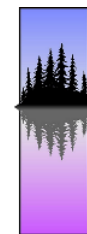




30-inch Water Main Rehabilitation Design Case Study

PNWS-AWWA Conference

May 3, 2019



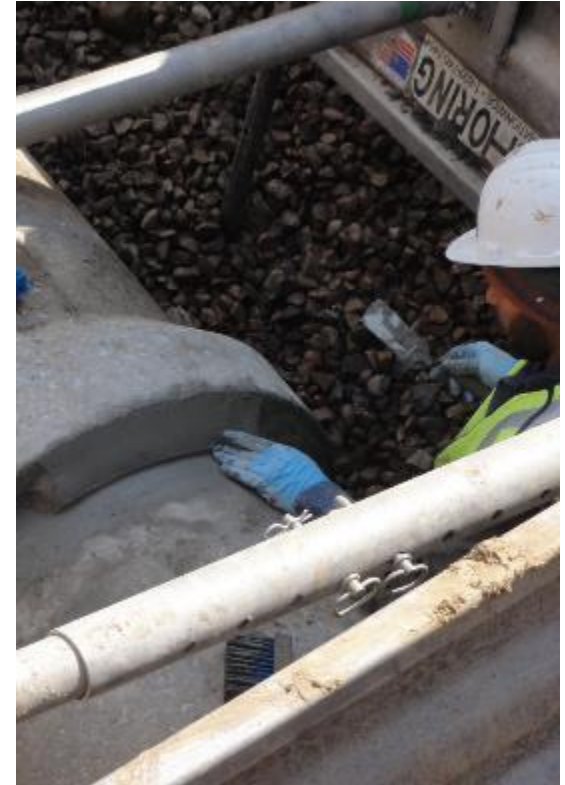
**Weber
Basin
Water
Conservancy
District**

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Agenda

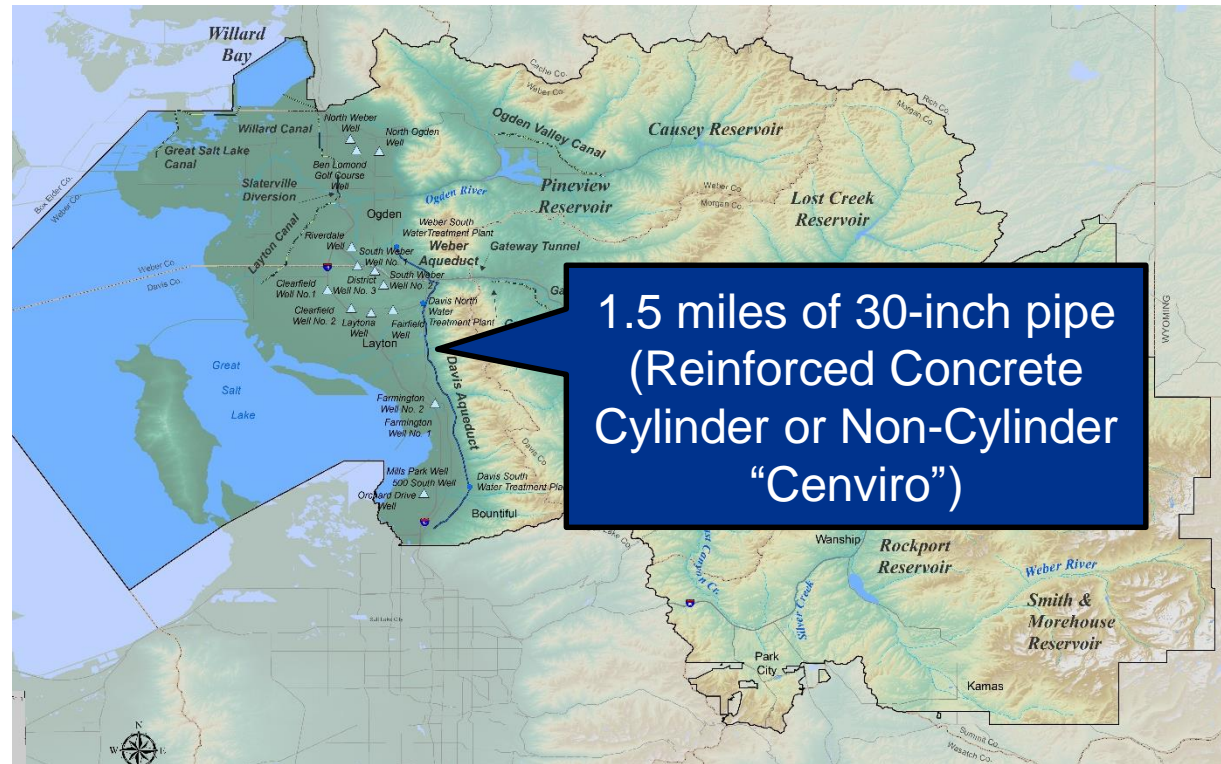
1. Case Study Background
2. Design Challenges
3. Rehabilitation Alternatives Analysis
4. Partially Deteriorated Rehab Design Approach
5. Summary and Further Research
6. Q&A



