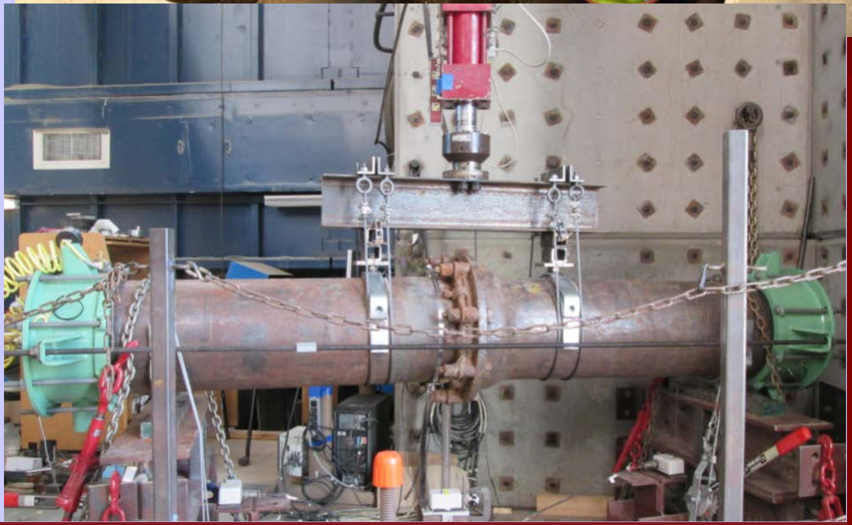
CIPL PROJECT WORKSHOP: Results of Mechanical Aging & CIPL Materials Property Tests

Cornell University

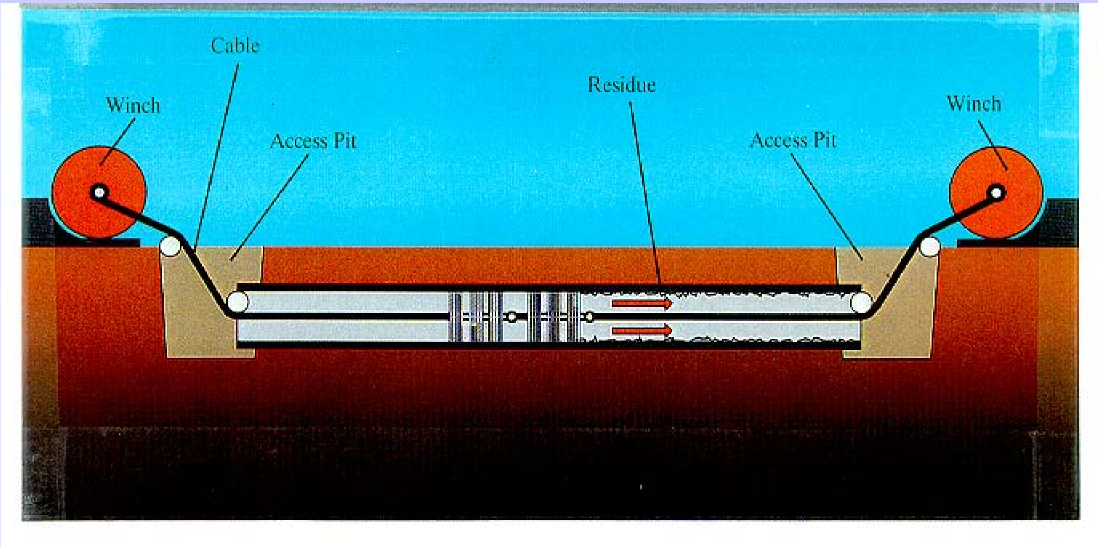
Northeast Gas Association



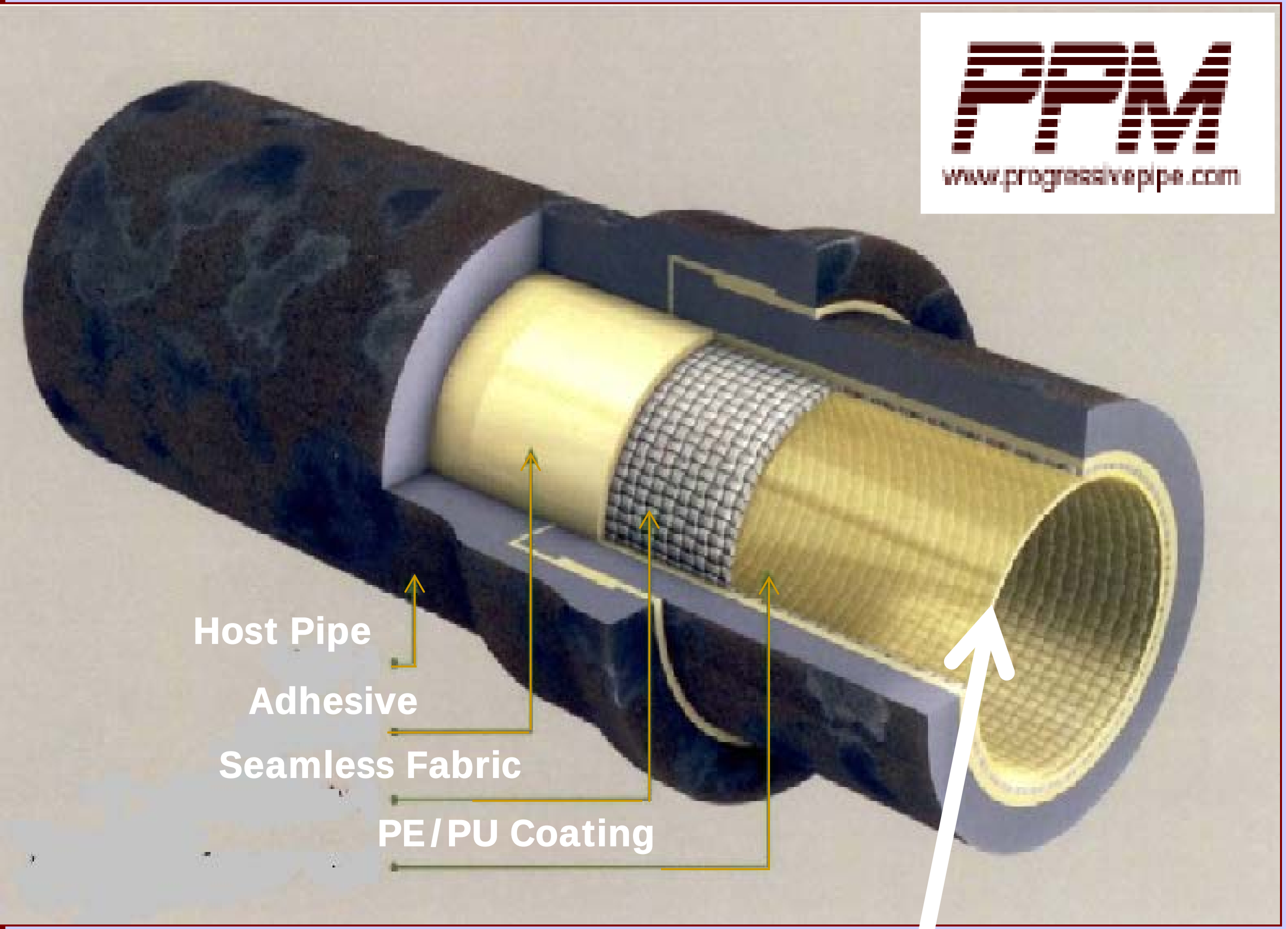
PRESENTATION

- CIPL Systems & Previous Cornell Research (Tom O'Rourke)
- Retrieval of Pipe Specimens from Field (Harry Stewart)
- Mechanical Aging Tests (Tom O'Rourke)
- Mechanical Aging Test Results (Harry Stewart)
- Material Properties Test Results (Anil Netravali)
- Summary (Harry Stewart)

TRENCHLESS CONSTRUCTION & IN SITU PIPE LININGS



CIPP LININGS: STARLINE



Diameter Range	**4 - 48 in. & services**
Pipe Section Length	**2500 ft maximum**
Bends	**YES**
Host Pipe	**Cast Iron, Ductile Iron, & Steel**
Thickness	**0.05 - 0.1 in.**

Tough, impervious polyurethane membrane

CORNELL QUALIFICATIONS

- **35 Years R&D for Gas Distribution & Transmission Systems**
  - **Cast iron pipelines, railroad/highway crossings, pipeline rehabilitation, aging protocols, reinforced polymer linings, risk reduction, seismic performance**
- **Cornell Large-Scale Lifelines Testing Facility**
- **35 Years R&D, Design, and Construction Experience for Large Geographically Distributed Systems**

CORNELL PROJECTS

Cast Iron Pipelines

- Response of Jointed Cast Iron Pipelines to Parallel Trench Construction, NYGAS, 1983
- Factors Affecting the Performance of Cast Iron Pipe, NYGAS, 1984
- Field Tests of Cast Iron Pipeline Response to Shallow Trench Construction, NYGAS, 1984
- Manual for Assessing the Influence of Excavations on Parallel Cast Iron Gas Mains, NYGAS, 1984
- Field Monitoring of Cast Iron Gas Main Response to Deep Trench Construction, NYGAS 1987
- Evaluation of Cast Iron Pipeline Response at Excavation Crossings, NYGAS, 1988

Mechanical/Mechanical Aging & CIPP Systems

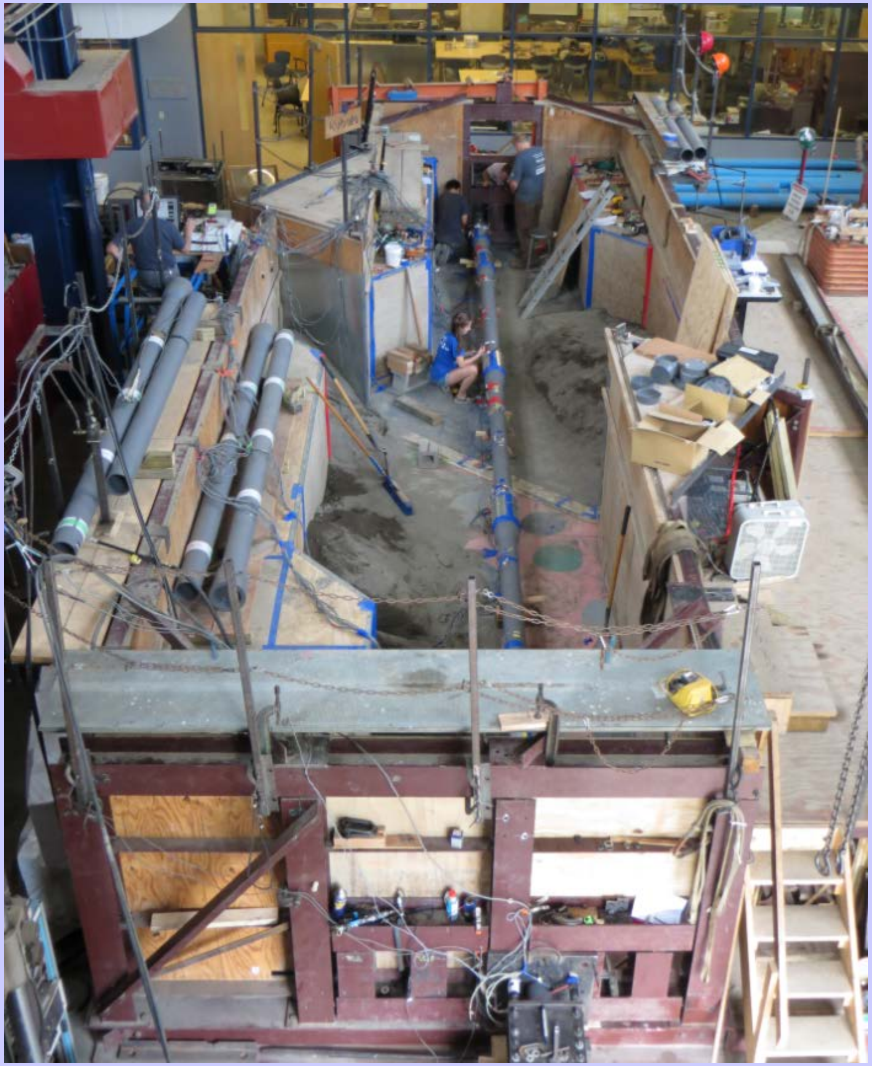
- Evaluating Service Life of Cast Iron Joint Sealing Products and Techniques, NYGAS, 1985
- Evaluating Service Life of Anaerobic Joint Sealing Products and Techniques, Gas Research Institute, 1996
- Advanced Pipeline Support and Stabilized Backfill for Gas Mains, New York Gas Group, 2000
- Evaluation of Starline Cured-in-Place Lining System for Cast Iron Gas Distribution Pipelines NYSEARCH/NGA, 2003
- Longevity Testing of Anaerobic Sealants in Cast Iron Pipe Joints, National Grid, LCC, 2011

KEY CIPP RESEARCH FINDING

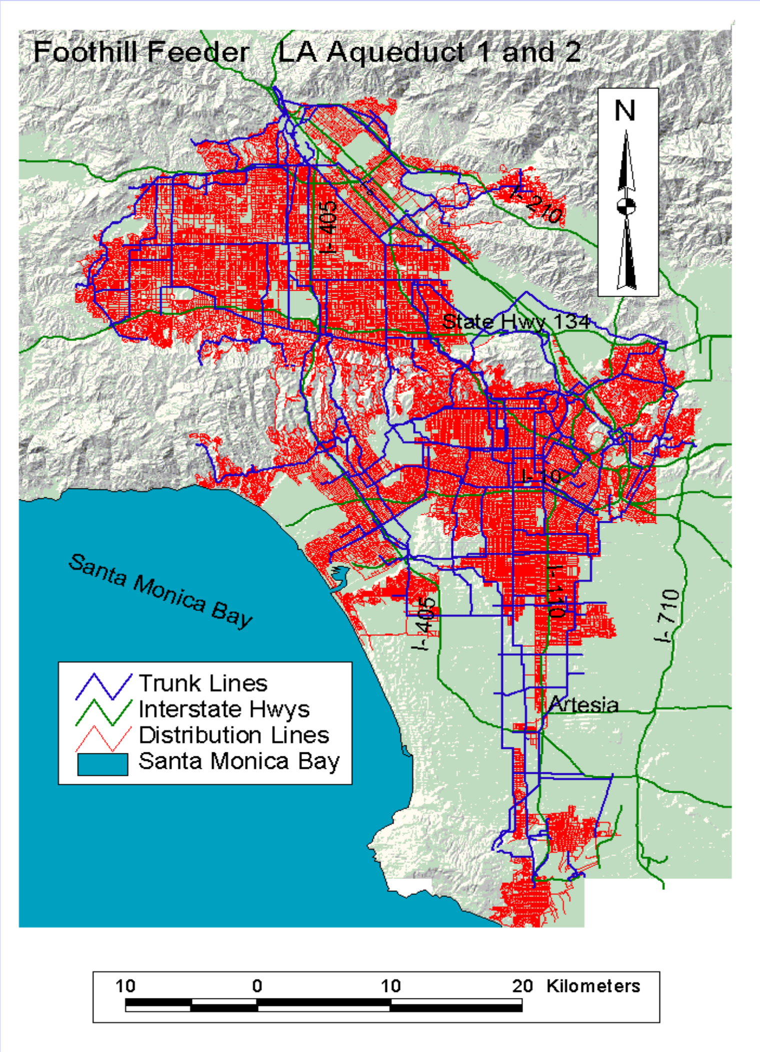
- Local de-bonding required to accommodate movement at cracks & weak joints
- De-bonding confined to a distance of one diameter from crack
- Installation engineered for local de-bonding


