

**Axial Pull Tests on Insituform IMain Liner**

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## Axial Pull Tests on Insituform IMain Liner

### 1. Introduction

Axial pull tests were performed on several sections of 150 mm (6 in.) nominal diameter ductile iron (DI) pipe sections lined with InsituForm IMain pipe liners. The composition of the liner was IMain epoxy resin with IMain hardener. The overall goal of the testing procedure was to characterize the pullout resistance and failure mechanics of lined DI pipes considering varying composite interfaces and discontinuities.

The standard DI pipes used in the tests were provided by LADWP (Los Angeles Department of Water & Power) and sent to InsituForm Technologies (Chesterfield, MO) to be lined with IMain liner technology and cut to a prescribed length. Twelve specimens were shipped to Cornell University for use in the Axial Pull tests (Specimens 4 – 9 and 11) and Four-Point-Bending tests (Specimens 1, 2, 3, 10, and 12). The Four-Point-Bending tests are discussed in a separate document (“Four Point Bending Tests of Ductile Iron Pipe with InsituForm Pipe IMain Liner” prepared by Cornell University NEESR Group, September 2011.)

Axial Pull specimens were prepared at lengths ranging between 2140 mm (84 in.) and 2650 mm (105 in.). Before the IMain liner was applied the pipes consisted of ductile iron with an approximately wall thickness of 7.6 mm (0.30 in) and an interior mortar lining approximately 3.3 mm (0.13 in) thick. The outer and inner diameters of the unlined pipes were respectively 175 mm (6.87 in.) and 153 mm (6.01 in.) (Figure 1). With an average thickness of 6.50 mm (0.256 in.) the IMain liner reduced the inner diameter of the lined pipes to approximately 144.5 mm (5.689 in.). Four different sample types were prepared and tested, including joint and gap sections. Jointed sections consist of a standard bell and spigot connection sealed with a greased rubber gasket, as shown in Figure 1. The connection is prepared by inserting the spigot into the bell until metal contact between the spigot and toe of the bell is achieved. The other sample type consisted of a length of pipe with a full circumferential break. The specimen was cut in two pieces prior to lining and then aligned for the lining process. This type of specimen was intended to simulate a previously broken or cracked pipe that was repaired by introduction of the liner. These are referred to as “gap” specimens.

When the IMain liner is applied in the field, the curing process results in a bond between the outside of the liner and the mortar at the inside face of the pipe. In an effort to better understand

the effect of this bond, half of the samples were prepared as they would be in the field with a bond between liner and pipe. The other half were prepared with a polyethylene bond breaker sheet installed between the liner and the inside wall of the pipe as an attempt to prevent the formation of this bond.

