GLWA WRF 5069 Kercheval Cast Iron Pipe Pilot:

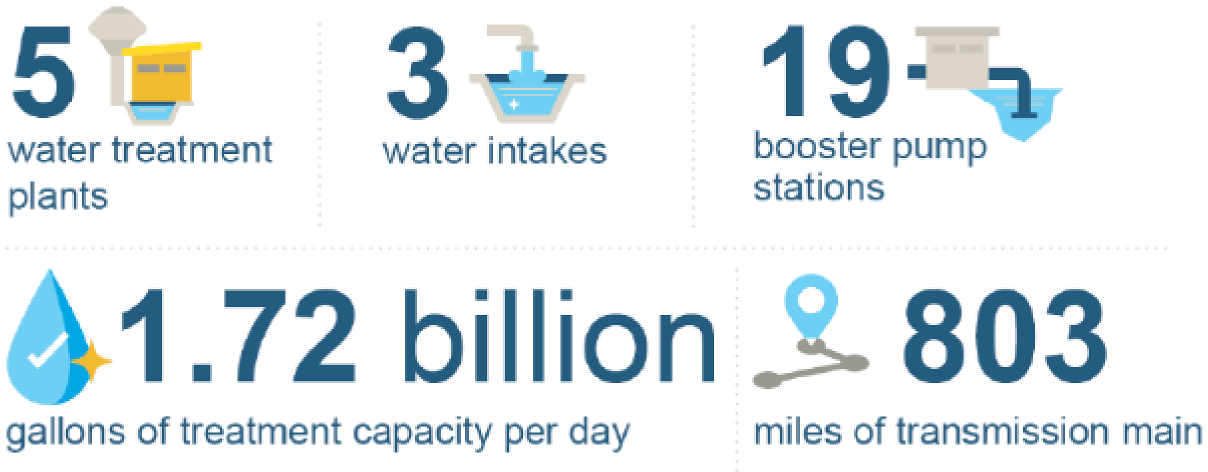
Steel Composite Liner, of 108-year-old 48" cast iron water main with embedded real time structural health monitoring

Graham E.C. Bell, John Norton, Todd King, Ali Alavi, Wentao Wang, and Jerry Lynch

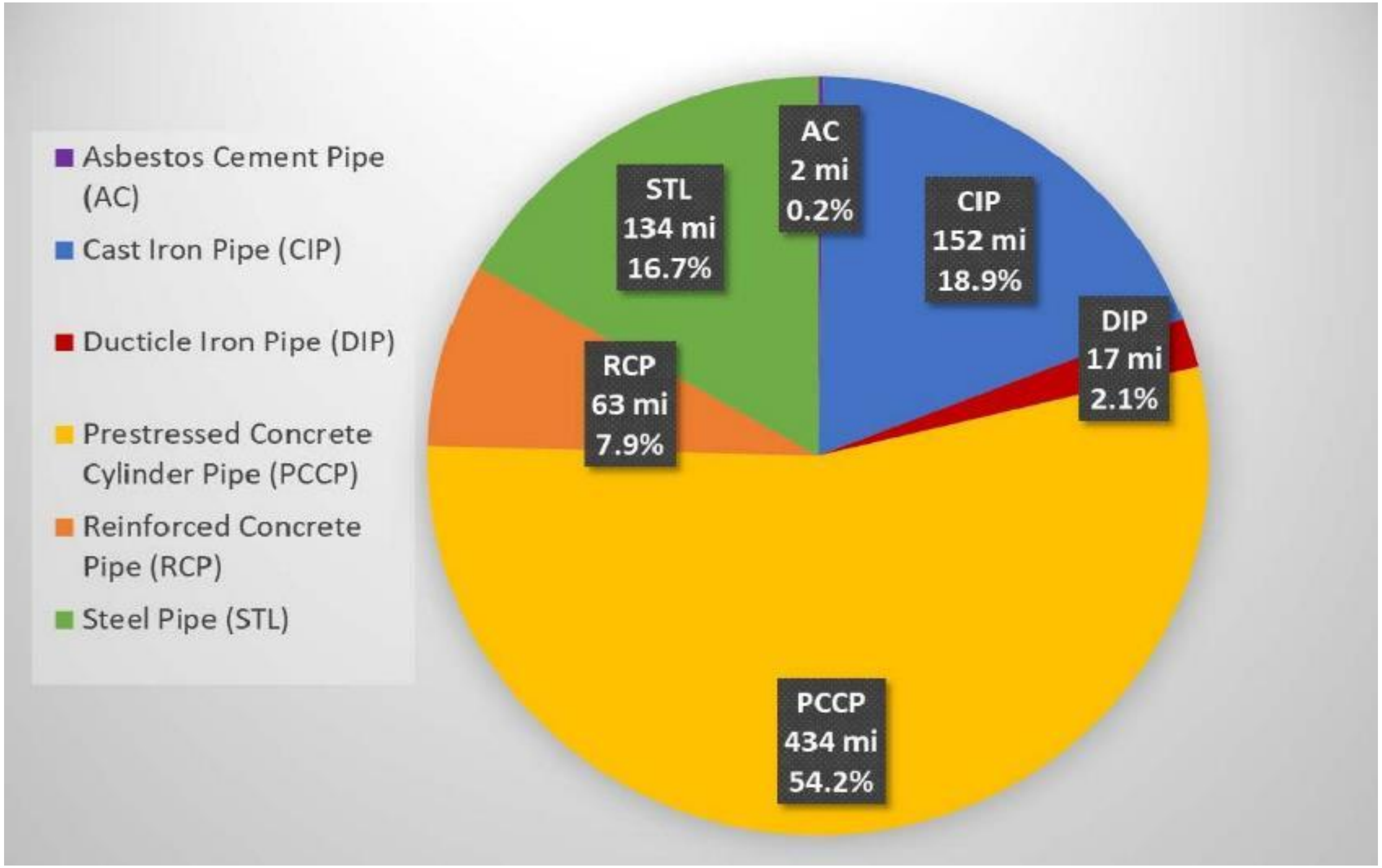
UCT Nashville, July 13, 2021

Great Lakes Water Authority (GLWA) was formed out of the 2013 bankruptcy of Detroit

- The "Grand Bargain" for Detroit Renaissance and Emergence from the Ashes of Bankruptcy
- Began operation on January 1, 2016
- Regional wholesale provider for water and wastewater with 120+ member partners
- GLWA has been recognized as an innovative and world class water system



GLWA is the Largest Domestic Owner of PCCP and allof their pipes are Large Diameter (>24 inch)

