Acoustic Methods for Determining Remaining Pipe Wall Thickness in Asbestos Cement and Ferrous Pipe

Asia Water, 27th March 2012
Mark Nicol, Regional Manager – Asia Pacific
Presentation Outline

• Why do we need condition assessment
• Equipment used & inspection methods
• How the inspection results are used - and the benefits
• Case study: application of the technology in Asbestos Cement and Ferrous piping
## The Question At Issue

<table>
<thead>
<tr>
<th>Pipeline 1</th>
<th>Pipeline 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed 1860</td>
<td>Installed 1860</td>
</tr>
<tr>
<td>Brown sandy soil</td>
<td>Brown clay soil</td>
</tr>
<tr>
<td>Moderate soil corrosivity</td>
<td>Moderate soil corrosivity</td>
</tr>
<tr>
<td>Exhumed &amp; sand blasted:</td>
<td>Exhumed &amp; sand blasted:</td>
</tr>
</tbody>
</table>

![Image of pipeline corrosion](image1.png)

![Image of corrosion-free pipeline](image2.png)
A pipe’s lifetime

- Installed defect failure period
- Random failure period
- Degradation related failure period

Bursts per km per yr

Maximum economical failure rate
Methods of pipe assessment

- Direct
  - Visible internal conditions
  - Presence of non-surfacing leaks
  - Material analysis of pipe samples
  - Remaining pipe wall thickness

- Indirect
  - Failure history
  - Water loss rate
  - Flow testing
  - Soil testing
Pipe Wall Thickness

- Direct indicator of structural condition.
- Indicator of level of degradation of the asset.
  - Metallic pipes lose thickness due to corrosion.
  - Asbestos cement pipes lose *effective thickness* by the weakening of the wall as calcium leaches out of the cement due to aggressive waters.
  - Reinforced concrete pipes lose strength as a result of the weakening of the concrete or corrosion-failure of pre-tensioning steel.
Structural Thickness in Cast Iron

Tuberculation and graphitic material cannot bear load.

Remaining structural thickness.
**Structural Thickness in Asbestos Cement**

- Calcium leaches out of cement in reaction to aggressive waters
- Remaining material cannot bear structural load
- Phenolphthalein dye reveals remaining thickness from samples

![Remaining structural thickness](image-url)
Established Methods to Measure Remaining Wall Thickness

- Pipe sampling programs
  - A sample or coupon is taken every 1 km of pipe
    - Intrusive and disruptive
  - Sample is sand-blasted and measured, and remaining life of entire pipeline extrapolated from sample
    - Exhumed samples may not be representative
    - Difficult to account for local environmental variations
Established Methods to Measure Remaining Wall Thickness

- Inline electromagnetic methods
  - Required instrumentation is sent inside pipes using smart pigs
    - Often requires shutdown of the line, installation of launch & retrieval sites, and cleaning of pipes to remove tubercles and debris
  - Provides a continuous profile of pipe-wall thickness.
    - Data acquisition and analysis are labour and cost intensive
    - Cost and level of disruption are too high to be justified for most pipes
Acoustic Wall Thickness Testing

- Determines the average remaining wall thickness between two points of the pipeline
  - Typically about 100 meters of pipe
- Works on any diameter, most materials
- Completely non-destructive, non-invasive technique
- Direct indication of
  - The current structural strength of the pipe
  - The state of degradation of the pipe
- Can be used to evaluate
  - The fitness for service of the line
  - The remaining useful life
Acoustic Condition Assessment

- A low frequency acoustic pressure wave is induced in the pipe
  - Dominated by a non-dispersive axi-symmetric \((S_1, n=0)\)
- This pressure wave causes pipe wall to “flex” on a microscopic level
- Thicker (and therefore stiffer) pipe walls are more resistant to this “breathing,” causing the wave to travel faster
- Measuring this phenomenon allows calculation of remaining wall thickness
Velocity Equation

Where:

\[ v = v_o \sqrt{\frac{1}{1 + \left(\frac{D}{e}\right)\left(\frac{K_{\text{water}}}{E_{\text{pipe}}}\right)}} \]

- \( v \) = propagation velocity of leak noise in pipe
- \( v_o \) = propagation velocity of sound in an infinite body of water
- \( D \) = internal diameter of pipe
- \( e \) = thickness of pipe wall
- \( K_{\text{water}} \) = bulk modulus of elasticity of water
- \( E_{\text{pipe}} \) = Young’s modulus of elasticity of pipe material
Equipment Used

PC-based leak noise correlator
Correlation Theory

- Leaks make noise
- Time of flight technology
- Correlation function:
  - Leak bracketed with 2 Sensors
  - Leak noise takes longer to arrive at Sensor 1 than Sensor 2
  - Correlator measures time difference to identify exact leak location
Typical Correlation: High and Low Frequency
Acoustic Condition Assessment Process

