ***Demonstration testing if you can't measure something directly***
3. ***Design Process***

- Protocol Submissions and Records

4. ***Acceptance Testing (verification tests)***
   - Visual
   - Hydrostatic integrity
   - Confirmation of meeting design intent (confirmation of relevant mechanical properties)

ASTM D1599

ASTM D2992

Design basis – best we have is White Paper non-mandatory section

Wet out and Inversion Logs; ASTM F2994 or ASTM F1216 (CIPP impregnation)

Curing Logs – monitor for compliance with Design Intent

Sampling Approach to confirm design; White Paper and new AWWA Standard

Closure

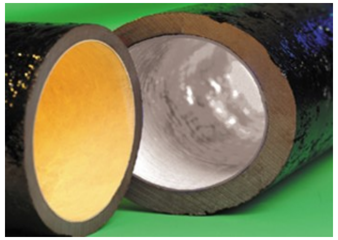
There's a lot going on out there in the world of Water Main Rehab

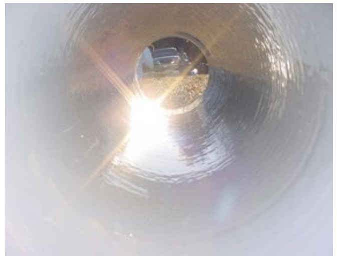
- Spray-on Polymerics AWWA C630 – 2019
- Structural Classifications White Paper – fall 2019
- AWWA Pipe Bursting for Winter 2019/2020
- New AWWA M28 for 2020
- 1st AWWA CIPP for WM Rehab in 2020
- WM Sliplining Rehab for 2020

CIPP for pressure applications is considerably more complex than gravity sewer applications

- Don't be discouraged much knowledge and experience is in place to facilitate looking at increasing your tool box for small and large scale water main rehabilitation programs
- The release of the AWWA Structural Classifications White Paper provides considerable quantitative tests in your hands complete with some process to apply them
- Solve this generation of pipe rehab problems and move on to the next one

Queries





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