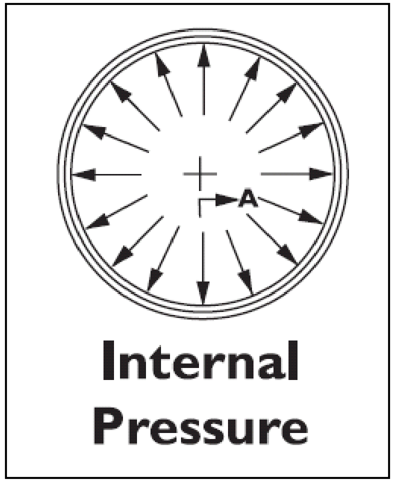


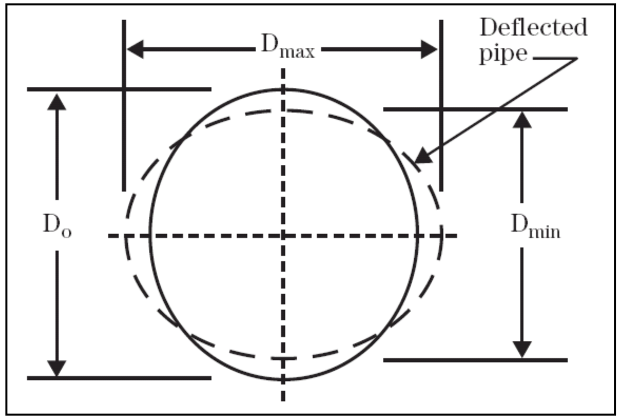
For ANY TYPE OF PIPE, Renewal Process Begins by with how much renewal is needed

Liner Characteristic / AWWA Classification	Rehabilitation: Structurally Interactive			Renewal: Structurally StandAlone
	Internal Coating	Hole and gap span	Hole and gap span + ring stiffness	Structural Resistance for all specified loads (Does Not Rely on Host Pipe)
	Class I	**Class II**	**Class III**	**Class IV**
Internal corrosion protection	✔	✔	✔	✔
Reliable adhesion to host pipe	✔	✔		
Hole and gap span at maximum allowable pressure (MAOP)		✔	✔	✔
Inherent ring stiffness (hydrostatic pressure loads)			✔	✔
Positive connection to service taps and sealed at other discontinuities (water tightness)			✔	✔
Inherent ring stiffness (all external and vacuum loads)				✔
Pressure rating of liner ≥ MAOP of host pipe				✔
Liner survives host pipe failure				✔

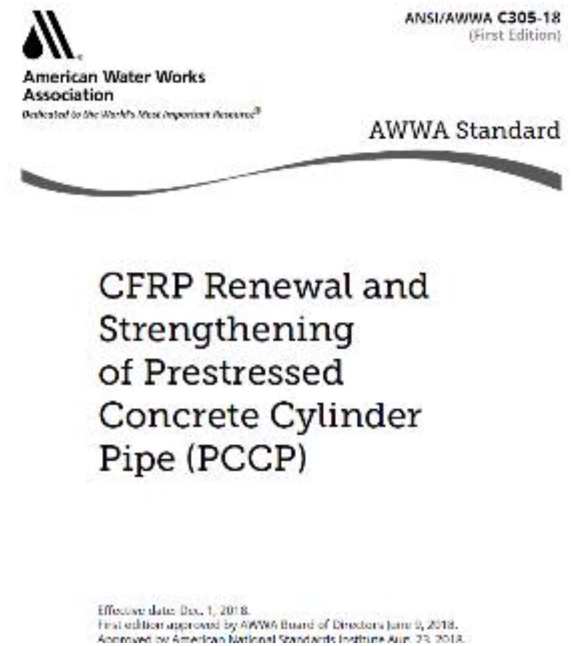
Design Methodologies should be consistent between renewal methods

- ✓ **Internal working pressure**
- ✓ **Internal working-plus-transient pressure**
- ✓ **Weight of pipe and fluid**
- ✓ **Earth load above the pipe**
- ✓ **Live loads at the ground surface**
- ✓ **Groundwater above the pipe**
- ✓ **Negative pressure inside the pipe**
- ✓ **Poisson's ratio**
- ✓ **Temperature changes**
- ✓ **50 + year Design Life**

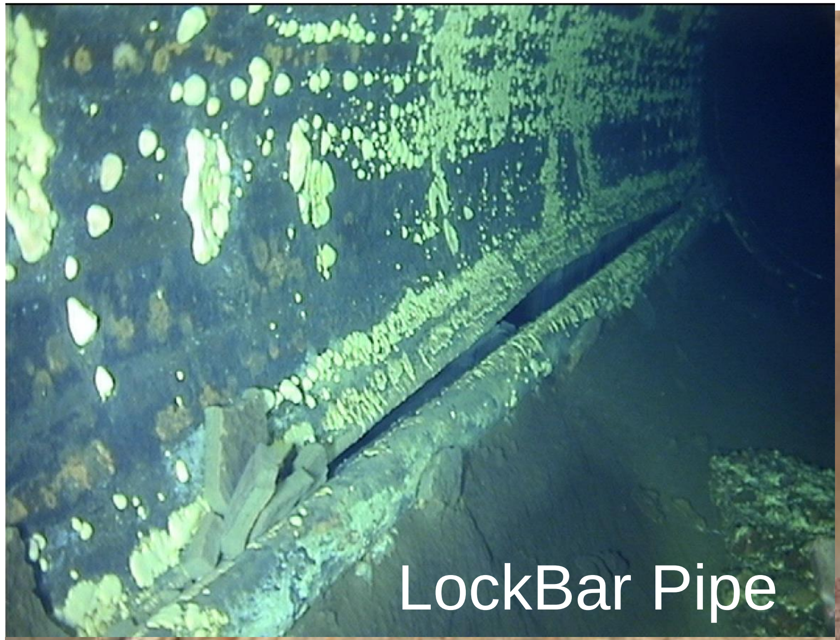




AWWA C305
Load Resistance Factor Design (LRFD)



AWWA Class IV Systems need to be designed to cover a broad range of specific pipe types and their failure mechanisms



All Design Methodologies are NOT equivalent

ASTM F1216 - Appendix X1
Allowable Stress Design (ASD)

Designation: F1216 – 09

An American National Standard

Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube[1, 2]

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CONSIDERATIONS

X1.1 *Terminology*:

X1.1.1 *partially deteriorated pipe*—the original pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and up to 10.0% distortion of the diameter. If the distortion of the diameter is greater than 10.0%, alternative design methods are required (see Note 1).

X1.1.2 *fully deteriorated pipe*—the original pipe is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe. This condition is evident when sections of the original pipe are missing, the pipe has lost its original shape, or the pipe has corroded due to the effects of the fluid, atmosphere, soil, or applied loads.

$$P = \frac{2KE_L}{(1-\nu^2)} \cdot \frac{1}{(DR-1)^3} \cdot \frac{C}{N} \quad \text{(X1.1)}$$

where:

- P = groundwater load, psi (MPa), measured from the invert of the pipe
- K = enhancement factor of the soil and existing pipe adjacent to the new pipe (a minimum value of 7.0 is recommended where there is full support of the existing pipe),
- E_L = long-term (time corrected) modulus of elasticity for CIPP, psi (MPa) (see Note X1.1),
- ν = Poisson's ratio (0.3 average),
- DR = dimension ratio of CIPP,
- C = ovality reduction factor =

AWWA C305
Load Resistance Factor Design (LRFD)

American Water Works Association

Dedicated to the World's Most Important Resource®

ANSI/AWWA C305-18

(First Edition)

AWWA Standard

CFRP Renewal and Strengthening of Prestressed Concrete Cylinder Pipe (PCCP)

Effective date: Dec. 1, 2018.
First edition approved by AWWA Board of Directors June 9, 2018.
Approved by American National Standards Institute Aug. 23, 2018.

