

# **Strain-Based Design and Assessment in Critical Areas of Pipeline Systems with Realistic Anomalies**

## **Appendix F: Task 11 Full-Scale Test Results Draft Final Report**

Contract No. DTPH56-14-H-00003

### **Prepared for**

US Department of Transportation  
Pipeline and Hazardous Materials Safety Administration  
Office of Pipeline Safety

### **Prepared by**

Jason Bergman, Stephane Bussiere, Mark Stephens, Chris Timms

**C-FER**  
Technologies

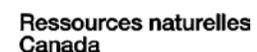
CFER

**June 24, 2017**

## Notice

This project was funded by the Department of Transportation, Pipeline and Hazardous Materials Safety Administration under the Pipeline Safety Research and Development Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Pipeline and Hazardous Materials Safety Administration, or the U.S. Government.

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## Nomenclature

### Abbreviations

D	Diameter
$D_{\min}$	Minimum Diameter
$D_{\max}$	Maximum Diameter
$D_{\text{nom}}$	Nominal Diameter
OD	Outside Diameter
ID	Inside Diameter
1D	One Diameter
2D	Two Diameters
SMYS	Specified Minimum Yield Strength
VIC	Visual image correlation,

### Symbols

$\epsilon$	Strain
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### Organizations

PHMSA	Pipeline and Hazardous Materials Safety Administration,
C-FER	C-FER Technologies Inc. (1999)
CRES	Center for Reliable Energy Systems

## Appendix F Task 11 Full-Scale Test Results



## Task 11 Compression Test

Specimen Identification: **11.a (Compression 1)**  
 C-FER Specimen Number: **X80-DSAW-M5a**

C-FER Test Summary: **Rev. 4, June 23, 2017**  
 Test Date: **March 30, 2015**

**Pipe Characteristics**

Nominal OD (mm) =	<u>609.6</u>
Average OD (mm) =	<u>610.4</u>
Nominal Wall Thickness (mm) =	<u>12.70</u>
Average Wall Thickness (mm) =	<u>12.94</u>
Specimen Length (mm) =	<u>1 837.5</u>
Length/OD =	<u>3.0</u>
SMYS (MPa) =	<u>552</u>
Target Pressure, 72% SMYS (MPa) =	<u>16.5</u>

**Test Loading Procedure**

- Specimen was pressurized at rate of -2.8 MPa/min to 16.5 MPa with the UTS adjusted as necessary to keep the strain measured by the 2D linear potentiometers near zero.
- After holding for at least 2 minutes, pressurization continued, in the same manner, to burst.

**Internal Pressure History**

Elapsed Time (min)	Pressure (MPa)
0	0
25	16.5
60	16.5
70	31.2
90	31.2
95	0

**General Test Data**

Net Tensile Load at Burst (kN) =	<u>4379</u>
Maximum Net Tensile Load (kN) =	<u>4 682</u>
Maximum Net Axial Stress (MPa) =	<u>193</u>
Maximum Pressure (MPa) =	<u>31.2</u>
Max Top Hoop Strain from Circ. Meas. (%) =	<u>1.4</u>
Max Bottom Hoop Strain from Circ. Meas. (%) =	<u>6.4</u>

**Displacement Transducers**

1D Top Strain at Burst (%) =	<u>-0.49</u>
1D Bottom Strain at Burst (%) =	<u>-0.31</u>
2D Strain at Burst (%) =	<u>0.15</u>

**Strain Gauges**

Top Strain at Burst (%) =	<u>-0.25</u>
Bottom Strain at Burst (%) =	<u>-0.90</u>
Average Hoop Strain at Burst (%) =	<u>2.91</u>

**General Comments:**  
 Burst failure in bottom section.

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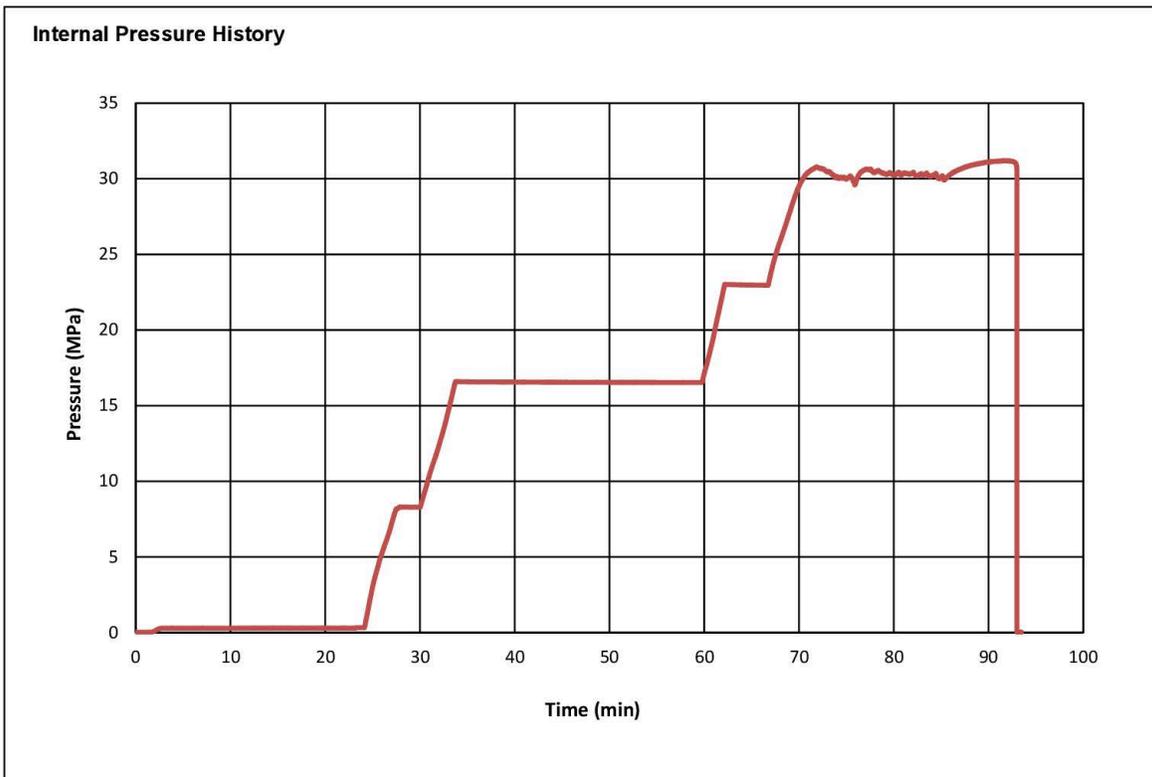
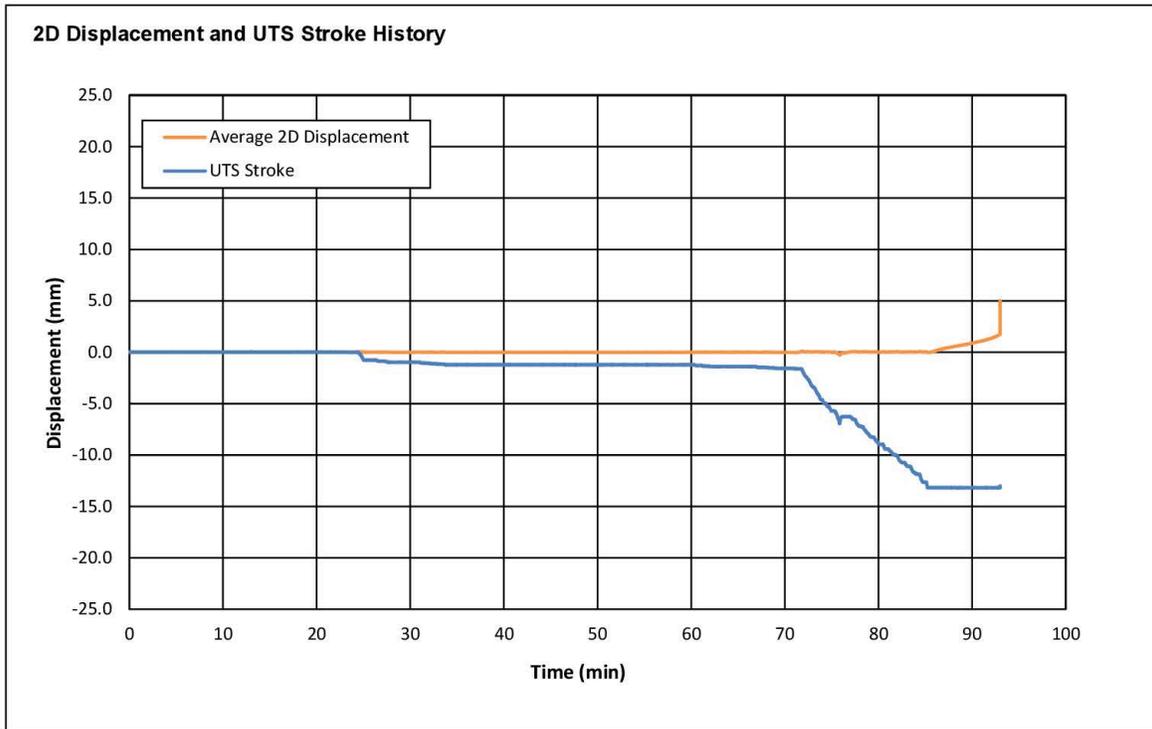
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Pipe after Testing:



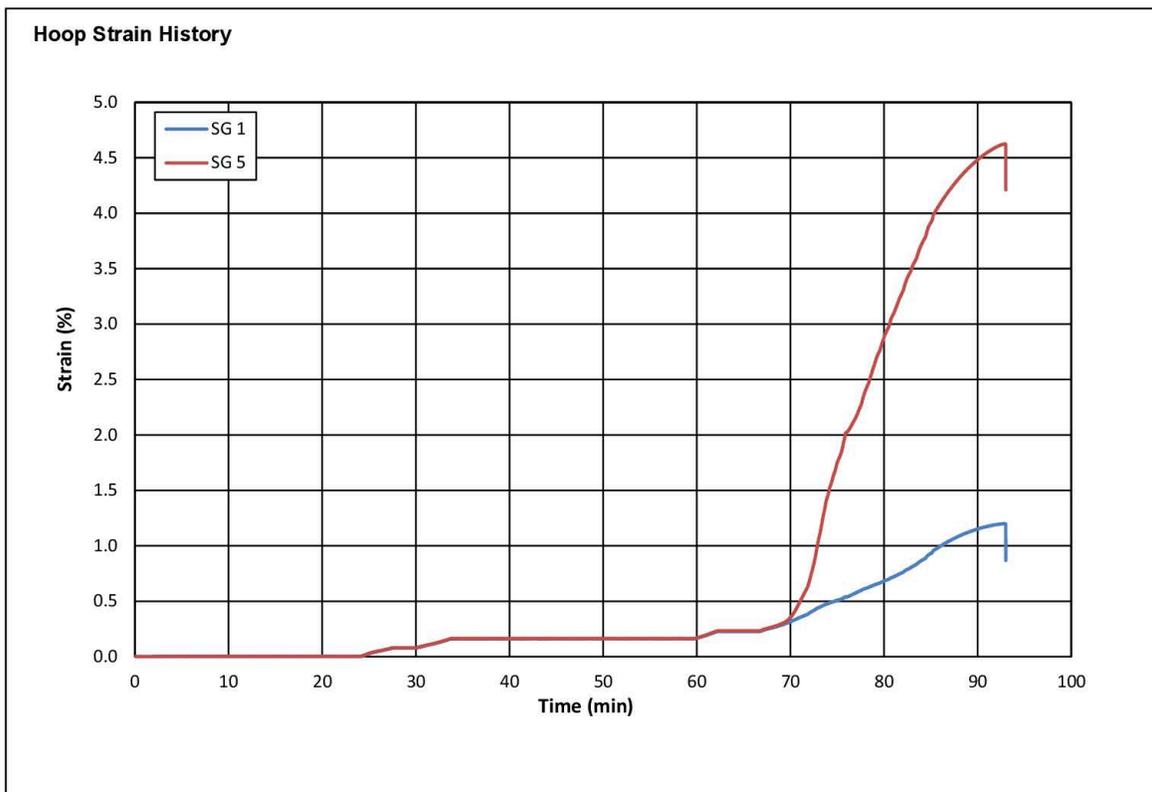
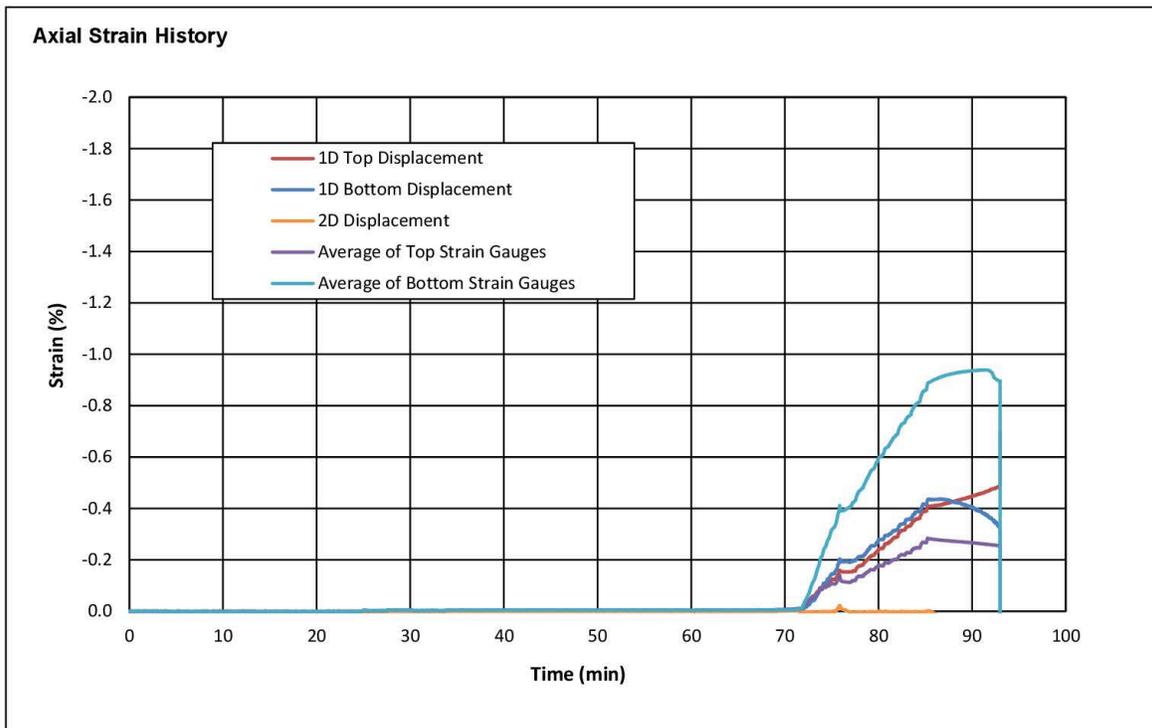
		Title: <b>Task 11 Compression Test</b>	
Complied By: <b>CMJT</b>	Date: <b>23-Jun-17</b>	Specimen Identification: <b>11.a (Compression 1)</b>	

