Ongoing Evolution of Pressure Pipe Rehabilitation

Chris Macey, P. Eng.
Americas Technical Practice Lead
Condition Assessment and Rehabilitation
Conveyance Infrastructure

Andrew Costa
Vice President of Sales, East Region
Insituform Technologies, LLC

AECOM
AEGION
Insituform
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

1652 - Boston, MA – hollowed out logs

1804 – 1st NA CI install Philadelphia, PA

1800

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

The Age of Iron Pipe

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

- **1905**: Man-entry CML in Australia
- **1925**: CML in New Jersey
- **1940's**: Sliplining in NA
- **1950**: 1st NA HDPE
- **1955**: 1st NA HDPE
- **1970**: PL – Epoxy (UK)
- **1971**: Gravity CIPP
- **1975**: HDPE and PVC as CFL
- **1990's**: HDPE and PVC as CFL
- **2002**: Fully Structural CIPP
- **2005**: PL – PU in NA
A brief history of everything else – what rehab technologies will work on these materials?
Composite Tube Materials

- Advancements in Fiberglass
- Increased Technical Envelope
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
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
ISO’s Journey from Qualitative to Quantitative taught us some subtle lessons

- 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>
<thead>
<tr>
<th>Liner Characteristics</th>
<th>Non-Structural</th>
<th>Semi-Structural (Interactive)</th>
<th>Fully Structural</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal Coating</td>
<td>Hole and gap span</td>
<td>Hole and gap span + ring stiffness</td>
</tr>
<tr>
<td>Class I</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Class II</td>
<td>❌</td>
<td>✔</td>
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<tr>
<td>Class III</td>
<td>❌</td>
<td>See Note 1 Below</td>
<td>✔</td>
</tr>
<tr>
<td>Class IV</td>
<td>❌</td>
<td>See Note 2 Below</td>
<td>✔</td>
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1. Internal corrosion protection
2. Reliable adhesion to the host pipe
3. Hole and gap span at MAOP
4. Inherent ring stiffness (hydrostatic pressure or vacuum loads only)
5. Positive connection to service taps and sealed at other discontinuities (water tightness)
6. Inherent ring stiffness (all external, hydrostatic and vacuum loads)
7. Pressure rating of liner ≥ MAOP of host pipe
8. Liner survives host pipe failure

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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
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.
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
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).
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
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
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
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

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

**Drilling tool**
Detects exact location of plug prior to drilling

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

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

**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
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.
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 need 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
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

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

Understanding Creep Failure of Plastics, Jeffrey Jansen
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
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)

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

- Spray-on Polymericics 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

Chris Macey, P. Eng.
chris.macey@Aecom.com

Andrew Costa
ACosta@aegion.com