LRFD approach embodied in AWWA C305 (CFRP) for PCCP Renewal has been adopted and implemented by many water utilities

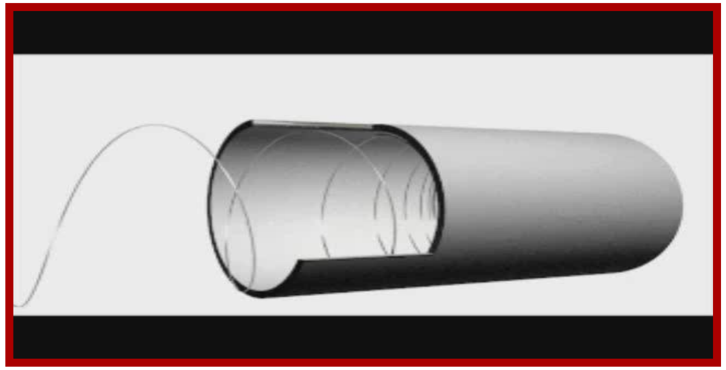
- Major US water agencies have adopted the use of the CFRP technology as part of an effective asset management program
- LRFD design methodology is also adopted in many other design standards and MOP for ASCE for Penstocks and large diameter gravity pipe renewal.
- AWWA C305 has significantly reduced risk associated with large diameter pipe renewal

ASTM F1216 (ASD) is not equivalent to AWWA C305 (LRFD) for Large Diameter Pressure Pipe

Design Checks	ASTM F1216 (ASD)	AWWA C305 (LRFD)
Hoop Design		
Internal Working Pressure	X	X
Internal Transient Pressure		X
Internal Vacuum Pressure		X
External Soil Load	X	X
External Traffic Load	X	X
Pipe Ovality	X	X
Deflection Limit		X
Combined Loading		X
Longitudinal Design		
Poisson's Ratio Effect		X
Temperature Change Effect		X
Thrust Effect		X
Design Life up to 50 Year?		X

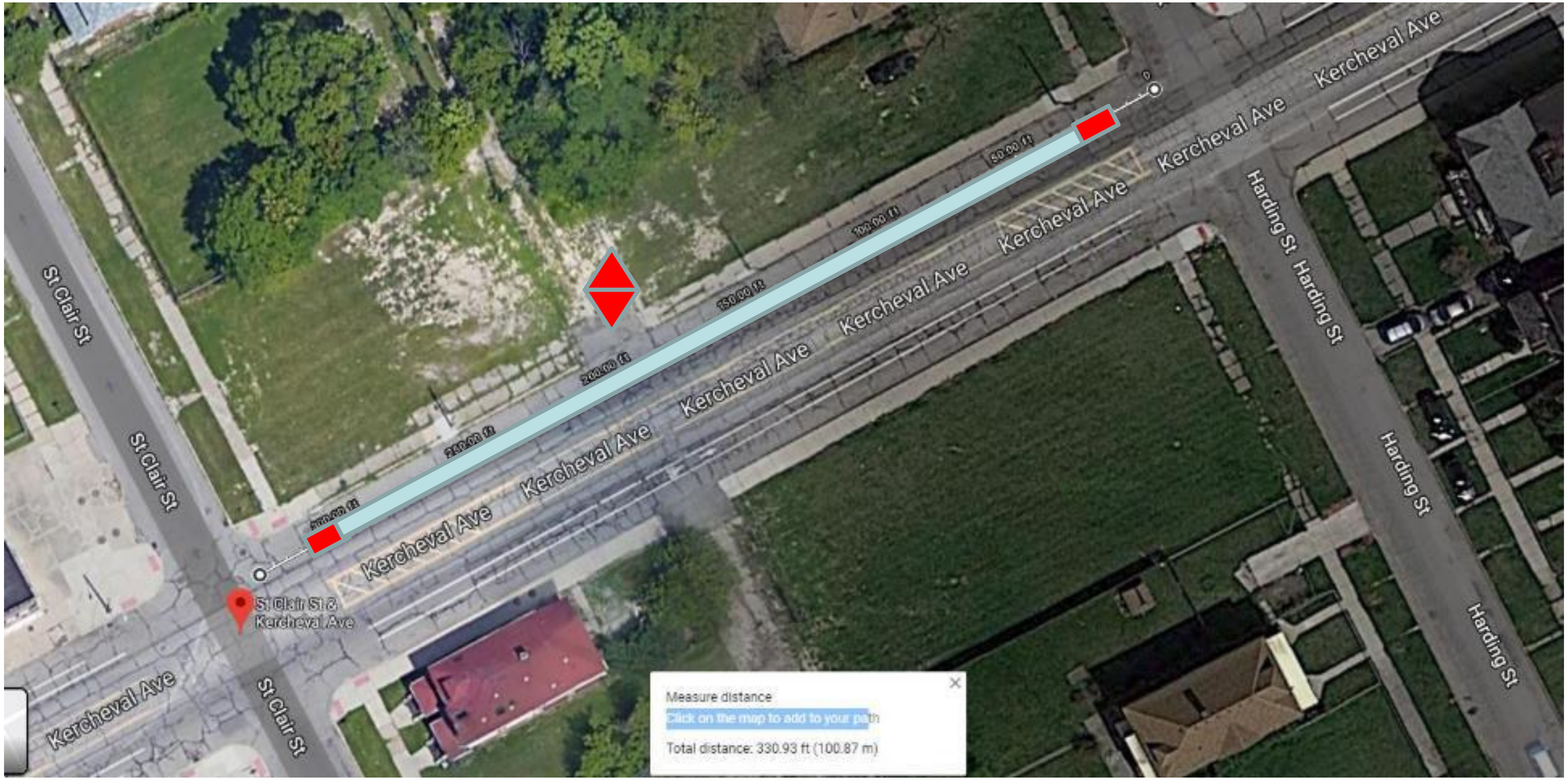
GLWA objectives of pilot are focused on liner application and monitoring methods

- Applied research on innovative, emerging technologies for Class IV renewal of large diameter pipe
  - Polymer-based System (MICP)
  - Steel Reinforced Cement Mortar (StrongPIPE SRC)