### Test Control Plots



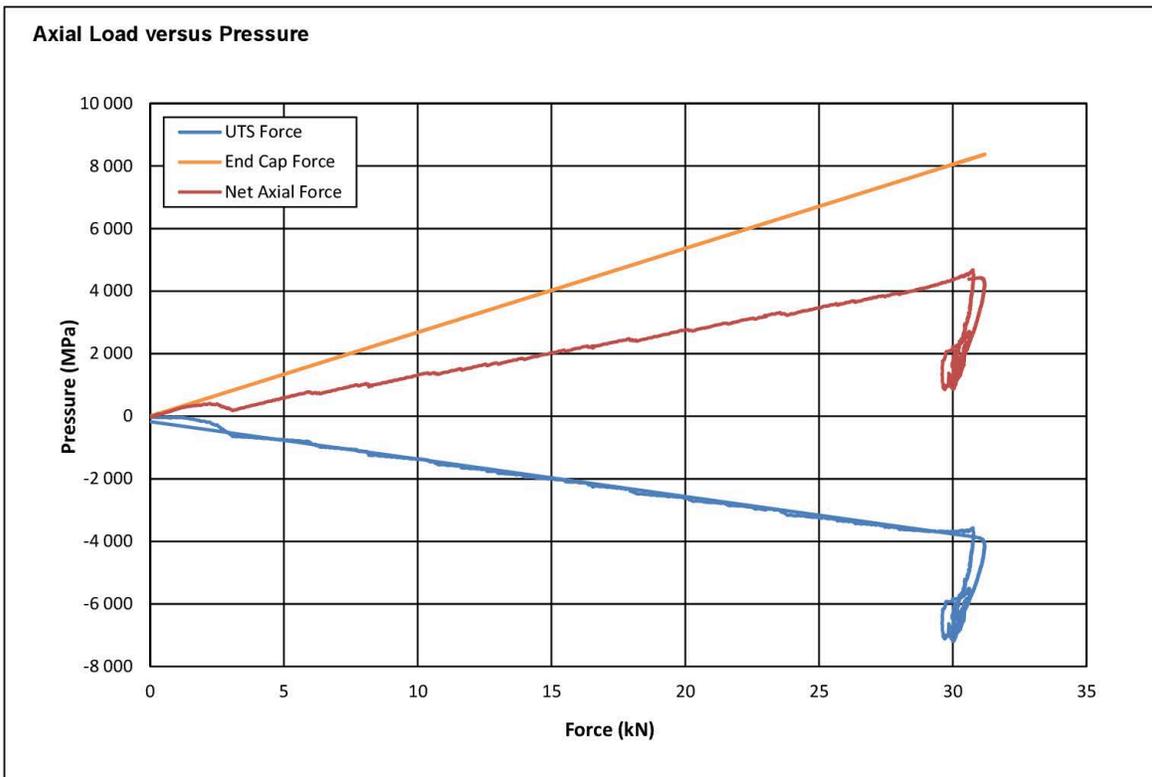
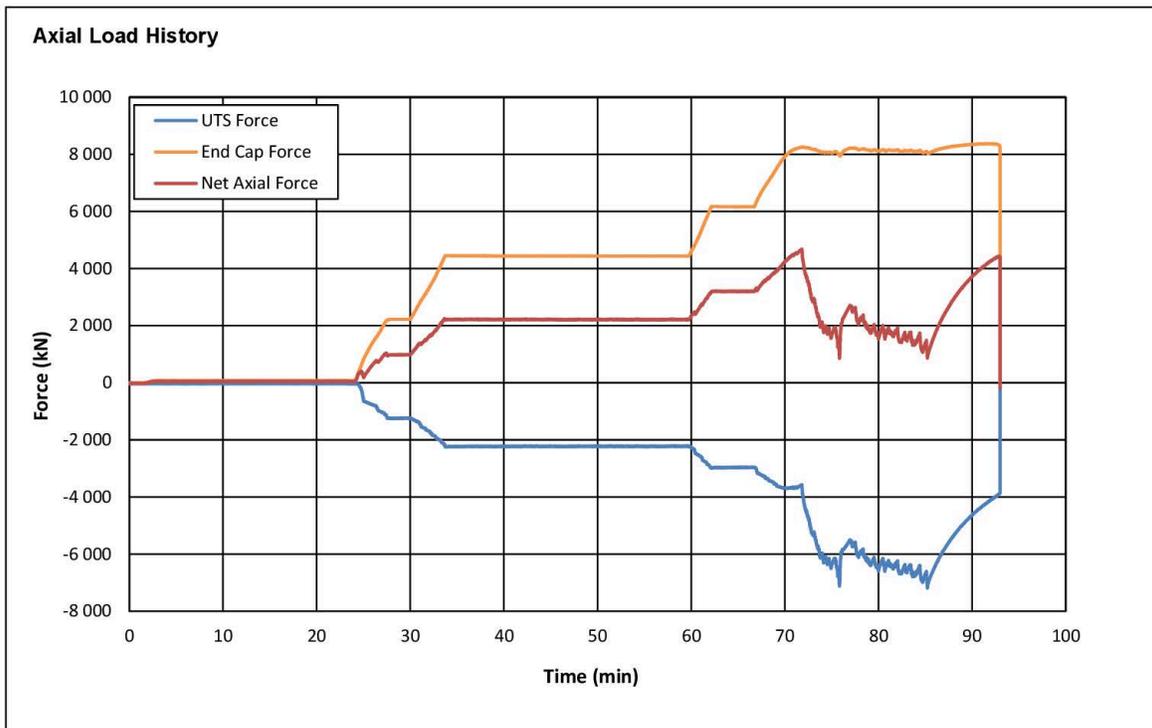
Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.a (Compression 1)	

