Critical Force Main Assessments for the City of Raleigh Public Utilities Department (CORPUD)

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Overview

• Program Objectives
• Staged Approach Overview
• Technical Approach for Initial Condition Assessment
  • Primary deterioration risks
  • Internal
  • External deterioration
• Review of Serious Vulnerability by Site
  • Glenwood (ductile iron)
  • Highway 50 (ductile iron)
  • Wendell (PVC)
• Closure and Phase 2 Objectives
Program Objectives

- 6 critical force main systems
  - 40 miles of force main
  - Systems range from 1500 feet to 55,000 feet of force main
  - Size of piping from 6”-8” to 24”-30” systems
  - Ductile iron (DI) with various lining systems, PVC and CIPP lined DI
  - Failure history extensive in Glenwood Avenue system
  - No failure history to date in other systems
- Drivers for assessment varied by site

<table>
<thead>
<tr>
<th>Force Main</th>
<th>Primary Driver for Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway 50</td>
<td>Force main has high flow volume and is very long in length. CORPUD desires a baseline of how this force main is aging.</td>
</tr>
<tr>
<td>Wendell Force Main</td>
<td>Force main is aged and is critical due to volume of flow. CORPUD desires a baseline of how this force main is aging.</td>
</tr>
<tr>
<td>Maxwell Drive – North South</td>
<td>Force main has segments that are located under the major highway crossings and contains ductile iron pipe at the high points. CORPUD desires a baseline of how the force main is aging.</td>
</tr>
<tr>
<td>Falls Lake System</td>
<td>Low pressure force mains that are expected to be fairly septic. CORPUD desires to have a baseline for how the force mains are aging.</td>
</tr>
<tr>
<td>Glenwood Avenue</td>
<td>Force main has had failures and has been rehabbed at the high points. CORPUD is interested in the condition of the remaining portions of the force main.</td>
</tr>
<tr>
<td>Big Branch South</td>
<td>Force main has high volume flow. CORPUD desires to have a baseline of how the force main is aging.</td>
</tr>
</tbody>
</table>
What is a staged approach and why?

- CA for force mains is not cheap
  • Continuous measurement techniques alone (electro-magnetic and leak/air pocket detection) would be > $18 million
  • Considerable risk to implement
  • Considerably steep cost with no failure history on most mains
  • A lot of unknowns that would compromise assessment certainty

- Staged process built on science of material degradation. Allows you to:
  • Understand where failure is more probable
  • Understand how condition assessment process is best advanced technically, logistically, and using best value for knowledge concepts

- Understand certainty of observations
  • For clarity in cost effectiveness
  • For clarity in risk exposure

- Factor economics of condition assessment into the process

• Need to know where to start and when to stop!
### What were the primary drivers for the 6 systems?

<table>
<thead>
<tr>
<th>Force Main</th>
<th>Size</th>
<th>Length (ft)</th>
<th>Materials</th>
<th>Install Years</th>
<th>Failure History</th>
<th>Vulnerability Checks</th>
<th>CORPUD initial Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenwood Avenue</td>
<td>24&quot;-30&quot;</td>
<td>30,534</td>
<td>DI, PVC, CIPP</td>
<td>1988-2008</td>
<td>Extensive</td>
<td>DI - internal and external face corrosion; PVC - cyclic loading; CIPP - applied load and fatigue</td>
<td>Condition of unrepaired sections</td>
</tr>
<tr>
<td>Highway 50</td>
<td>30&quot;</td>
<td>55,000</td>
<td>DI</td>
<td>2004</td>
<td>None to date</td>
<td>DI - internal and external face corrosion; era of DI - pressure class verus thickness class pipe</td>
<td>Status of condition; important FM</td>
</tr>
<tr>
<td>Big Branch South</td>
<td>24&quot;</td>
<td>1,500</td>
<td>DI</td>
<td>1993</td>
<td>None to date</td>
<td>DI - internal and external face corrosion; - thickness or pressure class pipe??</td>
<td>Status of condition; important FM</td>
</tr>
<tr>
<td>Wendell</td>
<td>16&quot;</td>
<td>51,000</td>
<td>PVC &amp; little bits of DI</td>
<td>1997</td>
<td>None to date</td>
<td>PVC - applied load checks and fatigue loading</td>
<td>Status of condition; important FM</td>
</tr>
<tr>
<td>Maxwell Drive/North South</td>
<td>8&quot;</td>
<td>25,000</td>
<td>PVC &amp; DI</td>
<td>1989-2010</td>
<td>None to date</td>
<td>DI - internal and external face corrosion; PVC - cyclic loading; Overall staging of development on loads</td>
<td>Baseline condition and condition of critical road crossing locations</td>
</tr>
<tr>
<td>Falls Lake System</td>
<td>6&quot;-8&quot;</td>
<td>53,000</td>
<td>PVC &amp; DI</td>
<td>1997</td>
<td>None to date</td>
<td>DI - internal and external face corrosion; PVC - cyclic loading;</td>
<td>Low flows, $H_2S$ effects on DI</td>
</tr>
</tbody>
</table>
Initial Assessment for each material

**Ductile Iron**
- External corrosion screening using USDA and available data
- Internal corrosion risk
  - Steady state hydraulic model to understand system operations
  - Transient model to assess air movement, and
  - Waste stream characteristics in simple Pomeroy H₂S model

