Developing and Implementing a Force Main Condition Assessment Program

WWAdCon  January 24, 2019
Outline

• Understanding Modes of Pressure Pipe Failure
• Risk-Based Assessment Approach
• Condition Assessment Technologies
• Examples
Pressure Pipe Failure Modes

- PCCP
- PVC
- DIP/CIP
- ACP
• PCCP relies on compressive forces applied by pre-stressing wire. Loss of this force results in tensile forces higher than the tensile strength of the concrete.

• The steel cylinder, while not considered in design does provide some resistance.
PCCP Failure

• Corrosion at joints
  ✓ Direct H2S
  ✓ Sulfuric acid attack

• Internal pipe corrosion

• Wire breaks
  ✓ External corrosion
  ✓ Hydrogen embrittlement
  ✓ Internal corrosion
PVC Pipe Failure

• Bell failure
  ✓ Over-homing
  ✓ Excessive deflection

• Point load failure
  ✓ Poor bedding

• Cyclic fatigue

• Excessive deflection
DIP/CIP Pipe Failure

- Corrosion
  - Internal
  - External
- Joint failure
- Split
- Graphitization
- Erosion
Steel Pipe Failure

• Corrosion
  ✓ Internal
  ✓ External

• Loss of mortar lining

• Joint failure
Asbestos Cement Pipe Failure

- Calcium Leaching
- Acid attack
Condition Assessment Options

Indirect condition assessment

Use of known pipe and surrounding environment characteristics to infer risk of failure

Direct condition assessment (Level 1 and Level 2)

Use of destructive and non-destructive tools to directly measure in-situ conditions
Overall Phased Risk-Based Approach

Phase 1
- Conduct Desktop Risk Assessment
  - Indirect PoF and CoF

Phase 2
- Develop and Implement Level 1 Inspection Plan

Phase 3
- Develop and Implement Level 2 Inspection Plan
Desktop Risk Analysis

Risk = 
Likelihood of Failure  \times  Consequence of Failure

Physical Attributes
Condition Attributes
Environmental Attributes
Operational Attributes

Critical Customers
Pipe Size
Pipe Location
Redundancy

ESRI Model Builder is Excellent Tool For This
## Desktop Risk Analysis

Risk analysis: consequence and likelihood of failure

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Insignificant</th>
<th>Minor</th>
<th>Moderate</th>
<th>Major</th>
<th>Severe</th>
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<tbody>
<tr>
<td>Almost certain</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Likely</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>E</td>
</tr>
<tr>
<td>Possible</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>E</td>
</tr>
<tr>
<td>Unlikely</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Rare</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
</tbody>
</table>
Phase 1 Risk Analysis - Desktop Condition Assessment

- Material
- Age
- Profile
- Soil
- Pressure

POWER TRANSMISSION TOWERS
(Exterior Corrosion)

DISSIMILAR METAL PIPE CROSSING
(Exterior Corrosion)

CORROSIVE SOILS

DEFECTIVE ARV
(Interior Corrosion)

HYDRAULIC JUMP
(Interior Corrosion)
Indirect Condition Assessment

Environment factors

- Soil (AWWA C105)
  - Resistivity
  - pH
  - Sulfides
  - Redox potential

- Groundwater

- External loads

Pressure Monitoring
Phase 1 Risk Analysis—Cyclic Fatigue for PVC

Analysis of Cyclic Cumulative Damage:

- Cumulative affect of variable-amplitude surge events can be estimated using Miner’s rule by “adding up the percentage of life consumed by each stress cycle.”
- Using this method, life expectancy of 8” DR18 PVC pipe is estimated to be about 19 years.

