INNOVATIVE PVC WATER PIPE
Flexibility for the Future

Dave Hughes

Modernizing Distribution

What is i(nnovative)PVC?

- A “ductile” PVC pipe made by PPI in South Korea
- Employs a modified additive and mixing process with the PVC resin developed by LG Chem LTD.
- Installed in South Korea, Japan, China and the US

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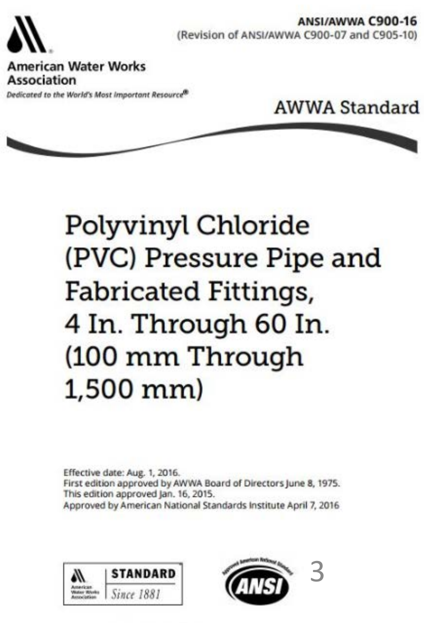
LG Life's Good

Qualified C900 PVC pipe

- Certified as meeting AWWA C900 Pipe Standards
  - Sized appropriately for DR18 and DR14
  - Exceeds HDB, pressure, stiffness and impact testing criteria
  - Testing by NSF including NSF61


ANSI/AWWA C900-16
(Revision of ANSI/AWWA C900-07 and C905-10)

American Water Works Association
Dedicated to the World's Most Important Resource®

AWWA Standard

Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm)

Effective date: Aug. 1, 2016.
First edition approved by AWWA Board of Directors June 8, 1975.
This edition approved Jan. 16, 2015.
Approved by American National Standards Institute April 7, 2016

STANDARD Since 1881

ANSI

Additional US Research

- The Water Research Foundation funded American Water to test the pipe in US
- Tests confirmed strength and ductility, examined possible modes of failure
- Tests performed by qualified U.S. based labs
  - (University of Texas-Arlington and Microbac)
- Pipe installations by MO, NJ American Water

WRF Project # 4650

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Tensile Test (ASTM D638)

- 7,930 psi - exceeded AWWA criteria by 13%
- Calculated Average Modulus of elasticity 461 ksi – exceeded AWWA standard criteria by 15%

AWWA requirements:

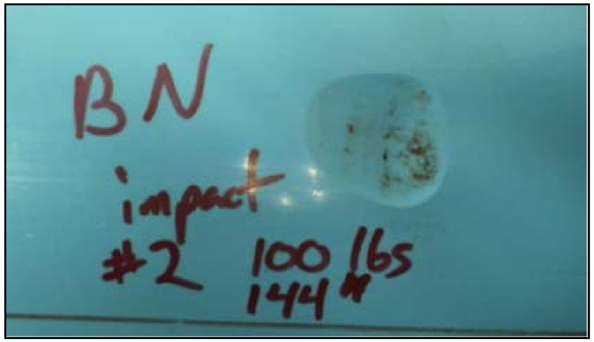
7,000 psi (tensile strength) and 400 ksi (modulus of elasticity)

Source: AW and Microbac Lab

Impact Test (ASTM D2444*)

Standard. TUP type A

- Tested by Microbac at specified 73°F (23°C)
- Dropped TUP at equipment maximum
  - 100 pounds TUP A dropped from 12 foot height (1,200 foot-pounds)
  - Minor dents observed on pipe surface
- Pipe samples further tested at 32°F (0°C)
  - Samples fractured at about 1,080 foot-pounds



Source: Microbac Lab

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Hydrostatic Burst Test (ASTM D1599)

- Designed test with rapid increase of pressure to failure
- Average ultimate pressure and time at failure
  - CUIRE – average 1,065 psi (84 seconds), 4 catastrophic failures
  - Microbac – average 1,033 psi (123 seconds), 4 ductile failures and 6 catastrophic failures
  - Exceeded allowable AWWA failure pressure by 37%

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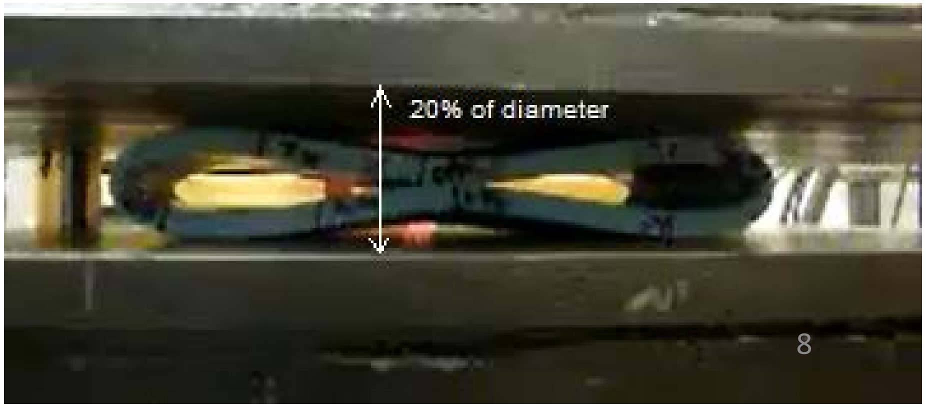
Stiffness Test (ASTM D2412)