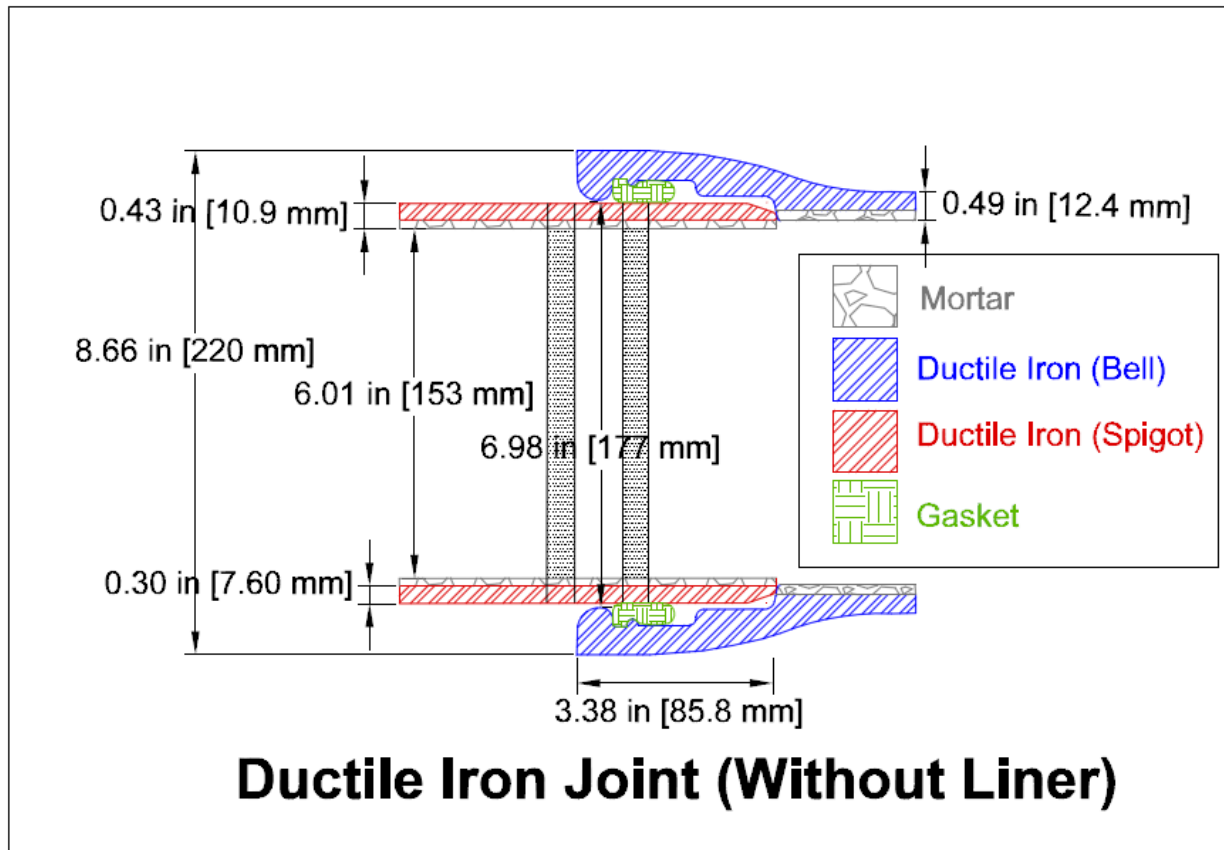


Figure 1. Ductile Iron Joint Cross-section

## 2. Test Procedure

A special test frame was fabricated to hold the pipe specimens and apply tensile and compressive force to the composite pipes as shown in Photo 1. Utilizing this frame the general procedure was:

- 1) Install the pair of pipe clamps at each end of the pipe specimen,
- 2) Cut through the plastic liner 6 in. from the end of the pipe specimen, to prevent the bearing bolt from effecting the rest of the liner during the test,
- 3) Drill the outer clamp on each side of the pipe and mount the bearing bolts at each end,
- 4) Retract the actuator,
- 5) Place the pipe specimen to be tested between the actuator end and the end of the test frame,

- 6) Extend the actuator to nearly touch the end of the pipe specimen,
- 7) Mount the two DCDTs for measuring the gap or bell to spigot opening,
- 8) Adjust the clamps to be vertical,
- 9) Connect the long bolts to the actuator end plate and the fixed frame end plate,
- 10) Tighten the bolts and nuts to get a snug grip,
- 11) Start the measuring system,
- 12) Retract the actuator until the test is complete and
- 13) For the push-pull specimen extend and retract actuator incrementally until failure is achieved.

The actuator in the test was an MTS 25 Metric Ton 204.71 (55 Kip, +/- 3 in. stroke capacity). The load cell was an MTS 661.23A-51 model with a 25 Metric Ton (55 Kip) capacity. The servo-controller was an MTS Flextest SE. The pump was an MTS SilentFlo with a gpm capacity at 3000 psi. Photo 1 shows the experimental setup for the pull tests.



Photo 1. Experimental Setup for Lined Pipe Pullout Testing

### 3. Test Data

Table 1 summarizes the pullout test data. The two gap specimens failed by slippage of the liner-mortar or DI-mortar interfaces. Liner break was the failure mode for Specimens 4, 8, 9, and 11, which all had a pipe joint. The failure mode for Specimen 6, also with a joint, was slippage between the mortar and liner.

Table 2 presents tensile test data supplied by Insituform for their IMain product.

Table 1. Pull Testing on Lined Pipe Sections

Specimen	Liner Type	Connection	Date	Failure Mode	Displacement	Force
4	Unbonded	Joint	4/15/11	Liner Break	0.246 in. (6.25 mm)	26.71 kips
5	Unbonded	Gap	4/5/11	Liner/Mortar Slip	0.063 in. (1.60 mm)	0.78 kip 0.87 kip
6	Unbonded	Joint	4/13/11	Liner/Mortar Slip	0.103 in. (2.62 mm)	3.0 kip 1.60 kip Cycle 5
7	Bonded	Gap	4/11/11	Mortar/DI Slip	0.226 in. (5.74 mm)	26.1 kip
8	Bonded	Joint	4/18/11	Liner Break	0.104 in. (2.64 mm)	26.8 kip
9	Bonded	Joint	4/15/11	Liner Break	0.229 in. (5.82 mm)	31.3 kip
11	Bonded	Joint	4/18/11	Liner Break	0.237 in. (6.02 mm)	32.2 kip

Table 2. Insituform Tensile Test Data of IMain in Axial Direction

	Specimen Thickness (in.)	Tensile Strength (psi)	Tensile Modulus (psi)	Strain @ Break (%)	Specimen Comment
1	0.209	8,487	597,816	2.90	Break
2	0.216	8,389	682,603	2.43	Break
3	0.207	8,356	531,356	2.79	Break
4	0.216	8,613	719,858	2.51	Break
5	0.215	8,311	554,096	2.66	Break
Mean	0.213	8,431	617,146	2.66	
Std. Dev.	0.004	120	81,461	0.19	

The following properties were provided by InsituForm for their IMain liner: E = 617 ksi, t = 0.216 in., liner OD = 6 in. Using these properties the unbonded length of pipe, L, to produce the displacements listed in Table 1 for specimens with liner breakage can be calculated as:

$$L = \frac{(\text{Displacement})(\text{Area} = A)(\text{Young's Modulus} = E)}{\text{Force} = F} \quad (1)$$

Table 3 lists the unbonded lengths of pull specimens which experienced liner fracture. Results of strain calculations based on unbonded lengths (Disp./L) are also provided. Note that in Table 2, the average strain at failure for the Insituform test data is 2.66%. The InsituForm test data are not a direct analog to the axial pull data, but are shown for comparison.

