Performance of Structural Liners at Locations of Ring Fracture when Subjected to Bending, Axial or Shear Loads.

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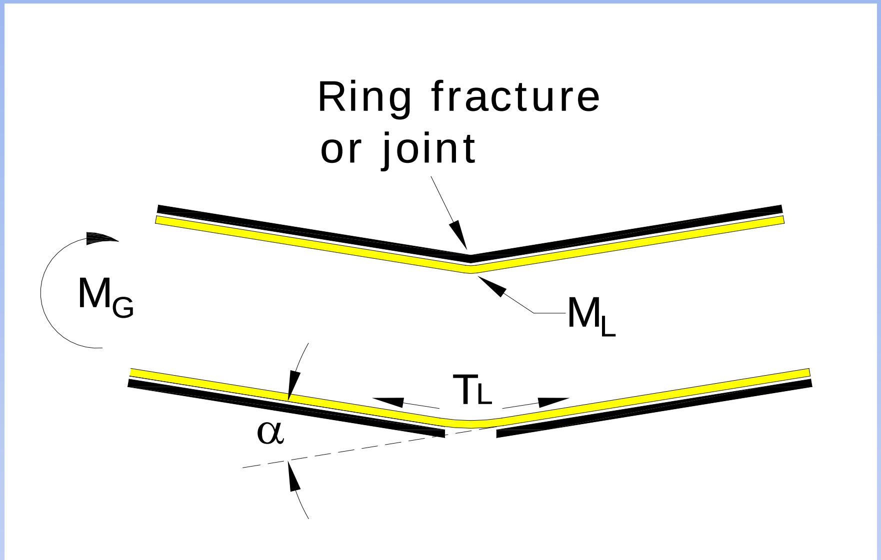
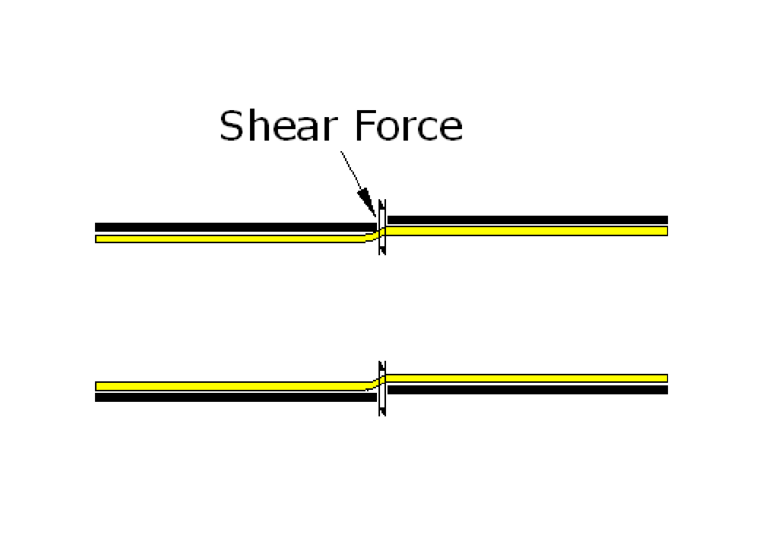
Objectives

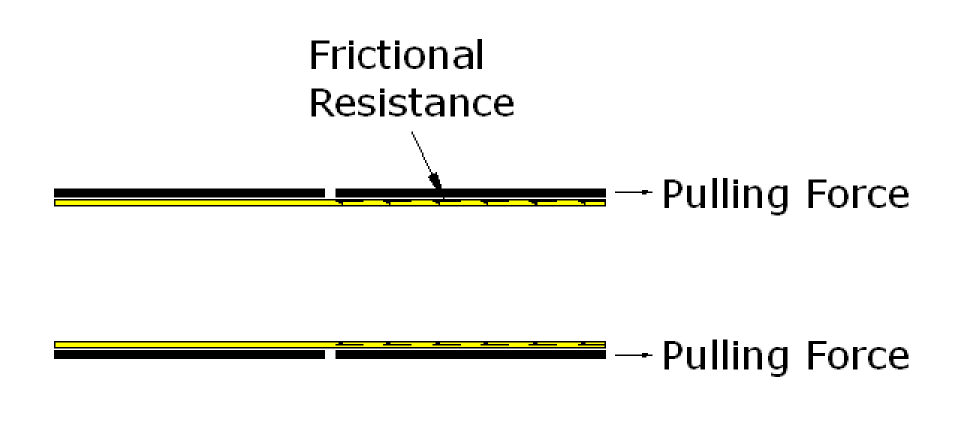
- The study aims at investigating selected limit states of a structural liner used in the rehabilitation of small diameter cast iron water mains.

- Limit states evaluated in this study are bending, axial tension and shear at the location of ring fracture in the host pipe (under pressurized & non-pressurized conditions).