A
B
C
D
E

CORNELL LARGE-SCALE LIFELINES TESTING LABORATORY

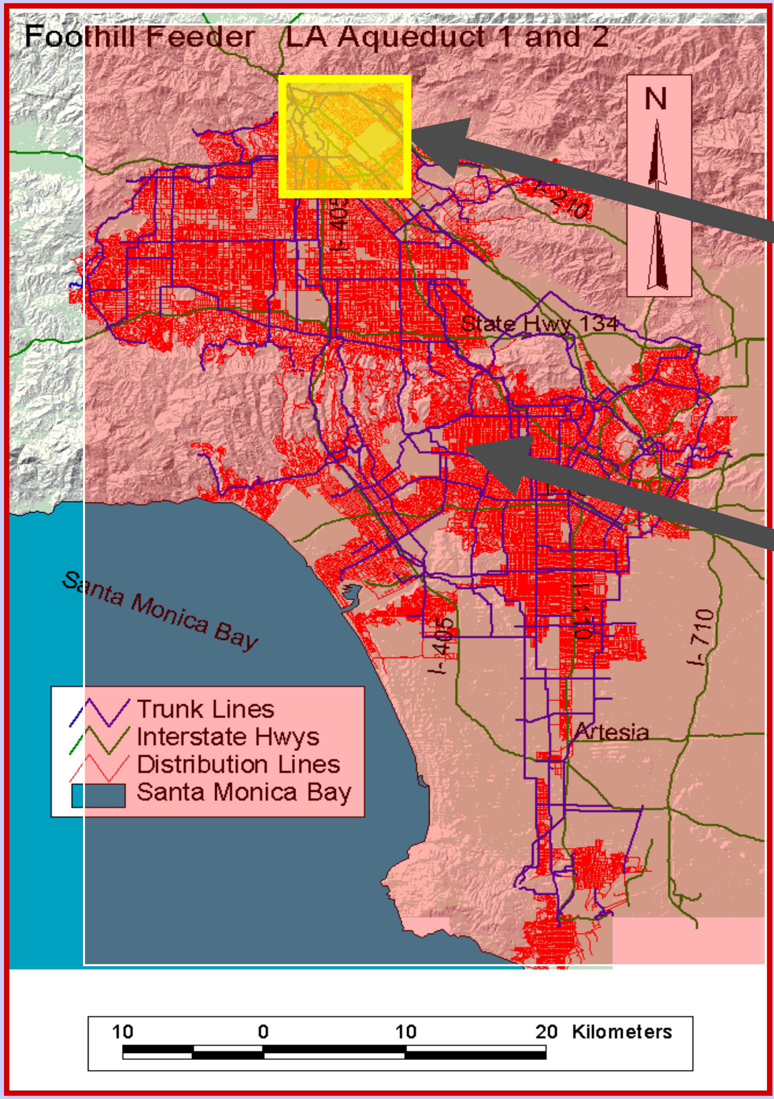


DECISION LADWP SUPPORT SYSTEM



- **Simulates 7,500 miles pipelines & facilities**
- **Comprehensive seismic & geohazards**
- **Special software for damaged hydraulic network analysis**
- **System risk & reliability**
- **Water & electric interdependencies**
- **Economic/social impacts**

MULTI-MODAL SIMULATION



Simulation for Ground Failure, Accidents, Human Threats

Probabilistic Simulation for System-wide Seismic Wave Effects

Combined Simulation for Permanent Ground Deformation & Seismic Wave Effects

Field Retrieval of Cast Iron Lined Pipe - Two Sites

- **Elmwood Park, NJ**
  - **PSE&G**
  - **6 in. diameter**
  - **Operating at in. water column pressure**
  - **Starline®2000 in 1998**

Field Retrieval of Cast Iron Lined Pipe - Two Sites

- Garden City, Long Island, NY
  - National Grid
  - 12 in. diameter
  - Operating at 60 psi
  - Starline®2000 in 2004

Specimen Retrieval

Specimen No.	Diameter and Length	Lined Pipe Location	Liner Installation	Specimen Retrieval Date	Cornell Begins Testing
6-1 and 6-2	6 in. dia., 8 ft	Elmwood Park, NJ	1998	May 21, 2014	July, 2014
12-1 and 12-2	12 in. dia., 8 ft	South Garden City, Long Island, NY	2004	August 21, 2014	March, 2015

Palsa Ave, Elmwood Park, NJ

6 in. Specimen Retrieval

PSE&G, Elmwood, Park, NJ

Live gas

6 in. Specimen Retrieval

12 in. Specimen Retrieval

Nat Grid, Garden City, LI

60 psi MAOP

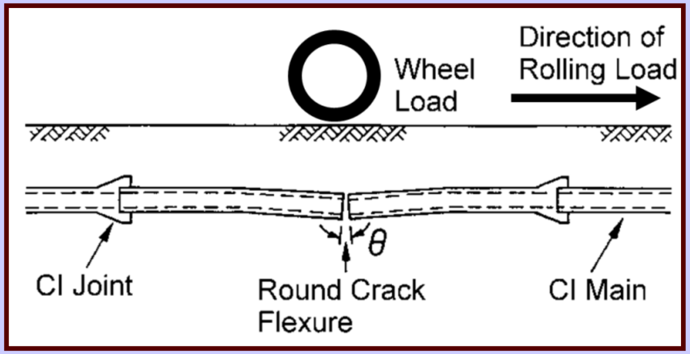
12 in. Specimen Retrieval

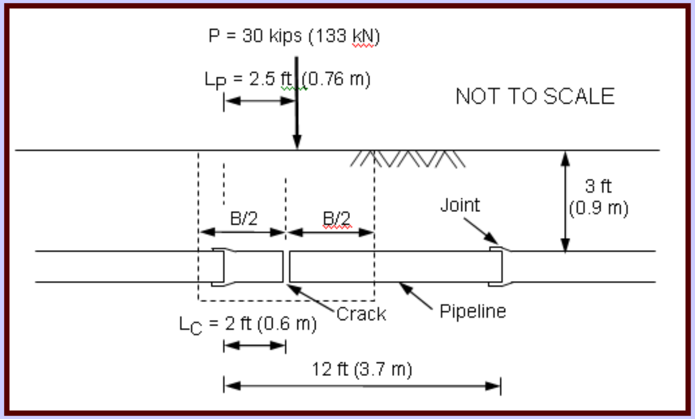
Ship to Cornell

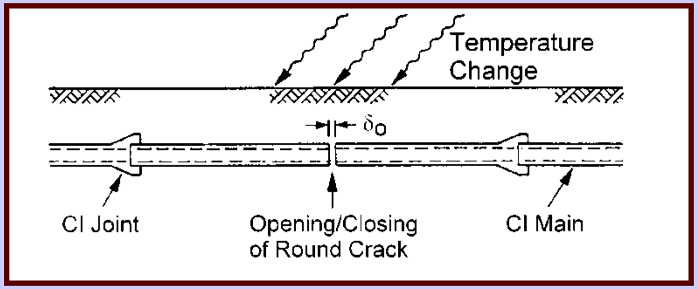
- Ship in Special Crates to Avoid Damage in Transit
- At Cornell
  - Clean & De-Scale
  - Photograph
  - Begin with 6 in. Vehicular Loading

MECHANICAL AGING

- Repetitive Heavy Traffic Loads
- Undermining & Backfilling
- Thermal Expansion & Contraction

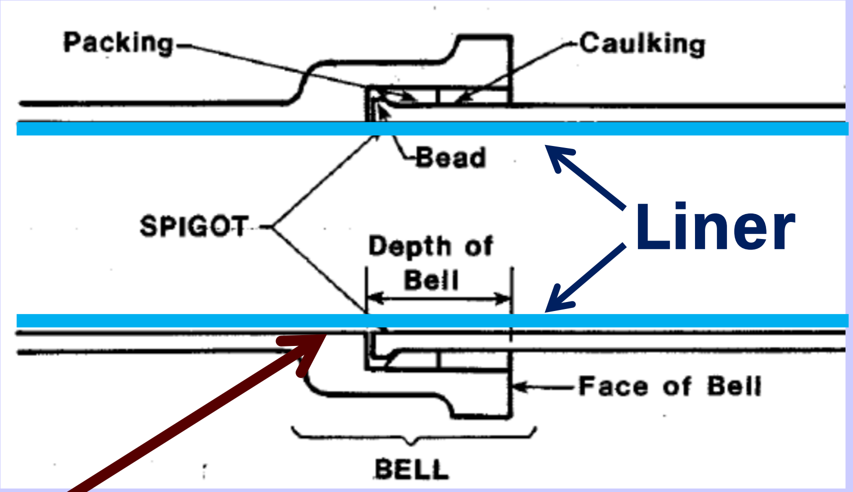






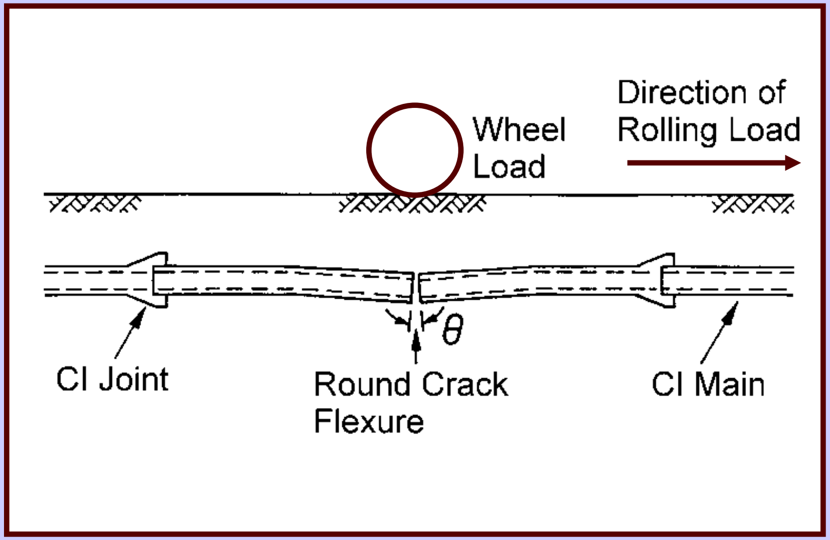
MATERIAL CHARACTERIZATION

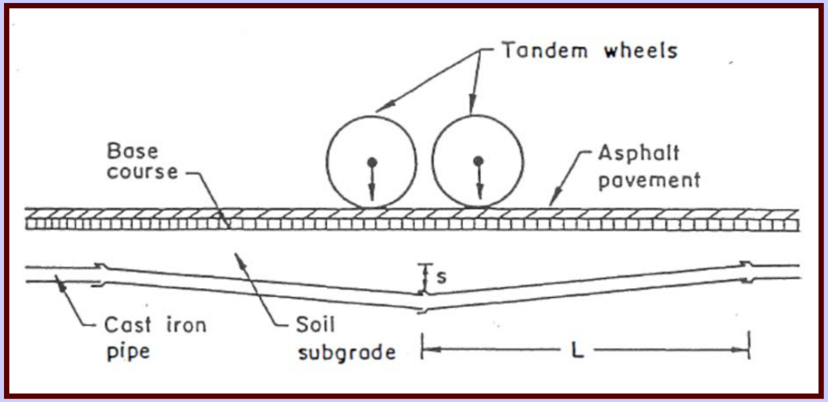
- Liner Tension Tests
  - ➢Longitudinal Tension
  - ➢Hoop Tension
- Liner Adhesion Tests
  - ➢Lap Shear
  - ➢Peel Strength
- Chemical Aging Tests



Liner Tension & Adhesive Shear Strength of Primary Importance

REPETITIVE HEAVY TRAFFIC LOADING



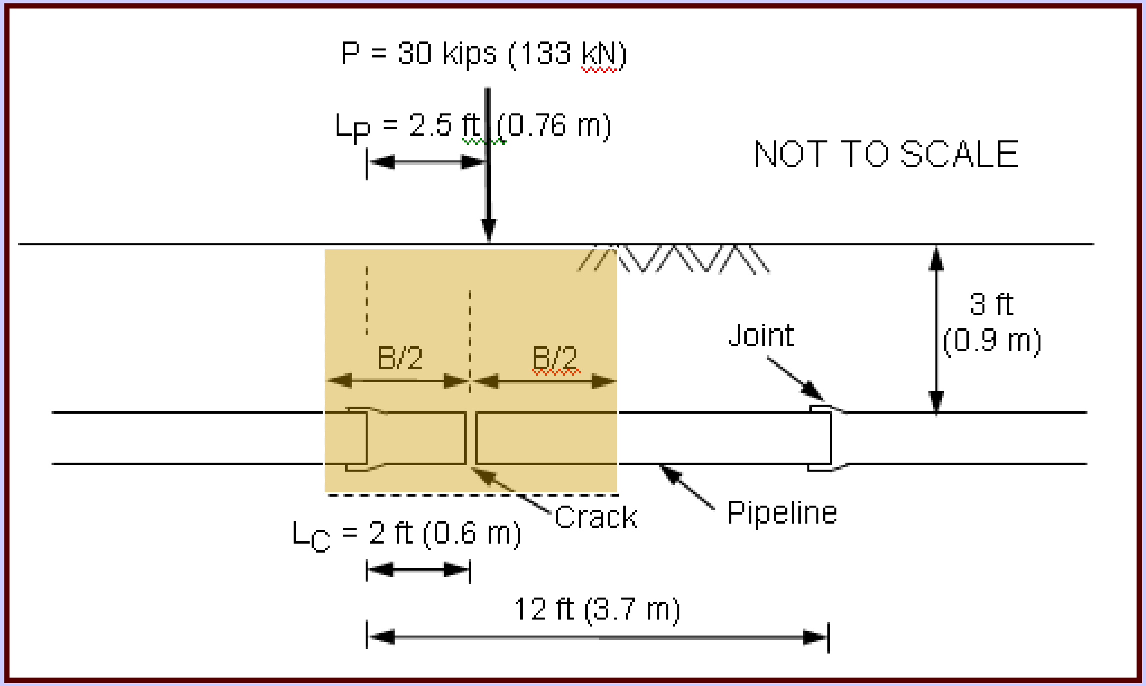


- Heaviest double tandem axle loads permitted in NYS
- Number of axle loadings over 50 years determined from traffic surveys
- Vehicular speed ≈ 40 mph
- 780,000 axle loads over 50 years, rounded to 1 million
- Finite element simulations to set repetitive deflections
- Simulations validated by by full-scale field tests in U.S. and U.K.