Case Study Background

Weber Basin Water Conservancy District

- WBWCD is 2nd largest water wholesaler in Utah
- Backbone of infrastructure installed in late 50's
- In 2013 operational changes were made to balance current demands



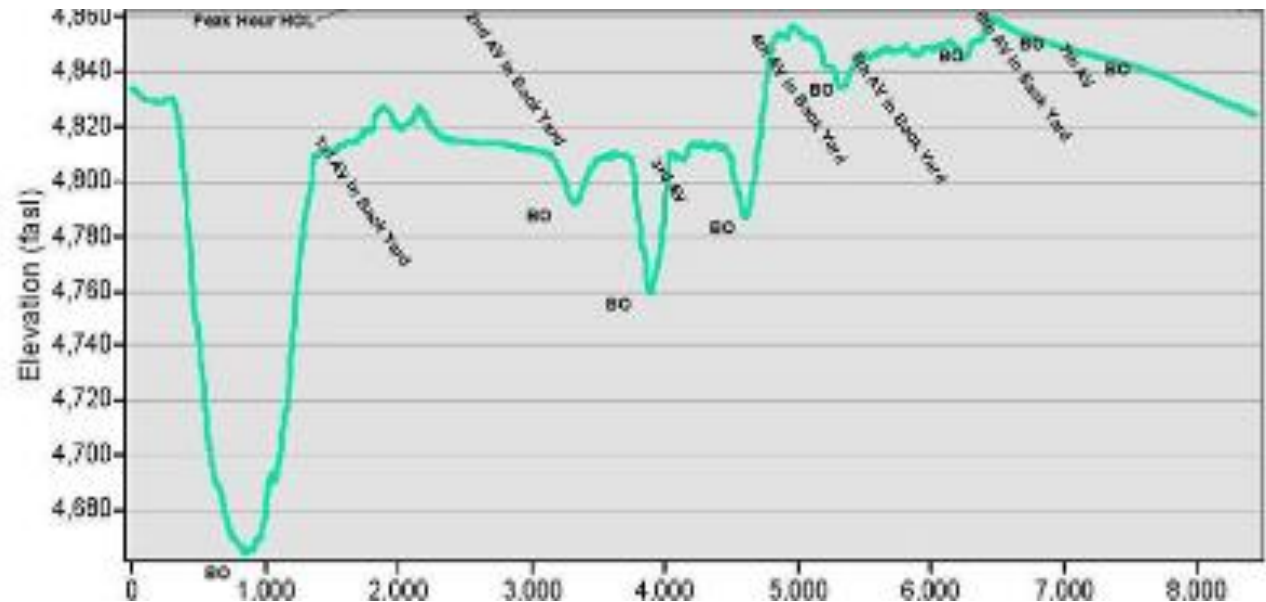
Impact on Infrastructure

- Change in operations detrimental to aged pipe
- Introduced cyclical vacuum pressures
- Surface leaks and sinkholes manifested



Condition Assessment and Forensic Analysis

- Pressures up to 100 psi
+15 psi surge
- Negative pressure swings exceeded the unrestrained gasketed joint tolerances



Condition Assessment and Forensic Analysis



- Exterior sealing of joints provided a temporary solution
- Sealing not durable for long-term
- Large sinkhole developed