Selected Limit States



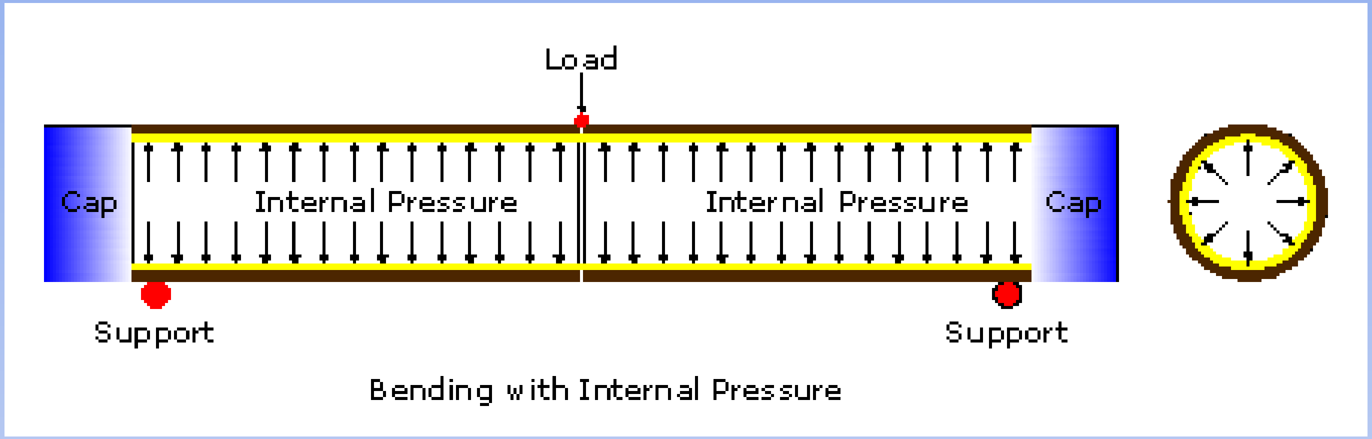




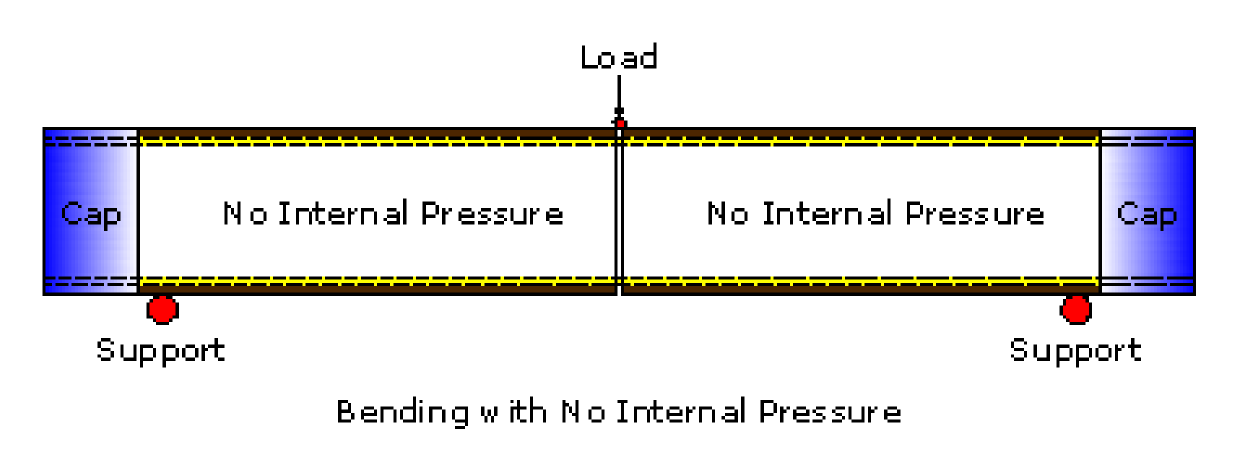
Preparation of the Specimen

- 70-year old, 4 ft long, 6" ID cast iron pipe specimens were cut into two equal halves to replicate a ring fracture along the circumference of the host pipe.
- The host pipe was then lined with reinforced CIPP liner throughout the entire 4 ft long segment.


Bending Test Procedure



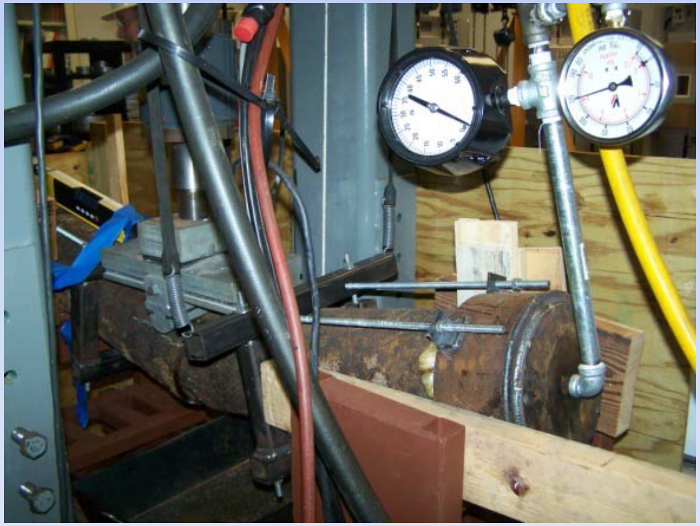
Combined Internal Pressure and 3-Point Bending



3-Point Bending only.