REPETITIVE HEAVY TRAFFIC LOADING

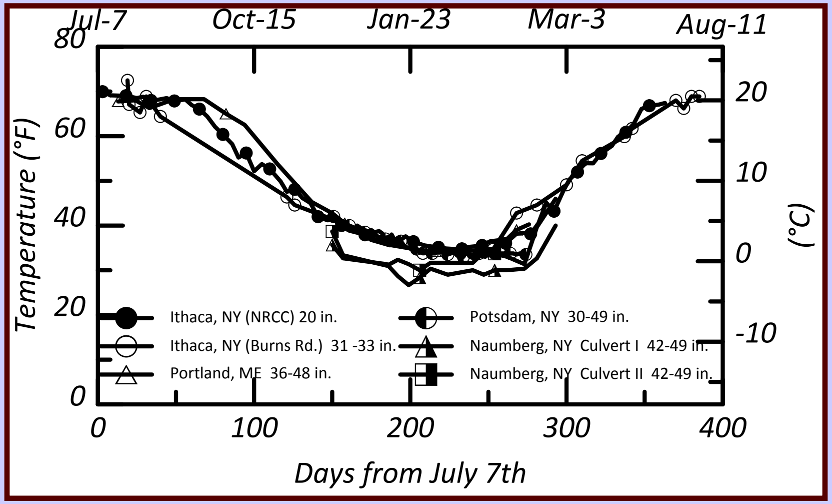
Movie

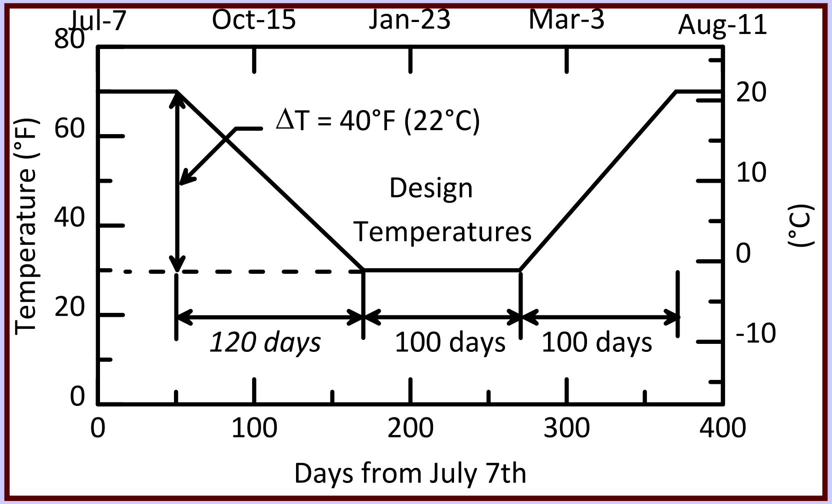
UNDERMINING & BACKFILLING



- **Undermining widths: 4-12 ft**
- **Lightly compacted backfill**
- **Single Axle Load: 30 kips**
- **Deflection from simulations: 0.35 in. & 0.5°**
- **100,000 cycles**

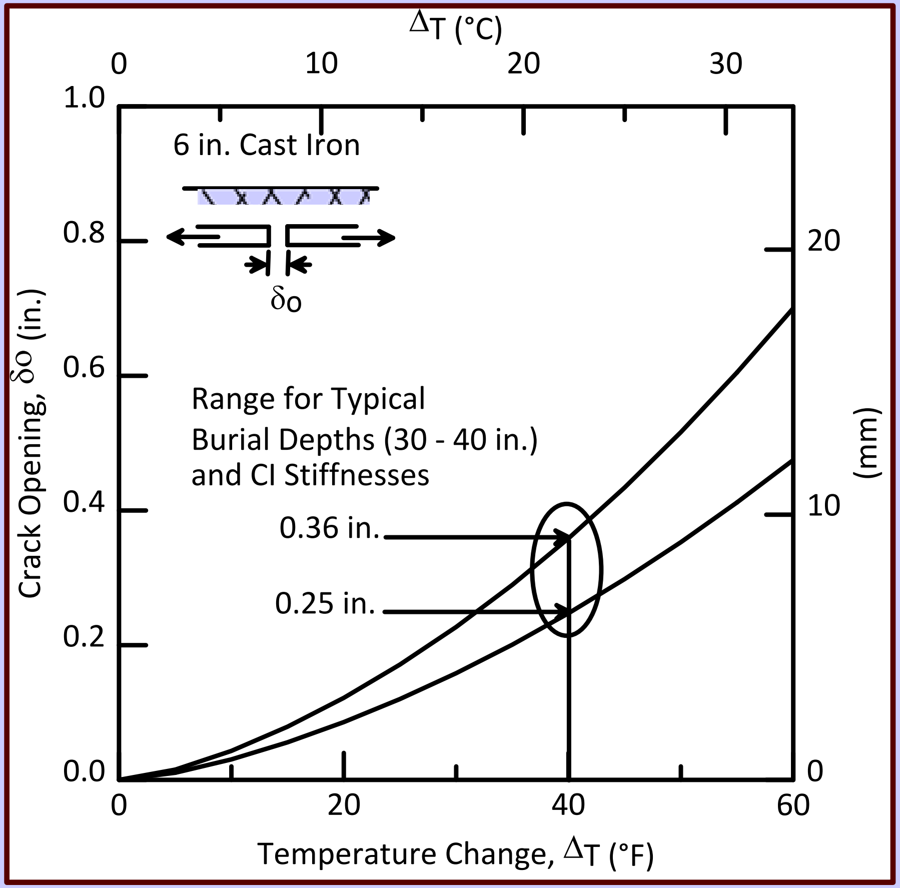
THERMAL CONTRACTION & EXPANSION

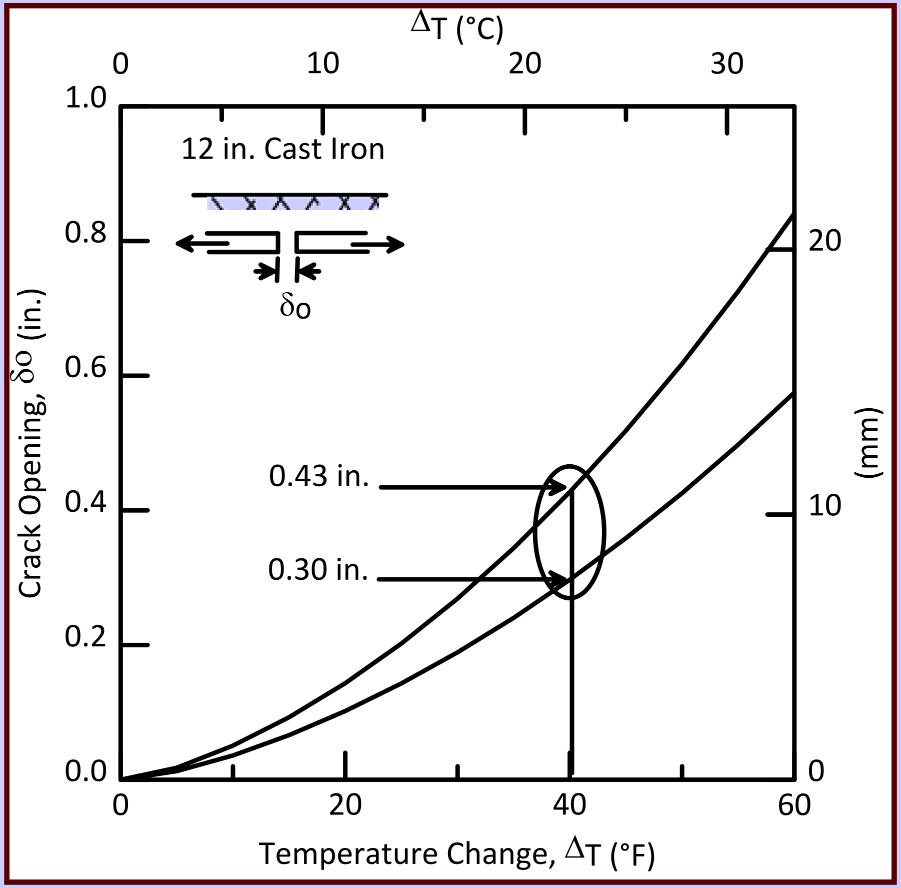




- Subsurface year-long temperature measurements in New York State
- Closed-form subsurface thermal contraction & expansion analytical model
- Assumes liner provides negligible resistance to contraction/expansion
- Upper bound on axial liner displacement
- Rate of loading > 1000x faster than occurs in the field

THERMAL CONTRACTION & EXPANSION





LABORATORY TESTING FOR THERMAL CYCLES

Experimental Setup Overview

Actuator

DCDTs

Load Cells

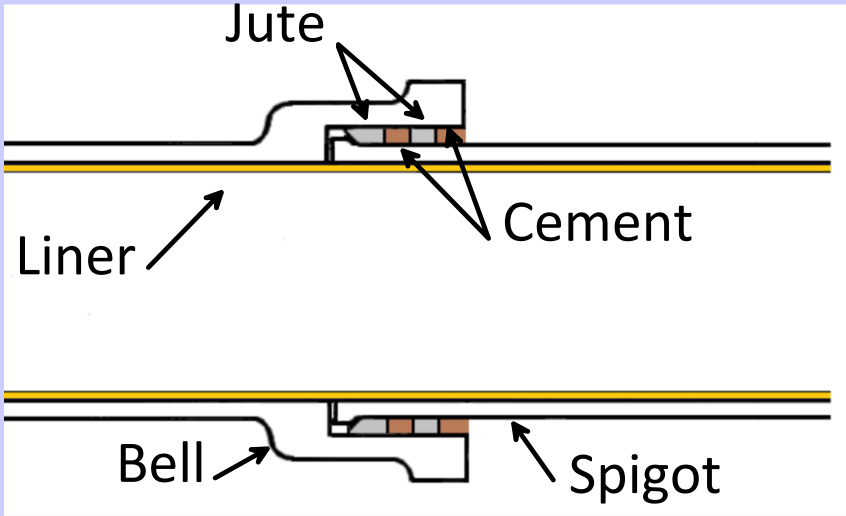
Top View of the Joint,
Bovay Laboratory Complex, Cornell University

Mechanical Aging Tests
6 in. Lined Cast Iron Joints

- Joint Type
- Vehicle Cycles
- Undermining/Backfilling Event
- Thermal Cycles
- Pressurization

6 in. Lined Cast Iron Joints

- **Initially Cement Caulked**
- **Removal of Cement to Weaken Joint after 1st 50 Years Vehicle Loading**
- **Further Weakening after Thermal Cycles**



6 in. Lined Cast Iron Joints Testing Sequence

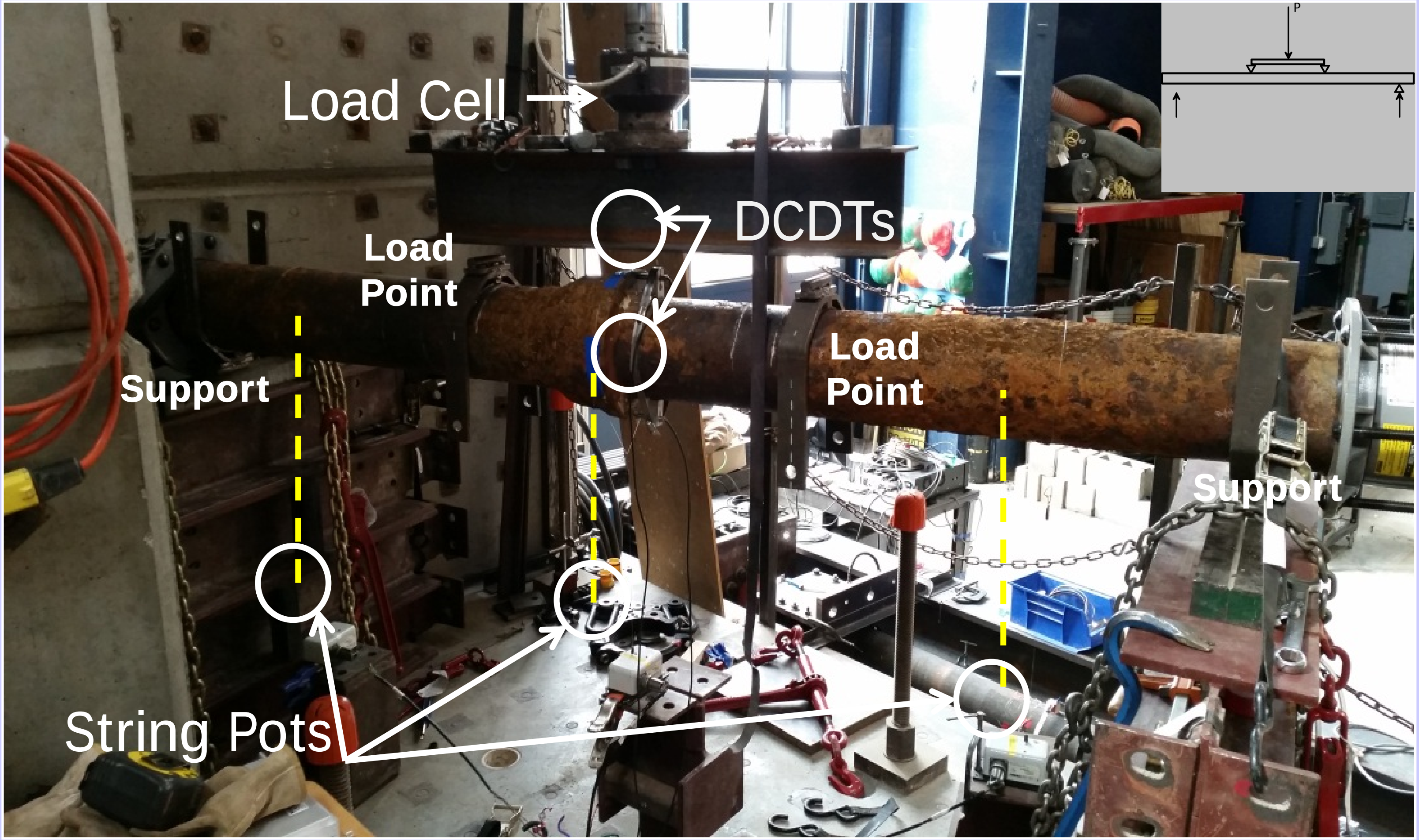
	Years	Internal Pressure
Vehicle loadings/bending cycles (1 M cycles)	Up to 50	15 in. water column
Undermining excavation event (1)	1	15 in. water column
Additional vehicle loadings/bending cycles (100 K cycles)	+0.5	15 in. water column
Thermal expansion/contraction cycles (50 cycles)	1 - 50	15 in. water column
Vehicle loadings/bending cycles (another 1 M cycles)	50 - 100	15 in. water column
Excavation event (1)	1	15 in. water column
Additional vehicle loadings/bending cycles (another 100 K cycles)	+0.5	15 in. water column
Thermal expansion/contraction cycles (another 50 cycles)	50 - 100	15 in. water column
Post-Testing Verification Pressure	1	90 psig(then + 60)

The cement/jute caulking was mostly removed in to provide a weak joint condition.
During mechanical aging the internal pressure was N_2, pressure verification used water.