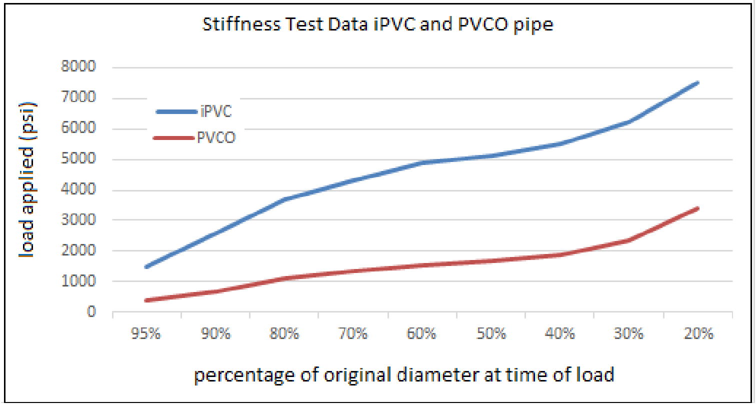
- 5% steps of deformation from 95% through 20% deflection
  - Reached 95% OD at 451 psi at 95% OD, >23% over standard
  - Deformed below 20% pipe O.D. - no wall cracking
- **Maximum load– 10,100 psi**



Stiffness Test Comparison

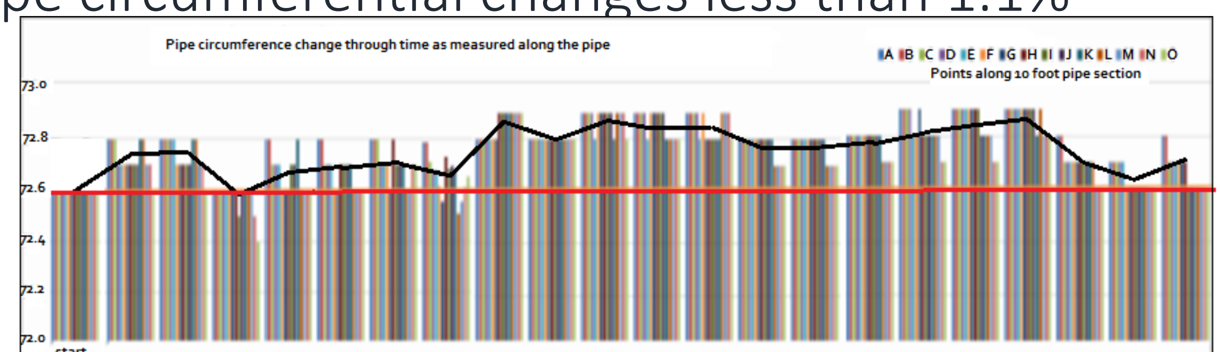
- PVCO (AWWA C909) is an extruded thin-walled PVC pipe
    - Like iPVC exhibits ductility and resistance to splitting
    - Lighter weight but more readily flexes under load

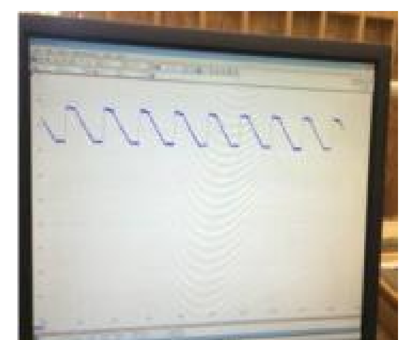
- 1500 PSI load, iPVC deflects 5%,
- 1500 PSI load, PVCO deflects 40%



Fatigue Test (UTA Configuration)

- Surge Pressure Setup
  - 10 foot (3m) pipe cycled between 150 -225 psi
  - 4 Million cycles - 7 cycles/minute - 8 months
  - Water temperature maintained 60°F - 65°F
- Pipe circumferential changes less than 1.1%





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PVC pipe testing before & after 4 million surges

	Before cycling	After cycling
Tensile Strength	7,930 psi (54.8 MPa)	8,267 psi 57.0 MPa
Modulus of Elasticity	461,000 psi (3,178 MPa)	467,313 psi (3,222 MPa)
Stiffness test	No damage or cracking at 20% of diameter	No damage or cracking at 20% of diameter

Summary of Tests

- Product Characteristics (test results versus PVC standards) standards)

Tests``	AWWA C900 Requirements	C-909 criteria	Tested Pipe
Impact Test(for 8" pipe) at 73° F	100 foot-pounds	200 foot-pounds	1,200* foot-pounds
Tensile Strength at 73° F	7,000 psi	7,000 psi	7,930 psi
Modulus of Elasticity	400,000 psi	400, 000 psi	461,000 psi
Hydrostatic Burst Test	755 psi	755 psi	1,033 psi
Stiffness Test at 73° F	364 psi	364 psi	479 psi
Empty Pipe Weight (pounds/foot) – 8" SDR 18	10.5 - 11.5	4.2	10.9