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots + \frac{n_k}{N_k} = 1 \quad \text{or} \quad \sum_{j=1}^{j=k} \frac{n_j}{N_j} = 1$$

From Appendix A of *Long-Term Cyclic Testing of PVC Pipe* by Jeffrey, Moser & Folkman, Utah State University, for Uni-Bell PVC Pipe Association, February 26, 2004.
Indirect Condition Assessment – Failure Data Analytics

- Utilize available pipe leak and failure data to identify trends and most “at-risk” pipes
- Visual analytics can be very powerful
- Tableau software is an example
- Dashboard views allow slicing and dicing of data
Failure Cohort Analytics Example

[Graph showing average yearly failure rates for different time periods, with peaks in the 1940s and 1950s.]
Example Phase 2 Field Plan

9. Ultrasonic Thickness Testing
   Soil Testing
   120 L.F. Downstream of ARV

8. Ultrasonic Thickness Testing
   Soil Testing
   50 L.F. Downstream of ARV

10. Ultrasonic Thickness Testing
    Soil Testing
    Pipe Sample Collection
    20 L.F. Upstream of Discharge Manhole

7. Ultrasonic Thickness Testing
   Soil Testing
   20 L.F. Downstream of ARV

200 L.F. of Protective Pipe Coating

377 L.F. of Protective Pipe Coating

Highly Corrosive Soils
Direct Condition Assessment

**Level 1** – Direct condition assessment that results in a screening level condition analysis. Generally less expensive but is generally qualitative. Can be used to target a Level 2 assessment.

**Level 2** – Direct condition assessment that provides more quantitative measurements of defects. Typically, but not always more expensive than a Level 1 assessment.
Direct Condition Assessment

Non-destructive

– Ultrasonic/Acoustic – Level 1 & 2
  • Handheld – Level 1
  • Free swimming – Level 2
  • Guided wave – Level 1

– Electromagnetic – Level 2
  • Magnetic flux leakage
  • Remote field technology
  • BEM – Pulse Eddy Current

– Laser profile – Level 2

– CCTV – Level 2
Direct Condition Assessment – Level 2

Destructive

- Coupons
- Failure specimens
- Core sample
- Phenolphthalein dye test
Direct Condition Assessment Level 1 – Acoustic Echologics E-Pulse Guided Wave

- Uses acoustic “pressure wave”
- Measures average minimum remaining wall thickness over 100’-500’
- Requires 15 psi
- Air pockets cause error

<table>
<thead>
<tr>
<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic, ACP,</td>
<td>Any</td>
<td>$15,000</td>
<td>$5 per foot</td>
</tr>
<tr>
<td>PCCP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Direct Condition Assessment Level 1 - Acoustic

- Pure Smartball
  - Measures leaks and detects gas pockets using sound detection
  - Can indicate where there are risks of corrosion
  - Smart ball free swimming needs about 1.7 fps and 15 psi for leaks
  - Requires 4” minimum inlet

<table>
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<tbody>
<tr>
<td>Any</td>
<td>&gt;=8”</td>
<td>$25,000</td>
<td>$4-$5 per ft.</td>
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</table>
Direct Condition Assessment Level 1 – p-CAT

- Uses “transient pressure wave”
- Measures average wall thickness over 30’ lengths
- Requires 30 psi
- Air pockets cause error

<table>
<thead>
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<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic, ACP, PCCP</td>
<td>&lt;= 36” (up to 54” by 2019)</td>
<td>$15,000</td>
<td>$5-7 per foot</td>
</tr>
</tbody>
</table>

Micro-reflections result from changes of pipe properties. These micro-reflections are detected by the transducers.
Direct Condition Assessment Level 1 – Acoustic

- Pure Sahara
  - Measures leaks and detects gas pockets using sound detection
  - Can add video
  - Tethered with range of about 2,500 LF each access
  - Approximately 2” access needed
  - Very accurate location capabilities
  - Requires 1 fps and about 3-5 psi

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<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCCP/Metallic</td>
<td>&gt;6”</td>
<td>$25,000</td>
<td>$6 per foot</td>
</tr>
</tbody>
</table>

![Image of Pure Sahara device in use](image1.jpg)

![Image of a gas pocket](image2.jpg)
Direct Condition Assessment Level 1 – Acoustic Impact Echo

- Uses small sphere to generate transient sound waves
- Reflects off of defects and measures strength
- Can be internal or external
- External is point measurement

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<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
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</thead>
<tbody>
<tr>
<td>PCCP, RCP</td>
<td>Any</td>
<td>$10,000</td>
<td>$5,000 per day</td>
</tr>
<tr>
<td>PCCP, RCP</td>
<td>&gt;48” (internal)</td>
<td>$10,000</td>
<td>$11 per foot</td>
</tr>
</tbody>
</table>
Guided Wave Testing (GWT)