### Strain Plots



Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.a (Compression 1)	

### Strain Plots



Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.a (Compression 1)	

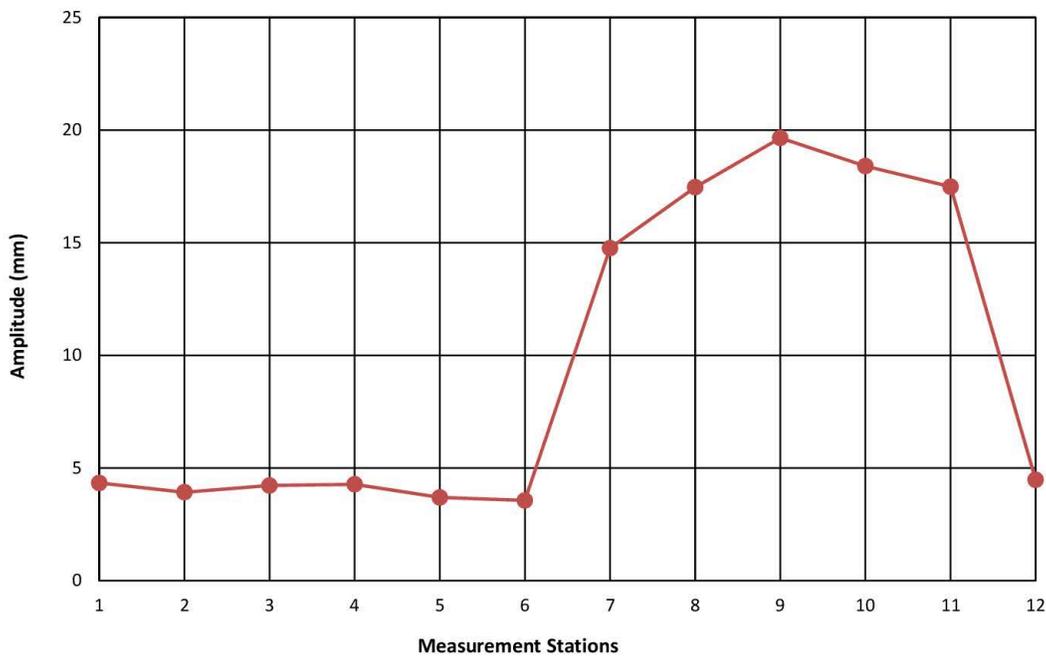
### Circumference Measurements

Station*	Pre-test	Circumference*	Post-test	
	Circumference (mm)		Bulge Amplitude (mm)	Hoop Strain (%)
1	1918	1945	4.3	1.4
2	1917	1942	3.9	1.3
3	1917	1944	4.2	1.4
4	1918	1945	4.3	1.4
5	1918	1941	3.7	1.2
6	1918	1940	3.6	1.2
7	1917	2010	14.8	4.8
8	1917	2027	17.5	5.7
9	1918	2041	19.7	6.4
10	1918	2034	18.4	6.0
11	1918	2028	17.5	5.7
12	1917	1945	4.5	1.5

\* refer to "Pipe Markings and Length" sheet

\*\* fracture opening width subtracted if present.

**Bulge Amplitude**



Compiled By:

SEB

Date:

30-Mar-15

Title:

Task 11 Compression Test



Reviewed:

CMJT

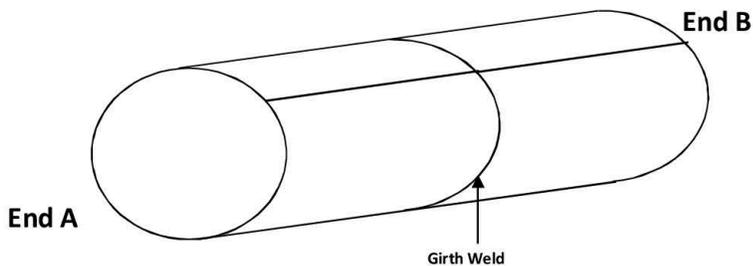
Date:

19-May-17

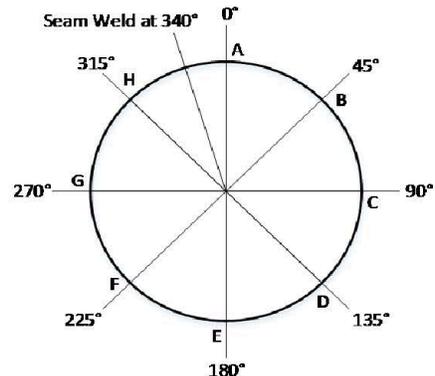
Specimen Identification:

11.a (Compression 1)

### Pipe Measurements



Pipe Specimen



View from End A

**Pre test Pup Lengths:**

End A to 1	<u>154</u>	mm
1 to 2	<u>304</u>	mm
2 to 3	<u>75</u>	mm
3 to 4	<u>77</u>	mm
4 to 5	<u>78</u>	mm
5 to 6	<u>77</u>	mm
6 to 7	<u>303</u>	mm
7 to 8	<u>75</u>	mm
8 to 9	<u>73</u>	mm
9 to 10	<u>80</u>	mm
10 to 11	<u>77</u>	mm
11 to 12	<u>303</u>	mm
12 to End B	<u>161</u>	mm