* exceeded maximum testing limits

Pilot Installations American Water

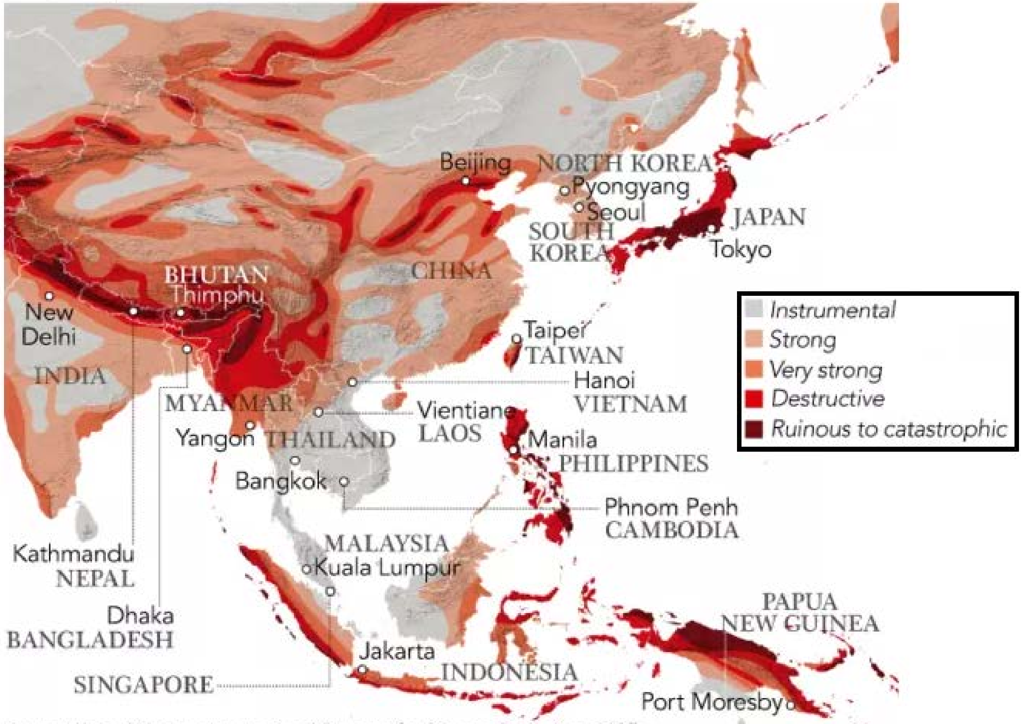
- Installation of 1,500 feet; 8 inch DR 18 pipe
    - Corrosion soils -replaced 55 year old cast iron pipe
    - Located in Missouri flood plain, soil saturated by flooding
    - Pipe installed in January, no issues with cold temperatures
- Installation of 2,200 feet; 8 inch DR 18 pipe
    - Replaced 8 inch cast iron pipe in Manville, NJ
    - Contractor installed, NJ American inspected
    - Wet tapping, cutting, pipe handing, PVC and cast iron connection, and installation of bends and hydrant lateral

Pilot Installation East Bay MUD

- 24,000 feet - 6 and 8 inch DR 14 pipe
  - Installation in Albany area north of Berkeley
  - Replacing 60-90 year old cast iron pipe.
  - Neighborhood has experienced 70 breaks over years associated with pipe corrosion and ground movement.
  - Wet tapping, cutting, pipe handing, PVC and cast iron connection, and installation of bends and hydrant laterals

Seismic Testing?

EARTHQUAKE INTENSITY RISK ZONES IN ASIA-PACIFIC



Source: United Nations International Strategy for Disaster Reduction, 2008

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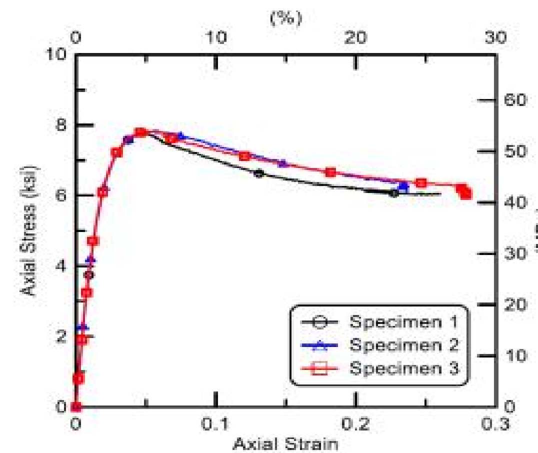
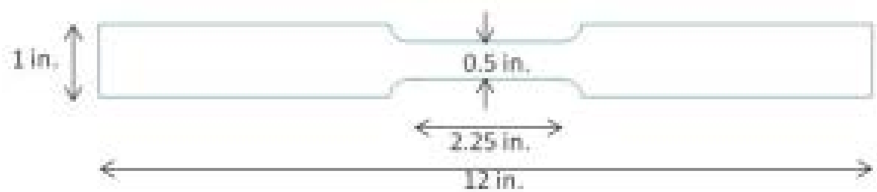
Earthquake Simulation

- University of Cornell School of Civil & Environmental Engineering
  - Cornell Large Scale Lifelines Testing Facility in the Bovay Laboratory Complex
  - Have performed earthquake related testing of ductile, iron, steel and PVC pipes
- Tests performed
  - Tensile tests
  - Compression test
  - 4 Point Bending test
  - Soil Axial test
  - Split Basin test

Material Tensile Test

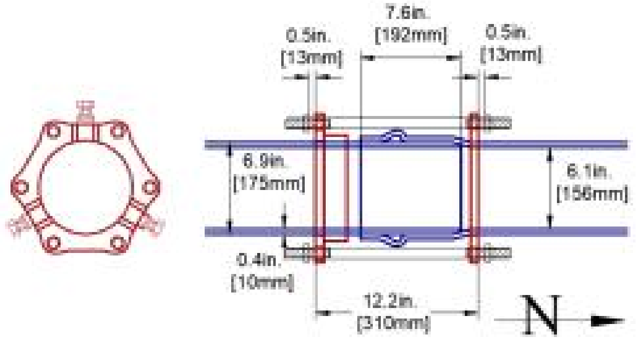
- Steadily increasing tensile force applied to 3 specimens
- Young's modulus calculated based upon ratio stress/strain at point of max stress
- Average peak tensile strength 7.8 ksi, average max stress/strain ratio 5.0%
- Young's modulus E = 450.3 ksi, (C900 PVC E = 420.0 ksi)