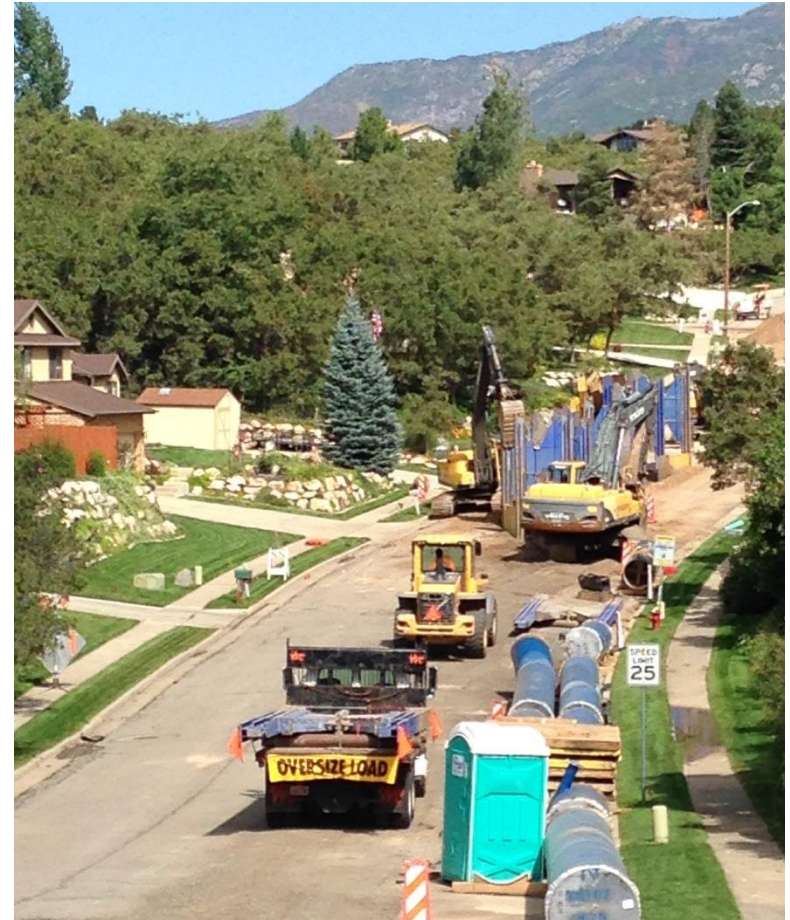
Condition Assessment and Forensic Analysis

- Emergency sliplining repair performed
- Installation of redundant welded steel pipeline
- Decommissioning of the concrete pipeline



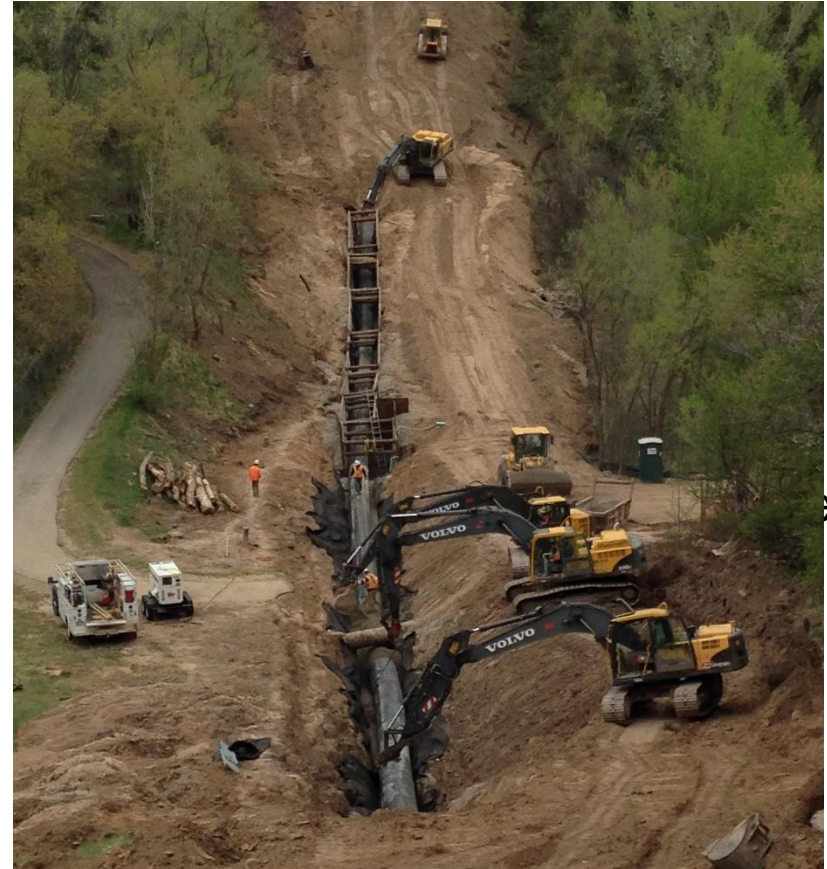
Rehabilitation of Pipe

- Growth and demands continued to increase in area
- In 2017, the District elected to rehabilitate the remainder of the concrete pipeline



Design Challenges

Main Performance Criteria



“Fully” or “Partially” Deteriorated Host Pipe?

| Liner Requirements | Fully Deteriorated Host | Partially Deteriorated Host | WBWCD Pipeline Condition |
|-----------------------------|-------------------------|-----------------------------|--|
| Bear overhead loads | X | | Host pipe conservatively designed |
| Carry internal pressure | X | | Pressures within tolerance and FoS |
| Resist hydrostatic buckling | X | X | Unseated joints exposed to groundwater |
| Span holes and gaps | X | X | Pulled joints observed |
| Implications | Thicker, Higher Cost | Thinner, Lower Cost | Capacity priority |

