VALIDATION OF THE LONG LIFE OF PVC PIPES

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Outline

- Introduction
- Life Cycle Costing
- Expected Life of PVC Pipe Literature Review
  - United Kingdom & Europe
  - Australian Testing
  - North America Results
- Recent Test Results from Utah State University
- Conclusions
Introduction

- 2013 ASCE USA Infrastructure Report Card “D” grade for drinking water and wastewater infrastructure
- Large amounts of iron pipe are failing due to corrosion
- More than a million miles of pipes in USA are at or near the end of useful life
- Municipalities struggle with water service affordability, the rise in service interruptions, and declining water quality
Life Cycle Costs

- Used to minimize costs over the life of a system
- All competitive pipe materials need to be compared
- Timing and all costs associated with pipe replacement are important
- Expected longevity of a pipe is a critical factor
- A pipe which has a long life at a low cost is the most affordable
Expected Life of PVC Pipe

- There are contradictory sources of information about the expected life of PVC.
- Clark, et al* claims PVC pipe life less than DI.
- A survey by Folkman showed that PVC pipe has the lowest overall failure rate when compared to cast iron, ductile iron, concrete, steel and asbestos cement pipes.

Early PVC Pipe Failure

- There are examples of PVC failure after short life spans
- Forensic investigations have shown two primary causes:
  - Defective pipe (e.g. due to incomplete gelation)
    - Was a problem in 1970’s with a few manufacturers
    - Quality control tests will prevent this
  - Improper installation and/or operation
    - Cause of the vast majority of early PVC failures
Expected Life of PVC Pipe

How long can a correctly installed PVC Pipe Last?

- This has been studied by numerous researchers across the world
- A literature review completed
- Will briefly summarize their results
- Will focus on exhumed (dig-up) test results
- Results combined with testing done at Utah State University
Lancashire (1985) investigated PVC-U pipe

- Exhumed pipe with 4 to 16 years service
- Performed tensile tests of 19 samples
  - Material modulus not affected by age
  - Concluded initial pipe quality (gelation and inclusions) are critical to performance
- Stress regression tests showed all pipes tested expected to exceed 100 year life


- Tested exhumed pipe with up to 37 years service
- Virtually no change in tensile and impact strength due to age
- Stress regression testing showed that PVC pipes after 35 years of service still were meeting CEN stress regression requirements
- “old PVC water pressure pipes still fulfill the most important functional requirements.”

Hülsmann (2004)
- Tested some of the first PVC pipes installed in Germany
- Included 24 pipe specimens between 23 and 53 years service
- Stress regression testing at 60°C
- Another 100 years of safe operation could be expected

Hülsmann, T., and Reinhard, E. N., “70 years of experience with PVC Pipes,” 13th World Pipe Symposium, Milan, Italy, April 2004
Breen (2006)

- Examined pipes up to 46 years old
- Tests include tensile, craze initiation, burst test, slow crack growth, impact test, and fatigue measurements
- He concluded “existing PVC tap water pipe systems in the Netherlands will operate for at least 100 years”

Stahmer and Whittle (2001)

- Examined pipes after 25 years of service from a variety of terrains and installation conditions
- Tests include tensile, flattening, impact, fracture toughness
- Degradation in strength or elongation of the PVC material not observed

Whittle and Teo (2005)

- Summarized previous research on PVC fatigue failure
- Conducted rotating beam tests
- Able to match fatigue failure results from pressure cycling PVC pipes
- An endurance limit exists in PVC-U pipes at stress amplitudes less than 2.5 MPa (362 psi)

Australian Testing

- Burn, et. al. (2005)
  - A comprehensive review of methods to analyze the expected life of PVC pipe funded by Water Research Foundation
  - Utilized a survey of water main failures and predictions of fracture mechanics failures
  - Reported that 100 years is a conservative estimate for a properly designed and installed pipe

Moser and Kellogg (1994)

- An AWWARF funded survey of water utilities along with impact and acetone immersion tests on 59 PVC pipe samples from 16 different utilities and 10 manufacturers
- All acetone tests passed and only four samples failed impact testing
- Observed evidence of early PVC pipe failure attributed to improper installation

 Salah satu catatan yang penting adalah bahwa Edmonton’s corrosive soil force a transition from cast iron to asbestos cement in 1966 and then to PVC in 1977. The transition to PVC produced a dramatic reduction in water main break rates. Demonstrated that a PVC water main could be frozen in winter and not burst. Three PVC pipes with between 17 and 25 years of service were excavated and subjected to quick burst, impact resistance, flattening, and acetone immersion tests. The tests demonstrated the pipe met virtually all new pipe requirements.