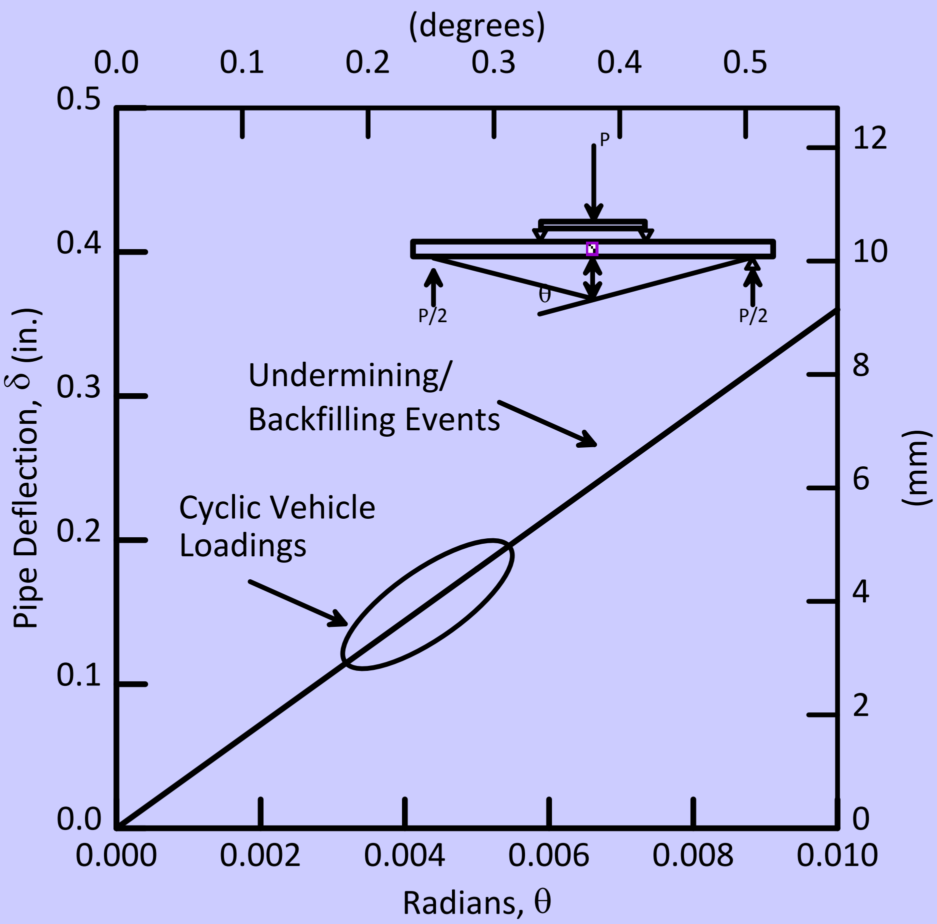
6 in. Lined Cast Iron Joints
Mechanical Aging due to Vehicle Loading

6 in. Lined Cast Iron Joints

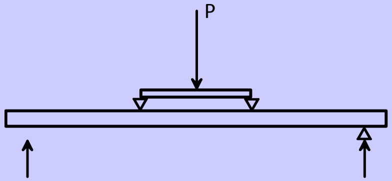
Mechanical Aging due to Vehicle Loading



Mechanical Aging due to Vehicle Loading



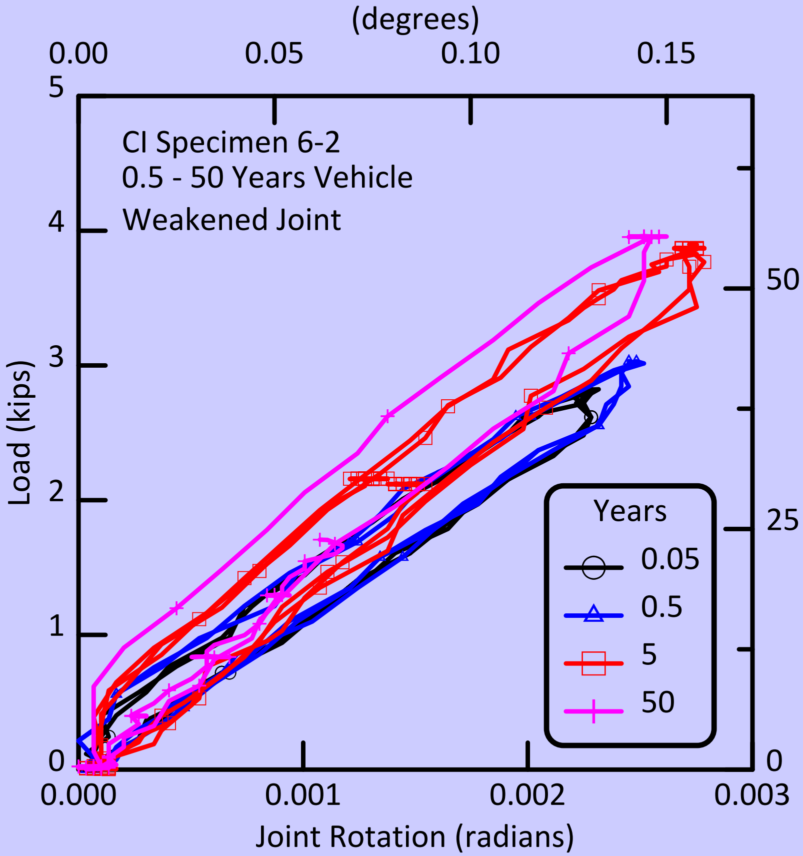
Deflections and Rotations are Small



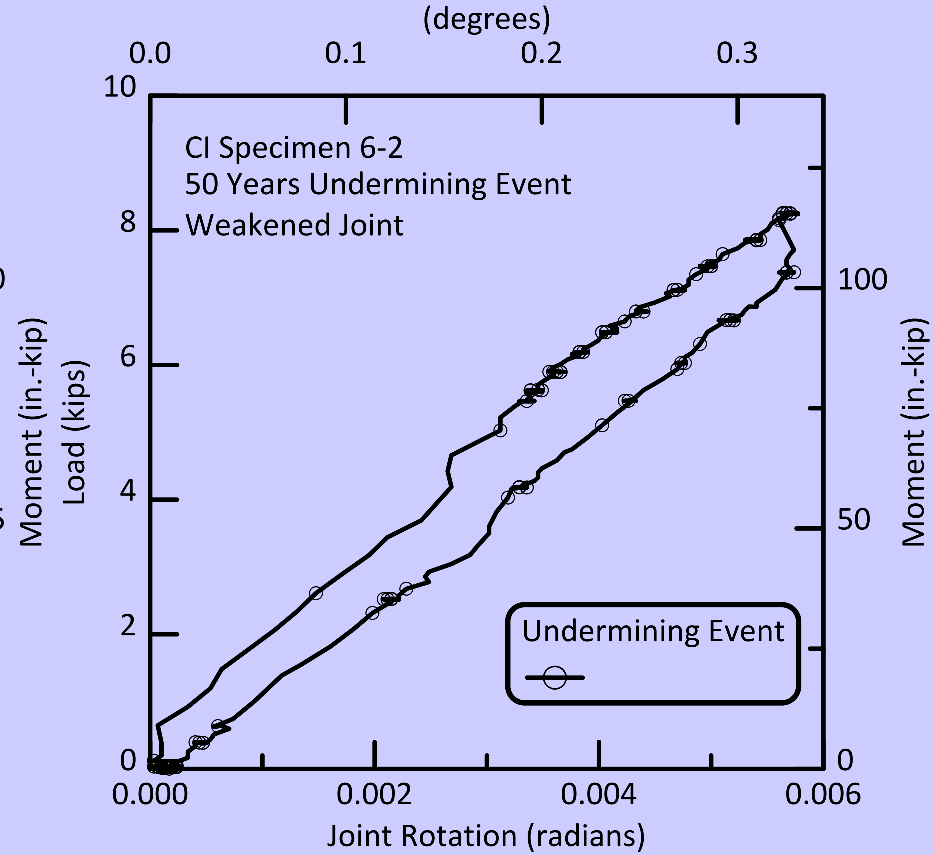
Can Determine Moment-Rotation Relationships

6 in. Lined Cast Iron Joints
First 50 Years Vehicle Loading

Vehicle Loadings



Undermining Event



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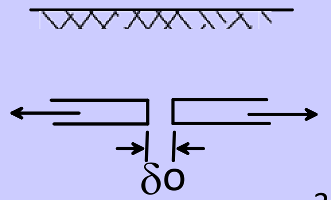
6 in. Lined Cast Iron Joints – Thermal Cycles

Experimental Setup Overview

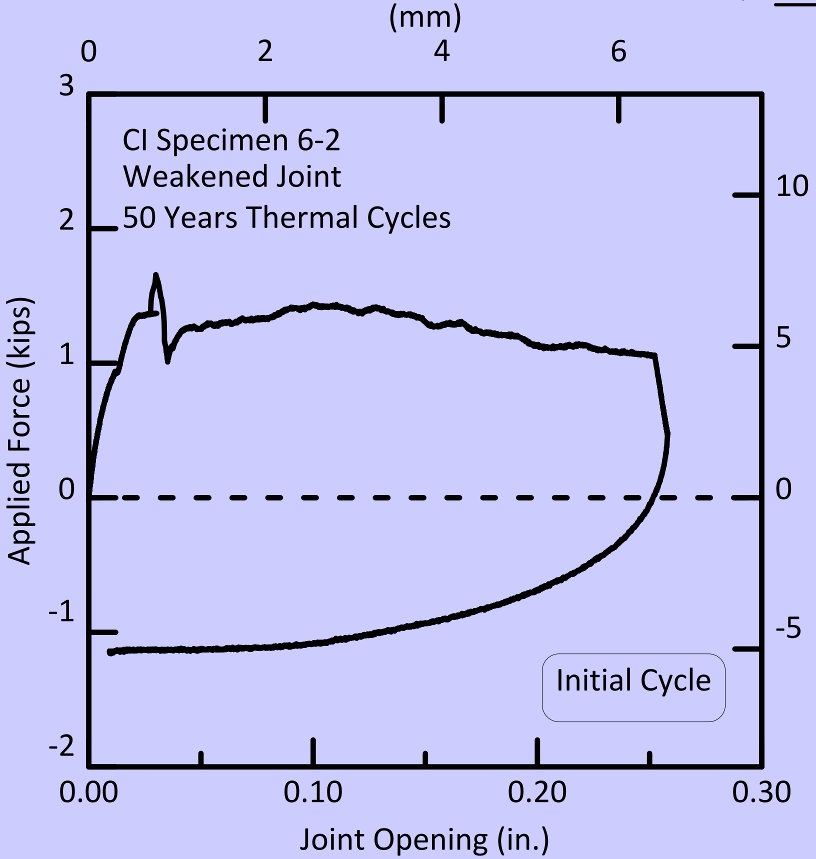
Top View of the Joint,
Bovay Laboratory Complex, Cornell University

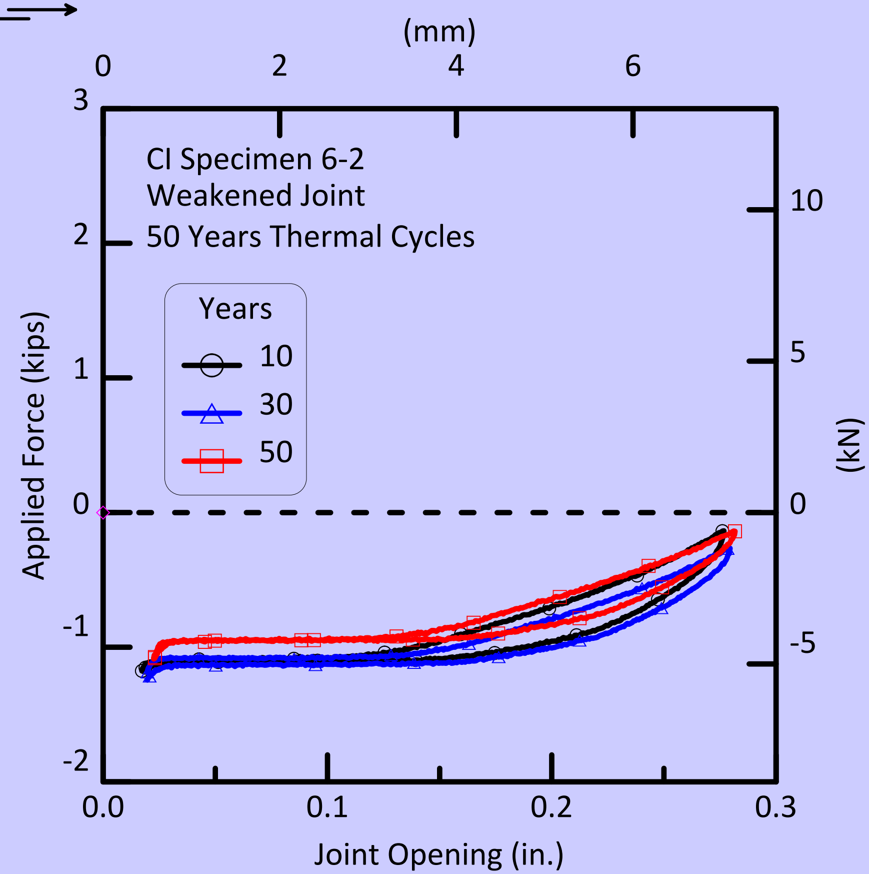
6 in. Lined Cast Iron Joints
First 50 Years Thermal Cycles