**Benefits:**
- Screening of long length of pipe (100’)
- 100% of pipe wall is inspected
- Detects corrosion in insulated and buried pipes

**Limitations:**
- Variable range: 1”-60” and 60-1,000 LF
- Exposure of pipe exterior is required
- Applies to metallic pipes only and primarily steel
- Interference from bends, welds, joints and may miss major point defects
- Cement lining significant issue

### Direct Condition Assessment Level 1 – Acoustic

### Materials | Diameter | Mobilization | Assessment Cost
--- | --- | --- | ---
Metallic | Up to 42” | $2,500 | $5,000 per day
Direct Condition Assessment Level 2 – Ultrasonic

Ultrasonic thickness testing

- Usually handheld
- Measures thickness directly
- Point measurement around multiple locations
- Coatings must be removed

<table>
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<th>Assessment Cost</th>
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</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Any</td>
<td>&lt; $1,000</td>
<td>$1,200 per day</td>
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</table>
Direct Condition Assessment Level 2 – Electromagnetic Broadband Electromagnetic (BEM)

• Relatively accurate, average thickness over small area (2 in)
• Typically external inspection for sewer force mains (over 3’ sections)
• Can work through coatings

<table>
<thead>
<tr>
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<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>any</td>
<td>$10,000</td>
<td>$10,000 ea</td>
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</tbody>
</table>
Direct Condition Assessment Level 2 – Electromagnetic Pure PipeDiver

- Uses remote field technology
- Measures wire breaks with pipe active
- Measures pipe wall defects in metallic pipe

<table>
<thead>
<tr>
<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
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<tbody>
<tr>
<td>Diver</td>
<td>PCCP/Metallic &gt; 24”</td>
<td>$70,000</td>
<td>$13 per foot</td>
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</table>
Direct Condition Assessment Level 2 – Electromagnetic Pure Robotics

• Uses remote field technology
• Can also take video, sonar, and laser
• Measures pipe wall defects in metallic pipe
• Internal

<table>
<thead>
<tr>
<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robotics</td>
<td>Steel/DI</td>
<td>&gt; 24”</td>
<td>$70,000</td>
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Figure 4 – Structural Analysis Model
Direct Condition Assessment Level 2 – Electromagnetic PICA See Snake and RAFT Remote Field Technology

- Uses remote field technology
- Internal inspection
- Requires some cleaning
- Must be depressurized
- Goes up to 3,300 LF in one setup

<table>
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<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>Up to 48”</td>
<td>$15,000</td>
<td>$8-$10 per foot</td>
</tr>
</tbody>
</table>
Direct Condition Assessment Level 2 – Electromagnetic

Magnetic Flux Leakage

- Accurate to detect wall loss and defects but very new to sewage force mains
- Internal or external inspection (external 3’ sections)
- Typically requires intimate contact but Pure claims up to 1” concrete coating

<table>
<thead>
<tr>
<th></th>
<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal (Pure)</td>
<td>Metallic</td>
<td>Up to 78”</td>
<td>Variable</td>
<td>Variable</td>
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<tr>
<td>External</td>
<td>Metallic</td>
<td>any</td>
<td>$15,000</td>
<td>$2,500-$7,400 ea</td>
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</tbody>
</table>

Figure 1: Smart Cat on Pipe
Direct Condition Assessment Level 2 – CCTV and Laser Profile

Redzone Robotics and Pure Robotics

- Accurate 3D Lidar scan of profile and CCTV in one unit
- Tethered with maximum range of about 8,000 LF each access
- Requires pipe to be out of service