Table 3. Unbonded Lengths from Pullout Tests

Specimen	Liner Type	Connection	Force (kips)	Disp. (in.)	L (in.)	Strain (%)
4	Unbonded	Joint	26.71	0.253	22.9	1.10
8	Bonded	Joint	26.8	0.104	9.4	1.11
9	Bonded	Joint	31.3	0.229	17.7	1.29
11	Bonded	Joint	32.2	0.237	17.8	1.33



## 4. Interpretation of Test Results

### 4.1 Specimen 5

Specimen 5 was an unbonded specimen and loaded in a Gap Pull Test (tension only). As shown in Photo 2, the pipe is loaded on either side of a gap in the DI pipe. This test design allows the liner strength to be considered without the contribution of the existing pipe, similar to lining a cracked, in-situ pipe. As shown in Figure 2, at an approximate displacement of 2.62 mm (0.103 in.) and force of 3.51 kN (0.79 kips) an abrupt reduction of applied force was observed. The specimen continued to accept load reaching a peak of 3.87 kN (0.87 kips) at approximately 63.5 mm (2.5 in.) of displacement. As expected in an unbonded specimen, failure occurred between the liner and mortar interface. It should be noted that the gap was located 724 mm (28.5 in.) from one end of the 2160-mm(85-in.) -long specimen instead of at its center which suggests that this length was adequate to develop a full bond between mortar and ductile iron.