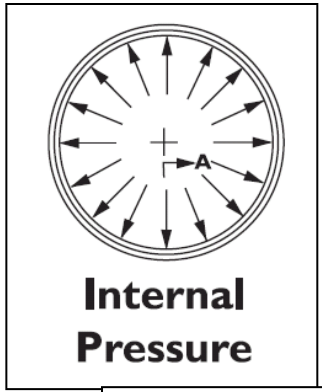


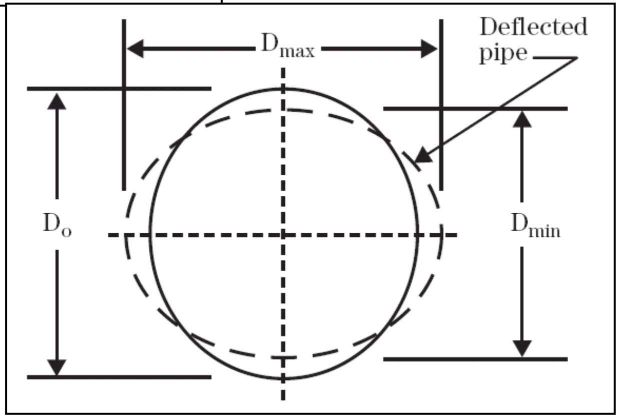
- Collect experience and information on
  - Design Methodology for Class IV Liner Systems
  - Production means and methods
  - Costs and Lessons Learned
- Conduct structural monitoring of systems
  - Laboratory of Intelligent Systems Technology
  - Dr. Jerry Lynch

GLWA Located an accessible portion of their Kercheval Avenue, 1913 Vintage, 48 inch diameter Cast Iron Pipe (CIP) for the renewal pilot



All Candidate Liner Systems were designed using LRFD methodology





- Class IV, structurally independent renewal
- 48-inch, 1912 vintage Cast Iron Pipe (Class D)
- “flat, straight pipe”, (per GLWA 1912/1913 field notes)
- Open cut excavation access on one or both ends of segment
- Working Pressure (max): 100 psi (actual operating 70 psi)
- Surge Pressure: +40 psi
- Depth of Cover to Crown: 10 feet
- Groundwater: No
- Water temperature change: **Δ**25 C = **Δ**40 F
- Internal surface condition like that of 42-inch samples provided by GLWA

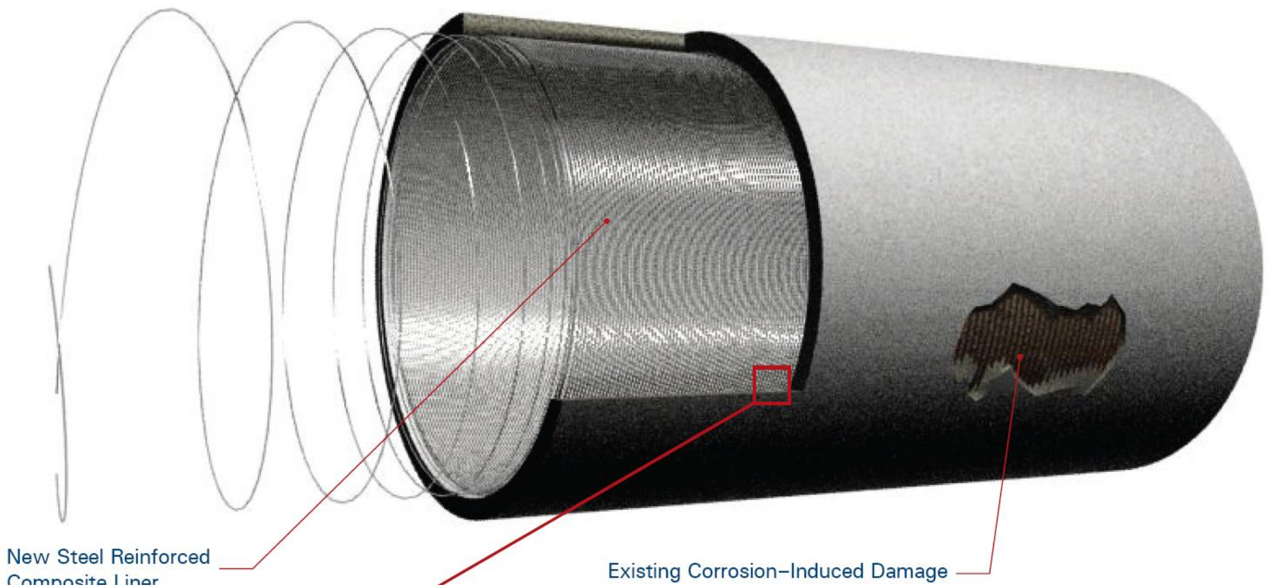
Results of LRFD “Apples to Apples” Comparison Lir Thicknesses were interesting and informative in decision making process

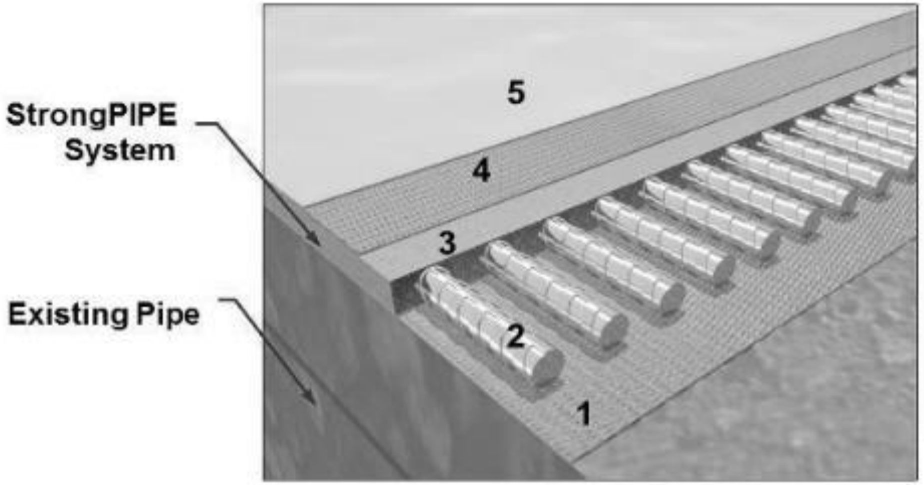
TICKLE COLLEGE OF ENGINEERING

- LRFD designs resulted in liner thicknesses:
  - CFRP - 3 circumferential wraps and 1 longitudinal layer (0.6 " thick)
  - SCL with thickened epoxy embedment (0.75” thick) ← 60 LF
  - SCL with cementitious embedment (~1” thick) ← 132 LF
  - HDPE (2.3” thick)

to provide stand alone, full-structural reinforcement per the requirements of AWWA Manual M28 Class IV.

