Analysis and Verification of PCCP Stiffness Testing Using Non-Invasive Acoustic Testing

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Presentation Outline

• Introduction
• PCCP Asset Management
• PCCP Condition Assessment
• Desktop Study
• Acoustic Wave Based Stiffness Testing
• Case Studies – New Jersey American Water
• Q & A
Older pipe networks:
- Leak more (background leakage)
- Leak quieter (more difficult to find)
- Have higher risk of catastrophic failure

Reference: AWWA M36

Figure 5-1 The four-pillar approach to the control of real losses
Utility Critical Main Management

Transmission Networks

Top Risks Identified by Water Utilities

1. Emergency Repairs & Damage From Bursts
2. Water Loss Management
3. Pressure Management

Not all transmission main segments carry the same level of risk
PCCP Condition Assessment

**Intrusive: Electromagnetic, Visual, Sounding**
- Useful when access to pipe interior is available
- Provides detailed assessment

**Non-Intrusive: Acoustic Methods**
- Hydrophones, Accelerometers, Acoustic Wave Propagation (AWG), etc.
- Useful when access to pipe interior not available
- Provides survey-level assessment
PCCP Asset Management – Accelerated

- GIS Map / Data
- Leak Detection
- **Pipe Stiffness (AWG)**
- External EM
- In-Pipe EM
- Monitoring
  - Distribution
  - Transmission

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**Desktop Model**

Survey level inspection:

- Acoustic Testing
- External NDT Inspection
- Internal NDT Inspection
- Monitoring

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**Options**

- Total Replacement
- Selective Replacement
- Selective Refurbishment
- No Action

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**Outcomes**

- Lowering of Risk
- Deferral of Capital
Asset Management – Life Cycle Mgmt

PCCP Planning / Repair / Replacement

• 1 small break 48 hours: ~ $200,000
• Repair of 60 LF: ~ $3,000/LF
• Replacement of 20-inch: ~ $350/LF
• Planning for future replacement with Echologics and SG&H: ~ $17-27/LF*

Includes pothole costs from $5-10/LF
Failure Risk Analysis - PCCP

• Evaluate the effects of broken pre-stressing wires on the pipe failure margin using risk curves
• Establish pipe repair priorities (immediate, mid term, no repair)
• Identify high risk pipes for repair to maintain pipeline reliability

• Risk Curves
• Serviceability Limit State – onset of visible cracking of core
• Damage Limit State – core structural cracking and increase in wire stress adjacent to BWZ
• Strength Limit State – pipe failure
PCCP Distress Signs

- Coating cracks and delaminations
- Corrosion of pre-stressing wires
- Broken pre-stressing wires
- Longitudinal cracks in inner core
- Hollow sounding inner core
- Corrosion of steel cylinder
- Leak (through joints or steel cylinder)
- Distress affects pipe stiffness
Acoustic-Wave Stiffness Testing

• Purpose: Identify sections of pipeline with reduced structural stiffness
• Survey level approach
• Acoustic sensors measure the velocity of an acoustic wave in a pipeline segment.

• Reduced wave speed may indicate reduced pipe wall stiffness and distress:
  ▪ Broken pre-stressing wires, lower pre-stress, deteriorated mortar coating, cracked concrete core.
Acoustic-Wave Stiffness Testing

- We calculated the *nominal hoop stiffness* of the 60 in. pipe designs and compared that to the *effective hoop stiffness* derived from the measured wave speeds according to the formula:

$$K_{\text{eff}} = 2c_{\text{l1}}/1/\rho_{\text{lw}}v_{\text{lw}}^2 - 1/K_{\text{lo}}$$

$c_{\text{l1}}$ accounts for longitudinal effects of bell & spigot joints, $ho_{\text{lw}}$ is the density of water, $v_{\text{lw}}$ is the measured wave speed, and $K_{\text{lo}}$ is the assumed bulk modulus of water.
Vacuum Excavation

Permanent Monitoring Points
New Jersey American Water

Pipeline Demographics

- New Jersey American Water serves ~ 2.7 million people in 189 communities
- System includes > 185 miles of PCCP
New Jersey American Water
60” PCCP Project Overview

- 36,000 feet of 60 inch PCCP owned and operated by New Jersey American Water in Central New Jersey
- The pipeline was installed between 1957 and 1981
Purpose of the Project

• Review and assess the pipes’ designs and operating conditions:
  ▶ Evaluate the structural adequacy of the pipe designs
  ▶ Review the current operating conditions of the pipe (pressure, hydraulic modelling information etc.)
  ▶ Assess the required level of distress necessary for failure

• Determine the condition of the main:
  ▶ Perform leak detection along the pipeline
  ▶ Perform ePulse® along approximate 300 foot segments
  ▶ Calculate the effective stiffness of the segments based on ePulse measured velocities for comparison with the nominal stiffness

• Prioritize areas of the main for additional testing:
  ▶ Review areas with low stiffness ratio and higher risk of failure for further investigation
ePulse® Condition Assessment

Leak Detection
• No leaks detected at the time of the survey. One POI noted and two other noise sources suspected to be draw from services or other pipes.

