Recap/Highlights
by Bill Chavez, PUG Vice-Chairman
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Microtunneling Technology Implemented for the Replacement of a 36-inch PCCP Force Main

- In 1994, 2001, and 2009 Fairfax County completed inspection and testing of one mile of 36-inch Prestressed Concrete Cylinder Pipe to determine if replacement or repair was required.
- Condition assessment consisted of pipe sounding, visual inspection, selected removal and testing of pre-stressed wire, and mortar coating analysis.
- The testing results showed no visible signs of distress in the pipe or delamination occurred. However, minor corrosion was visible on several of the pre-stressed wires.
- Based on testing analysis, risk factors associated with the proximity to wetlands and difficulty accessing pipe for future repairs, Fairfax County concluded that installing a parallel force main was the best approach. The existing FM will be used for redundancy.

- This FM was originally built in 1977 open cut, and traverses wetlands, streams, residential areas, a state highway, and Fort Belvoir Military Base.
- Trenchless Technology was needed:
  - Horizontal Directional Drilling (HDD)
  - Microtunneling (MT)
  - Horizontal Earth Auger Boring (HEB).

### Table 1. Condition Assessment Analysis of PCCP

<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose</th>
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<tbody>
<tr>
<td>Pipe Sounding</td>
<td>Determine if delamination is occurring in the pipe</td>
</tr>
<tr>
<td>Visual inspections</td>
<td>Assessment for visual cracks or other defects</td>
</tr>
<tr>
<td>Removal of pre-stressed wire</td>
<td>Test the wire for torsion, tensile and embrittlement properties</td>
</tr>
<tr>
<td>Removal of mortar coatings</td>
<td>Perform petrographic analysis to ascertain condition of mortar</td>
</tr>
<tr>
<td>Soil testing</td>
<td>Analyze soil pH, corrosivity, etc.</td>
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- Key attributes of each methods are summarized on table 2.
- Microtunneling was the option selected because it offers minimal disturbance due to the relatively small size of shafts compared to HDD and Auger Boring.
- Another factor was the nearby wetlands and ground water table and the better control over the soils at the face of the MT machine.
- Next step was the development of the alignment and identification of the number of shafts needed.

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Horizontal Directional Drilling (HDD)</th>
<th>Microtunneling (MT)</th>
<th>Horizontal Earth (Auger) Boring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of alignment</td>
<td>Accurate Drives</td>
<td>Very Accurate Drives</td>
<td>Not Accurate over longer runs</td>
</tr>
<tr>
<td>Suitable Drive Span or Tunneling Length</td>
<td>6.1 m - 1.524 m (200 ft - 5,000 ft)</td>
<td>30.5 m - 152.4 m (100 ft - 500 ft)</td>
<td>18.3 m - 121.9 m (60 ft - 400 ft)</td>
</tr>
<tr>
<td>Casing/Pipe Material</td>
<td>High Density Polyethylene (HDPE)</td>
<td>Prestressed Cylinder Concrete Pipe (PCCP), Glass Fiber Reinforced Plastics (GRP, Steel, Ductile Iron, and other options)</td>
<td>Prestressed Cylinder Concrete Pipe (PCCP), Glass Fiber Reinforced Plastics (GRP, Steel, Ductile Iron, and other options)</td>
</tr>
<tr>
<td>Shaft Space Requirements Comparison</td>
<td>Large Foot Print</td>
<td>Small Foot Print</td>
<td>Smaller Foot Print</td>
</tr>
</tbody>
</table>
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- Shaft design varied for each location depending on subsurface conditions, the three main designs are in table 3.
- Dewatering was a concern due to proximity to wetlands/streams. Plaxis flow modeling was used to estimate inflow requirements.
- Another factor was monitoring for ground settlement. County used 23 ground monitors and 5 facility monitors along the alignment. Contractor was responsible for surveying points to check for settlement.
- Due to concerns from previous project, additional vibration sensors, and subsurface utility monitors were added at key residential buildings.
- Data from sensors was uploaded to project website for monitoring by interested stakeholders.

MTBM was launched from shaft 6 on May 8 2012 and reached shaft 5 on June 20 (57 days).
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Advancement of the MTBM was dependent of subsurface condition and equipment maintenance.

Monitoring near Mt Vernon Hwy next to shaft 5 showed signs of settlement attributed to sandy conditions. Tunneling operation was stopped and chemical grout was injected into the soil to stabilize subsurface conditions.

Design of shaft 3 was based on sunk-in caisson construction. Contractor proposed sheet piling. However, it was not driving to the full length. They brought in a larger pile driving machine but it was unsuccessful. Finally, they had to excavate in lifts to reduce frictional forces until the sheet piles were driven to full depth.

The tunneling operation for all the shaft are summarized in Table 5.

Slurry dewatering consist of removing solids and then dewatering with a portable centrifuge. Water is recycle back to the head of the MTBM.