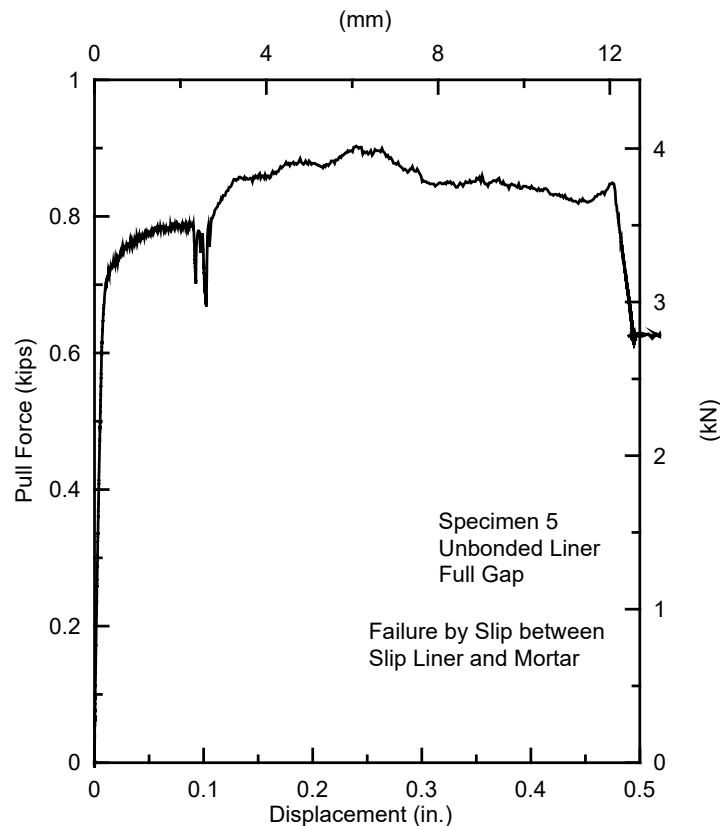


Figure 2. Force – Displacement Specimen No. 5, Unbonded Liner, Gap Pull Test

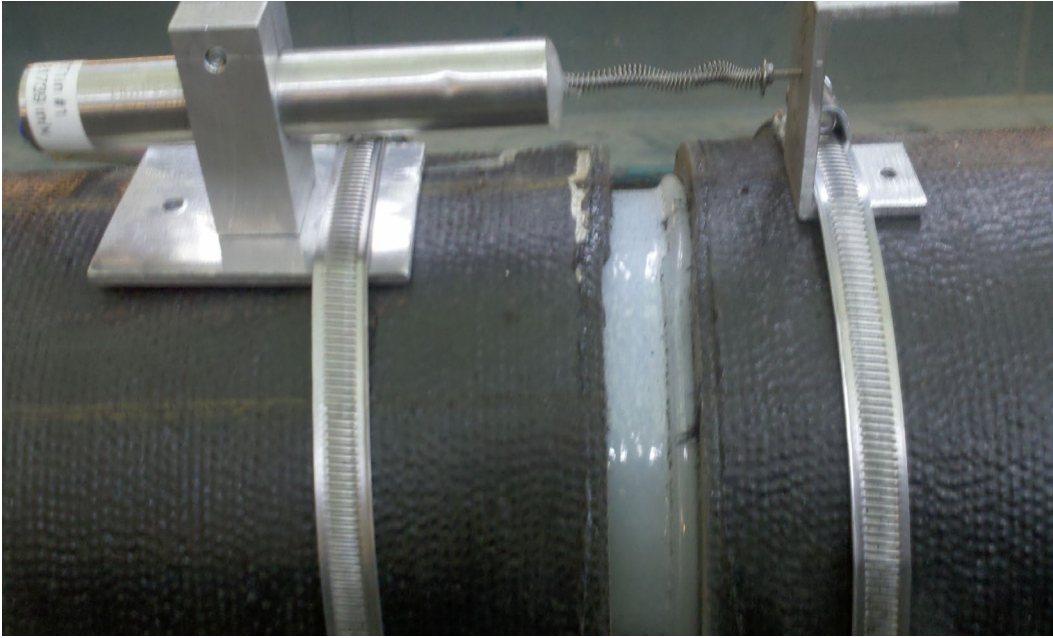


Photo 2. Specimen No. 5, Unbonded Liner, Gap Pull Test

#### 4.2 Specimen 4

Specimen 4 had an unbonded liner, a pipe joint at its approximate center, and was tested by means of the Joint Pull procedure. As shown in Figure 3, at a maximum displacement of 6.25 mm (0.246 in.) and force of 119 kN (26.7 kips) the specimen liner fractured. This failure mode does not comply with the other unbonded tests. As shown in Photo 3, the liner fracture occurred at the base of the bell. Unexpected mechanical behavior was likely present to produce a failure of the liner in an unbonded specimen.

One explanation is that the polyethylene liner used to preserve the unbonded interface between liner and mortar may have been damaged during installation allowing the epoxy to develop an unwanted bond.

Another possible explanation is that an increase in radial stress occurred because the outer diameter of the liner was larger than the interior diameter of the DI pipe resulting in greater frictional resistance along this interface. According to measurements that were performed on ring specimens, the average outside diameter of the liner is  $D = 152$  mm (6.00 in.), with standard deviation of 0.61 mm (0.024 in.) (Ring Compression Tests on Insituform IMain Liner, Cornell University NEESR Group 2011). It should be noted that the liner of Specimen 4 had consistently greater thickness when both undeformed and deformed than any other specimens tested. Specifically, Specimen 4 is about 5-10% thicker when undeformed and 6 - 38% thicker when deformed than bonded

Specimens 8, 9, and 11. However, the thickness ratio between the deformed and the undeformed liner is not significantly different than the thickness ratio of the other specimens. Measurements of liner thickness were performed assuming the thickness of the mortar and steel pipe remained constant.

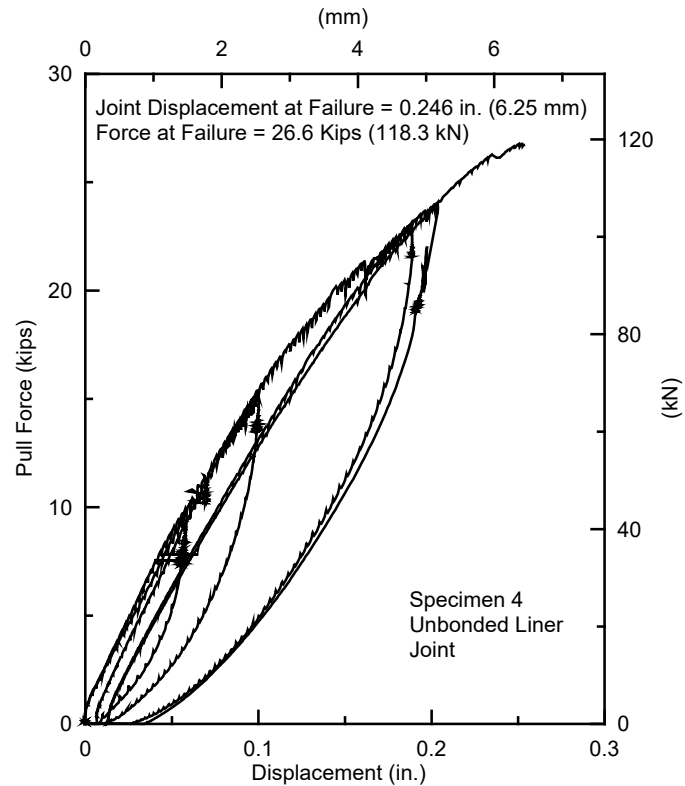


Figure 3. Force – Displacement for Specimen 4, Unbonded Liner. Joint Pull Test



Photo 3. Specimen No. 4, Unbonded Liner, Joint Pull Test

### 4.3 Specimen 6

Similarly to Specimen 4, Specimen 6 had an unbonded liner with a joint at its center. It was the only specimen subjected to a Push-Pull procedure. At a displacement of 2.62 mm (0.103 in.) and force of 13.3 kN (3.0 kips) failure along the liner-mortar interface was initiated. As shown in Figure 4, Specimen 6 force-displacement curve, additional cycles of tension and compression were applied beyond initial debondment. The liner-mortar interface continued resisting greater than 80% of initial load until cycle 5 when, at 18 mm (0.71 in.) of displacement, the resisting load dropped abruptly to 7.12 kN (1.6 kips). Beyond this cycle it became obvious that the liner-mortar interface had been completely disbanded.