StrongPIPE® SCL Solution utilizes cost effective HS steel for trenchless composite reinforcement since 2012





Legend

1. 1st Glass FRP Layer (longitudinal)
2. High Str. Steel Wire
3. Polymer Matrix
4. 2nd Glass FRP Layer (longitudinal)
5. Flexible Topcoat

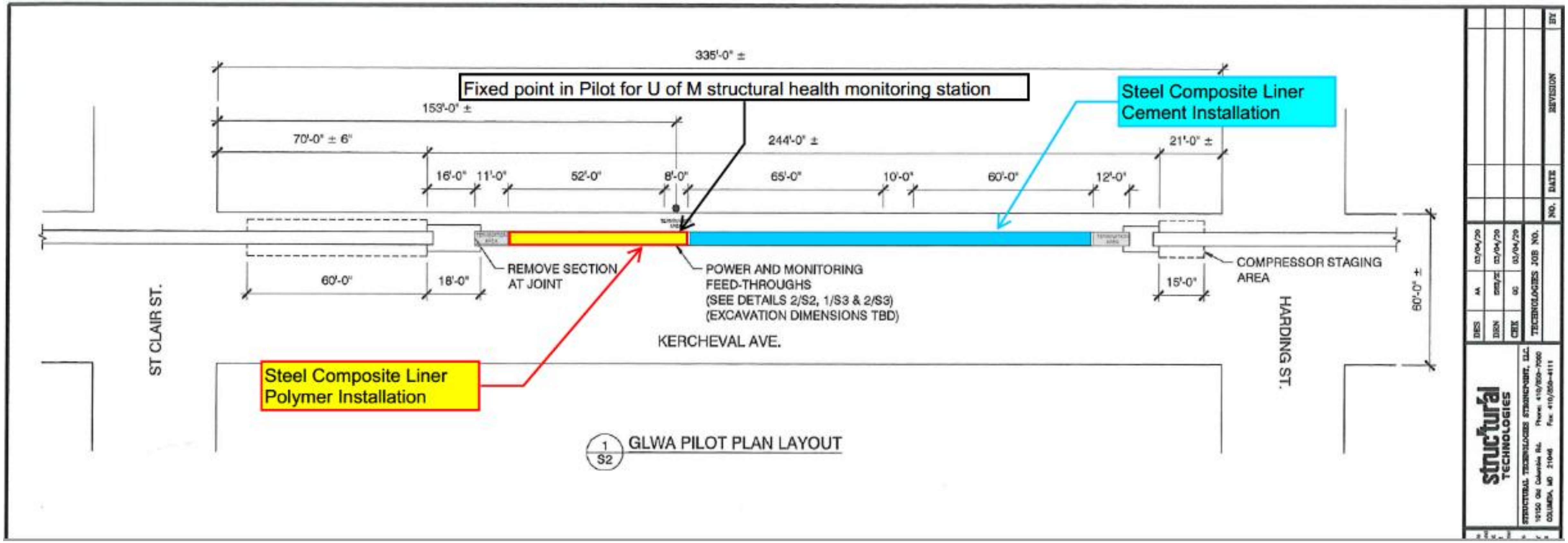
StrongPIPE is a structural strengthening system for the **restoration** of damaged/weakened pressure pipe and the **upgrade** of undamaged pipe. **StrongPIPE** utilizes a continuously wound tensile reinforcement that forms a steel composite lining inside the existing pipe.

Steel Composite Liner Systems use high strength wire embedded in a host matrix to provide primary circumferential strength renewal

- Longitudinal strength from HS steel, FRP or CFRP.
- Applicable for large diameter pressurized and non-pressurized pipelines (36 inches in diameter and up).
- Applicable for either targeted repairs or extended, straight runs.
- Installed through existing access.
- Similar structural strength to CFRP, but more cost effective for longer runs
- NOT PCCP

ASTM 881
270 ksi UTS

Final layout was SCL with 1/3 polymer and 2/3 cementit[...] embedment



Internal surfaces were prepared by scraping, high pressure water blasting and abrasive blasting to receive lining systems

Circumferential wire spacing was the same for SCL-C and SCL-P

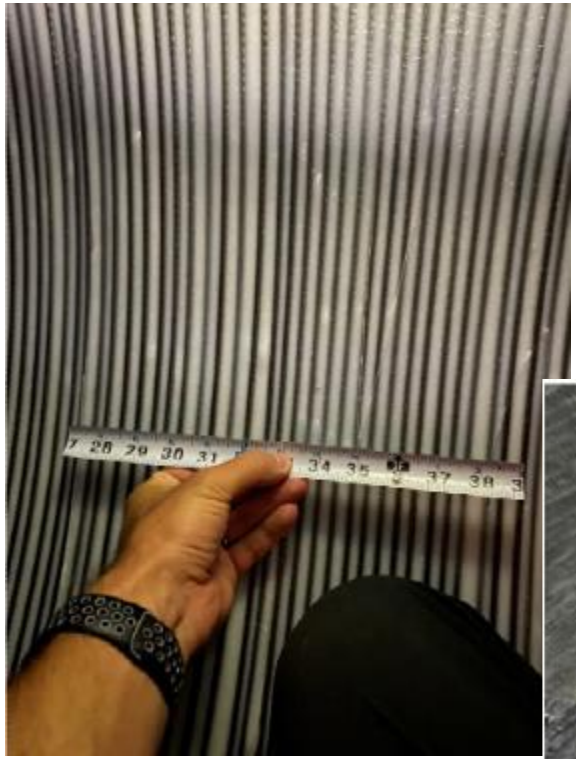
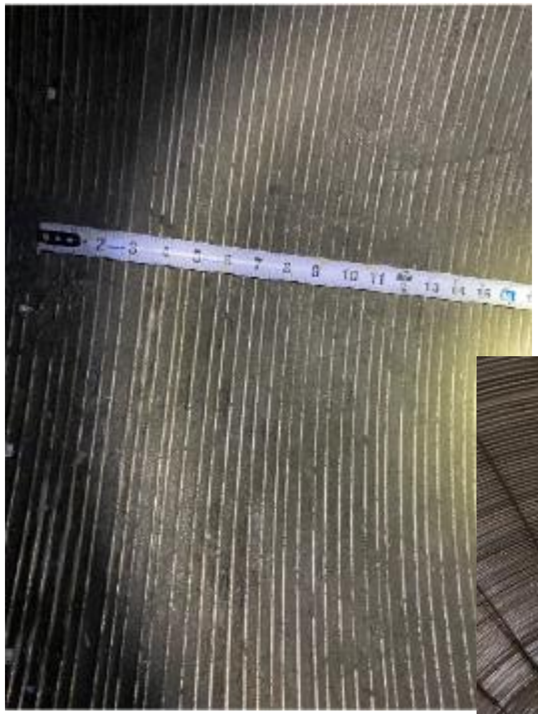


Figure 4 - Installing EG50 Longitude on SRP Segment



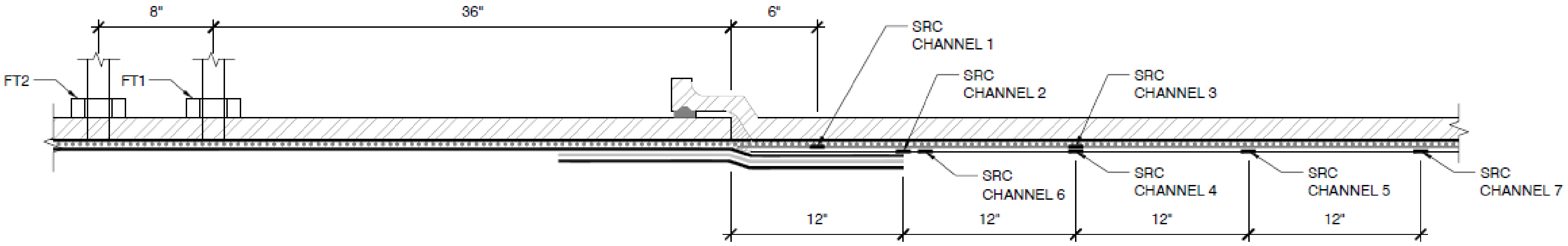
Spin cast mortar over SCL-C wires and top coat with polyurea and end seals for water tightness