Total Length 1 837 mm

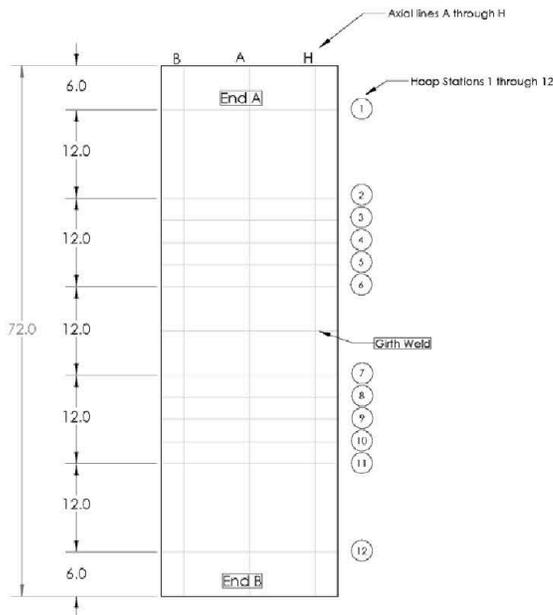
**Pre Test Pipe Lengths:**

Position B	<u>1 837</u>	mm
Position D	<u>1 837</u>	mm
Position F	<u>1 837</u>	mm
Position H	<u>1 839</u>	mm

Average 1 838 mm

**Post test Pup Lengths:**

End A to 1	<u>-</u>	mm
1 to 2	<u>308</u>	mm
2 to 3	<u>73</u>	mm
3 to 4	<u>79</u>	mm
4 to 5	<u>75</u>	mm
5 to 6	<u>78</u>	mm
6 to 7	<u>301</u>	mm
7 to 8	<u>74</u>	mm
8 to 9	<u>73</u>	mm
9 to 10	<u>79</u>	mm
10 to 11	<u>74</u>	mm
11 to 12	<u>301</u>	mm
12 to End B	<u>-</u>	mm



Grid Layout (Top view)

Measurement Grid

**Circumferences:**

End A measured circumference	<u>1 919</u>	mm
End B measured circumference	<u>1 919</u>	mm

Measurements Taken By: <b>SEB</b>	Date: <b>3-Mar-15</b>	Title: <b>Task 11 Compression Test</b>	
Measurements Approved By: <b>JHB</b>	Date: <b>3-Mar-15</b>	Specimen Identification: <b>11.a (Compression 1)</b>	

## Diameter Measurements

Micrometer: Mitutoyo 18-24" No 104-202

### 609.6 mm (24 in) Configuration (all spans) \*

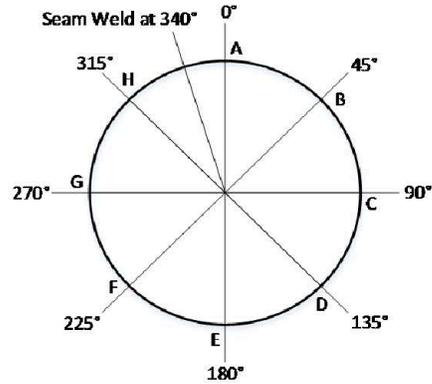
584.2 mm Verification rod reading No. 167-163: 584.25 mm  
609.6 mm Verification rod reading No. 167-164: 609.63 mm

Station	Spanned Positions (mm)			
	A-E	B-F	C-G	D-H
1	609.78	611.40	610.92	609.68
2	609.50	611.00	610.72	610.06
3	609.55	610.92	610.77	610.18
4	609.98	611.51	611.15	609.63
5	609.88	611.45	611.05	609.45
6	609.75	611.35	611.05	609.47
7	609.19	610.92	611.15	609.85
8	609.47	610.87	610.90	609.93
9	609.70	611.02	610.82	609.90
10	610.21	611.35	611.58	609.40
11	610.18	611.40	611.15	609.50
12	609.47	611.00	610.77	609.45

Micrometer: Mitutoyo 24-30" No 104-203

### 609.6 mm (24 in) Configuration (select spans) \*

603.6 mm Verification rod reading No. 167-163: 609.63 mm



View from End A

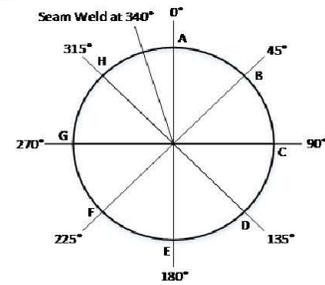
Station	Max. OD (mm)	@ Position	Min. OD (mm)	@ Position	Avg. OD (mm)	Stdev. (mm)	Ovality** (%)	Ovality incl. angle (°)
1	611.40	45	609.68	135	610.44	0.85	0.28	90
2	611.00	45	609.50	0	610.32	0.67	0.25	45
3	610.92	45	609.55	0	610.36	0.62	0.22	45
4	611.51	45	609.63	135	610.57	0.90	0.31	90
5	611.45	45	609.45	135	610.46	0.95	0.33	90
6	611.35	45	609.47	135	610.41	0.93	0.31	90
7	611.15	90	609.19	0	610.28	0.92	0.32	90
8	610.90	90	609.47	0	610.29	0.71	0.23	90
9	611.02	45	609.70	0	610.36	0.66	0.22	45
10	611.58	90	609.40	135	610.64	1.02	0.36	45
11	611.40	45	609.50	135	610.56	0.88	0.31	90
12	611.00	45	609.45	135	610.17	0.83	0.25	90

\* Imperial micrometer was used and measurements were converted.

$$** \text{Ovality} = \frac{(D_{\max} - D_{\min})}{(D_{\text{nom}})} * 100\%$$

Measurements Taken By: SEB	Date: 3-Mar-15	Title: Task 11 Compression Test	
Measurements Approved By: JHB	Date: 3-Mar-15	Specimen Identification: 11.a (Compression 1)	

# Wall Thickness Measurements



## Micrometer Measurements

### Pre-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	13.01	13.01
End A - Position D	12.84	12.85
End A - Position F	12.94	12.92
End A - Position H	12.92	12.91
End B - Position B	12.93	12.95
End B - Position D	12.91	12.88
End B - Position F	12.96	12.93
End B - Position H	12.88	12.87

**Micrometer ID:**

Mitutoyo 0-1"

No. 293-180

Calibration (1"): 1.00045"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX

±0.001"

Serial Number: 78000

### Post-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	13.05	13.05
End A - Position D	12.84	12.83
End A - Position F	12.95	12.95
End A - Position H	12.93	12.92
End B - Position B	12.93	12.93
End B - Position D	12.91	12.90
End B - Position F	12.92	12.90
End B - Position H	12.76	12.76

**Micrometer ID:**

Mitutoyo 0-1"

No. 293-180

Calibration (1"): 1.00026"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX

±0.001"