Initial Cycle



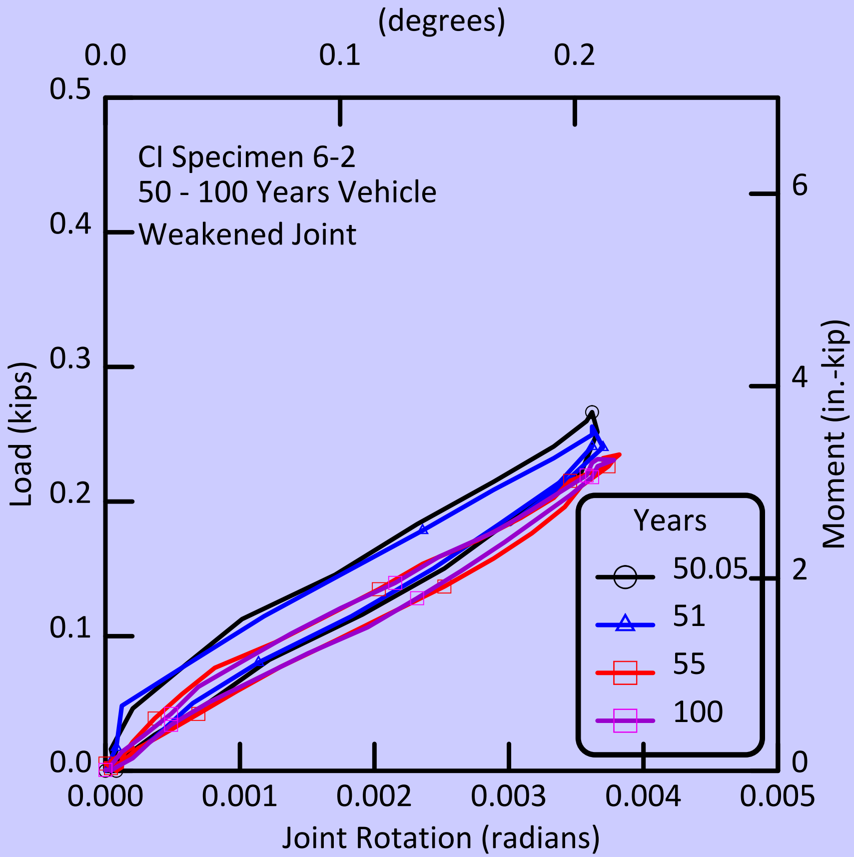
Next 50 Years



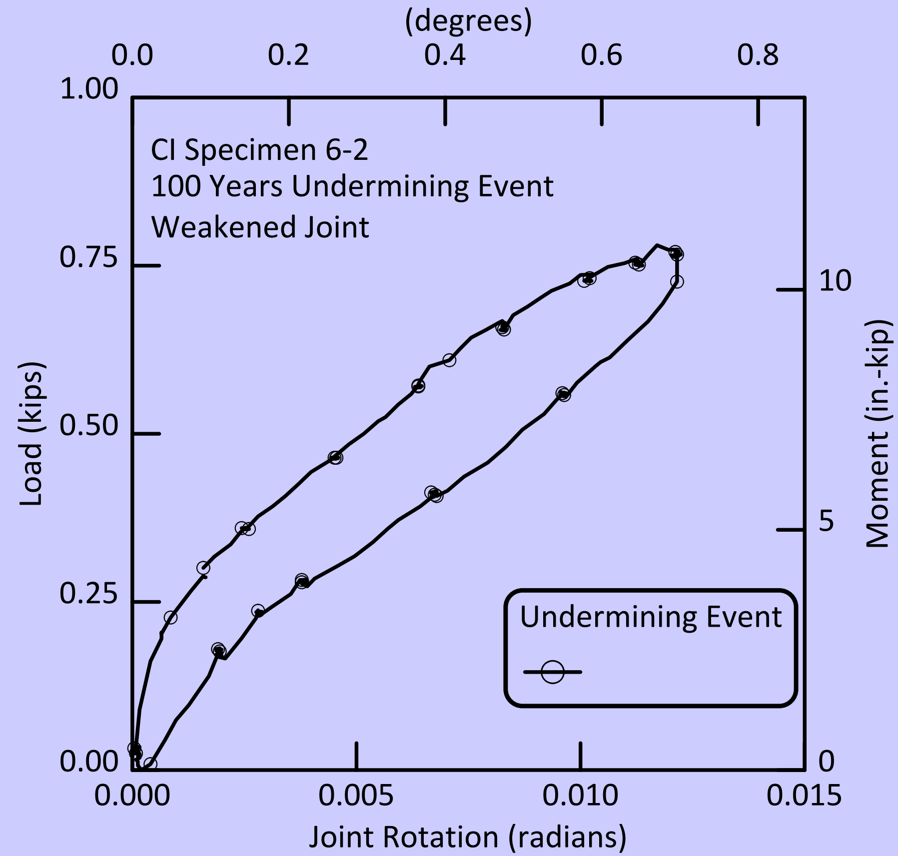


6 in. Lined Cast Iron Joints
50 - 100 Years Vehicle Loading

Vehicle Loadings



Undermining Event



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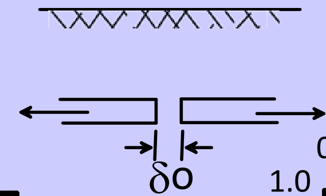
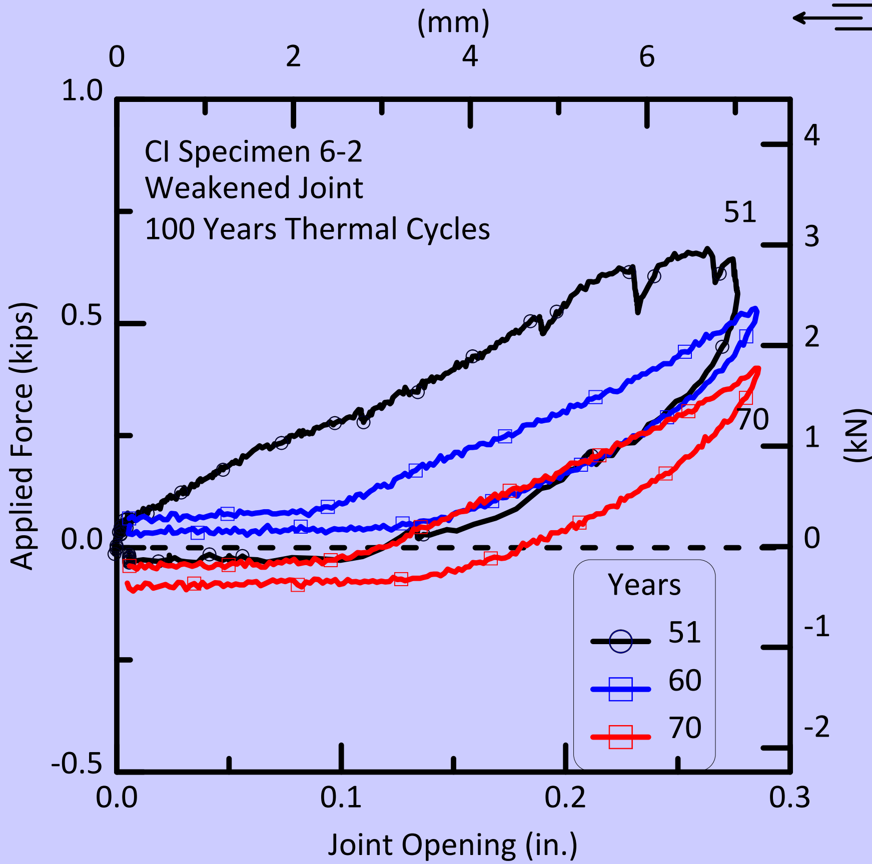
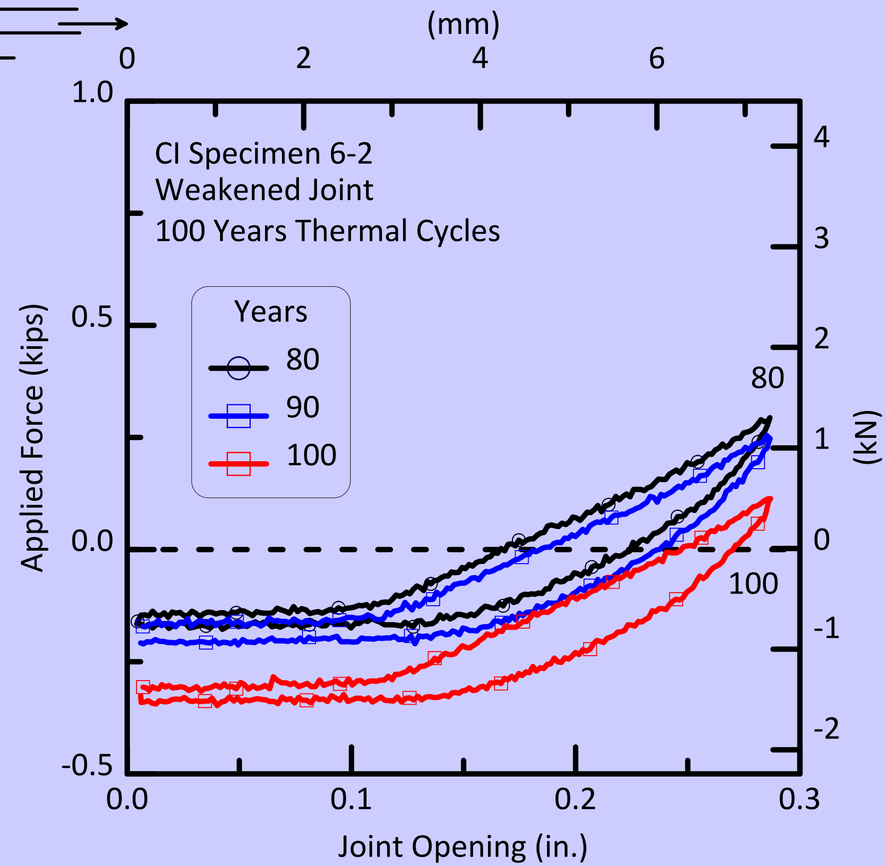
6 in. Lined Cast Iron Joints
51 - 100 Years Thermal Cycles