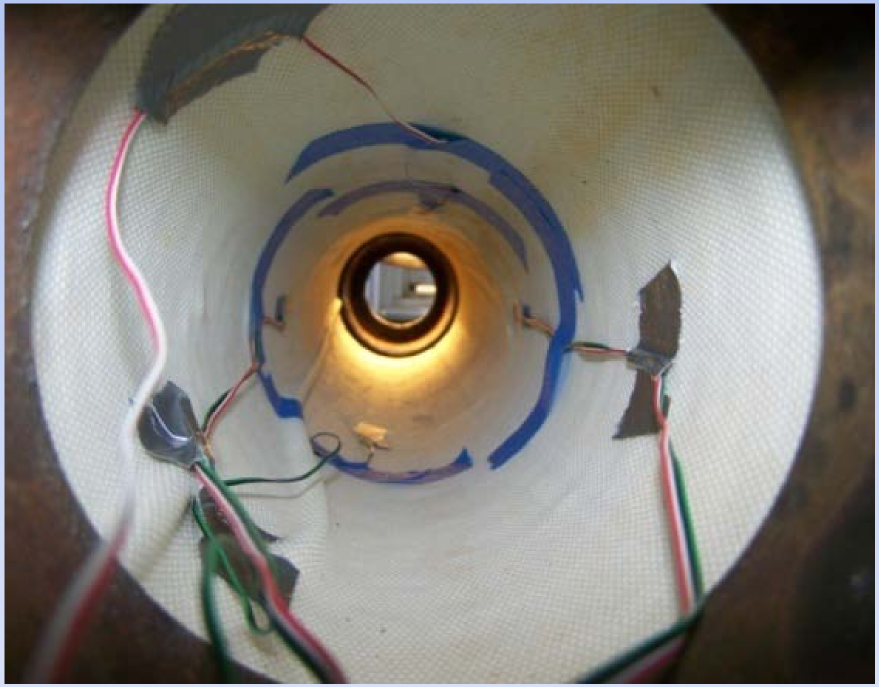
Results – Pressurized Condition

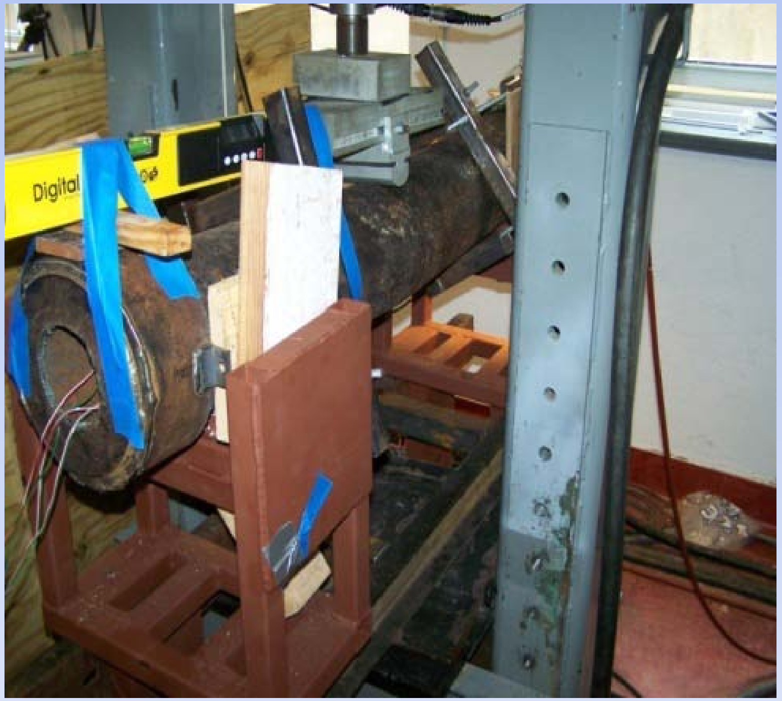
- Host pipe crushed at the crown at a vertical displacement of 4.5".
- At a vertical deflection of 5" the liner was holding 120 psi with little to no support from the host-pipe; no leakage was observed.