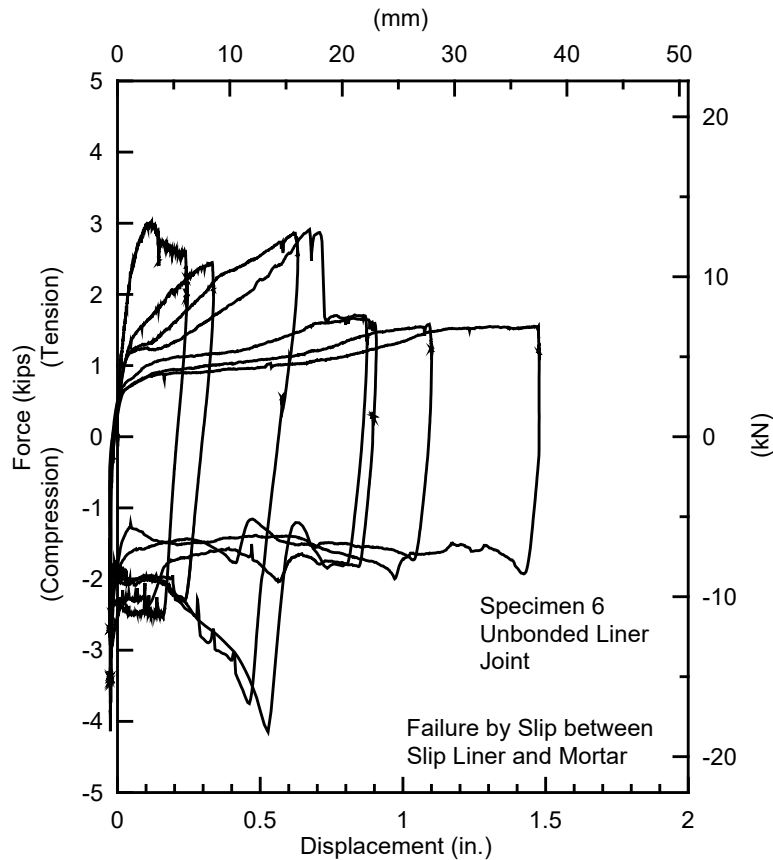


Figure 4. Force–Displacement for Specimen No. 6, Unbonded Liner, Joint Push/Pull Test

#### 4.4 Specimen 7

Specimen 7 had a bonded liner with full circumferential gap and was tested by means of an Axial Pull Test (Photo 4). As shown in Figure 5, the maximum load achieved before slippage along the DI-mortar interface was 117.9 kN (26.5 kips) at a displacement of 5.74 mm (0.226 in.). Upon continued loading the displacement increased with little change in load until a displacement of 16.5 mm (0.65 in.) when an abrupt decrease in load suggests further slippage along the DI-mortar interface. It should be noted that the gap was not located in the center of the 2160-mm (85-in.)-long specimen but rather 762 mm (30 in.) from one end. Further, slippage occurred in the shorter section which inherently had less available surface area to develop the bond between iron and mortar.

The failure between these surfaces suggests that the bond between liner and mortar is stronger than the manufactured bond between mortar and DI. It also provides evidence that to rupture the liner, the longitudinal development length between DI and mortar should be greater than 762 mm (30 in.).