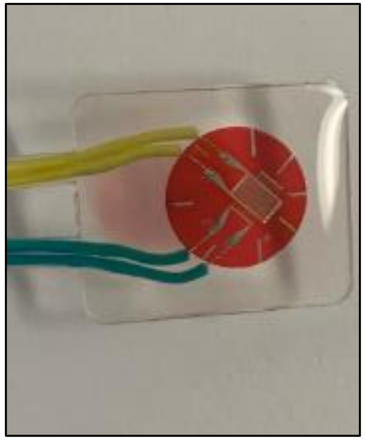
Pilot was compl  OVID

Steel Rein	RP) - 60LF
Scrape out Pipe	7/29/2020
Pressure Wash F	7/30/2020
Install Thickenec	7/31/2020
Polyurea Coatin	8/5/2020
Circumferential	8/1/2020
Longitudinal Wir	8/10/2020
HSS Wire Strain	8/19/2020
SRC Spin Casting	8/19/2020
Concrete Strain	8/20/2020
Abrasive Blast M	8/21/2020
Abrasive Blast T	8/19/2020
CFRP at Termina	8/24/2020
CFRP at SRC-SRP	8/23/2020
Prime Mortar	8/23/2020
Polyurea Coatin	8/25/2020
Expansion Ring a	8/26/2020

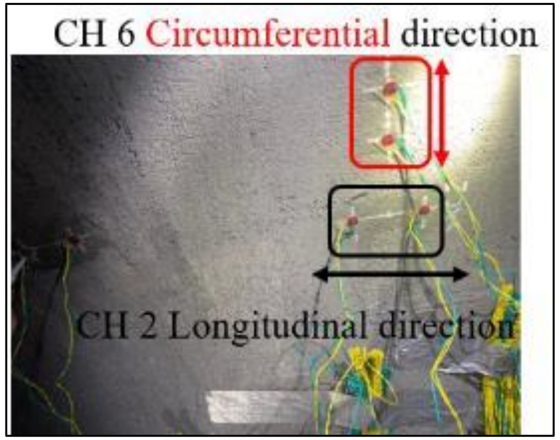
GLWA/UofM Kercheval Pilot is a first of its kind in situ pipe health monitoring system

- Seven (7) strain channels on the SCL-C liner:
  - CH 1, CH 3. CH 5. CH 7 on steel wires (quarter bridge)
  - CH 2 (L)

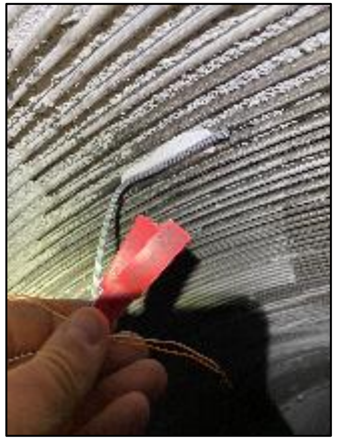




Rosette gages in polymer substrate



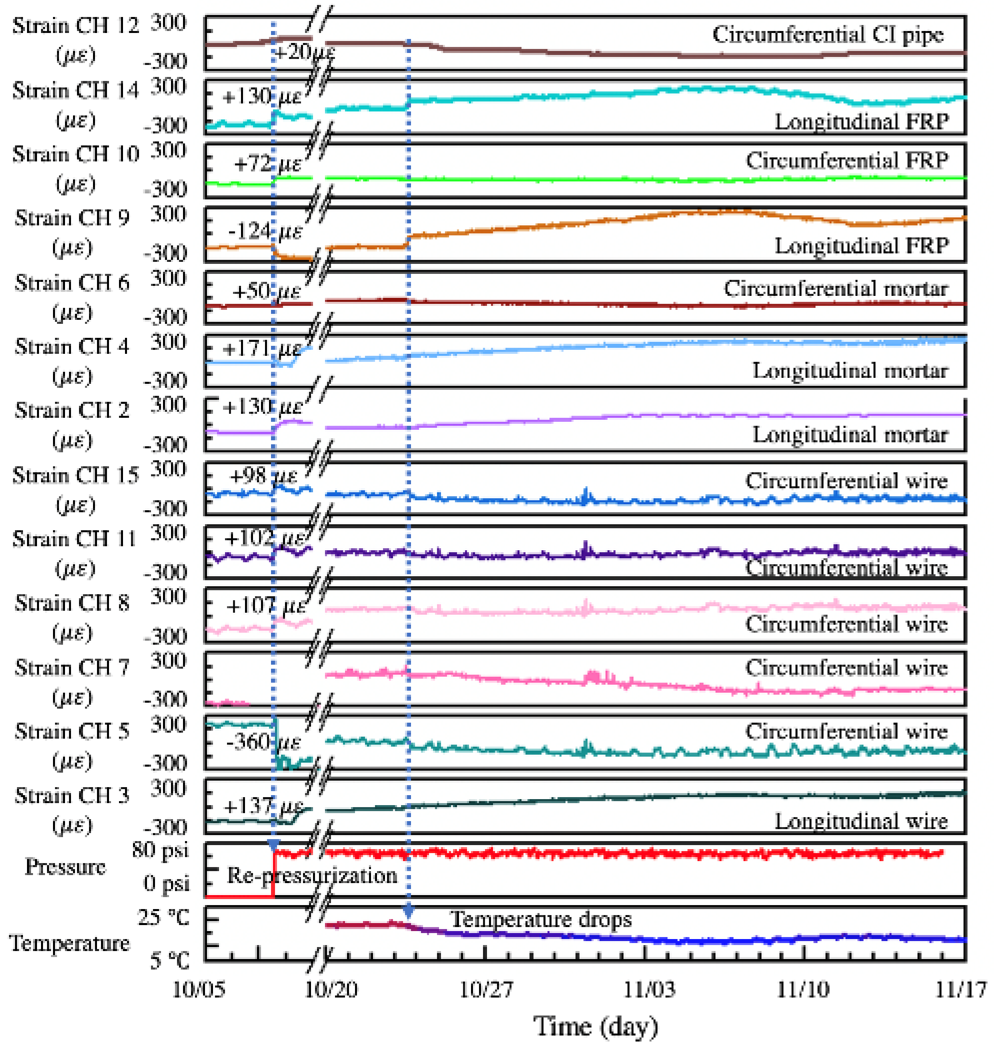
Full-bridge (thermally compensated) gages for circumferential and longitudinal strain