Test Setup - Non-pressurized Condition

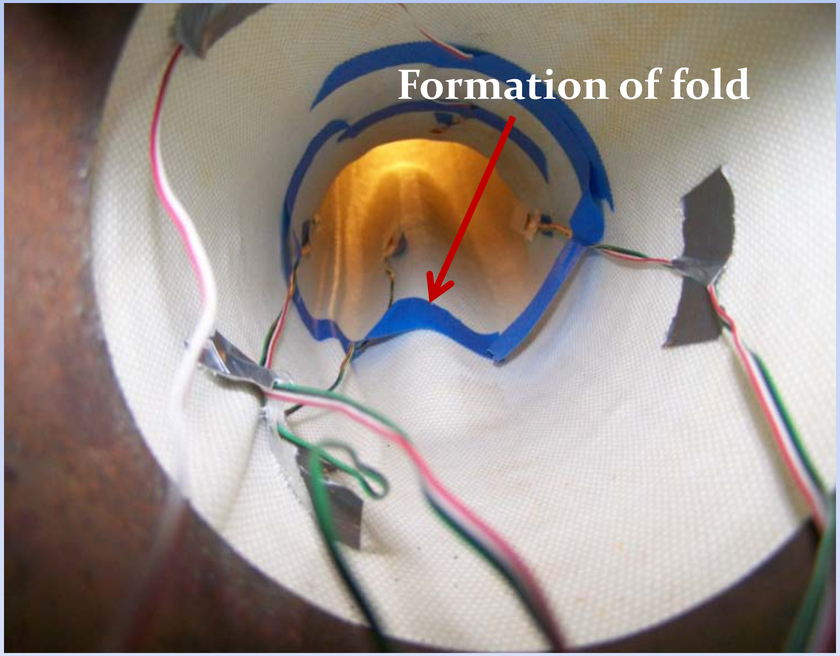
- The specimen was subjected to a 3-point loading (identical previously shown setup), but no internal pressure was applied.





Observations

- When the displacement reached 4" (angular displacement near center of the specimens ~ 11 °), a fold was formed at the invert; shortly thereafter the liner lost its structural integrity.

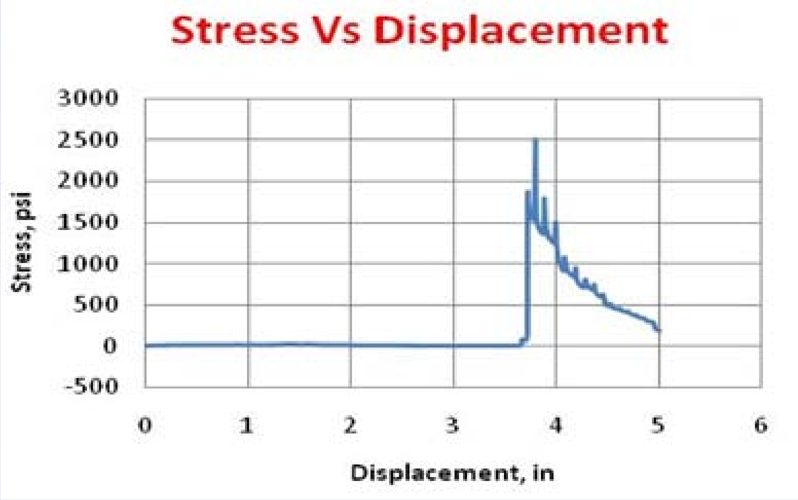


Test Result

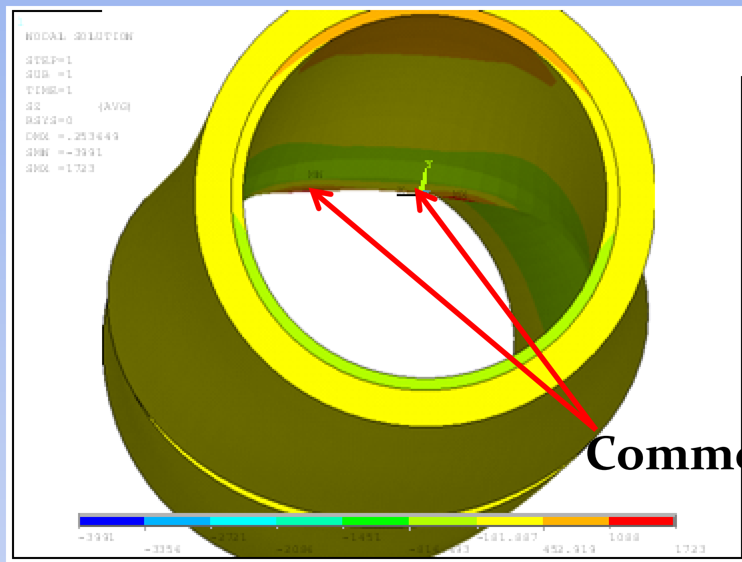
- Responses measured by strain gauges (compression at crown & tension at invert) commenced at deflection of approx. 3.7”.
- The responses suggested de-bonding at the host pipe-liner interface and transfer of the load from the host pipe to liner at the instrumented section.