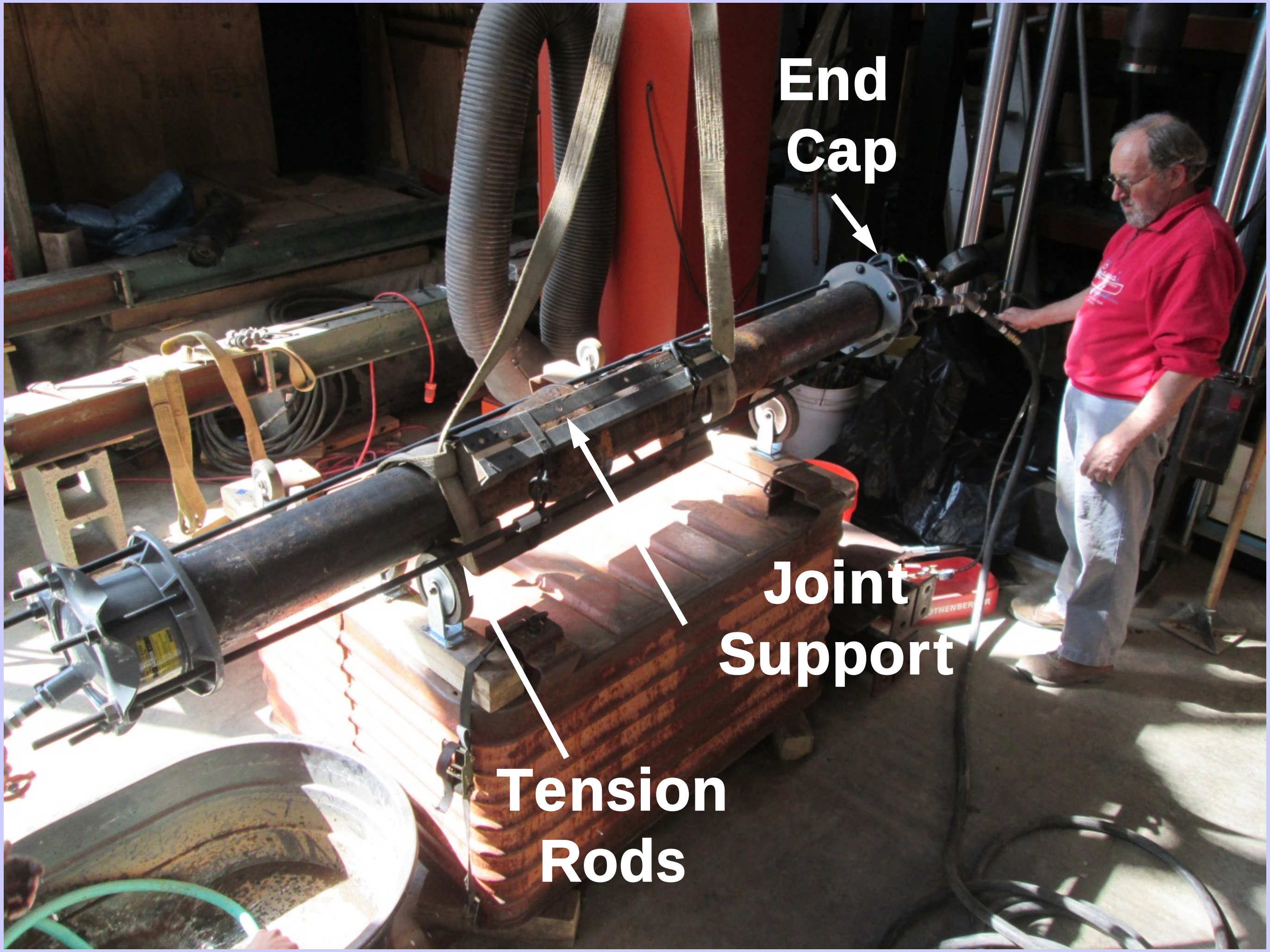
Years 51 - 70



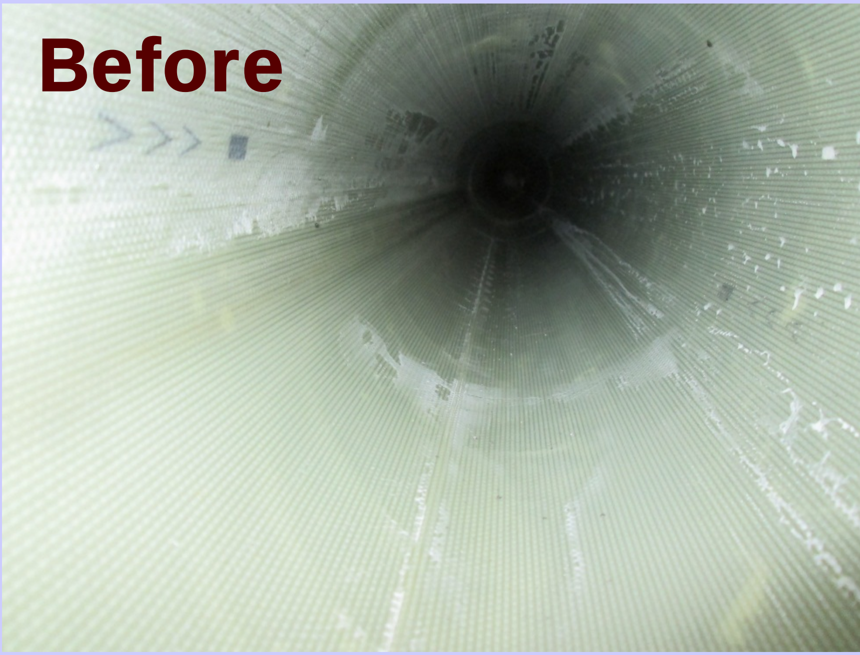
Years 80 - 100



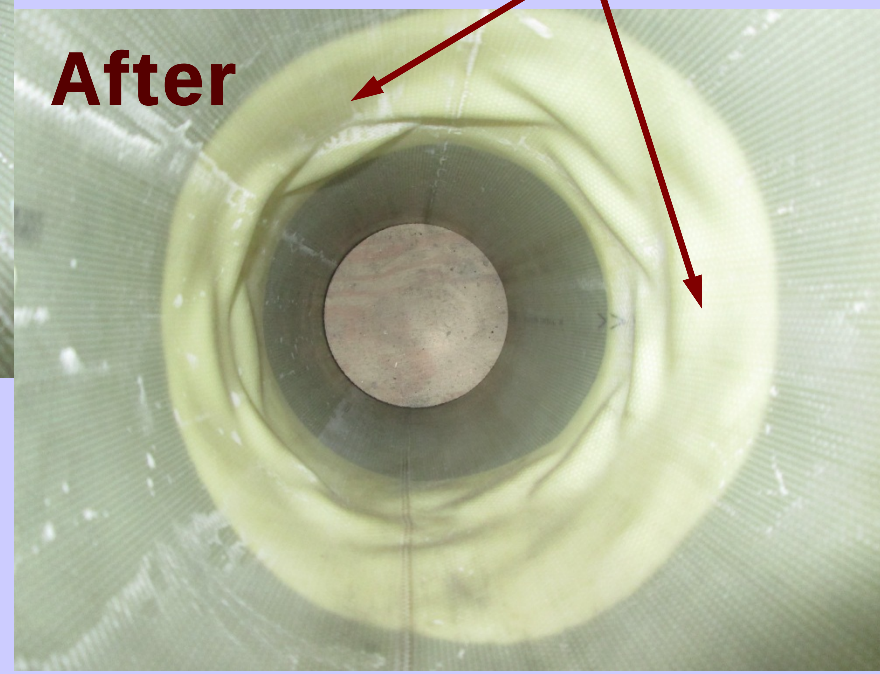
6 in. Post-Test Pressure Testing



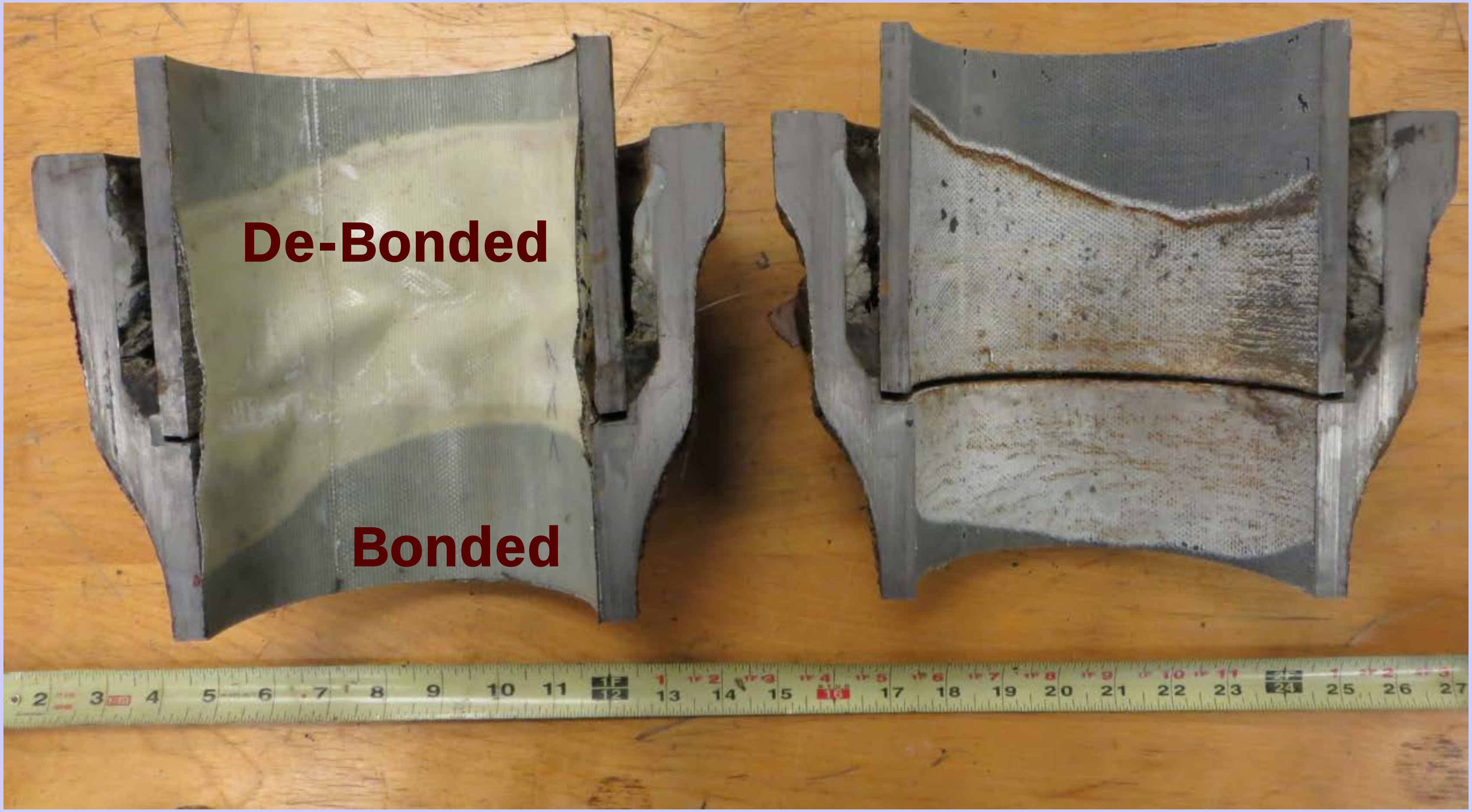
6 in. Specimen



De-Bonding



6 in. Lined Cast Iron Joints Post-Testing



Mechanical Aging Tests
6 in. Lined Cast Iron Joints

- **Joint Type – Cement/Jute Caulked (then Cement/Jute Removed to Weaken Joint)**
- **50 Years Vehicle Cycles**
- **Undermining/Backfill Event**
- **50 Years Thermal Cycles (Caused Further Joint Weakening)**

Mechanical Aging Tests
6 in. Lined Cast Iron Joints

- Additional 50 Years (100 Years Total) Vehicle Cycles
- Additional Undermining/Backfill Event
- Additional 50 Years (100 Years Total) Thermal Cycles
- Verification Pressure Test to 90 psig (and beyond)

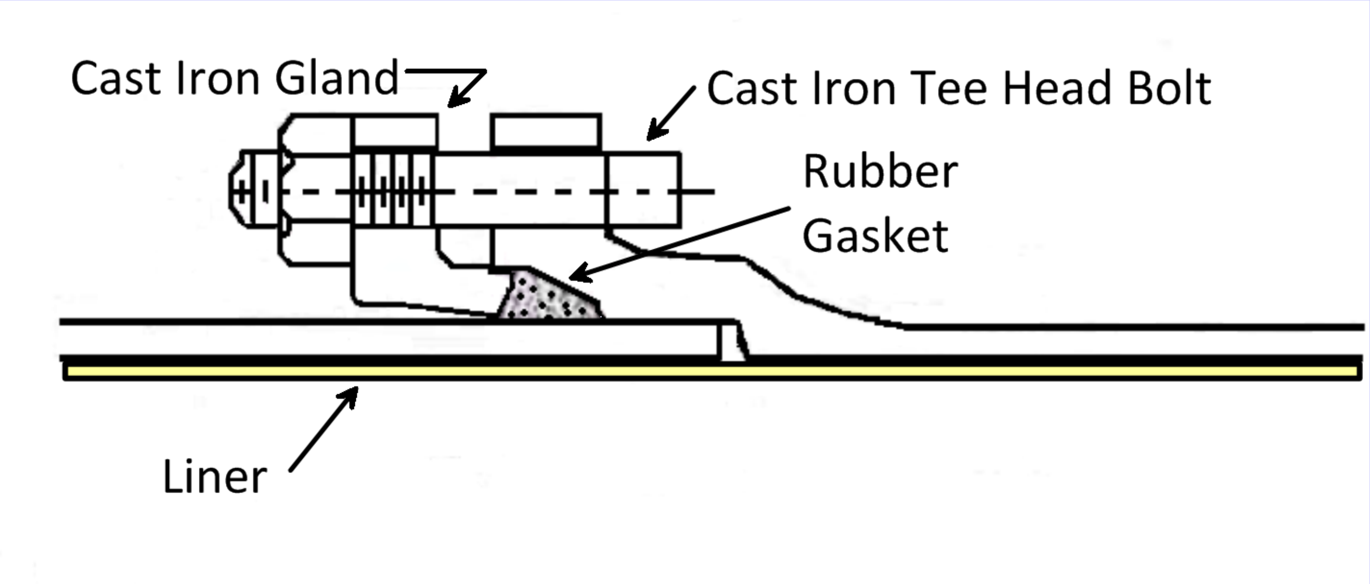
No Leakage, No Liner Damage

Mechanical Aging Tests
12 in. Lined Cast Iron Joints

- **Joint Type**
- **Vehicle Cycles**
- **Undermining/Backfilling Event**
- **Thermal Cycles**
- **Pressurization**

12 in. Lined Cast Iron Joints

- **Mechanical Joint**
- **Inner-Tite (or similar) with Clamp**



12 in. Lined Cast Iron Joints Testing Sequence

	Years	Internal Pressure
Vehicle loadings/bending cycles (1 M cycles)	Up to 50	15 psig
Undermining excavation event (1)	1	15 psig
Additional vehicle loadings/bending cycles (100 K cycles)	+0.5	15 psig
Thermal expansion/contraction cycles (50 cycles)	1 - 50	15 psig
Vehicle loadings/bending cycles (another 1 M cycles)	50 - 100	15 psig
Undermining excavation event (1)	1	15 psig
Additional vehicle loadings/bending cycles (another 100 K cycles)	+0.5	15 psig
Thermal expansion/contraction cycles (another 50 cycles)	50 - 100	15 psig
Post-Testing Verification Pressure	1	90 psig

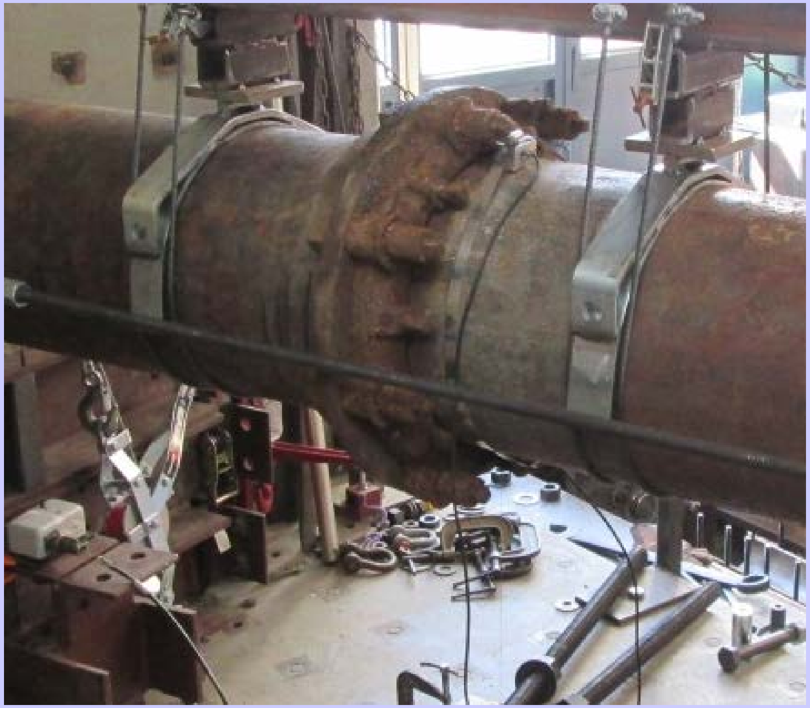
12 in. CI had Inner-Tite mechanical joints.
All internal pressurization used N_2.

Additional Evaluations for 12 in. Specimen 2

- After 1 Thermal Cycle
  - Depressurize
  - Remove End Seal
  - Inspect Lining
  - Drill Hole
  - Replace End Seal
  - Repressurize to 60 psig
  - Finish Additional 49 Cycles

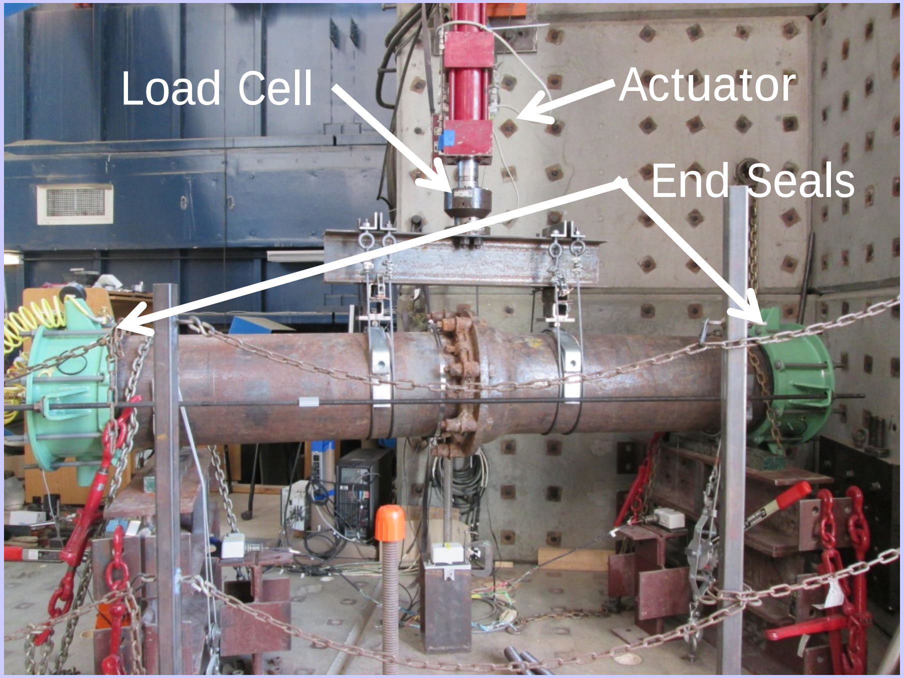
12 in. Lined Cast Iron Mechanical Joints

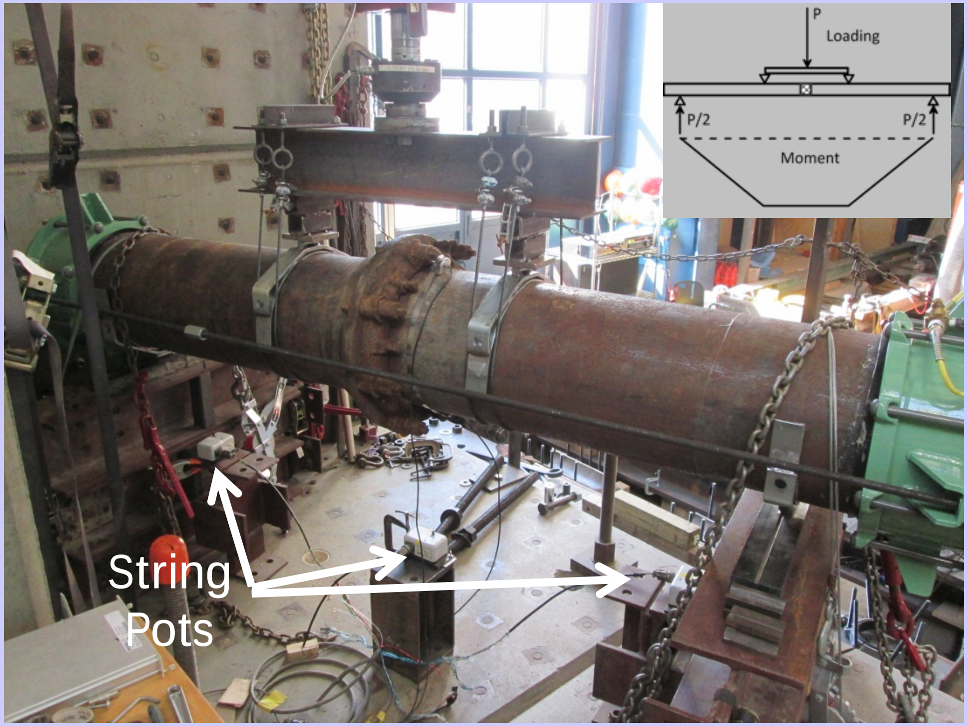
Field Retrieval



Lab De-Scaled

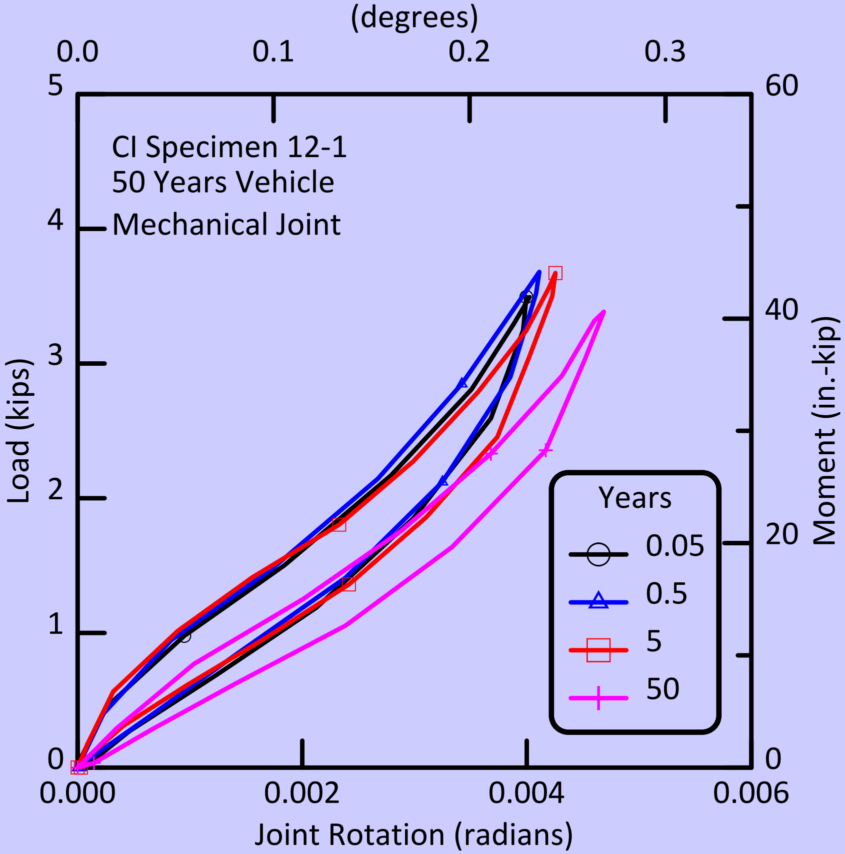
12 in. Lined Cast Iron Joints
Vehicle Loading / Bending