<table>
<thead>
<tr>
<th>Materials</th>
<th>Diameter</th>
<th>Mobilization</th>
<th>Assessment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any</td>
<td>&gt;=36”</td>
<td>$30,000</td>
<td>$7 per foot</td>
</tr>
<tr>
<td>Inspection Technology</td>
<td>Type</td>
<td>Pipe active</td>
<td>Mobilization Cost</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------------</td>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Pure Sahara</td>
<td>Acoustic</td>
<td>Yes</td>
<td>Approx $25,000</td>
</tr>
<tr>
<td>Pure Smartball</td>
<td>Acoustic</td>
<td>Yes</td>
<td>Approx $25,000</td>
</tr>
<tr>
<td>Pure Pipediver</td>
<td>Electromagnetic (RFT)</td>
<td>Yes</td>
<td>$70,000</td>
</tr>
<tr>
<td>Pure Robotics</td>
<td>Electromagnetic (RFT)</td>
<td>No</td>
<td>$70,000</td>
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<tr>
<td>Pure MFL Internal</td>
<td>Electromagnetic (MFL)</td>
<td>Yes</td>
<td>$70,000</td>
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<tr>
<td>Echologics Acoustic</td>
<td>Acoustic</td>
<td>Yes</td>
<td>$15,000</td>
</tr>
<tr>
<td>Smart-CAT MFL External</td>
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<td>$15,000</td>
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<tr>
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<tr>
<td>Handheld Ultrasonic</td>
<td>Ultrasonic</td>
<td>Yes</td>
<td>$1,200 day</td>
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<tr>
<td>Redzone Lidar/CCTV</td>
<td>CCTV/Laser</td>
<td>No</td>
<td>$30,000</td>
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<tr>
<td>BEM</td>
<td>Electromagnetic (RFT)</td>
<td>Yes</td>
<td>$10,000</td>
</tr>
</tbody>
</table>
| NDT Impact Echo       | Ultrasonic/Acoustic | No         | $10,000           | $11 ft           | No               | >48”          | Yes | PCCP/RCP                 | Point test. Measures thickness, wire breaks and strength
| NDT Impact Echo       | Ultrasonic/Acoustic | Yes         | $10,000           | $5,000 day       | Point measurement | No            | Any | Yes                      | PCCP/RCP |                                                                 |

Note: Costs do not include excavation of sites and installation of insertion points which can be $5,000-$30,000 each.
TOSA Outfall Pipediver Inspection

- 36” PCCP and Steel Ocean Outfall had failed
- Utilized PipedDver to assess condition of remaining pipe under pressure conditions
TOSA Outfall Pipediver Inspection

- Found sections were actually 33” rather than 36”
- Only one PCCP pipe had prestressing wire breaks
- Several steel sections did not meet design requirements for pipe thickness.
Assessment Case Study - Bullitsville Force Main Condition Assessment

- 13,360 LF of Ductile Iron FM
- FM has experienced numerous failures due to internal corrosion
- Desktop analysis showed history of failures, local high spots, failing ARV’s and gravity section
- Sahara leak detection selected to locate FM and identify potential leaks and gas pockets
- Surge analysis
Bullitsville PS and Force Main Condition Assessment

Results of gas and leak detection

- No evidence of leaks,
- Several gas pockets at high points and near ARVs were located which indicate possible corrosion location.
Bullitsville PS and Force Main Condition Assessment – Level 2 Inspection Plan

- Ultrasonic Thickness Testing (11)
- Pipe coupon
Bullitsville PS and Force Main Condition Assessment Results

Pipe: Pressure Class 350 DIP (0.280” nominal with +/-0.06” casting

Over 50% loss
Bullitsville PS and Force Main Condition Assessment Results

- Only vicinity of absolute high point had significant corrosion
- Surge not an issue
- Results correlate well with desktop assessment
- Gas pocket locations did not show metal loss likely due to fact that gas is anaerobic
- Most of the force main does not need to be replaced.
  - From >6,500 LF to less than 1,200 LF
- Phase approach saved over $400,000 in construction
- Ultrasonic thickness cost $3,400 for 11 locations
Summary

• There are numerous methods for assessing pressure pipe but costs are a major factor.
• Taking a phased/risk-based approach enables cost-effective decisions.
• For metallic pipe, our experience has shown desktop analysis is very good at predicting areas for corrosion for force mains.
• Ultrasonic thickness measurement is often the most-cost effective if corrosion is main concern.
• Electromagnetic inspection is shown to be accurate but can be expensive. However, amount of risk may make this type of inspection cost-effective.
• Technology is improving rapidly.