Strain gage at crown(Longitudinal)

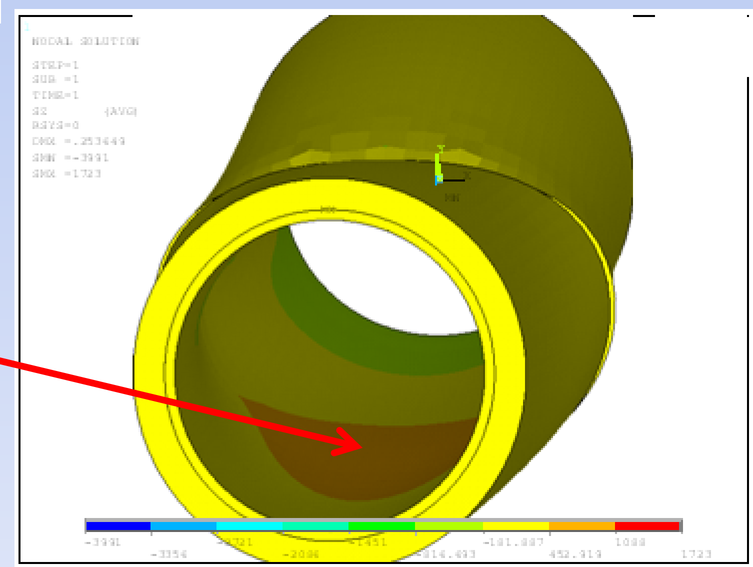
Strain gage at invert(Longitudinal)