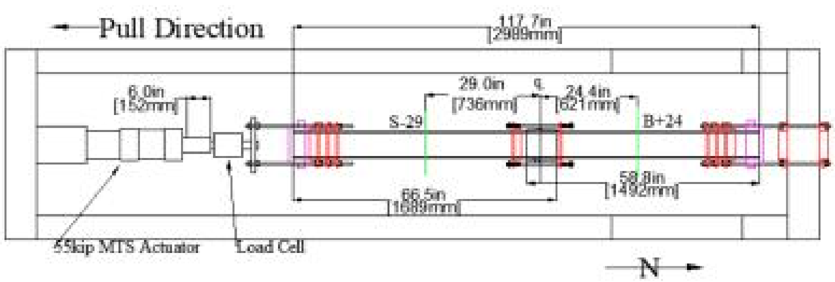


2019 PLASTIC PIPE CONFERENCE

Pipe Tensile Test



- Steadily increasing tensile force applied to 6” DR18 pipe equipped with Stargrip® Gen2 joint restraints
- Lab did interrupt test to check equipment prior to reaching maximum stress
- Young’s modulus calculated based upon ratio stress/strain at point of max stress

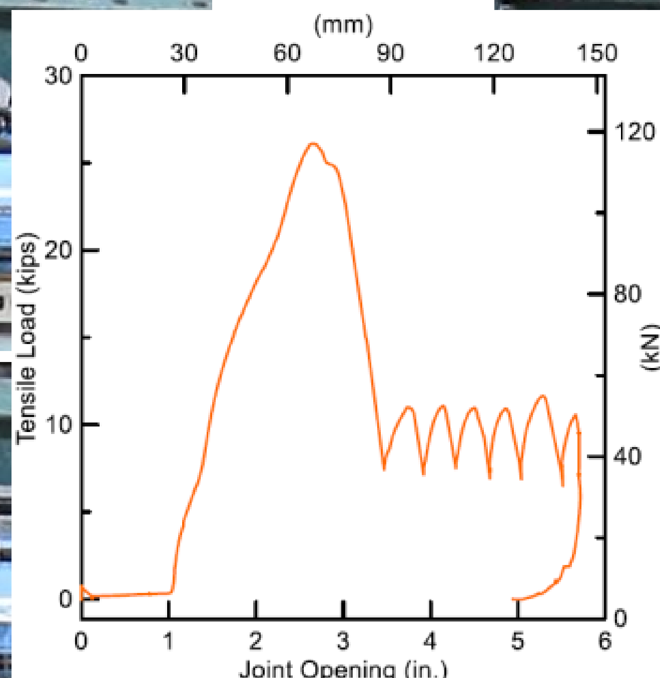


Pipe Tensile Test

- Two tests performed with spigot completely inserted into the bell
- Six 0.75 in. (19 mm) threaded rods spanned the restraints at either side of the joint.
- Nuts on restraining rods were loosened to allow 1 inch. (50 mm) of pullout before engagement.
- The pipe was pressurized with water to approximately 80 psi (550 kPa) during the tests and then tensile force applied at one end.

Start of Test

Allowable Displacement



Pipe Joint Slipping

Leakage after Depressurization

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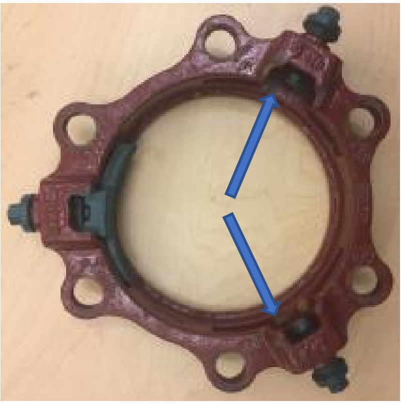
Pipe Tensile Test 1

- The first pipe attained a max tensile load of 26 kips (116 kN) at a joint opening of 2.65 inches (67 mm).
- After maximum load, 6 sudden displacements of ratcheting movement led to pullout at about 6 inches (150 mm).
- Fracture at 2 locations of the south restraining collar at the housing of the clamping teeth contributed to failure. allowing the pipe joint to open as the unit slipped.



Pipe Tensile Test 2

- The second pipe attained a max load of 28 kips (125 kN) at 2.79 in. (71 mm) of joint opening,
- The load then dropped steeply to 25 kips (111 kN) followed immediately by circumferential rupture of the spigot at the joint restraint.
- Fracture at the clamping teeth of the restraint contributed to failure. Forces conveyed by the teeth led failure after 3.2 inches of joint opening.

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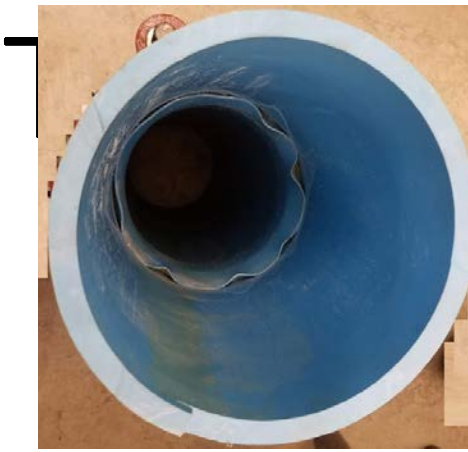
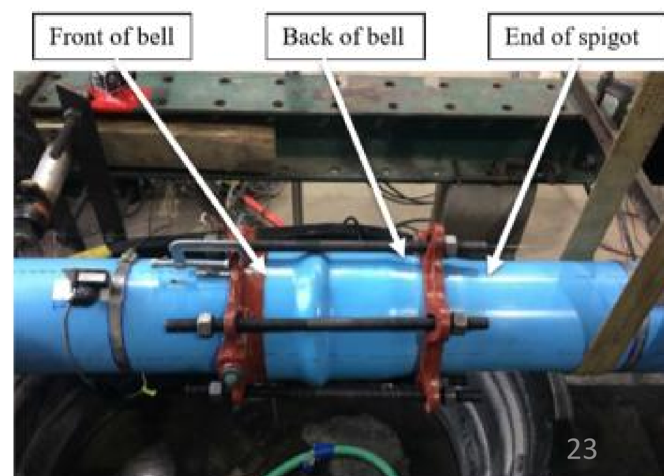
Pipe Compression T