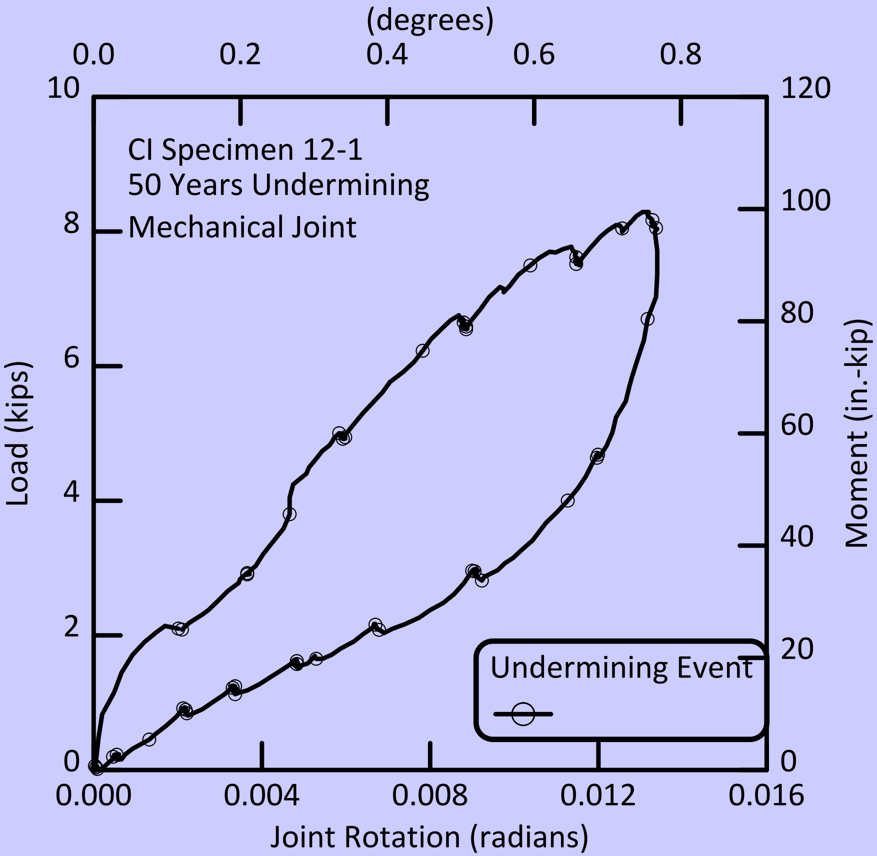


12 in. Lined Cast Iron Joints
First 50 Years Vehicle Loading

Vehicle Loadings



Undermining Event



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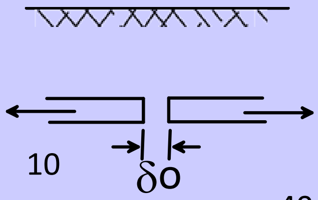
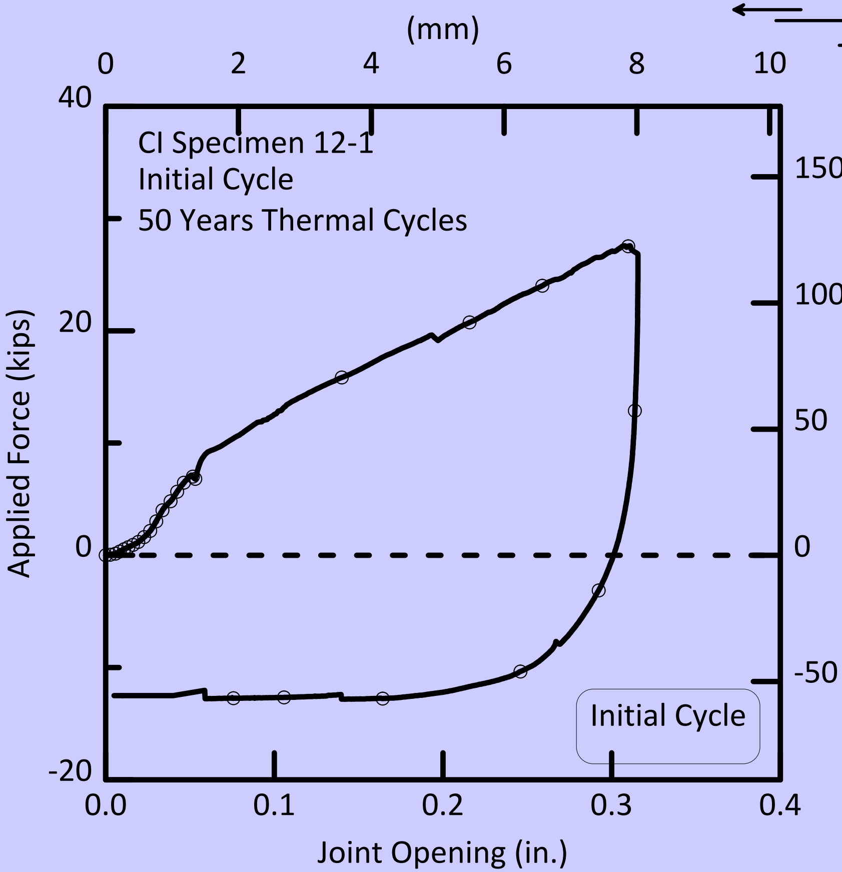
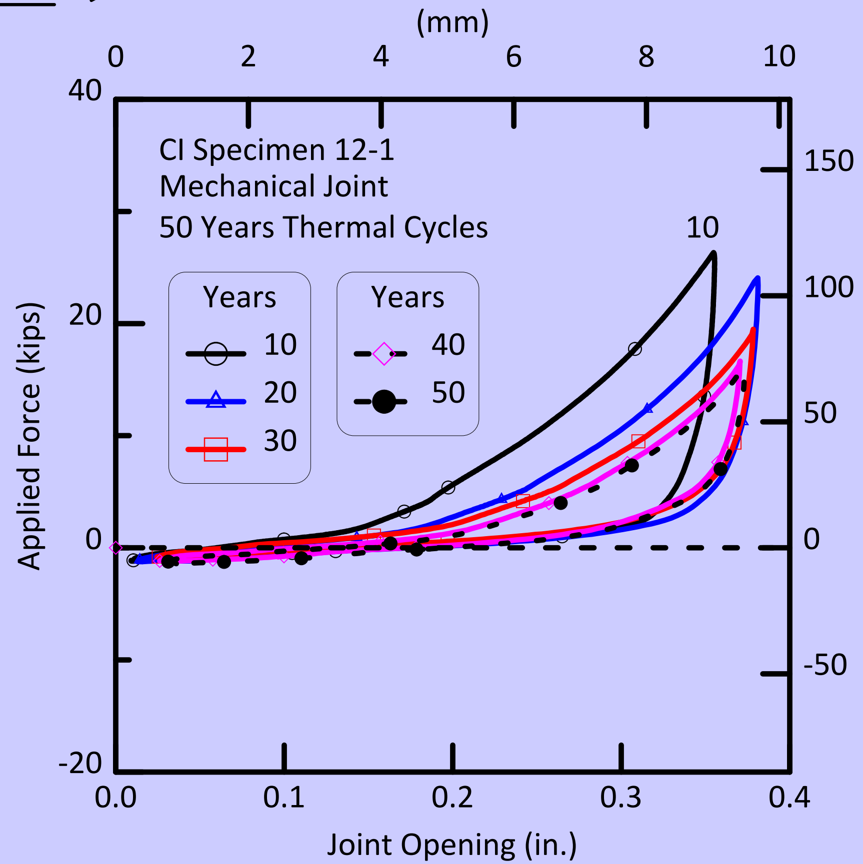
12 in. Lined Cast Iron Joints
First 50 Years Thermal Cycles



Initial Cycle



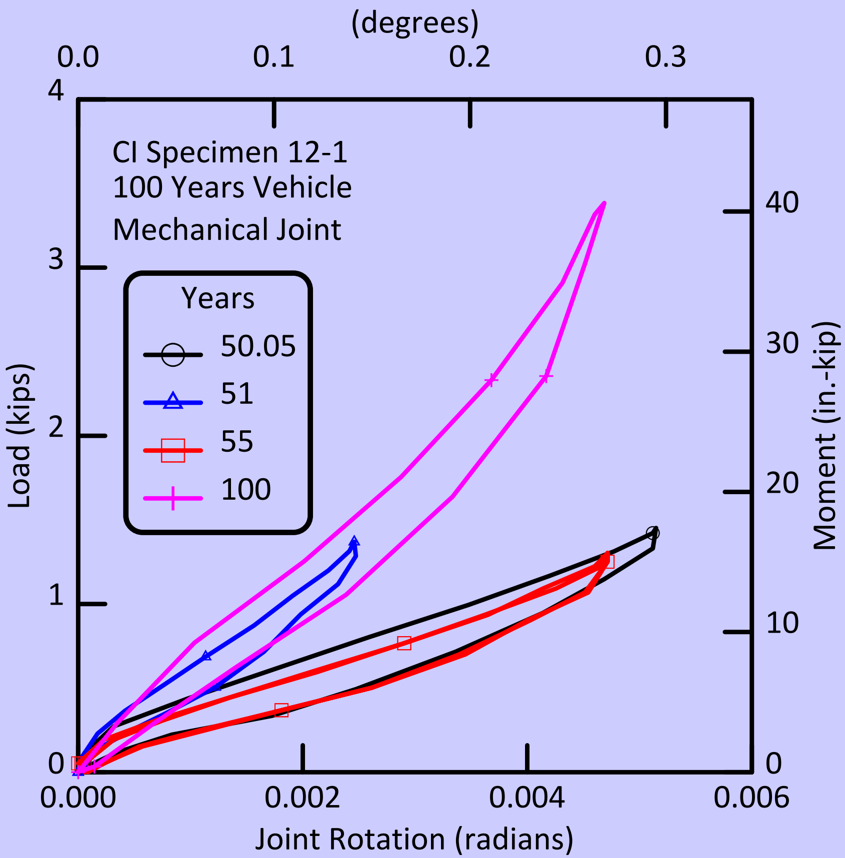
Next 50 Years



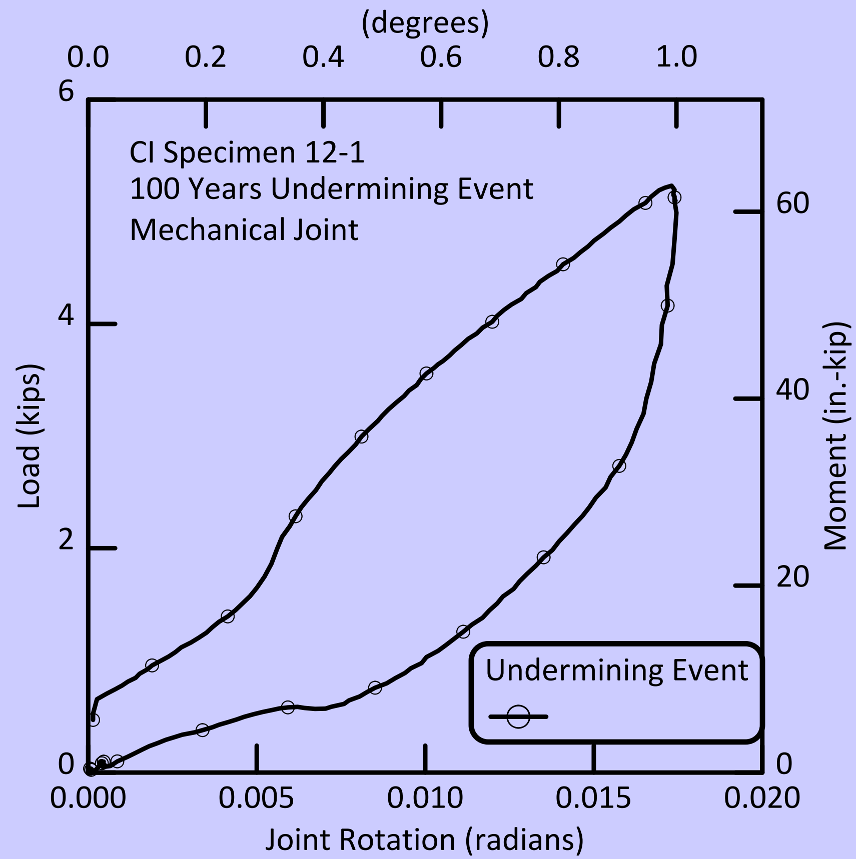
12 in. Lined Cast Iron Joints

50 - 100 Years Vehicle Loading

Vehicle Loadings



Trenching Event



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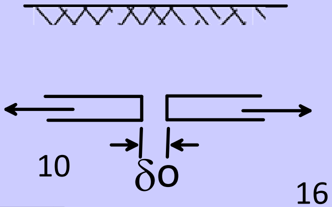
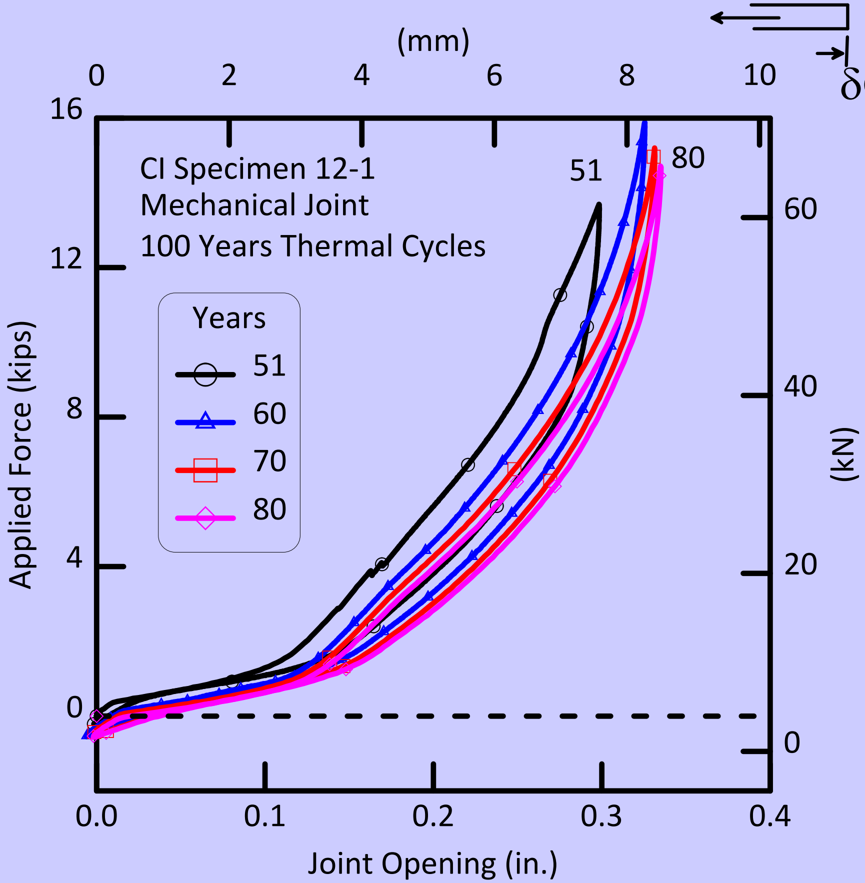
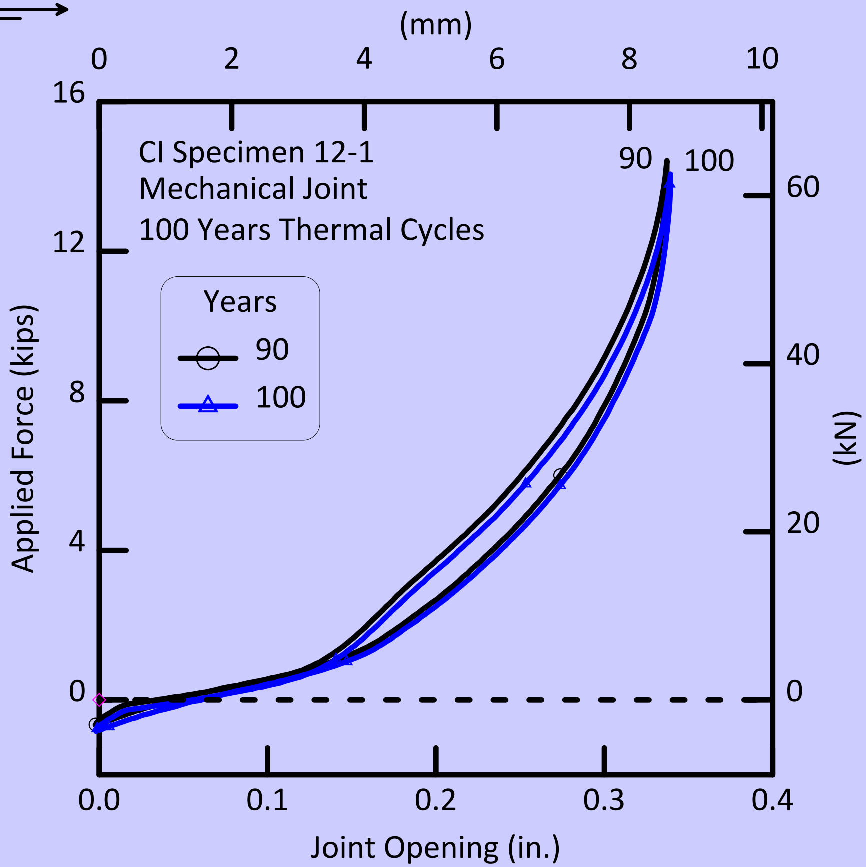
12 in. Lined Cast Iron Joints
100 Years Thermal Cycles