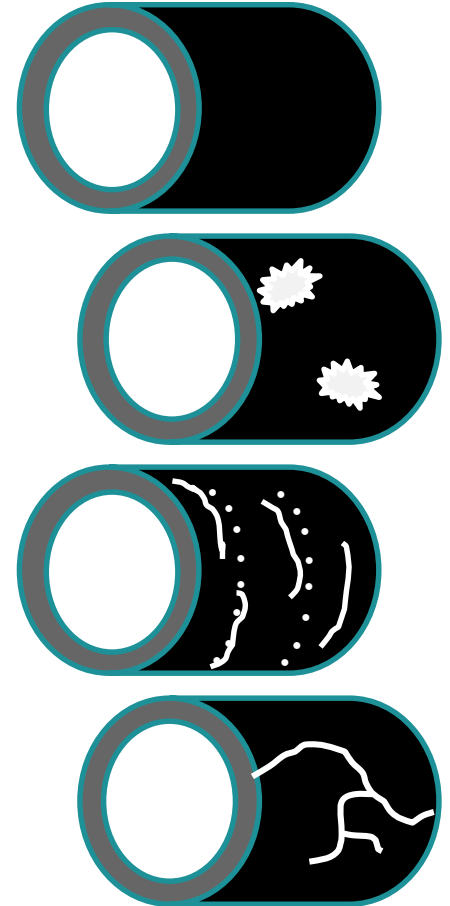
Partially Deteriorated Host Pipe condition selected to maximize capacity and reduce costs

Rehabilitation Alternatives Analysis

Rehabilitation Technology Classes

AWWA M28 Liner Classification

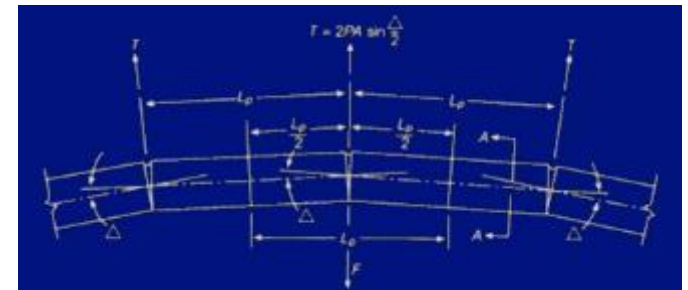
- **Class I:** Nonstructural liners; act only as corrosion barriers.
- **Class II:** Semistructural liners; designed to cover small holes or gaps in the host pipe.
- **Class III:** Semistructural liners; carries internal but not external loads.
- **Class IV:** Fully structural liners; carries all internal/external loads without support from the host pipe.



*No explicit design calculations, *yet...**

CIPP

- Flexible tube saturated with resin is inserted, expanded, and cured to form new pipe
- Thin, smooth liner can increase hydraulic capacity
- Pre-cleaning required
- Full isolation required
- Multiple available contractors, out-of-state crews possible
- Main technical issues were:
 - High test pressure rating requirements
 - Liner terminations and transition to existing pipe
 - Gap and hole spanning



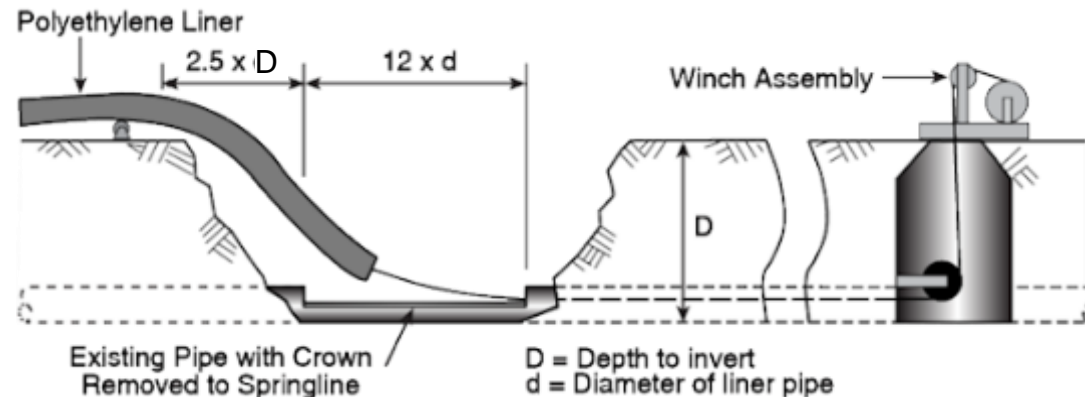
CIPP Design

- ASTM F-1216 (design and installation)
 - AWWA M28 Class III/IV
- “Partially Deteriorated Pressure Pipe”
 - Resists external groundwater
 - Spans holes (assumed post-install)
- “Fully Deteriorated Pressure Pipe”
 - Bears all external live and dead loads
 - Bears all internal pressure and vacuum loads
- No codified design standard for “interactive” liner+host structural rehab