Seargeant, D., “PVC Water Distribution Pipe; EPCOR’s Continuing Success,” Uni-Bell Annual Meeting, Newport Beach, CA, April 2013.
Recently Completed Dig-Up Tests at Utah State University

- Folkman and Barfuss (2013) reported on quality control testing on three excavated PVC pipes in service between 20 and 49 years
- Additional tests completed in 2014

Folkman, S, and Barfuss, S., “Validation of PVC Pipe’s Long Life Performance,” Uni-Bell Annual Meeting, Newport Beach, CA, April 2013
**Dig-Up Specimens**

- A total of 8 different specimens from across the USA tested
- Between 20 and 49 years of service before excavation
- The CS 256 and PS 22-70 standards were replaced with ASTM D2241 and the standards are nearly identical.

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Size (inches)</th>
<th>SDR</th>
<th>Usage</th>
<th>Standard</th>
<th>Year Installed</th>
<th>Year Excavated</th>
<th>Years of Service</th>
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<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>21</td>
<td>Water Main</td>
<td>CS-256</td>
<td>1964</td>
<td>2012</td>
<td>49</td>
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<td>2</td>
<td>4</td>
<td>21</td>
<td>Water Main</td>
<td>ASTM D2241</td>
<td>1987</td>
<td>2012</td>
<td>26</td>
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<tr>
<td>3</td>
<td>24</td>
<td>18</td>
<td>Forced Sewer</td>
<td>AWWA C905</td>
<td>1990’s</td>
<td>2012</td>
<td>~20</td>
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<td>CS-256</td>
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<td>~38</td>
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<td>6</td>
<td>6</td>
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<td>PS 22-70</td>
<td>~1976</td>
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<td>~38</td>
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<tr>
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<td>6</td>
<td>26</td>
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<td>ASTM D2241</td>
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<td>2014</td>
<td>20</td>
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<td>8</td>
<td>6</td>
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<td>Water Main</td>
<td>ASTM D2241</td>
<td>1979</td>
<td>2014</td>
<td>35</td>
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</tbody>
</table>
## Tests Completed

- Do these pipe meet original standards at manufacture?
- Selected tests outlined below

<table>
<thead>
<tr>
<th>Test</th>
<th>Test condition</th>
<th>Applicable Standards</th>
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<tbody>
<tr>
<td>Pipe Dimensions</td>
<td>6 specimens at 8 points</td>
<td>AWWA C905 &amp; ASTM D2122</td>
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<tr>
<td>Acetone Immersion</td>
<td>8 samples</td>
<td>ASTM D2152</td>
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<tr>
<td>Burst Pressure</td>
<td>DR 21, 630 psi in 60 s</td>
<td>CS-256, PS 22-70, ASTM D2241 &amp; D1599</td>
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<tr>
<td></td>
<td>DR 26, 510 psi in 60 s</td>
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<tr>
<td>Hydrostatic Integrity</td>
<td>DR 18, 470 psi in 60 s</td>
<td>AWWA C905 &amp; ASTM D1599</td>
</tr>
</tbody>
</table>
**Tests Results**

- Not all specimens passed
- Specimen 4 and 6
  - Made in the 1970’s when gelation problems were being addressed
  - functioned adequately for approximately 40 years

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Pipe Dimensions</th>
<th>Acetone Test</th>
<th>Burst or Hydrostatic Integrity Test</th>
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<tr>
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<td>3</td>
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<td>Pass</td>
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<tr>
<td>4</td>
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<td>Fail</td>
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<tr>
<td>5</td>
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</tr>
<tr>
<td>8</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>
2nd Round of Testing for Specimen 1

- Eckstein (1987) reported that samples of this pipe were excavated after 22 years of service and subjected to:
  - chemical extractant tests for water quality
  - stress regression
  - acetone immersion
  - flattening
  - impact resistance
- All of these quality control tests were passed
- Now at 50 years of service, this pipe functions just like a new pipe

Eckstein, D., “PVC Pressure Pipe Excavation Reveals 22 Years Old and Fit as a Fiddle,” Uni-Bell PVC Pipe News, Summer, 1987
**Accelerated Ageing vs. Dig-up Tests**

- Accelerated ageing studies all indicate that PVC pressure pipe can:
  - Provide reliable service for in excess of 100 years
  - Give the best estimates a laboratory can provide

- Validation of PVC longevity with exhumed samples provides additional confidence to the end user:
  - Contractor installed
  - Continuous use with disinfectants
  - From a variety of locations
Conclusions

- There is broad consensus that PVC pipe meeting today’s standards and properly installed will have a life in excess of 100 years.
- With many installations of PVC pipe reaching 50 years with no indication of loss of capacity, this provides further validation of PVC pipe’s long life.
Questions