Polyimide substrate gage (quarter bridge) on wire

System Data Collection

- **Data collected since August 26, 2020:**
  - All strain channels zeroed
  - Data collected at 2 kHz
  - Collect data for 1 second every 5 minutes
  - Locally stored on DAQ server at the site
  - Transmitted by cable modem to UM server ever day
  - Backup copy of the data stored in external hard drive at the site



Observable Behaviors

- **Internal pressure response:**
  - Negative longitudinal strain
  - Positive circumferential strain
- **Constraints at the pipe-liner end:**
  - Longitudinal strain

Related to pressure, and boundary conditions

- **Thermal contraction:**
  - Negative circumferential strain
  - Positive longitudinal strain

Temperature-driven behavior (seasonal)

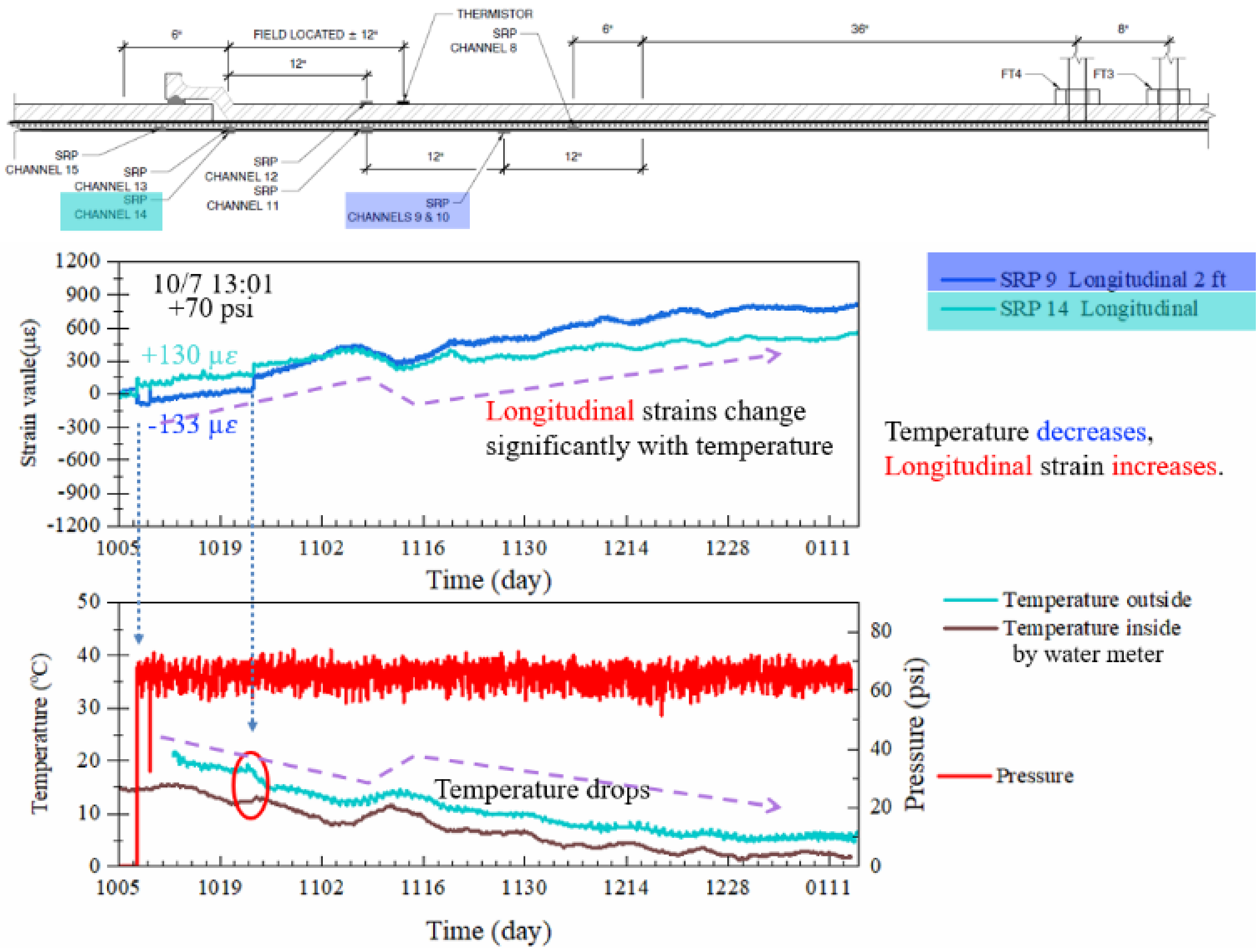
- **Liner cracking (mortar):**
  - Cracks along circumferential direction increases ε_x
  - Cracks along longitudinal direction increases ε_θ

Transient event driven

- **Deformations over time:**
  - Long-term creep
  - Less support from soil
  - Both strains increase as time goes by