- Increasing compression applied to 2 pressurized specimens (1 and 10 inch/min.)
- Spigots pushed 101.6 mm (5”) and 76.2 mm (4”) “telescoped” into adjoining pipe.
- No leakage during test



Four Point Bending Test

- Testing limits of restrained joint deflection
- Pressurized pipe is supported at 2 locations on both sides of joint.
- Deflection increased, paused at 10 inches and 18.5 inches, to observe.
- Test ended at 27 inch deflection, limit of equipment
- No leakage or loss of pressure

Soil Axial Test

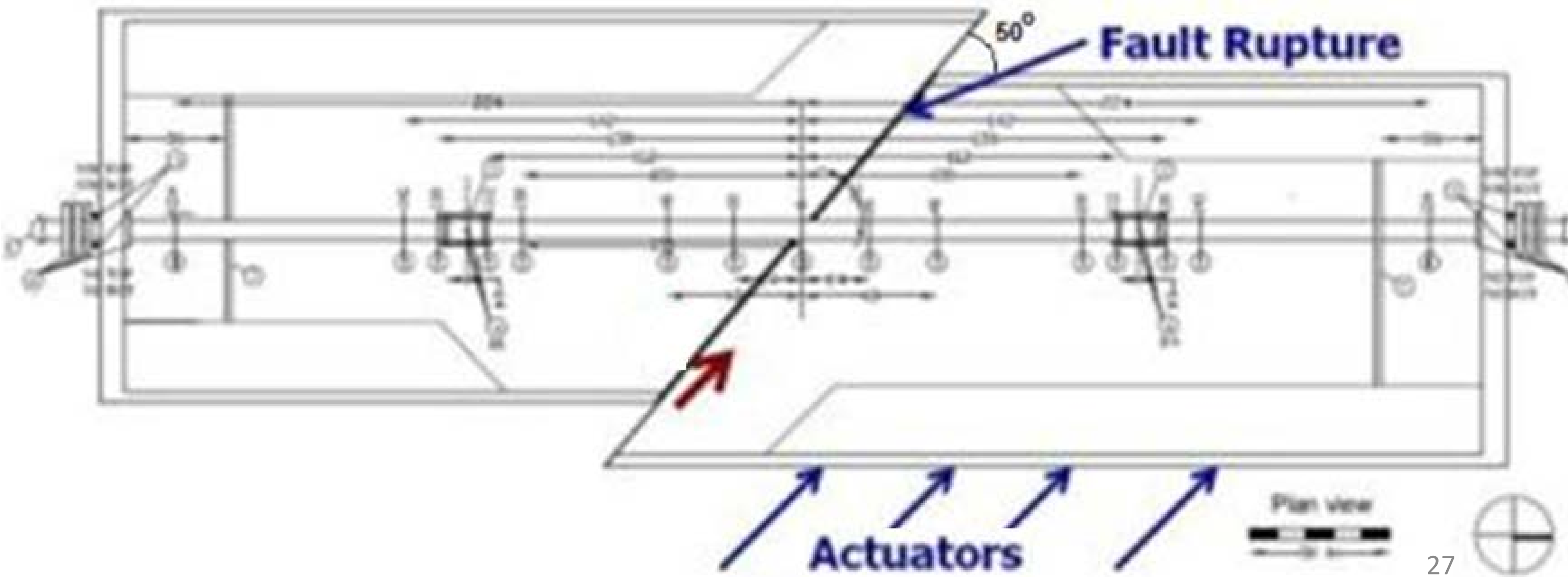
- Assess the resistance pipe joints and restraints to relative axial slip with soil
- Tests performed with 2.5 ft (0.75 m), 3.5 ft (1.1 m), and 4.5 ft (1.4m) of soil cover over pipe
- Resistance depends on pipe geometry, depth, and soil strength (not pressure).
- Pipe pulled 30 in. (760 mm) through soil at a rate of 1 in. (25.4 mm) per minute.