**PVC**
- Conventional material breakdown rare
- Screen operational characteristics and other risk factors
- Potential Failure and Deterioration modes include:
  - Sustained pressure – slow crack growth (SCG)
  - Short term transient event (overpressure or vacuum)
  - Fatigue
- Steady state and transient model to assess risks

**CIPP Lining**
- Conventional material degradation rare from external or internal face
- Primary deterioration and failure modes
  - Sustain or short term response to loads (hoop, hole spanning, or vacuum)
  - Fatigue if polyester versus vinyl ester resin used
- Steady state and transient models; revisit original design basis
Glenwood had some real failure history...
External corrosion potential and pressures
Glenwood

- Glenwood’s failure history showed evidence of both inside face and exterior face corrosion
- While both processes were present; *interior face corrosion* due to the lining failure was much more aggressive
- Watching the air movement in a transient model explained a lot interior face corrosion
  - H$_2$S corrosion was eating the main up, where the lining was totally inadequate
While Glenwood had been rehabilitated in 2010 it still has some distinct sampling requirements

Phase 2 objectives:
  - External face degradation in more corrosive soil units not quantified
    - An active process and its impact on residual design life needs to be understood
  - Combined internal and external face deterioration outside of limits of previous rehabilitation/replacement needs to be understood as well

Next stage of testing – planned/opportunistic sampling
  - Using air valves for metallic connection to DI pipe,
    - Use close interval survey to fine tune excavation location
    - Use ultra-sonic thickness (UST) techniques to assess condition in high risk areas
Maximizing the probability of finding something ~ intelligent versus random sampling with ECDA

Looking for spikes
Highway 50 is a newer piece of DI and should have a superior lining but has some eerie similarities to Glenwood.
Highway 50 Transient Response

Hwy 50 FM

Glenwood FM
Highway 50 Sampling Opportunities – overlay external with internal risk factors

Soil Corrosivity
- High
- Low
- Moderate
- Unknown

Column Separation Potential
- No
- Yes
1. PVC posed a unique risk factor for assessment

2. How to assess PVC for active deterioration processes?

3. Potential deterioration processes are much different
   - $\text{H}_2\text{S}$ coming out of solution not a concern
   - Corrosive soils not a concern
   - Needed to assess
     - Impact of potential for fatigue to limit design life
     - Understand the degree to which wall stress levels may be a concern
     - We don’t currently know wall thickness of pipe
Upstream portion of Wendell had some exposure to fatigue

- 1st of all, we don’t know wall thickness of Wendell presently
- Wall thickness impacts wall stress level
  - In conjunction with pressure provides insight into **fatigue** and **slow crack growth** (SCG) potential;
  - the two most prominent potential deterioration modes for PVC
Knowing how PVC fails makes it very important to ascertain whether it will fail over time.
For Wendell, we initially need to know sensitivity to wall thickness

- Sensitivity analysis on Wendell suggests fatigue not likely limiting
- Presence of branches on systems reduces fatigue risk
  - Dampens reflective wave rapidly
  - Reduces stress amplitude significantly
- Ran multiple scenarios from DR 18 through DR 41 in fatigue analysis
  - Design life in fatigue >>> 100 years
  - Fatigue not limiting for Wendell
So what about the potential for SCG

- The era of Wendell (1997) should be associated with higher extrusion quality
  - Although North American test (ASTM D2152) not particularly effective at assuring high extrusion quality

- How was the pipe designed?
  - Based on boundary conditions and short term overpressure it is likely that the pipe was designed with a wall thicker than a DR 41 (present day AWWA Standard would suggest a DR 41 was adequate)
  - Moderate to high risk level for SCG exists
    - Need to known wall thickness
    - Sample and confirm original extrusion quality over time

<table>
<thead>
<tr>
<th>DR</th>
<th>PR - Sustained</th>
<th>PR - short term</th>
<th>Operating Pressure (psi)</th>
<th>Wall Stress (psi)</th>
<th>Wall Stress (MPa)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>235</td>
<td>301</td>
<td>70</td>
<td>595</td>
<td>4.10</td>
<td>Relatively insensitive to extrusion quality</td>
</tr>
<tr>
<td>25</td>
<td>166</td>
<td>213</td>
<td>70</td>
<td>840</td>
<td>5.79</td>
<td>Moderately sensitive to extrusion quality</td>
</tr>
<tr>
<td>35</td>
<td>118</td>
<td>150</td>
<td>70</td>
<td>1190</td>
<td>8.20</td>
<td>Moderately sensitive to extrusion quality</td>
</tr>
<tr>
<td>41</td>
<td>100</td>
<td>128</td>
<td>70</td>
<td>1400</td>
<td>9.65</td>
<td>Very sensitive to extrusion quality</td>
</tr>
</tbody>
</table>

Rated and actual pressure limits based on 1997 AWWA C905
Closure

• Much can be learned in office level assessments before applying more advanced condition assessment techniques
  • Hydraulic modeling and transient analysis are under-used techniques that facilitate deterioration risk assessment in many materials

• Knowing where and what to look for is of considerable value when selecting more expensive and invasive condition assessment techniques

• Deterioration of materials happens by design, not by accident
  • Studying a balance of exposure conditions and applied loads are essential starting points for the condition assessment process
  • They provide the most advantageous roadmap for the rest of the process
Queries?

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