Actual dewatering rate was well below model predictions.
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Conclusions:
- Visual and physical testing of the PCCP proved to be a valuable tool in assessing the condition of the existing force main.
- Trenchless technologies are viable options for utility replacement in environmental sensitive areas.
- Dewatering model results should be validated with actual field testing.
- MTBM production rates depend upon subsurface conditions. In this case, average shift production ranged from 29 – 35 ft/day.
- The use of geotechnical instrumentation with automatic feedback and global positioning proved to be useful in monitoring ground settlement from remote locations.
A Repair Program to Minimize Failure Risk of Highly Distressed PCCP Circulating Water Lines

- Arizona Public Service (APS) Company’s Cholla Power Plant has four units with circulating water (CW) lines made of 66 in – 72 in. diameter prestressed concrete cylinder pipe (PCCP) in units 2, 3, and 4.
- This 995 megawatt coal-fuel power plant is located in northern Arizona.
- Characteristics of each water lines are presented in Table 1.
- In the late 1990s, APS experienced failures in the CW pipelines and performed repairs. In 2005, APS began using internal Electromagnetic (EM) inspections.
- These inspections indicated that 22% of PCCP in unit 2; 36% of PCCP in unit 3; and 25% of PCCP in unit 4 were distressed with broken prestressing wires.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Diameter (in.)</th>
<th>Approx. Length (ft)</th>
<th>Years in Service</th>
<th>Manufacturer</th>
<th>Prestressing Wire Class</th>
<th>Shorting Straps</th>
<th>Approx. No. of PCCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>66</td>
<td>1,700</td>
<td>37</td>
<td>Interpace</td>
<td>IV</td>
<td>No</td>
<td>119</td>
</tr>
<tr>
<td>3</td>
<td>66</td>
<td>2,600</td>
<td>35</td>
<td>Interpace</td>
<td>IV</td>
<td>No</td>
<td>173</td>
</tr>
<tr>
<td>4</td>
<td>72</td>
<td>2,200</td>
<td>34</td>
<td>Ameron</td>
<td>III</td>
<td>Yes</td>
<td>128</td>
</tr>
</tbody>
</table>

Reported information is approximate and for intake and discharge lines combined.
A Repair Program to Minimize Failure Risk of Highly Distressed PCCP Circulating Water Lines

- APS retained Simpson Gumpert & Hegr (SGH) in 2008 to provide engineering services to maintain the pipeline at an acceptable risk of failure and used planned outages to inspect pipelines, perform condition assessment, development of failure risk analysis and repair prioritization of distressed pipes.

- Condition assessment consisted of external inspection using wire continuity testing, laboratory tests on soil and pipe mortar coating samples for chloride ion profile, structural evaluation of pipe design classes and development of failure risk curves to determine repair priorities.

- Electromagnetic (EM) inspections can be used in failure risk analysis to determine how close a distressed pipe is to failure.

- In the case of the CW lines, interpretation of the EM signals and prediction of distress was more challenging than for typical pipelines. Close examination of the EM signals revealed that a non-distressed pipe and a pipe with all prestressing wires corroded away have similar signals except for a shift in the phase of the signal resulting in initial misinterpretation of data and inaccurate distress predictions.
A Repair Program to Minimize Failure Risk of Highly Distressed PCCP Circulating Water Lines

- This required a reevaluation of all EM data and a development of a new categorization system.
- External inspections were minimized to avoid excavations that could interrupt plant operation. However, external inspection provided valuable information. It provided an opportunity to check the prestressing wire diameter and spacing, mortar coating thickness, type of backfill, moisture at pipe depth, and take samples for laboratory testing.
- Laboratory testing and petrographic analysis performed on samples of soil and mortar coating showed that the environment is highly aggressive and corrosive to PCCP. Design of the pipeline should have included additional protective measures in form of moisture barrier or cathodic protection.
- The chloride content of the soil samples range between 660 – 3,800 ppm, well beyond the allowable limit for PCCP of 400 ppm.
Internal visual and sounding inspection were performed in every planned outage and the condition of each pipe documented for evaluation of progression of distress.

There were cases where repair of a pipe in a lower EM distress category was prioritized over that of a pipe in higher distress category due to the internal signs of advanced distress observed.

External inspections also allows for evaluation of the condition of previous repairs after exposure to the chemistry and temperature of the circulating water.
A Repair Program to Minimize Failure Risk of Highly Distressed PCCP Circulating Water Lines

Failure Risk of pipes in the severe distress category (1 and 2) is determined directly from the EM signal.

For pipes not in these categories, the failure risk is evaluated using the risk curves which define the relationship between the maximum pressure in the pipe and the effective number of broken wires required to reach serviceability, damage, and strength limit state while accounting for the effect of earth load and pipe and fluid weight.

The limit state curves divide the plots into different zones of repair priority in the order of descending risk of failure and need for repair.
The repair program considered different repair methods: internal lining, external post-tensioning, and relative cost of repair methods, ease of internal/external access to pipes, etc. The preferred method was lining with internally bonded carbon-fiber reinforced polymers (CFRP), picture 5a.

Where the number of repaired pipes had to be particularly maximized, external repair by post-tensioning and shotcrete encasement was also used in parallel with internal CFRP repairs, picture 5b.
A Repair Program to Minimize Failure Risk of Highly Distressed PCCP Circulating Water Lines

Murat Engindeniz, PM, Simpson Gumpertz & Heger, Inc.
Kevin Crosby and Ben Cluff, Arizona Public Service

Typical Outage Planning and Execution:

- **Pre-Outage**: Tentative repair drawings and specs are prepared for bidding based on “potential” repair pipes based on previous inspections. Agency receives bids from contractors and secures resources required to perform the estimated scope of work.

- **Outage**: CW lines are dewatered immediately and prepared for safe access for visual and sounding inspection (1st three days). Two days later results are available for comparison with results from previous years to determine progression of distress while contractor is on standby on site. Then, the list of pipes to be repaired in the order of descending repair priority is made available and the agency issues repair drawings. Field Engineering support is available throughout the repairs for verification of compliance with contract documents. Pipe is returned to service after agency verifies by testing that the repairs have cured sufficiently.

- **Post-Outage**: Consultant prepares a detailed report of all construction and testing activities including results of tension tests performed on CFRP including some recommendations for the following outage. A debriefing meeting is held soon after the outage to review what can be improved for the next outage.
THANK YOU!

All papers can be obtained from the ASCE website