Numerical Modeling of Deformed Liner *(3-point bending test)*

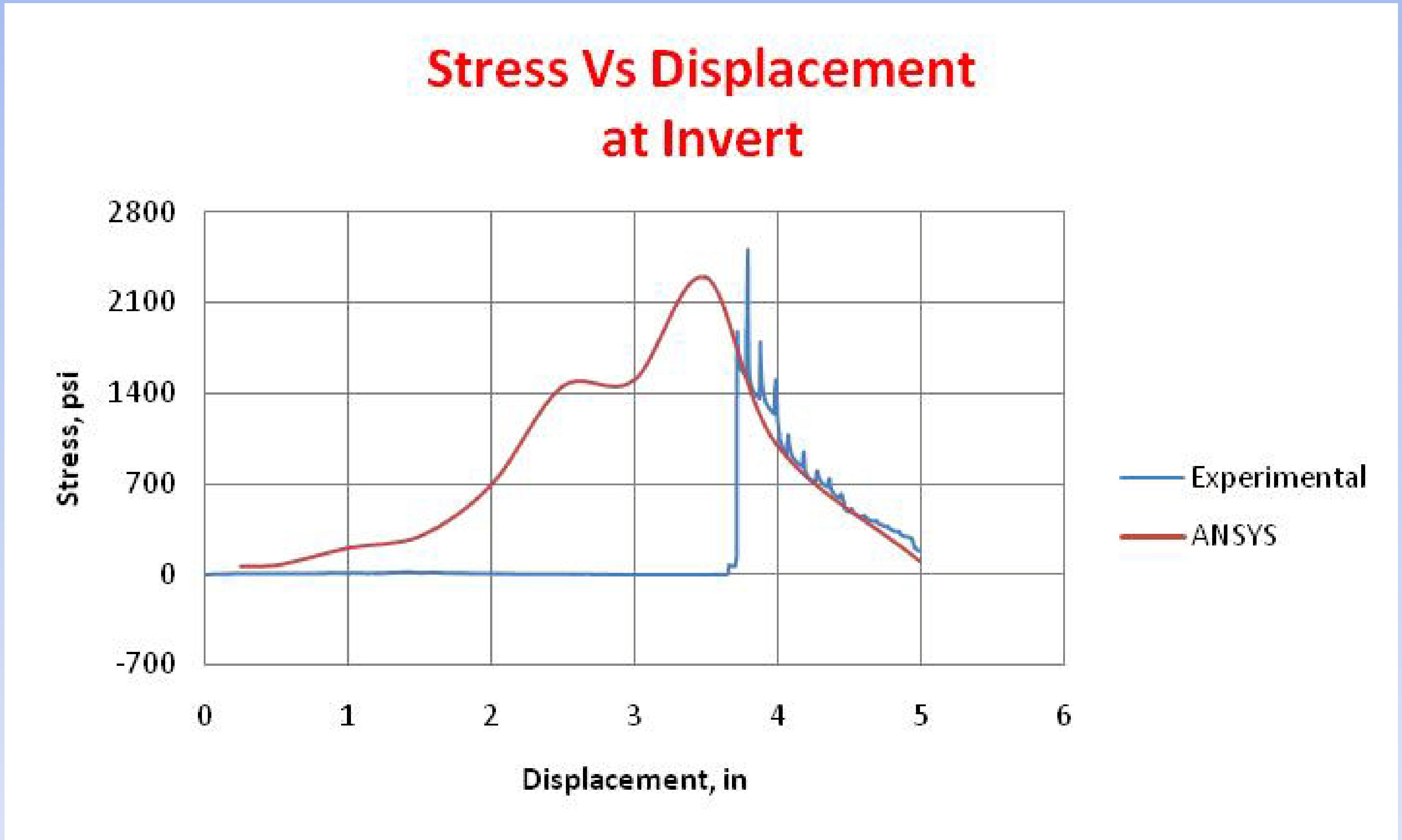


Commencement of localized Stress



Tensile stress on the Invert

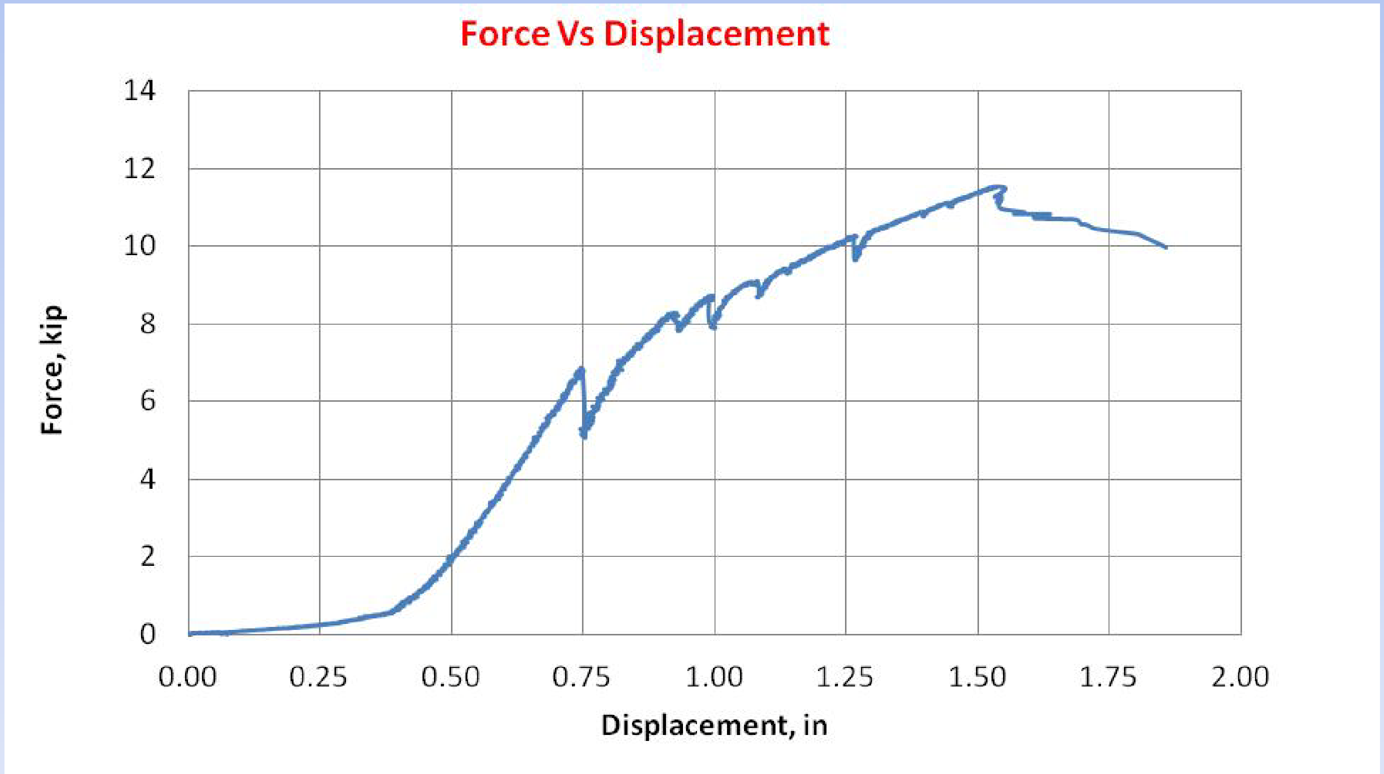
Comparison Between Experimental Measurements & Numerical Simulation



Axial Pull Test Setup

Axial Pull Test Results

- Initial slip occurred when specimens was subjected to an tensile axial load of 7 kip.
- Steady axial movement of the liner was observed under an axial tensile load of 11.5 kip.



