VALIDATION OF THE LONG LIFE OF PVC PIPES

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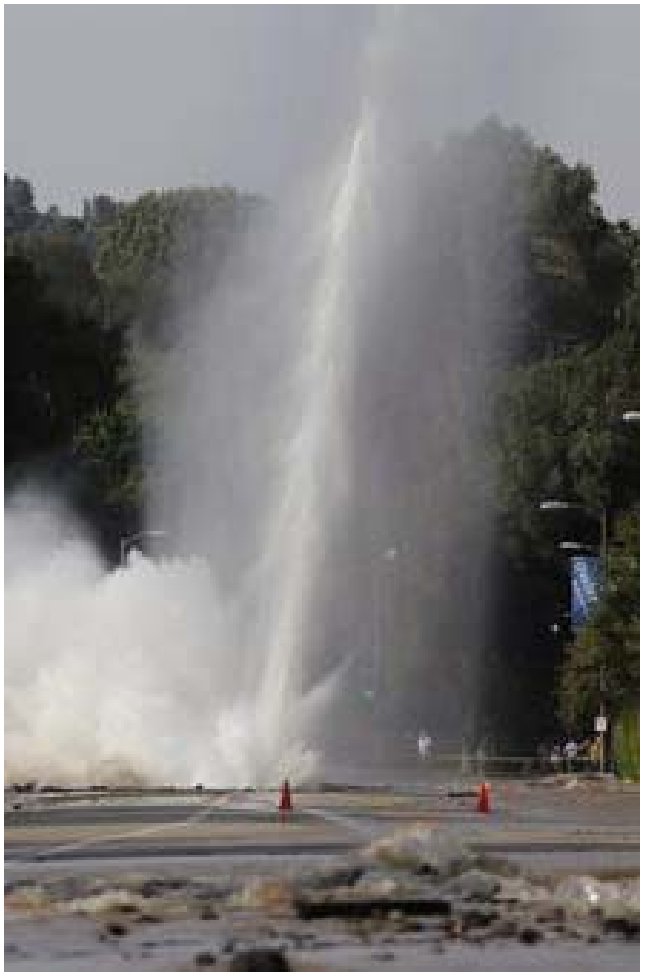
Channelling Performance

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

*Clark, M. C, Carson, J., Thurnau, R. C., Krishnan, R., and Panguluri, S., "Condition assessment modeling for distributions systems using shared frailty analysis," Journal AWWA, July 2010, pp. 81-91

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

United Kingdom & Europe

- 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

Lancashire, S. J., “In-Service Durability of uPVC Water Mains,” Plastics Pipes VI Conference, March, 1985

United Kingdom & Europe

- Alferink, et al (1996)
  - 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.”

Alferink, F., Janson, L. E., Holloway, L., “Old PVC-U Water Pressure Pipes: Investigation into Design and Durability,” PVC 1996 Conference Proceedings, 42C382 Institute of Materials, Brighton, England, April 1996, pp. 87-96

United Kingdom & Europe

- 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

United Kingdom & Europe

- Boersma and Breen (2005)
  - Examined chemical and physical ageing of pipe in service up to 30 years
  - No chemical ageing at 15°C observed
  - Accelerated ageing at 60°C increases yield strength
  - Aged at 15°C, measured yield strength does not change with pipe age
  - These pipes would last another 100 years of operation even at 7 bar (102 psi) and 60°C

Boersma, A., Breen, J., "Long term performance prediction of existing PVC water distribution systems," 9th International Conference PVC, Brighton, England, April 2005.

United Kingdom & Europe

- 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”

Breen, J., “Expected Lifetime of Existing Water Distribution Systems – Management Summary,” TNO Report MT-RAP-06-18692/mso, published by TNO Science and Industry, April 2006

Australian Testing

- 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

Stahmer, M. W., and Whittle, A. J., "Long Term Performance of PVC Pressure Pipes in a Large Rural Water Supply Scheme," Plastics Pipes XI Conference, Munich, Germany, Sept. 2001

Australian Testing

- 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)

Whittle, A. J., and Teo, A., "Resistance of PVC-U and PVC-M to cyclic fatigue," Plastics, Rubbers and Composites, vol. 24, 2005, pp. 40-46.

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

Burn, S. et. al., “Long-term Performance Prediction for PVC Pipes,” AWWARF Report 91092F, May 2006

North American Testing

- 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

Moser, A. P. & Kellogg, K., "Evaluation of Polyvinyl Chloride (PVC) Pipe Performance," AWWA Research Foundation, Project #708, Order #90644, February, 1994.

North American Testing

- Seargeant (2013)
  - Edmonton's corrosive soil forced 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

North American Testing

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

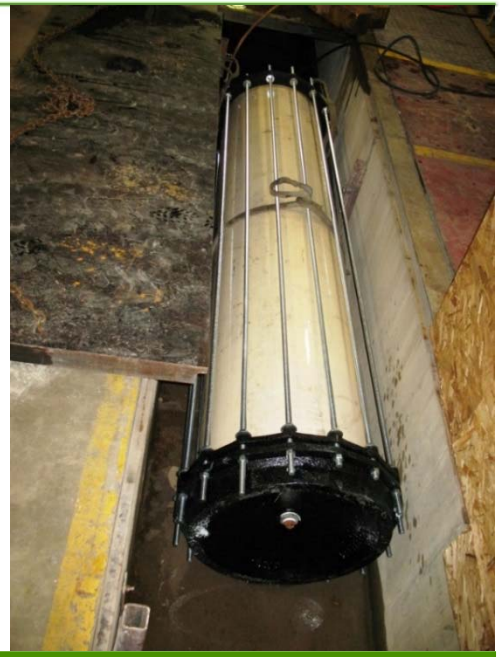
Dig-Up Specimens

- 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.

Specimen Number	Size (inches)	SDR	Usage	Standard	Year Installed	Year Excavated	Years of Service
1	4	21	Water Main	CS-256	1964	2012	49
2	4	21	Water Main	ASTM D2241	1987	2012	26
3	24	18	Forced Sewer	AWWA C905	1990's	2012	~20
4	2	26	Water Main	CS-256	~1972	2014	~42
5	4	26	Water Main	ASTM D2241	~1976	2014	~38
6	6	26	Water Main	PS 22-70	~1976	2014	~38
7	6	26	Water Main	ASTM D2241	1994	2014	20
8	6	26	Water Main	ASTM D2241	1979	2014	35

Tests Completed

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



Test	Test condition	Applicable Standards
Pipe Dimensions	6 specimens at 8 points	AWWA C905 & ASTM D2122
Acetone Immersion	8 samples	ASTM D2152
Burst Pressure	DR 21, 630 psi in 60 s DR 26, 510 psi in 60 s	CS-256, PS 22-70, ASTM D2241 & D1599
Hydrostatic Integrity	DR 18, 470 psi in 60 s	AWWA C905 & ASTM D1599

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

Specimen	Pipe Dimensions	Acetone Test	Burst or Hydrostatic Integrity Test
1	Pass	Pass	Pass
2	Pass	Pass	Pass
3	Pass	Pass	Pass
4	Pass	Fail	Fail
5	Pass	Pass	Pass
6	Pass	Fail	Pass
7	Pass	Pass	Pass
8	Pass	Pass	Pass

Tests Results

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