Serial Number: 78000

## Ultrasonic Measurements

### Pre-test Measurements

Station	Wall Thickness (mm)							
	Position							
	0	45	90	135	180	225	270	315
1	13.09	13.07	13.17	12.83	12.91	12.94	12.91	12.84
2	12.96	13.01	13.14	12.84	12.88	12.94	12.91	12.86
3	12.94	13.01	13.11	12.77	12.97	12.89	12.86	12.87
4	12.94	13.00	13.03	12.75	12.84	12.95	12.87	12.92
5	12.93	12.99	12.99	12.73	12.85	12.82	12.86	12.94
6	12.94	12.94	13.01	12.75	12.89	12.94	12.93	12.86
7	13.09	13.02	13.04	12.82	12.91	12.96	13.08	12.91
8	13.00	13.00	13.02	12.87	12.92	13.00	12.93	12.94
9	12.96	13.06	13.04	12.92	12.94	12.97	12.95	12.93
10	13.02	13.04	12.98	12.93	12.93	12.91	12.98	12.87
11	12.96	13.04	13.05	12.94	12.91	12.91	12.93	12.84
12	12.99	13.02	13.01	12.92	12.86	12.95	12.91	12.78

Average: 12.94  
Std. dev: 0.085

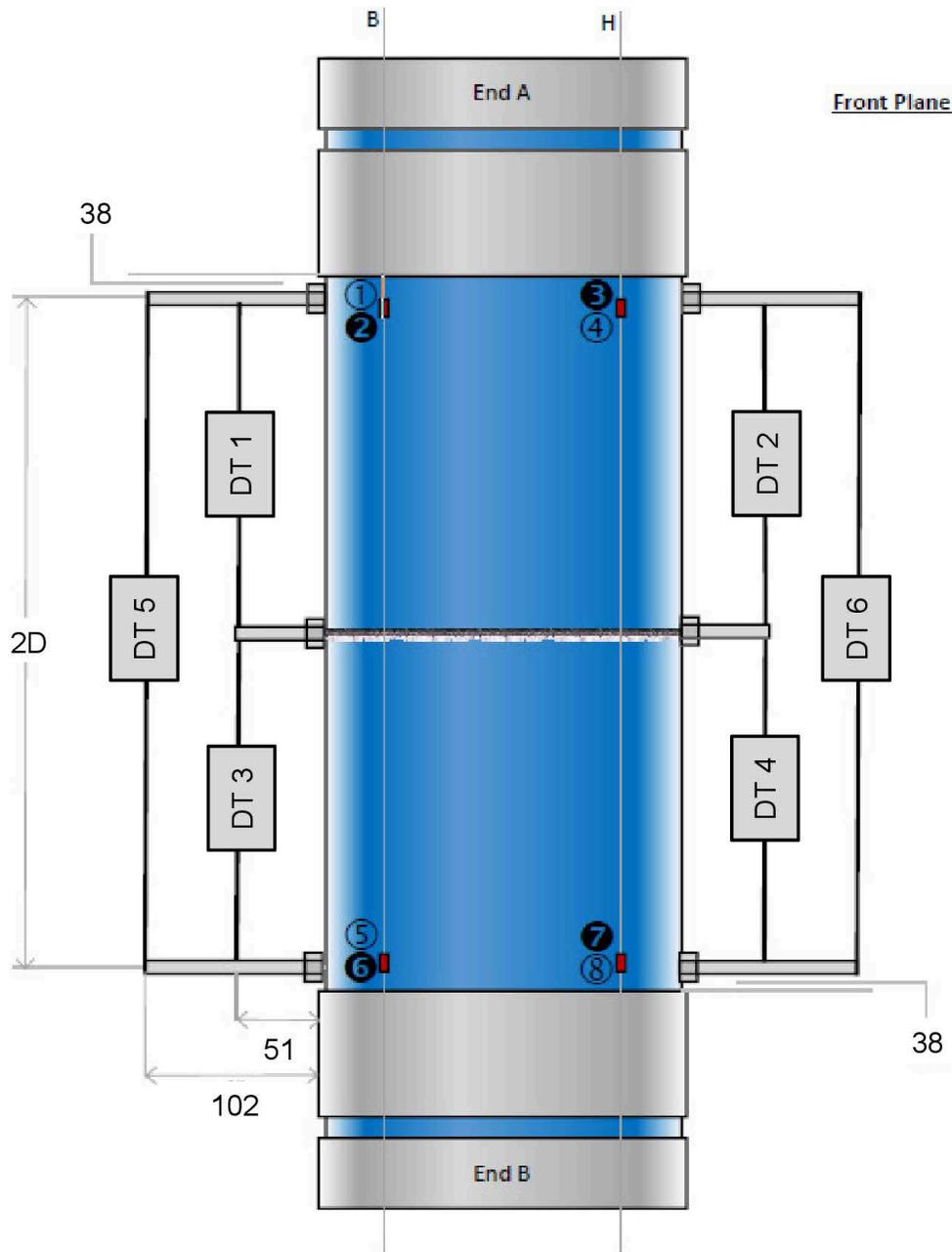
### Post-test Measurements

Station	Wall Thickness (mm)							
	Position							
	0	45	90	135	180	225	270	315
1	12.96	13.01	13.14	12.76	12.90	12.90	12.81	12.82
2	12.79	12.87	13.05	12.68	12.70	12.66	12.58	12.63
3	12.79	12.87	13.02	12.42	12.72	12.64	12.62	12.67
4	12.81	12.84	12.97	12.48	12.64	12.64	12.58	12.67
5	12.83	12.82	12.95	12.44	12.66	12.58	12.58	12.66
6	12.83	12.87	12.97	12.58	12.70	12.48	12.65	12.71
7	12.72	12.59	12.68	12.27	12.43	11.99	12.52	11.78
8	12.56	12.55	12.65	12.33	12.47	11.55	12.32	12.08
9	12.57	12.53	12.45	12.27	12.49	11.69	12.47	11.88
10	12.58	12.53	12.59	12.16	12.40	11.53	12.25	12.40
11	12.42	12.54	12.65	12.19	12.48	11.43	12.05	12.34
12	12.83	12.84	12.92	12.73	12.74	12.74	12.69	12.29

Average: 12.56  
Std. dev: 0.331

Pre-Test Measurements By: SEB	Date: 3-Mar-15	Approved By: JHB	Date: 3-Mar-15	Title: Task 11 Compression Test	
Post-Test Measurements By: SLS	Date: 4-May-16	Approved By: CMJT	Date: 21-Apr-17	Specimen Identification: 11.a (Compression 1)	

### Instrumentation Diagram



■ Uni-Axial Strain Gauge (2,3,4,6,7,8)

■ Bi-Axial Strain Gauge (1,5)

DT X Displacement Transducer

**Notes:**

Dimensions in mm

Two sets (pairs) of VIC cameras used. One set aimed at the front of the specimen and one at the rear.