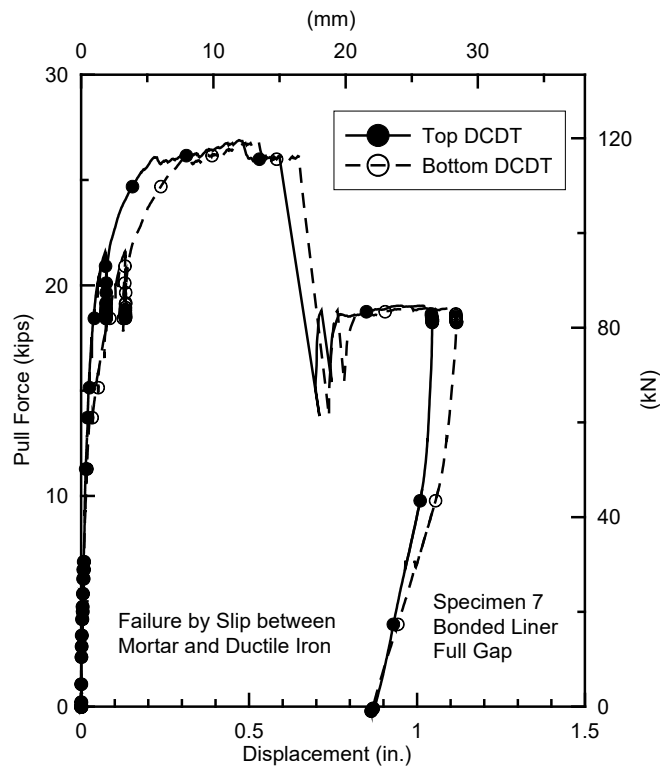


Figure 5. Force – Displacement for Specimen No. 7, Bonded Liner, Gap Pull Test

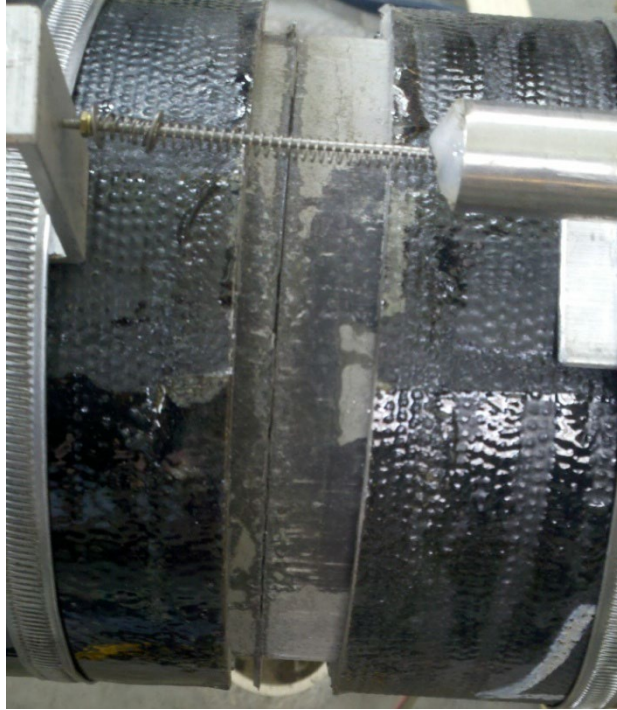


Photo 4. Specimen No. 7, Bonded Liner, Gap Pull Test

#### **4.5 Specimen 9**

Specimen 9 was bonded and subject to a Joint Pull Test in which the joint was located at the approximate center of the specimen. As shown Figure 6, at a displacement of 5.82 mm (0.229 in.) the peak load of 139.2 kN (31.3 kips) was achieved. At this point the liner fractured approximately 180 mm (7 in.) into the bell end of the pipe from the base of the bell as shown in Photo 5. Once fractured, the specimen was no longer able to resist force and the test was discontinued.

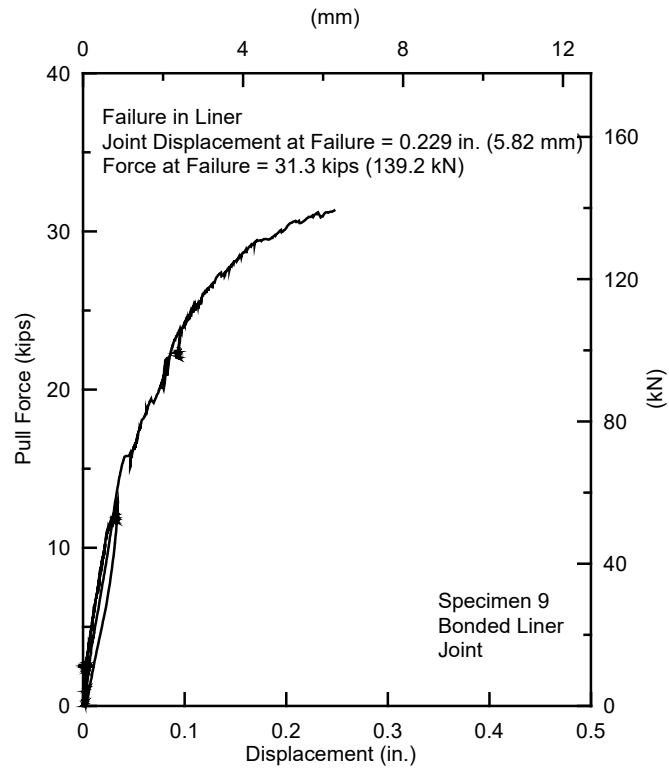


Figure 6. Force – Displacement for Specimen No. 9, Bonded Liner, Joint Pull Test



Photo 5. Specimen No. 9, Bonded Liner, Joint Pull Test

#### 4.6 Specimen 8

Similar to Specimen 9, Specimen 8 was bonded and subject to a Joint Pull Test. As shown in Figure 7, at a displacement of 2.64 mm (0.104 in.) the peak load of 119.2 kN (26.8 kips) was achieved. At this point the liner fractured several inches into the bell of the pipe as shown in Photo 6. After the specimen fractured it was no longer able to return to the peak force and testing was ended. Also noticeable in Photo 6, a portion of the mortar remained bonded to the liner. This further suggests that the mortar-liner bond has the potential to be stronger than the manufactured DI to mortar interface.