Split Basin Test

- Causes soil rupture and slip at the interface between the two parts of the test basin.
- Increasing both bending and tension stress
- Matches most severe seismic ground deformation, liquifaction

Split Basin Test

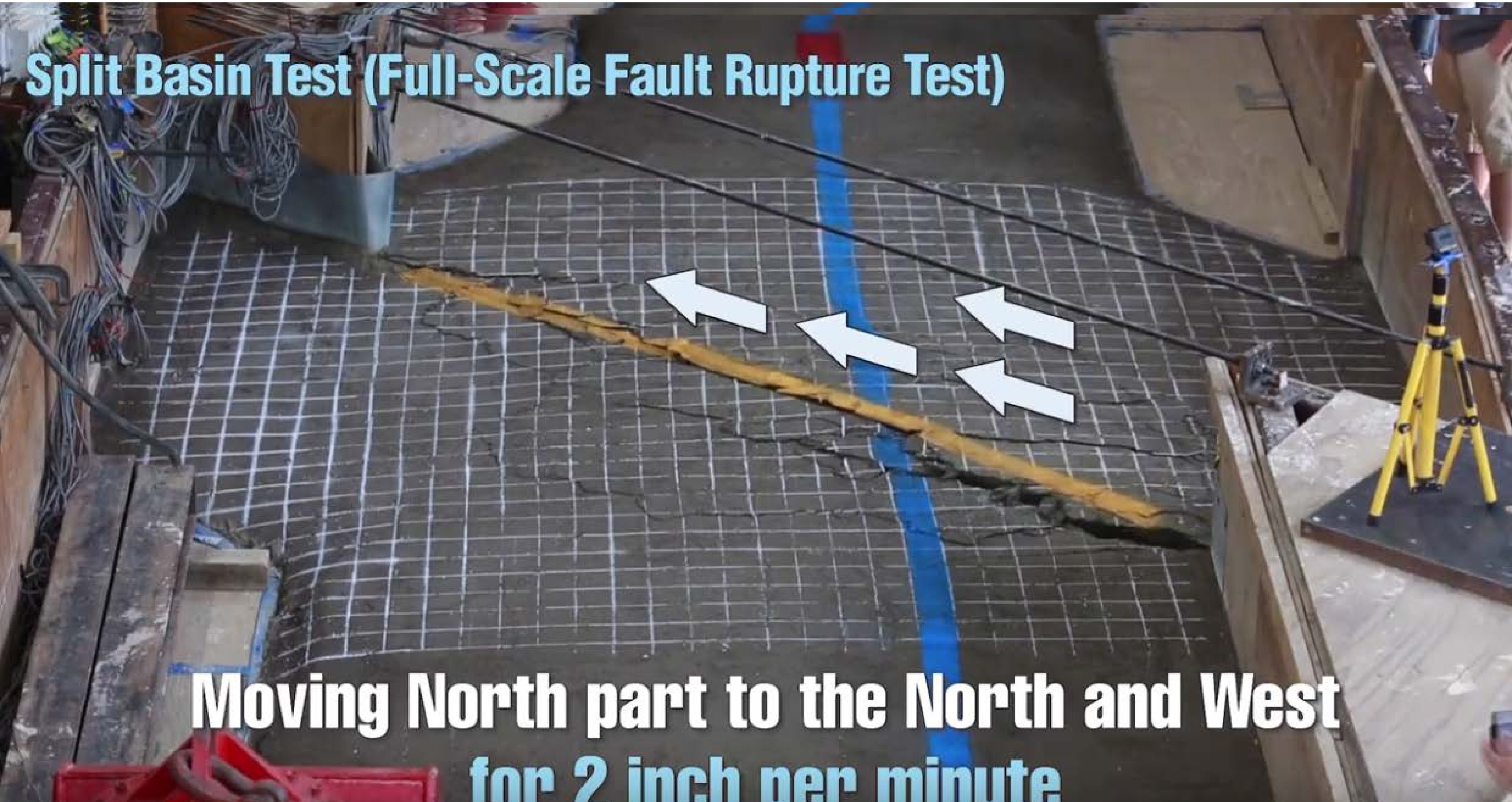
- Simulating ground shift to stretch and bend pipe



Split Basin Test

- The split basin test June 19, 2018
- 3 pipe segments connected with joint restraints at bell and spigots
- buried in test basin granular backfill approximately 2.5 ft (0.76 m) of cover.
- The south part of the basin remains stationary, while the north part is shifted

Split Basin Test



Split Basin Test

- Extended 16.4 inches before pipe lost pressure at fixed end joint.
- Tension pull 10.5”, Bending 12.5”

Future Actions by Vendor

- Continuing evaluation with restrained joints
- Continuing exhibition of product
- Further sales, distribution of product in North America
- Moving to establishment of manufacturing facility in US
- Exploration of complimentary products (fittings, restrained joints)

