GLWA WRF 5069 Kercheval Cast Iron Pipe Pilot: Steel Composite Liner, of 108-year-old 48" cast iron water main with embedded real time structural health monitoring

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UCT Nashville, July 13, 2021
Great Lakes Water Authority (GLWA) was formed out of the 2013 bankruptcy of Detroit

- The “Grand Bargain” for Detroit Renaissance and Emergence from the Ashes of Bankruptcy
- Began operation on January 1, 2016
- Regional wholesale provider for water and wastewater with 120+ member partners
- GLWA has been recognized as an innovative and world class water system

5 water treatment plants
3 water intakes
19 booster pump stations
1.72 billion gallons of treatment capacity per day
803 miles of transmission main
GLWA is the Largest Domestic Owner of PCCP and all of their pipes are Large Diameter (>24 inch)
For ANY TYPE OF PIPE, Renewal Process Begins by with how much renewal is needed

<table>
<thead>
<tr>
<th>Liner Characteristic</th>
<th>Structurally Interactive</th>
<th>Structurally StandAlone</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Internal Coating</td>
<td>Hole and gap span</td>
</tr>
<tr>
<td></td>
<td>Class I</td>
<td>Class II</td>
</tr>
<tr>
<td>Internal corrosion protection</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Reliable adhesion to host pipe</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Hole and gap span at maximum allowable pressure (MAOP)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Inherent ring stiffness (hydrostatic pressure loads)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Positive connection to service taps and sealed at other discontinuities (water tightness)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Inherent ring stiffness (all external and vacuum loads)</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Pressure rating of liner ≥ MAOP of host pipe</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Liner survives host pipe failure</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
Design Methodologies should be consistent between renewal methods

- Internal working pressure
- Internal working-plus-transient pressure
- Weight of pipe and fluid
- Earth load above the pipe
- Live loads at the ground surface
- Groundwater above the pipe
- Negative pressure inside the pipe
- Poisson’s ratio
- Temperature changes
- 50 + year Design Life
AWWA Class IV Systems need to be designed to cover a broad range of specific pipe types and their failure mechanisms.
All Design Methodologies are NOT equivalent

ASTM F1216 - Appendix X1
Allowable Stress Design (ASD)

AWWA C305
Load Resistance Factor Design (LRFD)

CFRP Renewal and Strengthening of Prestressed Concrete Cylinder Pipe (PCCP)
LRFD approach embodied in AWWA C305 (CFRP) for PCCP Renewal has been adopted and implemented by many water utilities

- Major US water agencies have adopted the use of the CFRP technology as part of an effective asset management program

- LRFD design methodology is also adopted in many other design standards and MOP for ASCE for Penstocks and large diameter gravity pipe renewal.

- AWWA C305 has significantly reduced risk associated with large diameter pipe renewal.
**ASTM F1216 (ASD) is not equivalent to AWWA C305 (LRFD) for Large Diameter Pressure Pipe**

<table>
<thead>
<tr>
<th>Design Checks</th>
<th>ASTM F1216 (ASD)</th>
<th>AWWA C305 (LRFD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hoop Design</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Working Pressure</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Internal Transient Pressure</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Internal Vacuum Pressure</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>External Soil Load</td>
<td>X</td>
<td>X</td>
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<tr>
<td>External Traffic Load</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pipe Ovality</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Deflection Limit</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Combined Loading</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Longitudinal Design</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poisson’s Ratio Effect</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Temperature Change Effect</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Thrust Effect</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Design Life up to 50 Year?</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
GLWA objectives of pilot are focused on liner application and monitoring methods

- Applied research on innovative, emerging technologies for Class IV renewal of large diameter pipe
  - Polymer-based System (MICP)
  - Steel Reinforced Cement Mortar (StrongPIPE SRC)

- Collect experience and information on
  - Design Methodology for Class IV Liner Systems
  - Production means and methods
  - Costs and Lessons Learned

- Conduct structural monitoring of systems
  - Laboratory of Intelligent Systems Technology
  - Dr. Jerry Lynch
GLWA Located an accessible portion of their Kercheval Avenue, 1913 Vintage, 48 inch diameter Cast Iron Pipe (CIP) for the renewal pilot
All Candidate Liner Systems were designed using LRFD methodology