1. Sensor
2. RF Transmitter

PC Based Correlator
Receiver

Noise Source

Monitor the sound waves

D
Technology Implementation

- Average distance 70m to 150m is optimal, can measure from 30m to 300m
- Typically measure between two valves or hydrants
- Can measure 0.75 to 1.5 km per day
- For transmission mains, can vacuum excavate to the crown of the pipe to obtain proper distance
- Average structural integrity between the two locations is obtained
- Pipe sampling may be done to confirm results
Sensor Attachment
Condition Assessment Results

- Presence and location of any leaks
- For each assessment interval:
  - Remaining structural thickness
  - Percent loss from original thickness
  - Qualitative assessment of condition
    - Based on pipes tested & exhumed for validation

<table>
<thead>
<tr>
<th>Wall Thickness Loss</th>
<th>Condition</th>
<th>Color Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10%</td>
<td>Good</td>
<td>Green</td>
<td>minor levels of uniform degradation and maybe some isolated areas with localized degradation</td>
</tr>
<tr>
<td>Between 10% and 30%</td>
<td>Moderate</td>
<td>Yellow</td>
<td>moderate uniform degradation or areas with localized degradation</td>
</tr>
<tr>
<td>Greater than 30%</td>
<td>Poor</td>
<td>Red</td>
<td>significant uniform degradation and numerous areas with localized degradation</td>
</tr>
</tbody>
</table>
What it tells you

<table>
<thead>
<tr>
<th>Pipeline 1</th>
<th>Pipeline 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed 1860</td>
<td>Installed 1860</td>
</tr>
<tr>
<td>Brown sandy soil</td>
<td>Brown clay soil</td>
</tr>
<tr>
<td>Moderate soil corrosivity</td>
<td>Moderate soil corrosivity</td>
</tr>
<tr>
<td>Test Results: <strong>31% thickness loss</strong></td>
<td>Test Results: <strong>1% thickness loss</strong></td>
</tr>
<tr>
<td>Condition Prediction: <strong>Poor</strong></td>
<td>Condition Prediction: <strong>Good</strong></td>
</tr>
</tbody>
</table>
Benefits of External Acoustic Pipe Wall Assessment

- Cost Effective
- Accurate & Proven
- Easy to Employ
- Actual data on physical pipe condition
- Negligible Risks
- Non-destructive
- Leak detection is part of the assessment
Case study: Applying the Technology in Asbestos Cement Piping

- Many US utilities faced with significant amounts of AC pipe nearing design life
- Cost of replacement is inflated by need to follow asbestos handling regulations
- Preferable to leave in service so long as it remains in good condition
Stage 1: Pilot project Field Testing
### Stage 2: Validation of results

<table>
<thead>
<tr>
<th>Line 1</th>
<th>Line 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echologics assessment: &lt; 5% thickness loss</td>
<td>Echologics assessment: 38% thickness loss</td>
</tr>
<tr>
<td>Actual conditions:</td>
<td>Actual conditions:</td>
</tr>
<tr>
<td><img src="image1.png" alt="Image 1" /> <img src="image2.png" alt="Image 2" /></td>
<td><img src="image3.png" alt="Image 3" /> <img src="image4.png" alt="Image 4" /></td>
</tr>
</tbody>
</table>
Las Vegas, NV: Excavated Pipe
Results of 24” lab testing
Stage 3: Make use of results

- Acoustic wall thickness measurements agree with destructive physical tests
- Pilot included 10 miles budgeted for removal
  - Found 2.5 miles of this to be in excellent condition
  - Savings to utility of over $2M
Stage 4: Systematic Program

- Include wall thickness in replacement prioritization model
- Network-wide assessment of AC pipe wall thickness and leakage
- Depending on size of network, and available funds, surveys may be spread over several years
Hamilton, Ontario: Pilot

- Tests performed at city water distribution system
  - 10 test sites selected
  - 5 suspected in poor condition based on statistical indicators (burst rate, age, etc.)
- Sites included large and small diameter cast iron pipes at different levels of deterioration
- Deterioration level judged on break history, pipe age and soil corrosiveness
- Selected pipes installed between 1860 and 1960
- Accuracy of remaining thickness predicted based on visual appearance and average wall thickness of exhumed samples
Exhumed as-found samples at site 3
Exhumed as-found samples at site 3
Pipe from site 3 after sand blasting
Summary: External Acoustic Condition Assessment

- Average wall thickness over ~100m intervals
- Reflects structural strength of pipe
- Non-destructive, non-intrusive method
- Survey-level technology, for network-wide application
- Leak detection performed concurrently
- Can be used to calculate remaining useful life
Q & A