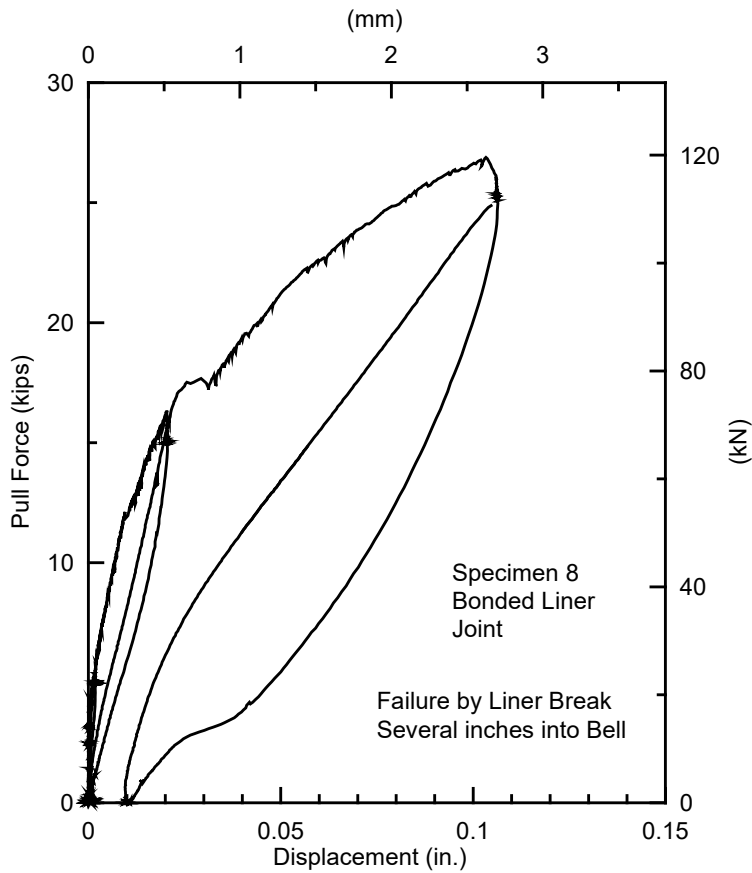


Figure 7. Force – Displacement for Specimen No. 8, Bonded Liner, Joint Pull Test





Photo 6. Specimen No. 8, Bonded Liner, Joint Pull Test

Despite Specimens 8, 9 and 11 being similarly bonded and joint centered, the liner of Specimen 8 failed at a displacement approximately 55% less than its counterparts. Assuming that the thickness of the mortar and DI pipe remain constant along the specimen, the thickness of the liner from the south to north end ranged between 8.23 mm (0.324 in.) and 10.4 mm (0.408 in.). Such variance in thickness was much more prominent in Specimen 8 than other pull test specimens. As a result, the thickness ratio between the deformed and undeformed liner ranged between 0.68 and 0.86 for the north or south ends respectively. The range in liner thickness ratio for Specimen 8 was greater than the range of any other tested specimen.

#### **4.7 Specimen 11**

Similar to Specimens 8 and 9, Specimen 11 was also bonded and subject to a Joint Pull Test. At a displacement of 6.02 mm (0.237 in.) a peak load of 143.2 mm (32.2 kips) was achieved (Figure 8). As shown in Photo 7 and Photo 8, the liner fractured cleanly at the base of the bell. After the specimen fractured it was no longer able to accept load and testing was discontinued.

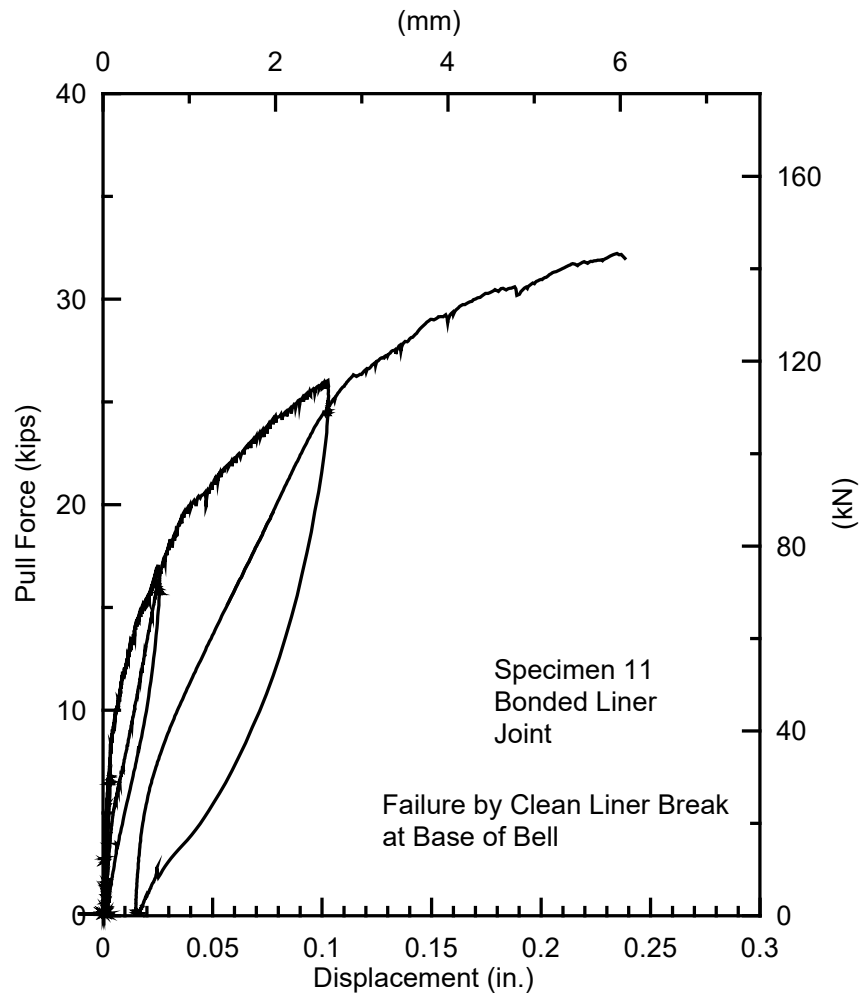


Figure 8. Force – Displacement for Specimen No. 11, Bonded Liner, Joint Pull Test