Sliplining

- Oldest trenchless rehab method
- Reduction in ID reduces capacity
- Minimal cleaning required
- Full isolation required
- Multiple available contractors
- Main technical issues were:
 - Providing access for stringing out of pipe
 - Hydraulic capacity
 - Controlling grout pressures



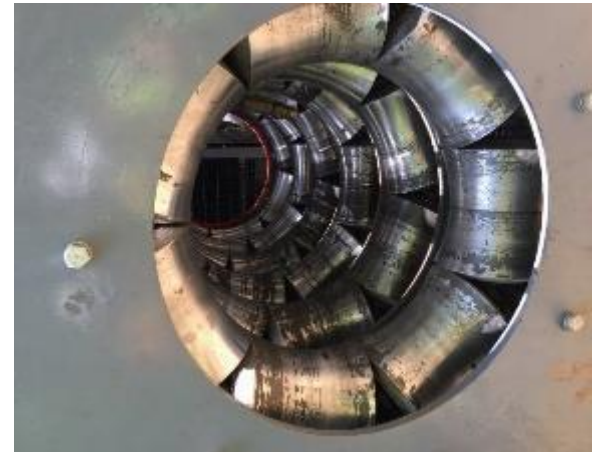
Sliplining Design

- ASTM F-585 (Installation), AWWA M55 (HDPE pipe design), PE Handbook Chp. 11 (HDPE pipe design),
 - AWWA M28 Class IV
- Design methods focus on buried HDPE pipe loading
 - Designer needs to loads during install (e.g. unconstrained buckling from groundwater, grouting)
- No formally defined “Partially Deteriorated” design case
 - but specific loads may be included/omitted (no calculation for hole/gap spanning)
- Design method is applicable for a “Fully Deteriorated” design case
- No codified design standard for “interactive” liner+host structural rehab



Tight Fit Lining

- HDPE is pushed/pulled through a reduction dye/rollers and inserted in cleaned host pipe. Relaxes and expands to form close-fit new structural pipe.
- Thin liner can maintain hydraulic capacity
- Pre-cleaning required
- Full isolation required
- Few available contractors, out-of-state crews likely
- Main technical issues were:
 - Access for stringing out of pipe
 - Radius of curvature tolerances



Tight-fit Lining Design

- AWWA M55 (Design)
 - AWWA M28 Class III/IV
- Design methods focus on buried HDPE pipe loading
- No formally defined “Partially Deteriorated” design case
 - but specific loads may be included/omitted (no calculation for hole/gap spanning)
- Design method is applicable for a “Fully Deteriorated” design case
- No codified design standard for “Partially Deteriorated” (e.g. external hydrostatic resistance only) nor “interactive” liner+host structural rehab