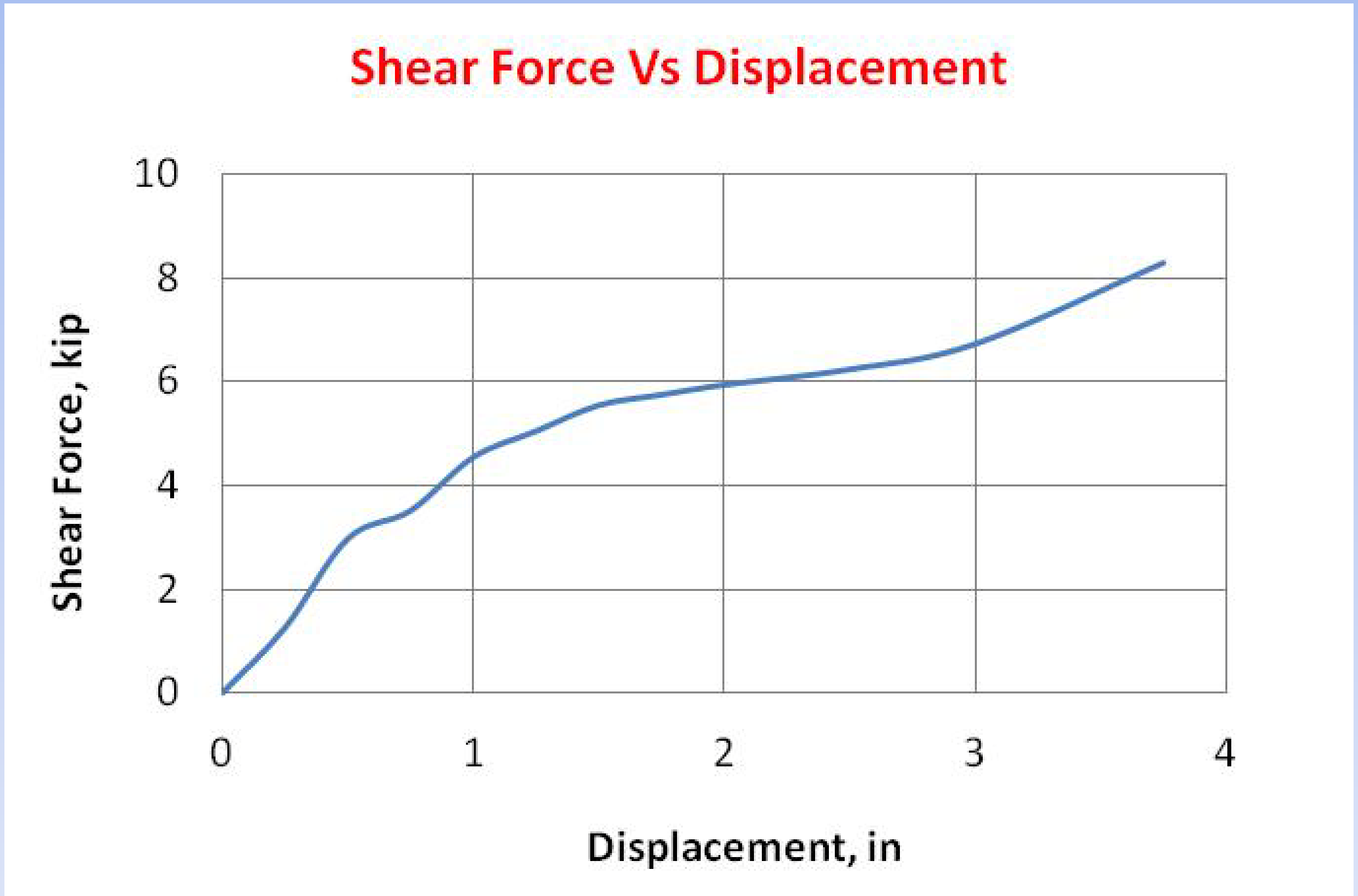
Shear Test Setup – Non pressurized

- The specimens were prepared as described earlier.
- A ½" gap was created at the location of ring failure to facilitate installation of strain rosettes at that location.
- Some bending moment was observed during test, which prompt modification of experimental setup for pressurized test.



Shear Test Result – Non-Pressurized

- De-bonding took place at approx. 3.5 kip.