- Class IV, structurally independent renewal
- 48-inch, 1912 vintage Cast Iron Pipe (Class D)
- “flat, straight pipe”, (per GLWA 1912/1913 field notes)
- Open cut excavation access on one or both ends of segment
- Working Pressure (max): 100 psi (actual operating 70 psi)
- Surge Pressure: +40 psi
- Depth of Cover to Crown: 10 feet
- Groundwater: No
- Water temperature change: Δ25°C = Δ40°F
- Internal surface condition like that of 42-inch samples provided by GLWA
Results of LRFD “Apples to Apples” Comparison Liner Thicknesses were interesting and informative in decision making process

- LRFD designs resulted in liner thicknesses:
  - CFRP - 3 circumferential wraps and 1 longitudinal layer (0.6" thick)
  - SCL with thickened epoxy embedment (0.75" thick)
  - SCL with cementitious embedment (~1" thick)
  - HDPE (2.3" thick)

To provide stand alone, full-structural reinforcement per the requirements of AWWA Manual M28 Class IV.
StrongPIPE® SCL Solution utilizes cost effective HS steel for trenchless composite reinforcement since 2012

Legend
1. 1st Glass FRP Layer (longitudinal)
2. High Str. Steel Wire
3. Polymer Matrix
4. 2nd Glass FRP Layer (longitudinal)
5. Flexible Topcoat

StrongPIPE is a structural strengthening system for the restoration of damaged/weakened pressure pipe and the upgrade of undamaged pipe. StrongPIPE utilizes a continuously wound tensile reinforcement that forms a steel composite lining inside the existing pipe.
Steel Composite Liner Systems use high strength wire embedded in a host matrix to provide primary circumferential strength renewal

- Longitudinal strength from HS steel, FRP or CFRP.
- Applicable for large diameter pressurized and non-pressurized pipelines (36 inches in diameter and up).
- Applicable for either targeted repairs or extended, straight runs.
- Installed through existing access.
- Similar structural strength to CFRP, but more cost effective for longer runs
- NOT PCCP
Final layout was SCL with 1/3 polymer and 2/3 cementitious embedment
Internal surfaces were prepared by scraping, high pressure water blasting and abrasive blasting to receive lining systems.
Circumferential wire spacing was the same for SCL-C and SCL-P
Spin cast mortar over SCL-C wires and top coat with polyurea and end seals for water tightness
Pilot was completed on schedule even during COVID.
GLWA/UofM Kercheval Pilot is a first of its kind in situ pipe health monitoring system

- Seven (7) strain channels on the SCL-C liner:
  - CH 1, CH 3, CH 5, CH 7 on steel wires (quarter bridge)
  - CH 2 (L)
System Data Collection

- Data collected since August 26, 2020:
  - All strain channels zeroed
  - Data collected at 2 kHz
  - Collect data for 1 second every 5 minutes
  - Locally stored on DAQ server at the site
  - Transmitted by cable modem to UM server ever day
  - Backup copy of the data stored in external hard drive at the site
Observable Behaviors

- **Internal pressure response:**
  - Negative longitudinal strain
  - Positive circumferential strain

- **Constraints at the pipe-liner end:**
  - Longitudinal strain

- **Thermal contraction:**
  - Negative circumferential strain
  - Positive longitudinal strain

- **Liner cracking (mortar):**
  - Cracks along circumferential direction increases $\varepsilon_x$
  - Cracks along longitudinal direction increases $\varepsilon_\theta$

- **Deformations over time:**
  - Long-term creep
  - Less support from soil
  - Both strains increase as time goes by

- Related to pressure, and boundary conditions
- Temperature-driven behavior (seasonal)
- Transient event driven
- Long-term, slow deformation
Example 1: Thermal Contraction

Temperature decreases, Longitudinal strain increases.

Longitudinal strains change significantly with temperature.
Example 2: Deformation with Time

Divided into three stages:
1) repressure stage
2) temperature significantly drops
3) temperature slowly changes

Evidence: Outside surface, No soil supports
Example 3: Radial Expansion

- Radial expansion in this stage because of creep and less support of soil pressure.
- Same trend when temperature change significantly.

Circumferential direction:
- Steel Wire 8
- Steel Wire 11
- Steel Wire 15

Strain value (µε):
- +50 µε

Temperature (°C):
- 10/7 13:01 +70 psi

Pressure (psi):
- Temperature outside

Time (day)
Many thanks to my colleagues John Norton, Todd King, Ali Alavi, Wentao Wang, and Jerry Lynch

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