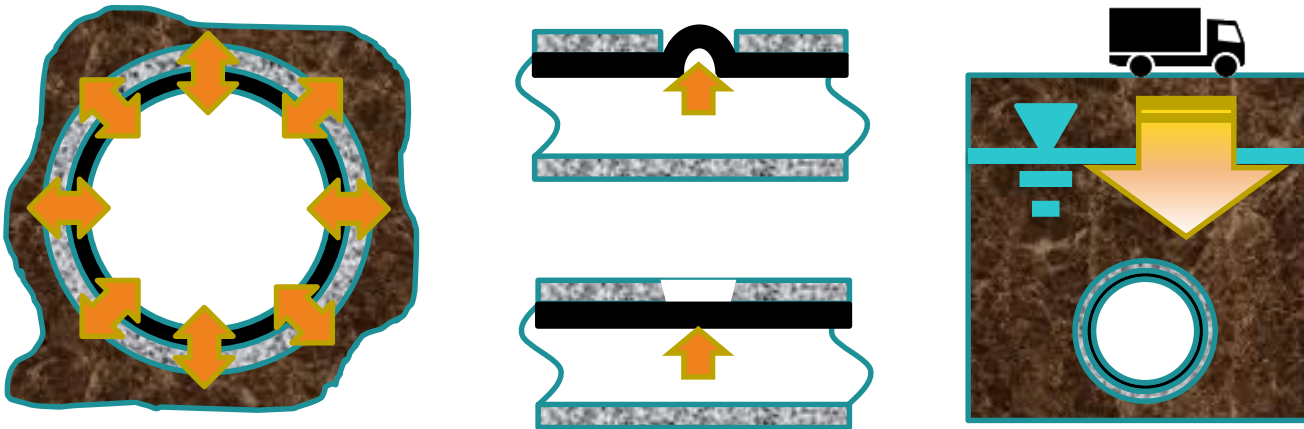
Trenchless Alternatives

| Method | Advantages | Limitations | Selection |
|------------------------------|--|---|---|
| Cured-in-Place Lining | Increases hydraulic capacity Flexible around fittings/sweeps | Access pits every 1,000 LF End seals may require ongoing maintenance Pressure limited | <i>Not cost-competitive in this case (mortar joints, secondary method for high pressures)</i> |
| Slip Lining | Engineered/flanged end seals High pressure cap. | Access pits every 1,000 LF (grout lim.) Reduced hydraulic capacity Cannot pass fittings | <i>Not able to maintain hydraulic capacity expectations</i> |
| Tight Fit Lining | Access pits 3,000 LF Maintains hydraulic capacity Standard end seals High pressure cap. | Cannot pass fittings Fewer experience contractors | Retained for detailed design |

Partially Deteriorated Rehab Design Approach

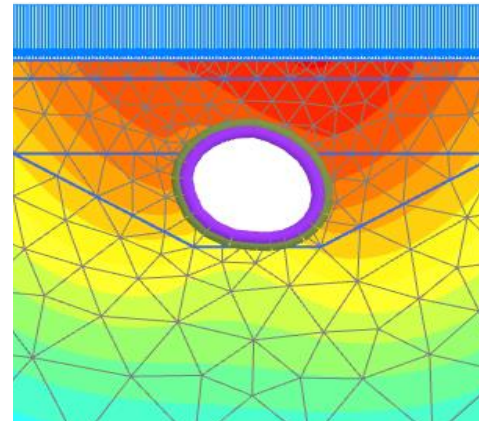
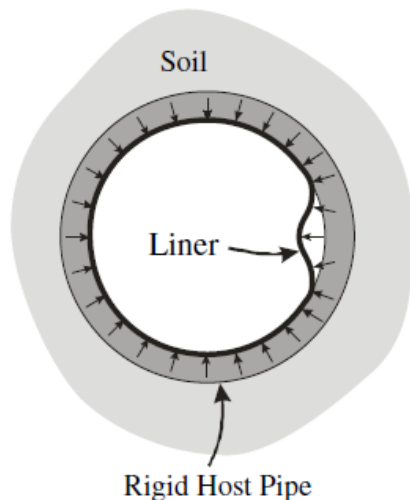
3 Main Checks for Liner Thickness

- Interpreting the interaction between the host pipe and the tight-fit HDPE liner.
- Understanding the required liner properties to span the gaps in the joints.
- Accounting for the extent and duration of actual in-situ loads on the liner.



Conservative Assumptions may be Used to Quantify Host/Liner Interaction

- Rigid host pipe may be represented as a very high soil modulus in the AWWA M55 calculations for constrained hydrostatic buckling resistance.



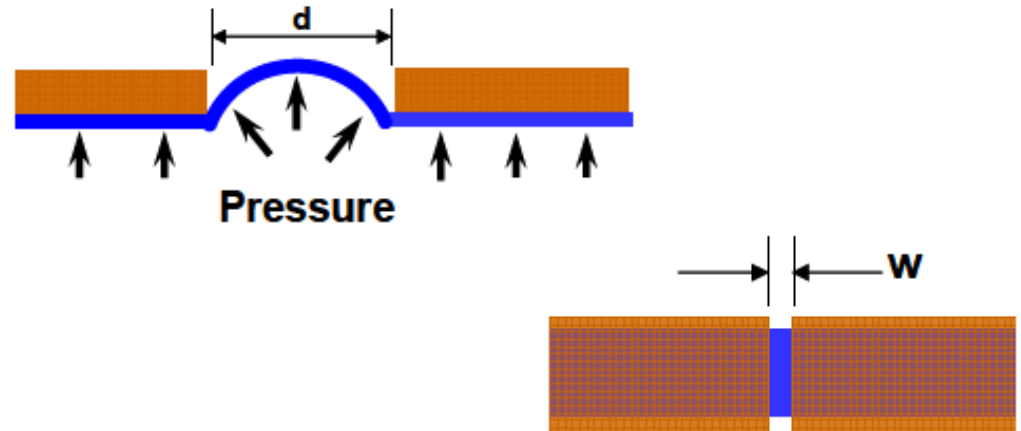
...For a fully deteriorated host pipe, FEA or other numerical methods may be required to calculate interactive behavior.