Condition Assessment
• Echologics measured the velocity of 36,000 feet of pipe in approximate 300 foot sections.
  ▶ **Stiffness is directly proportional to velocity**
Internal Pressure

- Working pressures from hydraulic analysis < design pressures
Structural Analysis

AWWA C304 Standard for design of PCCP
Pipe failure risk is sensitive to actual working and transient pressures
  ▶ At design pressure, pipe failure and significant damage can occur at 2 to 4 ft of pre-stress loss
  ▶ At hydraulic model working pressures failure can be expected at 4 to 8 ft of pre-stress loss

Determine (measure) working and transient pressures along pipelines

Control transients to reduce the risk of failure
Ratio Calculated Effective Stiffness to Nominal Stiffness
Pipeline Section 2

1965 Interpace

Sta. 24+22
Design $P_w = 125$ psi
Measured $P_w = 50-90$ psi
Pipeline Section 2

1965 Interpace

(3) PIT Phase II Segment 28
(Sta. 8+98-Sta. 12+36)

Approx. location of Area 4

(4) PIT Phase II Segment 31
(Sta. 30+19- Sta. 32+57)

(4) PIT Phase II Segment 31
(Sta. 30+19- Sta. 32+57)

Approx. location of Area 4
Conclusions – 60” PCCP

• Hydraulic analysis: Working pressures below design (44% to 88%)
• At Design P, 2 to 3 ft of pre-stress loss may result in pipe failure
• At Measured operating pressures, 4 to 8 ft of pre-stress loss may result in pipe failure
• Minimize transient pressures to reduce the risk of pipe damage and failure
• Evaluation of ePulse results
  ▶ Effective pipe stiffness testing results indicate that about 8% (10 out of 118 segments) of the inspected pipeline length has less than 90% of the nominal pipe stiffness
    • This is comparable to average distress rate for PCCP from electromagnetic inspection of about 4%
  ▶ Identify portions of each pipeline for further investigation:
    • Select from 10 pipeline segments with lower stiffness
New Jersey American Water
24/240” PCCP Project Overview

- 3.5 miles of 20-in and 24-in PCCP transmission mains
- Installed 1950’s
PCCP Inspections

SG&H performed detailed pipe inspections at two locations due to lack of any historical information related to the pipe.
PCCP Design Check

• Measure wire diameter and spacing, steel cylinder thickness and mortar coating thickness
Risk Failure Curves – 20” / 24”

- Corrosion of the steel cylinder and likely leakage are expected prior to failure of the 20-in. and 24-in. diameter pipelines.
- Approximately 2 to 4 ft of prestress loss may result in failure of the pipes after steel cylinder corrosion and development of through holes.
Petrographic Analysis of Mortar Coating

- No evidence of deterioration
- Banded variation on paste color
- Low chloride content in 20 in., and high in 24 in. pipe mortar (possible salt spray from bridge)
- High absorption
Soil Corrosivity Testing

- Resistivity
- pH
- Sulfate content
- Chloride content
- Soil from 20 in. pipe excavation is not corrosive to PCCP per AWWA M9 (pH = 5.21 < 5)
- Samples from potholes will be tested in Phase II
Ratio Calculated Effective Stiffness to Nominal Stiffness

Ratio of Calculated Effective to Nominal Stiffness

- 95th Percentile
- 5th Percentile

Segment No.

Ratio Effective/Nominal
Recommendations / Next Steps

• Review segments with lower stiffness design and construction records, potential for soil corrosivity, stray currents, and other features that may affect pipe distress

• To identify leaking pipes that may be highly distressed, consider performing periodic leak detection or leak monitoring

• Review pipeline valve and pump operation
  ▸ Adjust as needed, minimize transient pressures to reduce risk of pipe damage

• Next Steps
  ▸ 60” PCCP Field investigation: Stray current survey
  ▸ 20/24” PCCP Field Investigation
    • Permanent of entire pipeline
    • Replacement of failed segments
    • Follow the inverted pyramid
EchoShore-TX® Permanent Monitoring