Photo 7. Specimen No. 11, Bonded Liner, Joint Pull Test, Bell End



Photo 8. Specimen No. 11, Bonded Liner, Joint Pull Test, Spigot End

## 5. Discussion

When comparing results of the bonded to unbonded Gap Pull Tests it was found that the bonded specimen displaced much further (5.74 mm (0.226 in.) compared to 1.6 mm (0.062 in.)) and resisted a much larger applied load (115.5 kN (25.9 kips) compared to 3.87 kN (0.87 kips)). Comparing bonded to unbonded jointed specimens indicated a similar trend. The bonded liners can resist higher applied loads at generally greater displacements and commonly experience liner failure. Only Specimen 4 did not follow this trend. The high achieved load and displacement results suggest that the unbonded liner acted in a bonded manner. Also, Specimen 4 failed due to breaking of the liner, not slip along the liner-mortar interface, which is a common characteristic among bonded specimens.

The comparison of gapped to jointed specimens provide insight regarding the contribution of the joint to the axial strength of the pipe. While the force required to fail both the bonded and unbonded gap specimens was less than the jointed specimens, the data suggest that this difference is not substantial. Unbonded specimens seem to depend more on the type of connection (i.e., gap or joint) than bonded specimens. Specifically, the force required to cause slippage between the

liner and mortar in an unbounded specimen was shown to be about 74% greater for a jointed connection than gap connection.

Another observation is the inconsistent debondment of the liner to mortar and mortar to DI interfaces. Referring to Photo 6 it can be seen that the exposed debonded section of Specimen 8 liner has some mortar bonded to it. Mortar bonded to the unbonded liner also can be observed in Specimen 11 (Photo 9). This observation provides further evidence of the inconsistent bonding between both the liner to mortar and mortar to DI interfaces. It also can be inferred that the debondment and eventual failure of these lined specimens is complex and based on inconsistent factors that cannot be characterized easily.

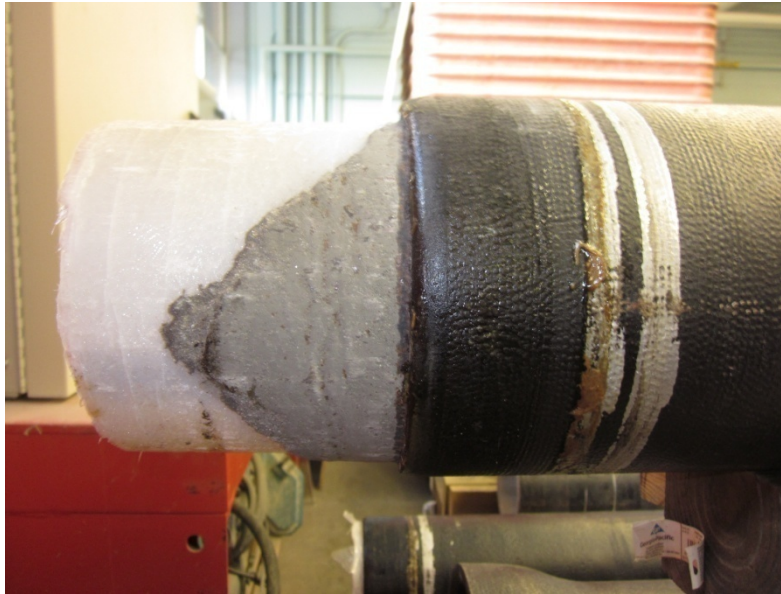


Photo 9. Specimen 11, Debonding of Mortar and Ductile Iron

## 6. Summary

Based on the failure mode results, it can be concluded that the bond between the liner and mortar of the pipe provides more resistance to axial load than the liner alone. However, if the liner is not bonded to the specimen, the liner-mortar interface is likely the weakest element and most probable to fail.

The average strain achieved in the joint tests where the liner failed was 1.21% strain while the value provided by InsituForm from their testing was 2.66% strain. This variation is likely a result of very different testing procedures used to develop the parameters. Also, the strain calculated

from this set of pull tests is based on an axial deformation equation (Equation 1) derived from Hooke's Law and based on Saint-Venant's Principle. While this procedure is useful for solid bars and rods, it does not accurately describe thin walled cross-sections such as pipes. Another method needs to be utilized to accurately predict the strain induced in the liner at failure. In addition, a method for determining the actual debondment of the interfaces would prove useful to determine the validity of the predicted values.