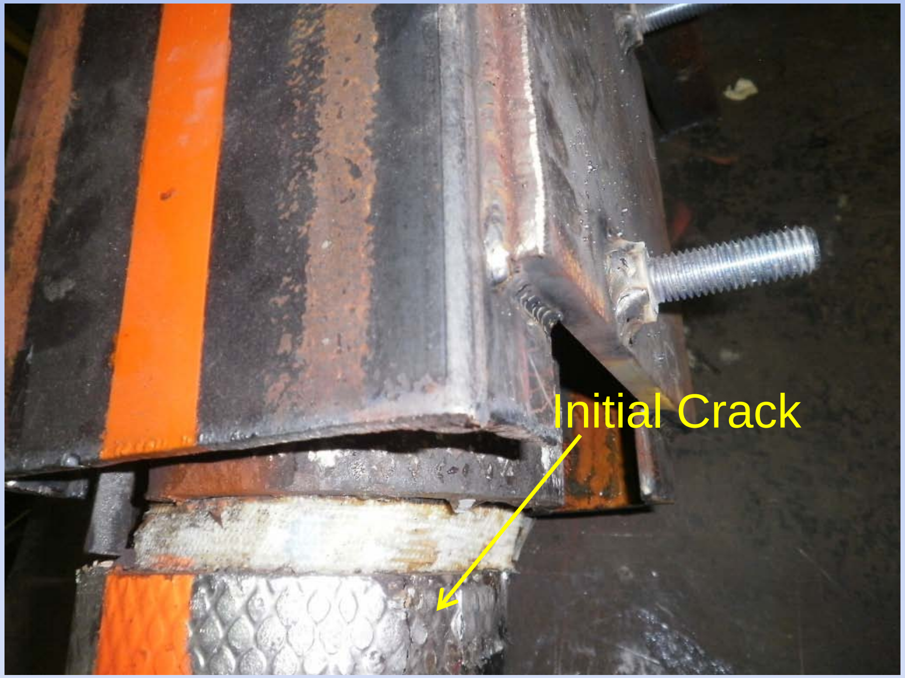
Shear Test Setup – Pressurized Condition

- To ensure pure shear loading the specimen was placed inside a steel casing, which allowed force to be transferred to the liner only at the location of the ring fracture and in a direction perpendicular to it.
- Orange line was use to mark centerline of host pipe


Shear Test Procedure – Pressurized Condition

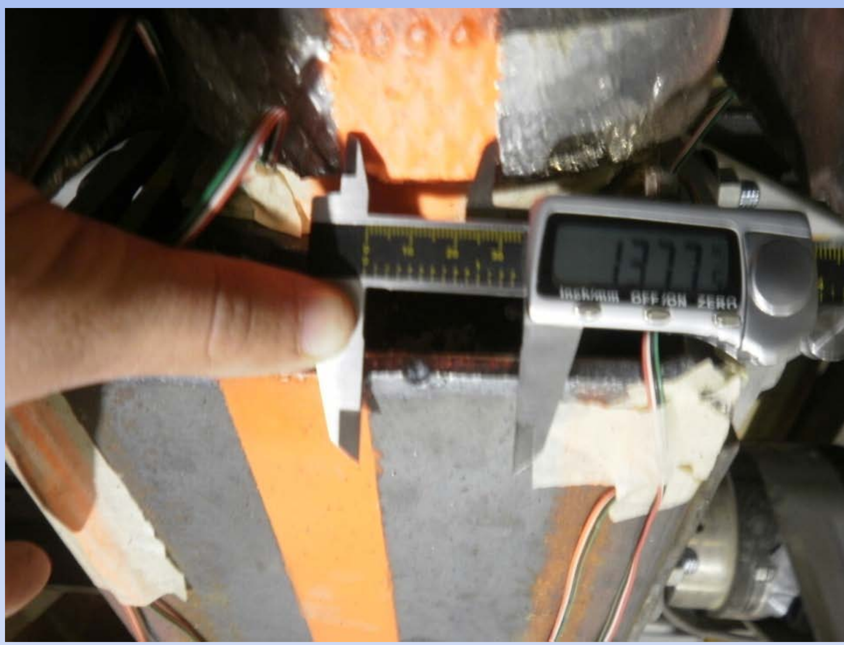
- After each increment (0.25”)of pushing, the internal pressure was increased to 60 psi.
- Initial crack occurred at the spring line at fixed half of the host pipe opposite the actuator.
- Major crack occurred at crown of host-pipe on *(loaded section)*.
- The liner cracked at a lateral displacement of 3.5” under 100 psi internal pressure; failure took place in the form of a rapture around the circumference of the liner.

Shear Test Procedure – Pressurized Condition



Complete Failure of Host-pipe

Shear Test Procedure – Pressurized Condition



Displacement = 1.37in

Liner failure at displacement of 3.50in

Conclusion – Bending

- A structural CIPP liner is capable of sustaining high internal pressure, for at least short time periods, at locations of extreme angular deflection well after the host pipe experienced complete failure.
- Buckling failure can be expected for a 6" non-pressurized liner at an annular displacement equal or greater than 3.7" *(a large deflection for a buried pipe)*.
- Predictions from the finite element model are in close agreement with the experimental results, and provide significant insight into the stresses in the liner as deflection progresses.

Conclusion – Axial Load and Shear

- An axial force of 11.5 kip was needed to mobilize the liner in the axial direction (~ 3400 lb/sf of liner's surface area), which assist in restraining liner's motion in the axial direction (e.g., thermal expansion and contraction).
- A structural CIPP liner is able to perform adequately even after undergoing an extreme lateral deformation at the location of a ring fracture, equal to 3.50 inches, making such product highly suitable for lining of fire fighting waterlines in areas prone to seismic motions.

Acknowledgements

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