Academic, Laboratory, and Field Trial Data Resources Address Gap/Hole Spanning

- I. Analytical academic formulas
- II. Laboratory results with empirical results scaled up
- III. Commercial industry reports with field trials

I. Academic Analytical Methods are Straightforward but Rely on Key Assumptions

- Flexible thermoplastic liner theory (presented succinctly by Downey, Heavens, and Ngo (2007))
- Assume the hole/gap occurs after the liner is installed
- Imperfections, burrs, and load cycling are assumed in the safety factor



For gap spanning:

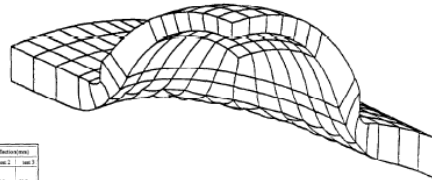
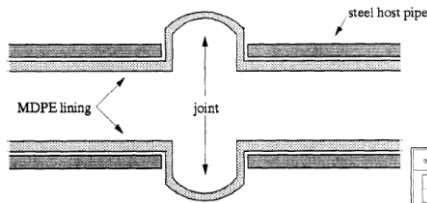
$$\sigma/N = 3P_i(1-\nu^2)/(\beta^2 t^2) \times (\sinh \beta W - \sin \beta W)/(\sinh \beta W + \sin \beta W)$$

Where:

| | | |
|----------|---|---------------------------------|
| P_i | = | Design Pressure (MPa) |
| W | = | Gap Width (mm) |
| B | = | $\{12/(D-t)^2 t\}^{0.25}$ |
| N | = | Safety Factor |
| σ | = | Long-term Lining Strength (MPa) |
| t | = | Lining Wall Thickness (mm) |
| ν | = | Poisson's Ratio |

II. Empirical Laboratory Results May be Scaled Up to Larger Projects but with Conservative Bounds

- Boot, Guan, and Toropova (1996) tested PE liners in a variety of hole and gap spanning configurations, and used FEA models to interpolate between results



| type of test | failure pressure (kPa) | | | failure mode | axial deflection (mm) | |
|--------------|------------------------|----------|----------|---|-----------------------|-----------|
| | test 1 | test 2 | test 3 | | test 1 | test 2 |
| | 0022 | 0083 | 0003 | patch at midspan | 35.3 m | 33.2 m |
| | 2780 kPa | 2800 kPa | 2810 kPa | | 30.7 m | 30.7 m |
| | 0017 | 3430 | 0022 | long pressure via longitudinal ridges | 17 m | 17 m |
| | | | | | 3070 kPa | 3700 kPa |
| | 0046 | 0046 | 0046 | flex line failed on longitudinal ridges, failed due to central patching | 35.7 m | 33.2 m |
| | | | | | 2840 kPa | 2840 kPa |
| | 0102 | 0037 | 0033 | long pressure via longitudinal ridges | 13.9 m | 13.9 m |
| | | | | | 3100 kPa | 3070 kPa |
| | 0170 | 1208 | 0170 | patch at midspan | 13.3 m | 13.3 m |
| | | | | | 1300 kPa | 1300 kPa |
| | 0170 | 1208 | 0306 | long pressure via longitudinal ridges | 12.2 m | 12.2 m |
| | | | | | 1350 kPa | 1350 kPa |
| | 0096 | 0096 | 0096 | patch at midspan | 24.1 m | 23.4 m |
| | | | | | 2800 kPa | 2810 kPa |
| | 0096 | 0096 | 0096 | patch at midspan | 19.7 m | 19.7 m |
| | | | | | 2800 kPa | 2810 kPa |
| | 12747 | 12747 | 12747 | patch at midspan | 12.2 m | 12.2 m |
| | | | | | 12747 kPa | 12747 kPa |

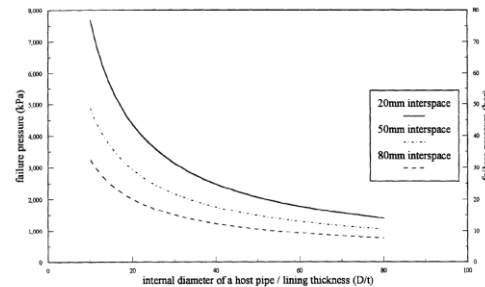


Fig. 17. 50 year life predictions for MDPE lining spanning a longitudinal gap in the host pipe under internal pressure.