Years 51 - 80



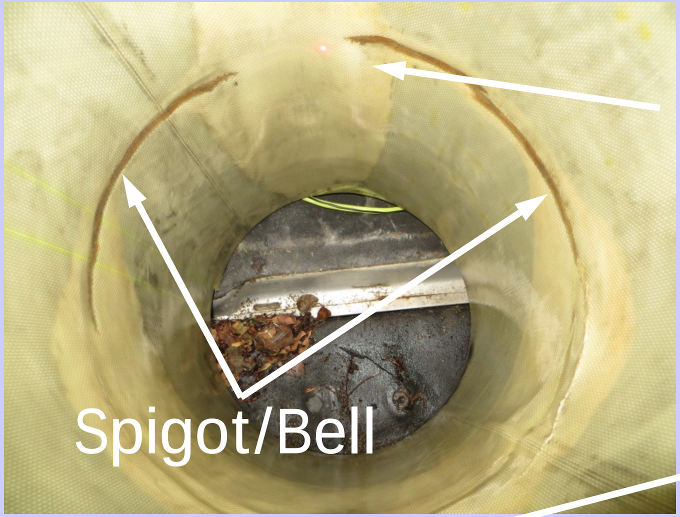


Years 90, 100

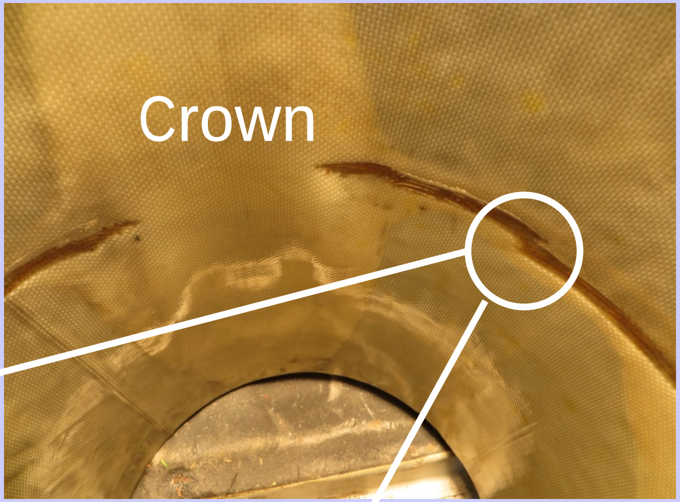


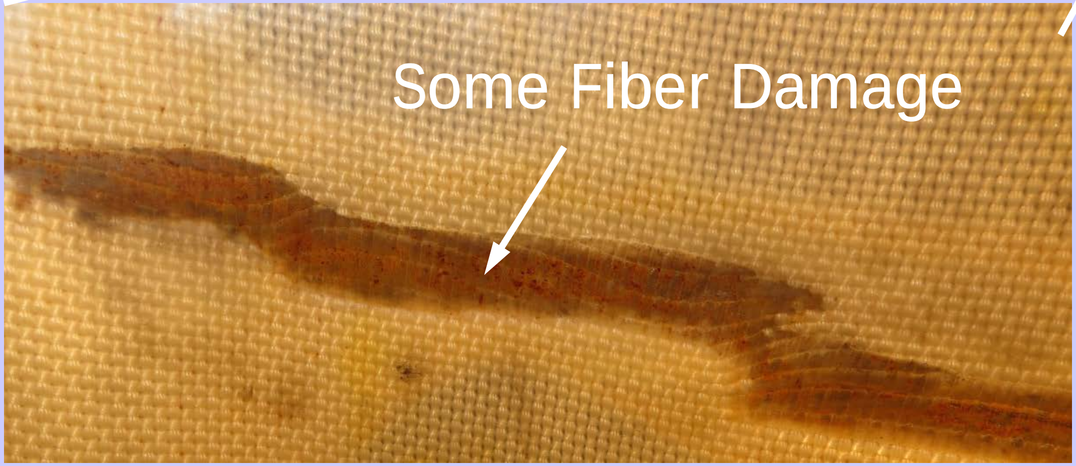
12 in. CI Lined Pipe Joint

Post-Mechanical Aging Tests



De-Bonding



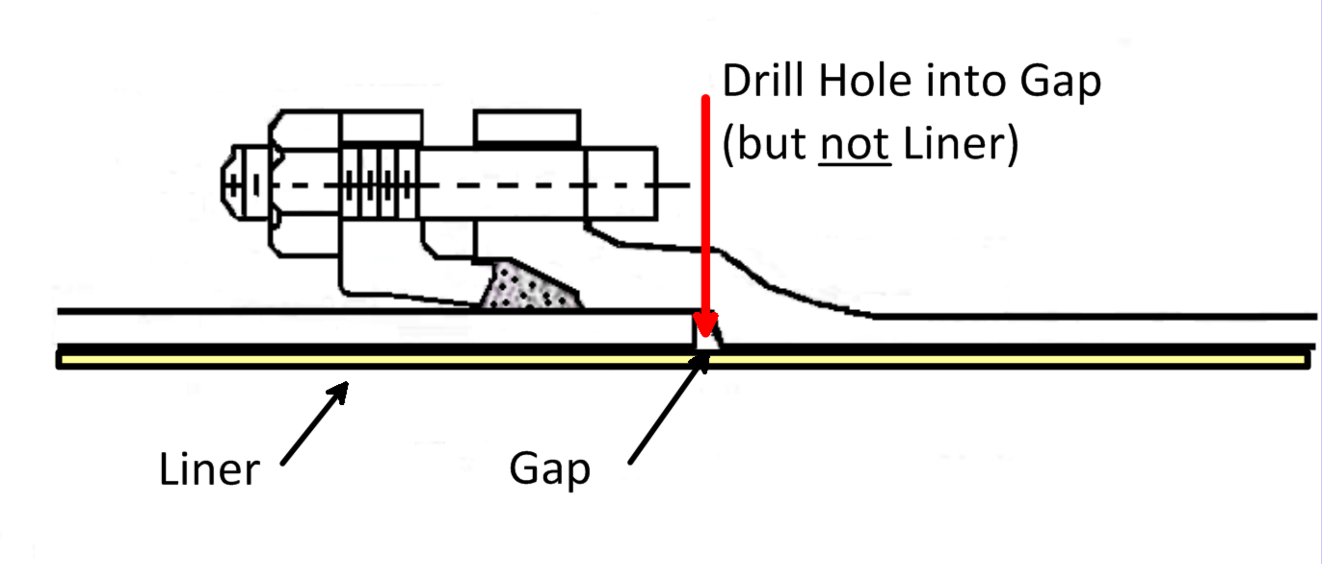


12 in. Lined Cast Iron Joints Post-Test Pressurization

- Drill hole through CI into bell/spigot gap but not liner
- Fill with soapy water
- Pressurize in 5-psi steps to 90 psig
- Hold each pressure 30 minutes

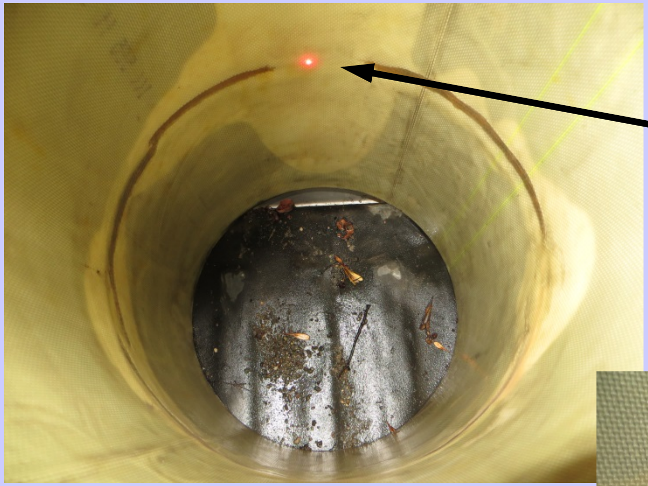
12 in. CI Lined Pipe Joint

Drill Hole into Gap

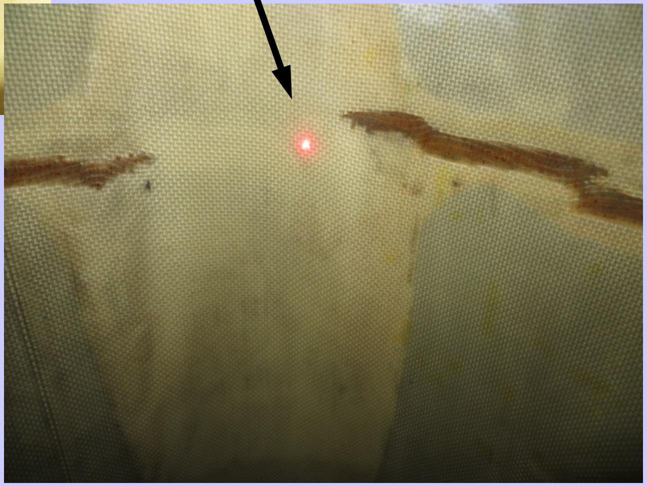


12 in. CI Lined Pipe Joint

After Pressurization with Hole into Gap



Laser Beam Shining through Drilled Hole



- 90 psig
- No Leaks

Mechanical Aging Tests
12 in. Lined Cast Iron Joints

- **Joint Type – Mechanical Joint**
- **50 Years Vehicle Cycles**
- **Undermining/Backfill Event**
- **50 Years Thermal Cycles**

Mechanical Aging Tests
12 in. Lined Cast Iron Joints

- **Additional 50 Years (100 Years Total) Vehicle Cycles**
- **Additional Undermining/Backfill**
- **Additional 50 Years (100 Years Total) Thermal Cycles**
- **Pressure Verification Test to 90 psig**

No Leakage, Some Liner Damage

Mechanical Aging and CIPL Property Tests of Field-Aged Lining Systems

Summary

AN Netravali

TD O'Rourke

HE Stewart

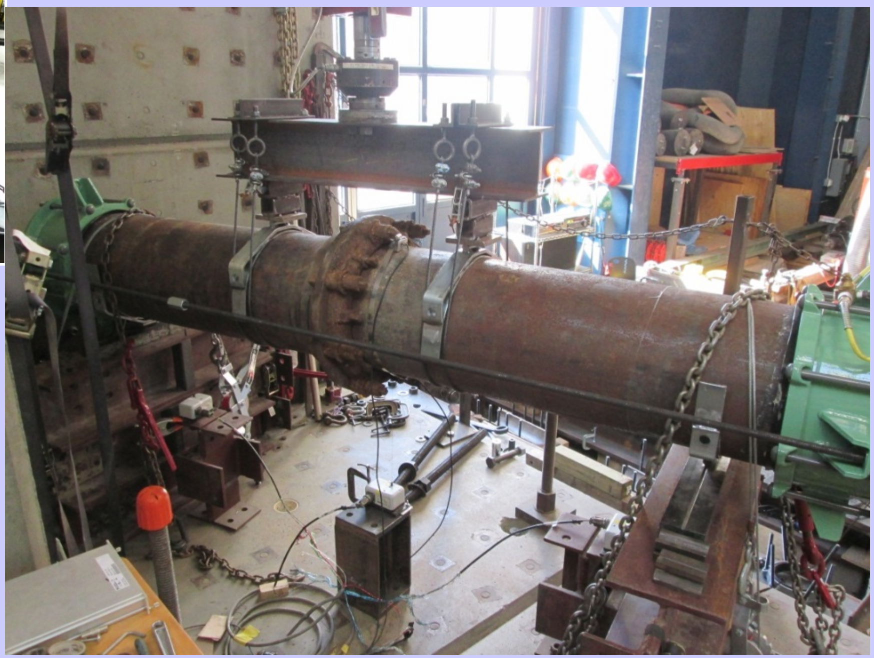
Summary

- Mechanical Aging - Lab Testing
  - Vehicular Loading
    - 40 kip Tandem Axle with Impact Factor of 1.5
    - 780,000 per 50 Years Rounded to 1M
    - 100 Years = 2M cycles
  - Undermining Events (1 every 50 Years)
    - Excavation and Backfill with Disturbed Soil
    - Additional Vehicle Load Directly over Crack
  - No Leakage

Vehicle Cycles

2 M Cycles

100 Years



Summary

- Mechanical Aging - Lab Testing
  - Thermal Cycles
    - $\Delta T = 40^{o}F\ (22^{o}C)$
    - Two 50 Years Cycle Sets = 100 Years
    - Weakening on First Cycle
  - No Leakage

Thermal Cycles

$\Delta T = 40^{o}$ F
(22^{o} C)

100 Cycles
100 Years

De-Bonding
on Cycle 1

MECHANICAL AGING TESTS

	6 in. Pipe	12 in. Pipe
No Liner Damage	YES	SOME*
No Leakage	YES	YES

* High likelihood of no liner damage if thermal contraction applied at actual rate of temperature change

TENSILE STRENGTH

Are the longitudinal and hoop (bonded) tensile strengths from field aged specimens comparable to those of field & mechanically aged (bonded & de-bonded) specimens?

	6 in. Pipe	12 in. Pipe (Global)	12 in. Pipe (Local)
Longitudinal Tension	YES	YES	NO*
Hoop Tension	YES	YES	NO*

*High likelihood of no liner damage if thermal contraction applied at actual rate of temperature change

Conclusion: Liner tensile strength is not affected by 100 years mechanical aging for 6-in. pipe specimens. Local strength reduction for 12-in. pipe specimens.

LAP SHEAR AND PEEL STRENGTH

Are lap shear and peel strengths from field / mechanically aged specimens comparable to unaged specimens?

	6 in. Pipe	12 in. Pipe
Lap Shear	YES	YES
Peel Test	YES	Not Comparable

Conclusion: No evidence of significant reduction in lap shear or peel strength due to chemical and mechanical aging