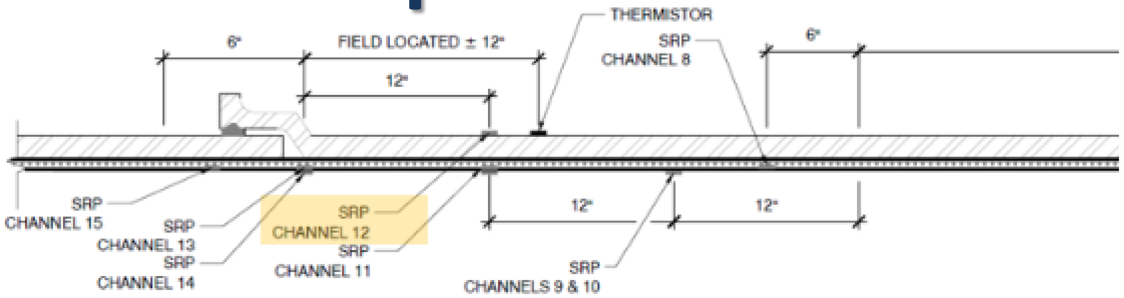
Long-term, slow deformation

Example 1: Thermal Contraction



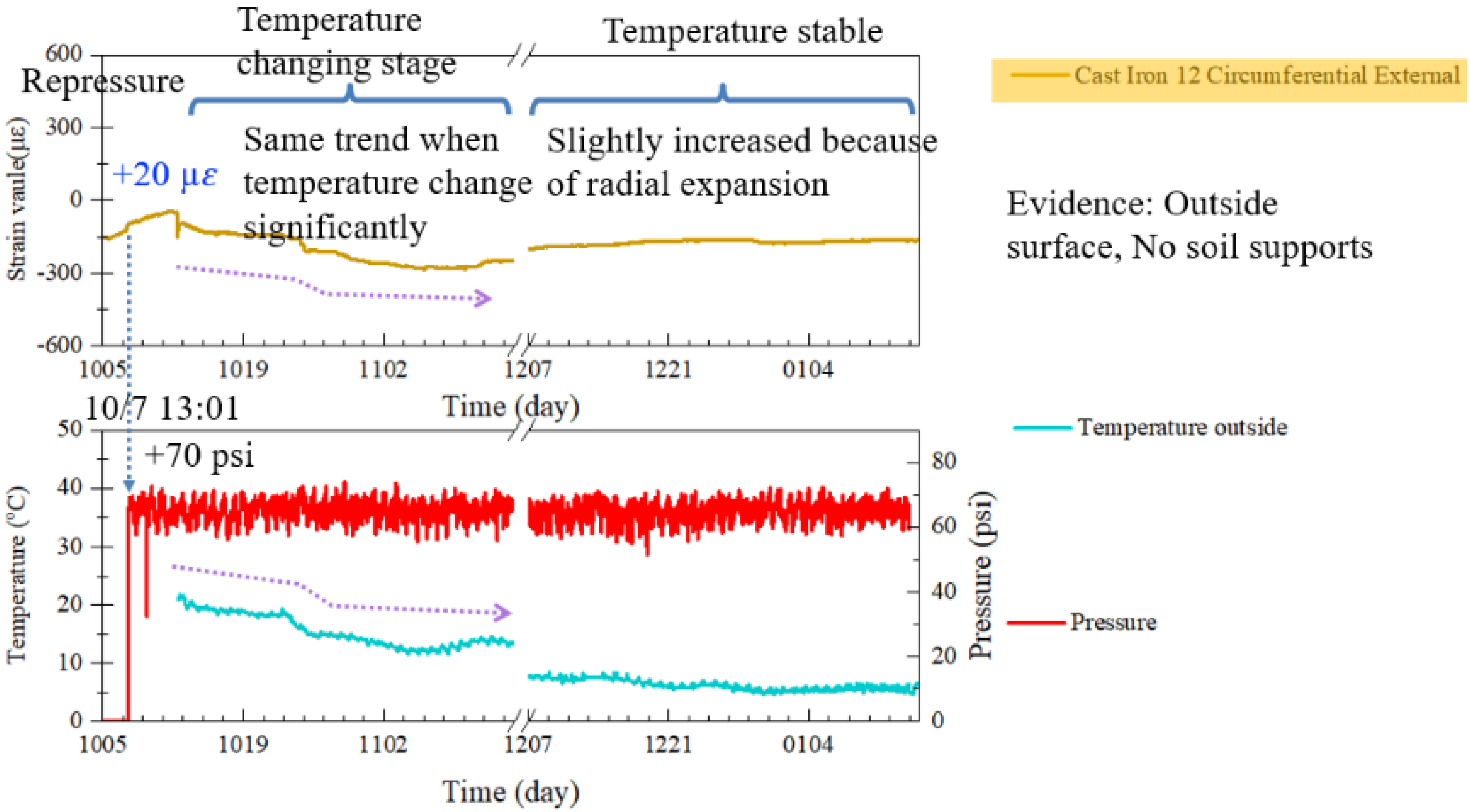
Temperature decreases, Longitudinal strain increases.

Example 2: Deformation with Time



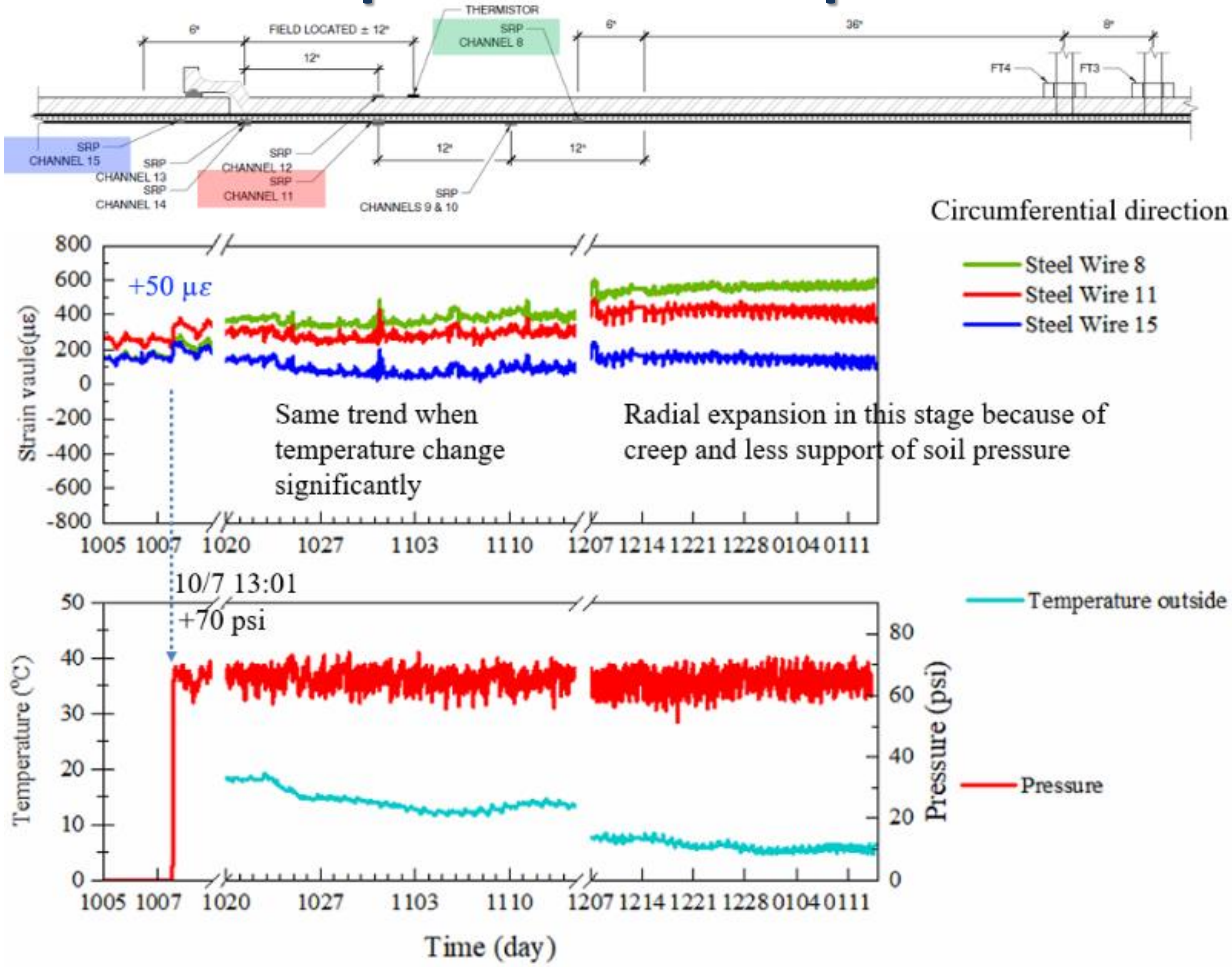
Divided into three stages:

1) repressure stage
2) temperature significantly drops
3) temperature slowly changes



Evidence: Outside surface, No soil supports

Example 3: Radial Expansion



Many thanks to my colleagues
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