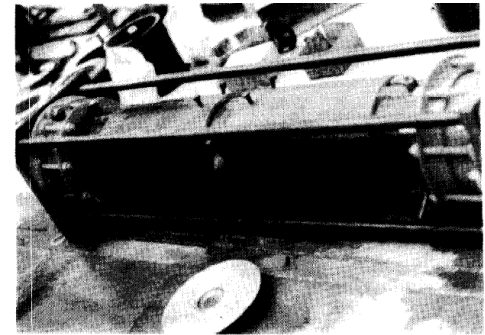


Fig. 10. The assembled pressure test apparatus.

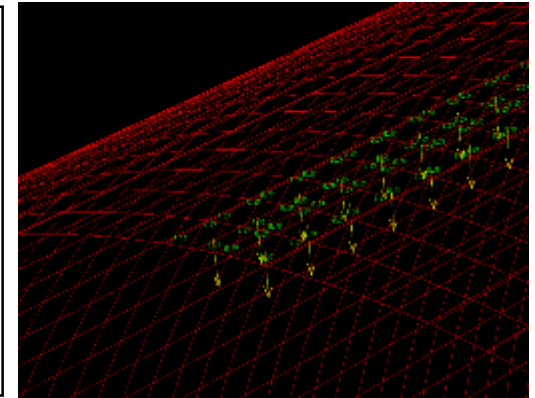
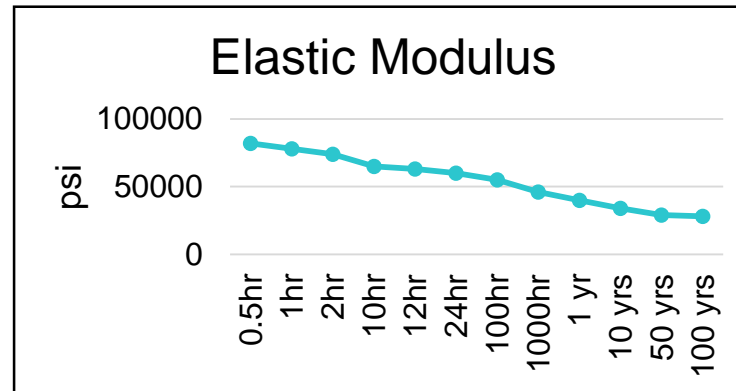
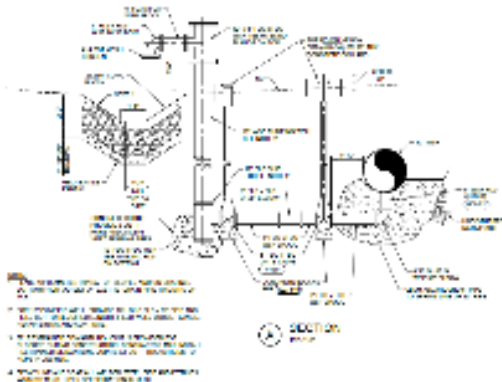
III. Larger-scale Industry Field Trials Demonstrate Practical Liner Performance

- Commercially sponsored reports tested larger diameter, proprietary pressurized lining system under different gap spanning conditions (United Pipeline Systems, 2007).
- Results can be qualitatively compared to similar cases



Practical Application of Anticipated In-Situ Loads Allow for More Economical Liners

- Simple design/construction considerations to reasonably mitigate liner loads (like building drains to prevent enduring groundwater pressure)
- Consider proper modulus for material performance (i.e. HDPE elastic modulus) for actual duration of loads seen
- Fully deteriorated cases may require FEA for more complex soil-structure interactions



Summary and Further Research

Comparison of “Partially” and “Fully” Deteriorated Host Design Conditions

| Design Factor and/or Performance Implication | Partially Deteriorated Design Condition | Fully Deteriorated Design Condition |
|--|---|-------------------------------------|
| SDR | 32.5 | 17 |
| Installed Liner Unit Cost Est. | \$209/LF | \$320/LF |
| Percent Loss of Original Hydraulic Capacity | 12% | 22% |
| Anticipated Installation Rate | 220LF/day | 170LF/day |



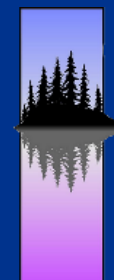
Next Steps and Further Research

- While it is not the case for all aging pipelines, a “partially deteriorated” condition can often be an appropriate design basis and, in some instances, be the cost differentiator between a trenchless rehabilitation project and an open-cut replacement project.
- As the industry continues to improve, there is an ever-increasing need for consensus on the definition of “partially deteriorated” and an established design basis for their corresponding rehabilitation liners.
- Design standards that lay out performance requirements, both by liner class, and by liner type (i.e. flexible, rigid, semi-rigid, etc.) may provide more benefits to the industry at-large. This would enable fair comparison between liners, but also allow competition based on the material properties of the liner itself.



Thank You

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