Questions

- David M Hughes

  Modernizing Distribution

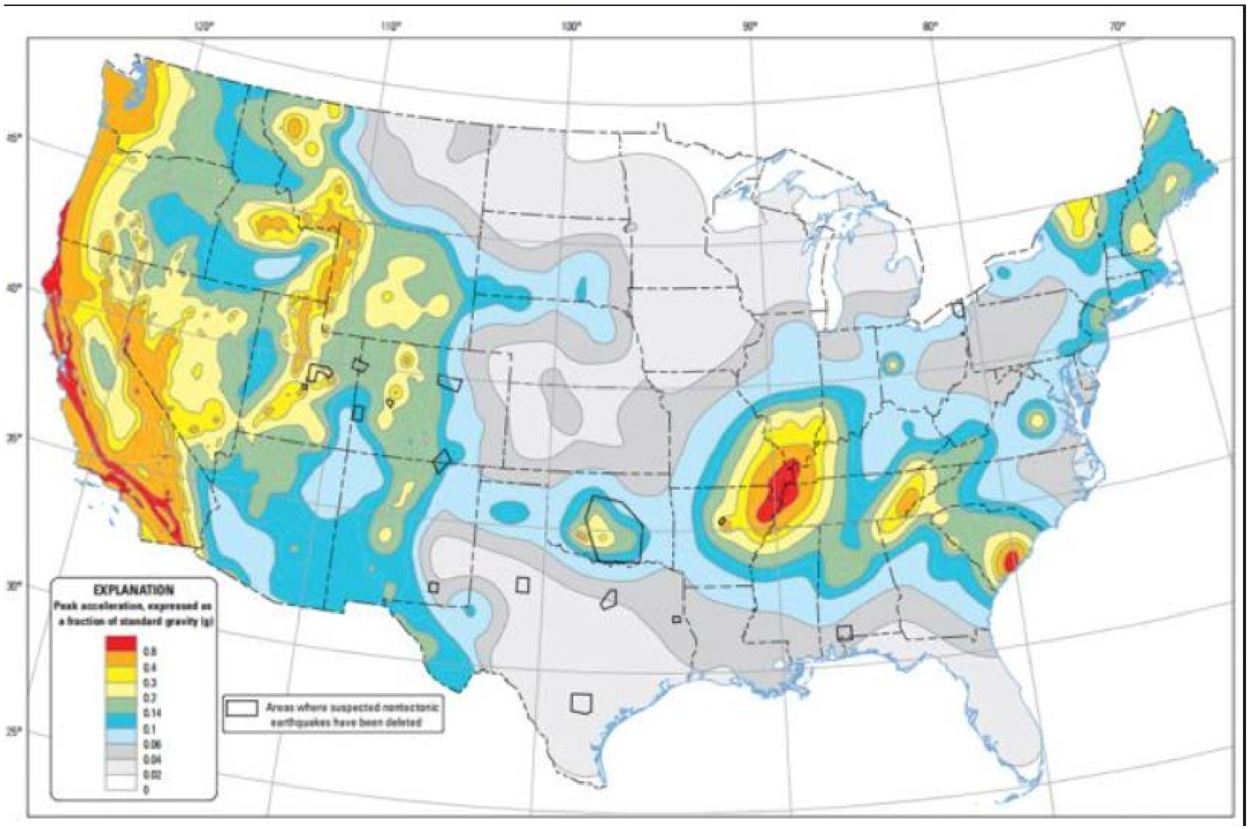
  16454 Roan Place

  Parker, CO 80134

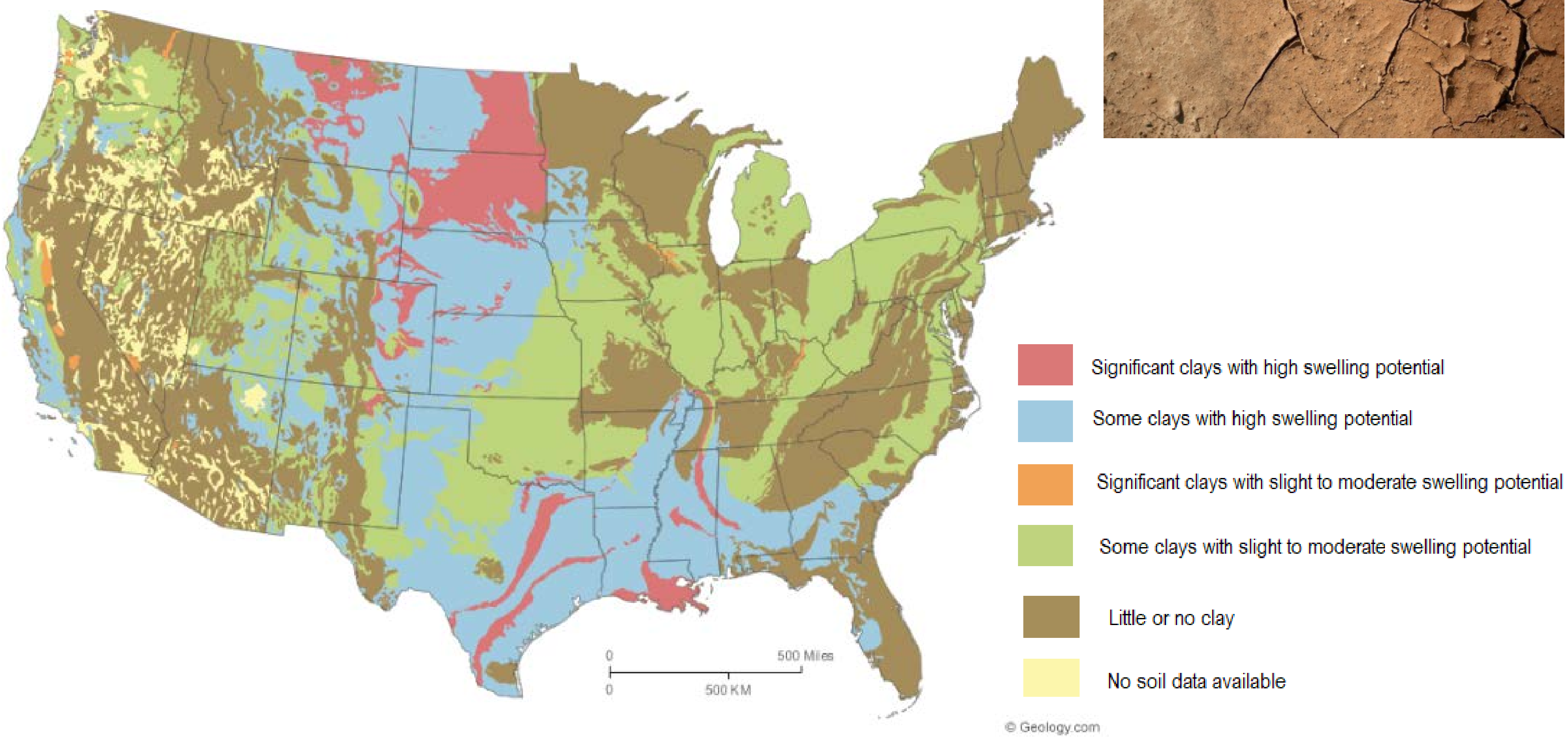
Ground Movement

- Earthquake zones
- Shifting Clays
- Groundwater

Where is the seismic activity

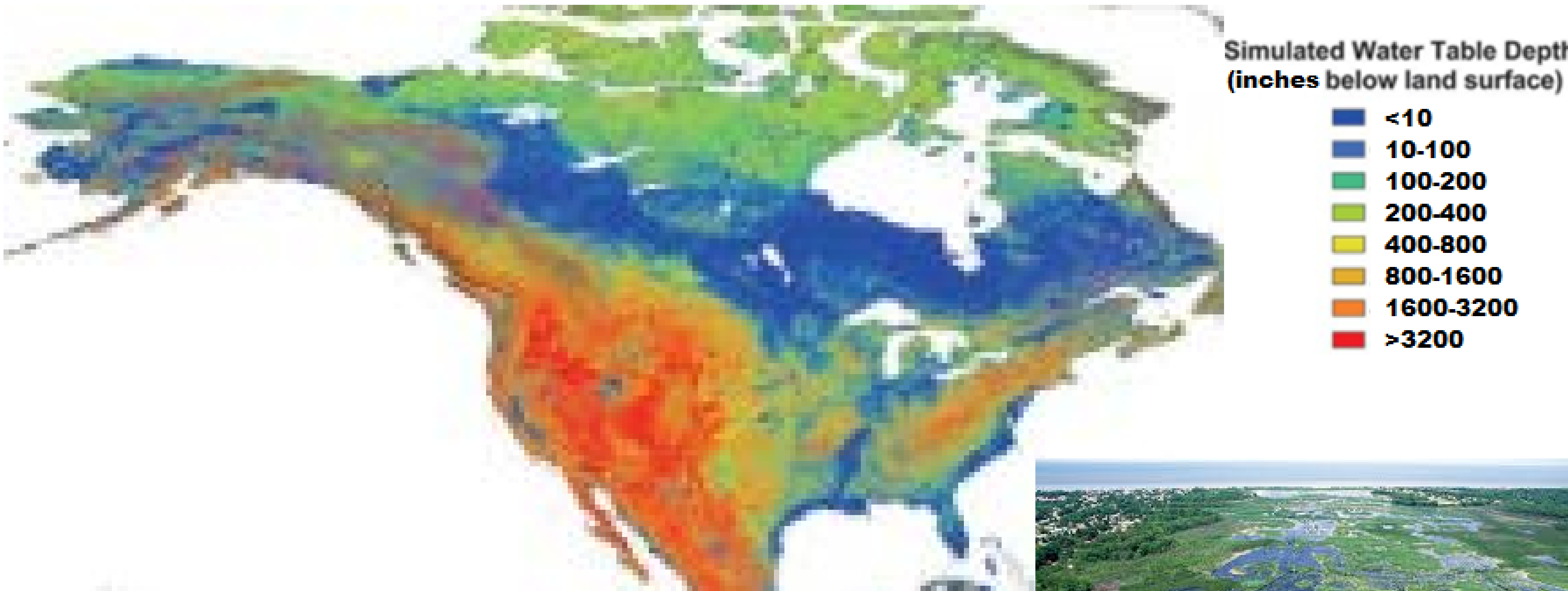


Where is the clay?



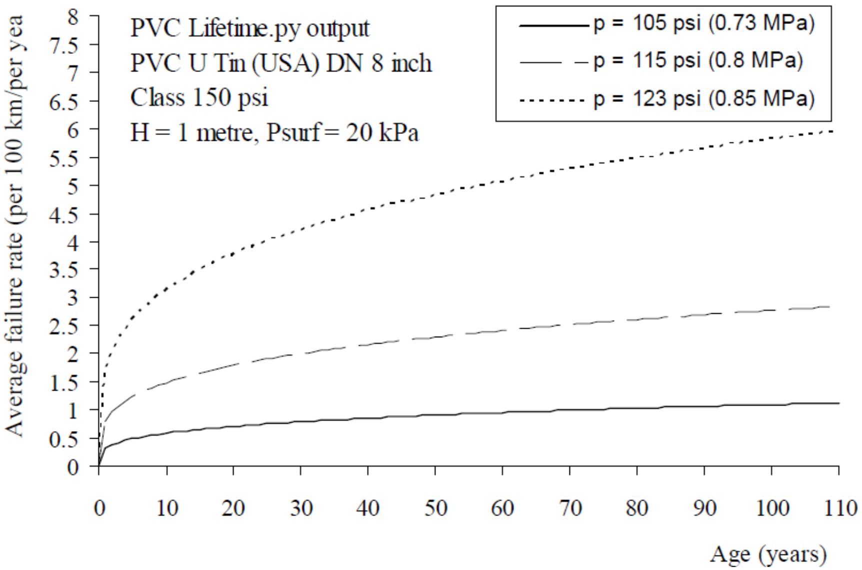
The map above is based upon "Swelling Clays Map of the Conterminous United States" by W. Olive, A. Chleborad, C. Frahme, J. Shlocker, R. Schneider and R. Schuster. It was published in 1989 as Map I-1940 in the USGS Miscellaneous Investigations Series.

What about the groundwater table?



Thickness, Pressure Matters

- For standard PVC, studies have shown thicker pipe is more resilient to higher pressure, surge and offer greater life (CSIRO)



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Ref: Water Research Foundation and CSIRO, Long Term Performance Prediction for PVC Pipes, 2005.