Drawing Done By: SEB	Date: 13-Mar-15	Title: Task 11 Compression Test	
Drawing Approved By: CMJT	Date: 19-May-17	Specimen Identification: 11.a (Compression 1)	

# Task 11 Compression Test

Specimen Identification: **11.b (Compression 2)**  
 C-FER Specimen Number: **X80-DSAW-M5b**

C-FER Test Summary: **Rev. 4, June 23, 2017**  
 Test Date: **April 9, 2015**

**Pipe Characteristics**

Nominal OD (mm) =	609.6
Average OD (mm) =	610.4
Nominal Wall Thickness (mm) =	12.70
Average Wall Thickness (mm) =	13.07
Specimen Length (mm) =	1830.8
Length/OD =	3.0
SMYS (MPa) =	552
Target Pressure, 72% SMYS (MPa) =	16.5

**Test Loading Steps**

1. Specimen was pressurized at at rate of -2.8 MPa/min to 16.5 MPa.
2. Specimen was then compressed 25.5mm while maintaining pressure.
3. Specimen was then pressurized to burst while the UTS Stroke (overall specimen length) was held constant.

**Internal Pressure History**

**General Test Data**

Net Tensile Load at Burst (kN) =	3743
Maximum Net Compressive Load (kN) =	-10 383
Maximum Net Axial Compressive Stress (MPa) =	-423
Maximum Pressure (MPa) =	31.9
Max Top Hoop Strain from Circ. Meas. (%) =	7.7
Max Bottom Hoop Strain from Circ. Meas. (%) =	1.4

**Displacement Transducers**

1D Top Strain After Step 2 (%) =	-2.26
1D Bottom Strain After Step 2 (%) =	-0.50
2D Strain After Step 2 (%) =	-1.11

**Strain Gauges**

Top Strain After Step 2 (%) =	-1.12
Bottom Strain After Step 2 (%) =	-0.48
Average Hoop Strain at Burst (%) =	4.15

**General Comments:**

Specimen was unloaded after compression to facilitate collar removal.

Buckle formed in top section.

Burst failure in top section.

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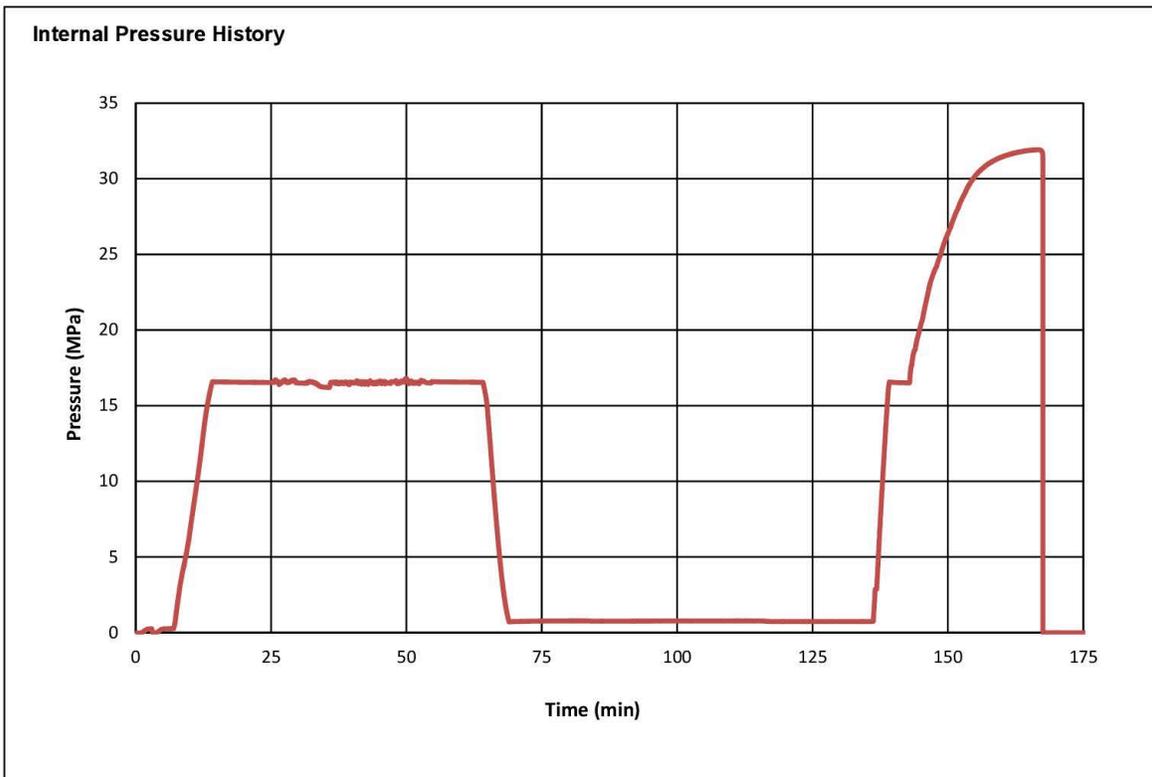
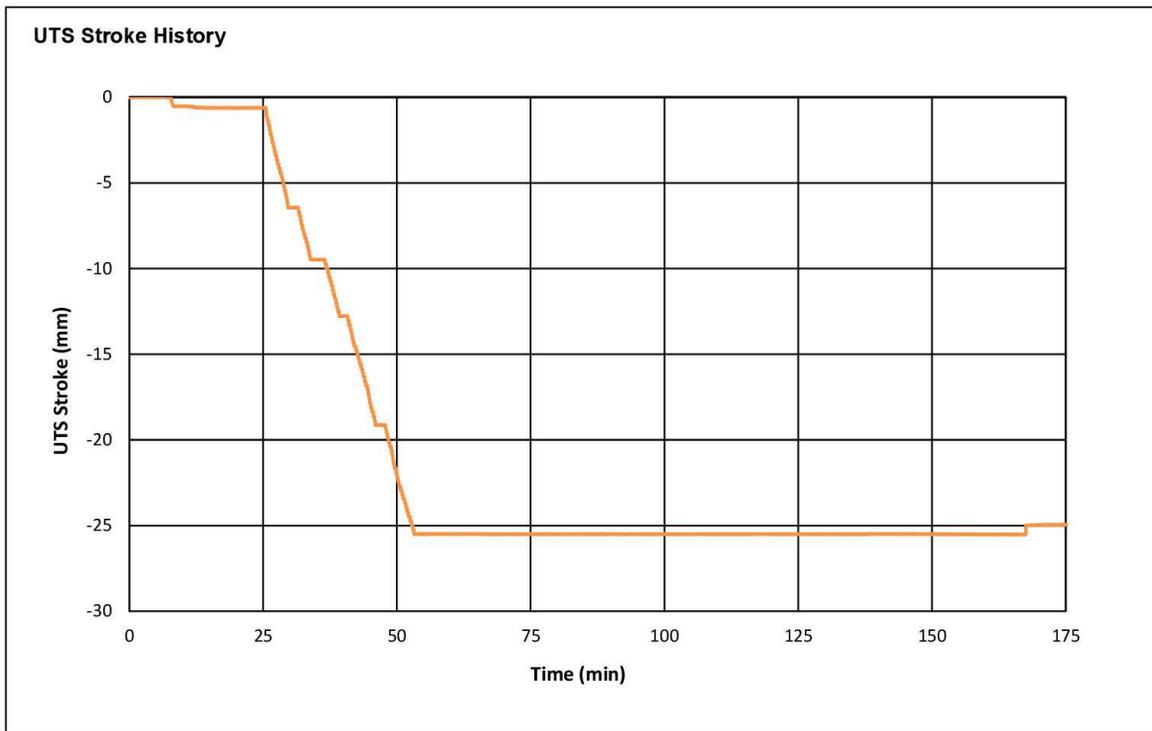
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Pipe after Testing:



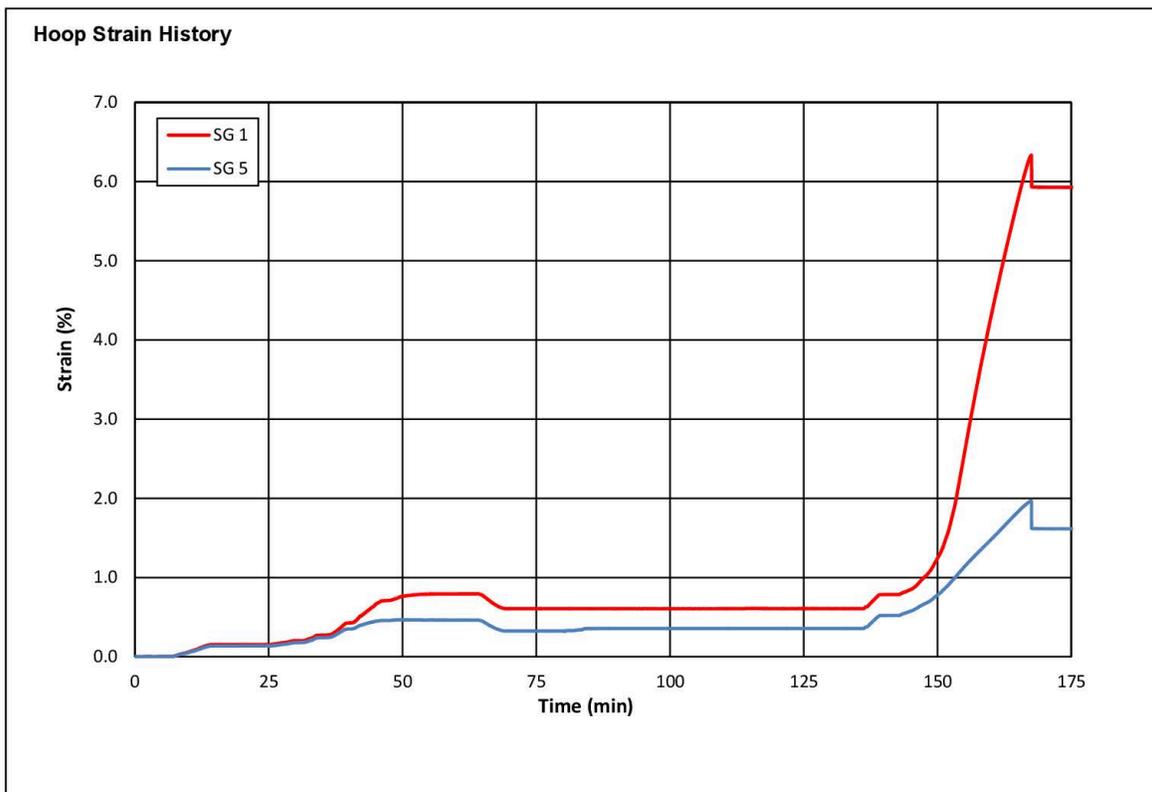
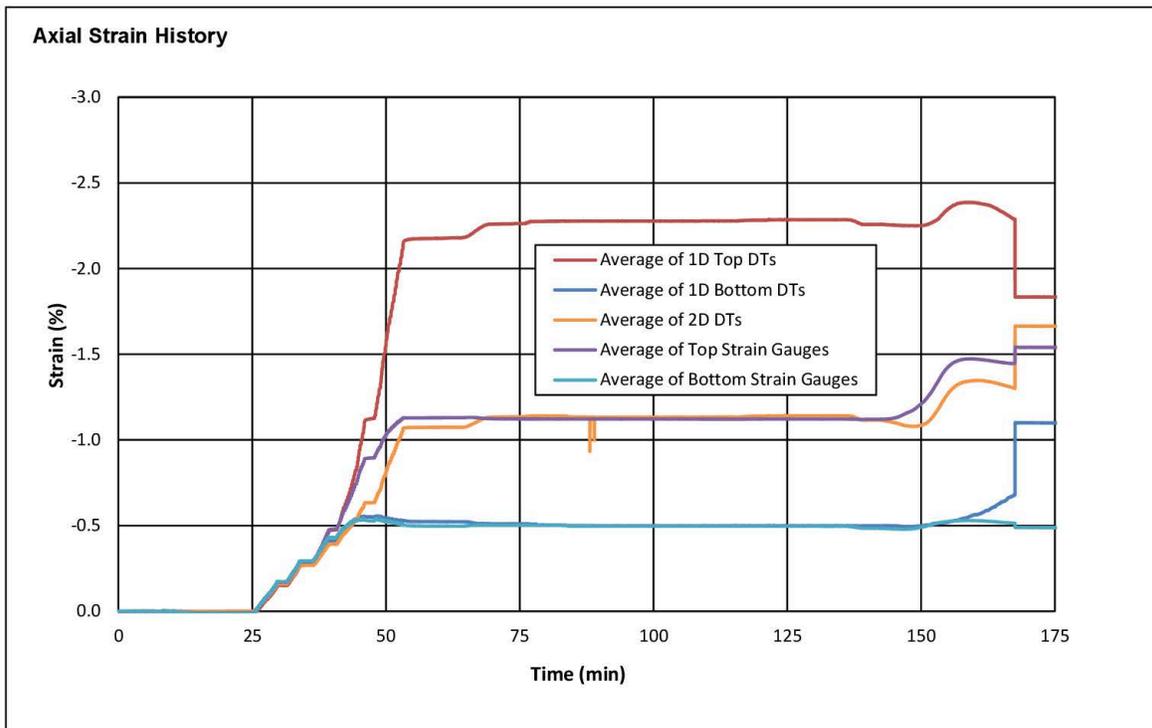
		Title: <b>Task 11 Compression Test</b>	
Complied By: <b>CMJT</b>	Date: <b>23-Jun-17</b>	Specimen Identification: <b>11.b (Compression 2)</b>	

### Test Control Plots



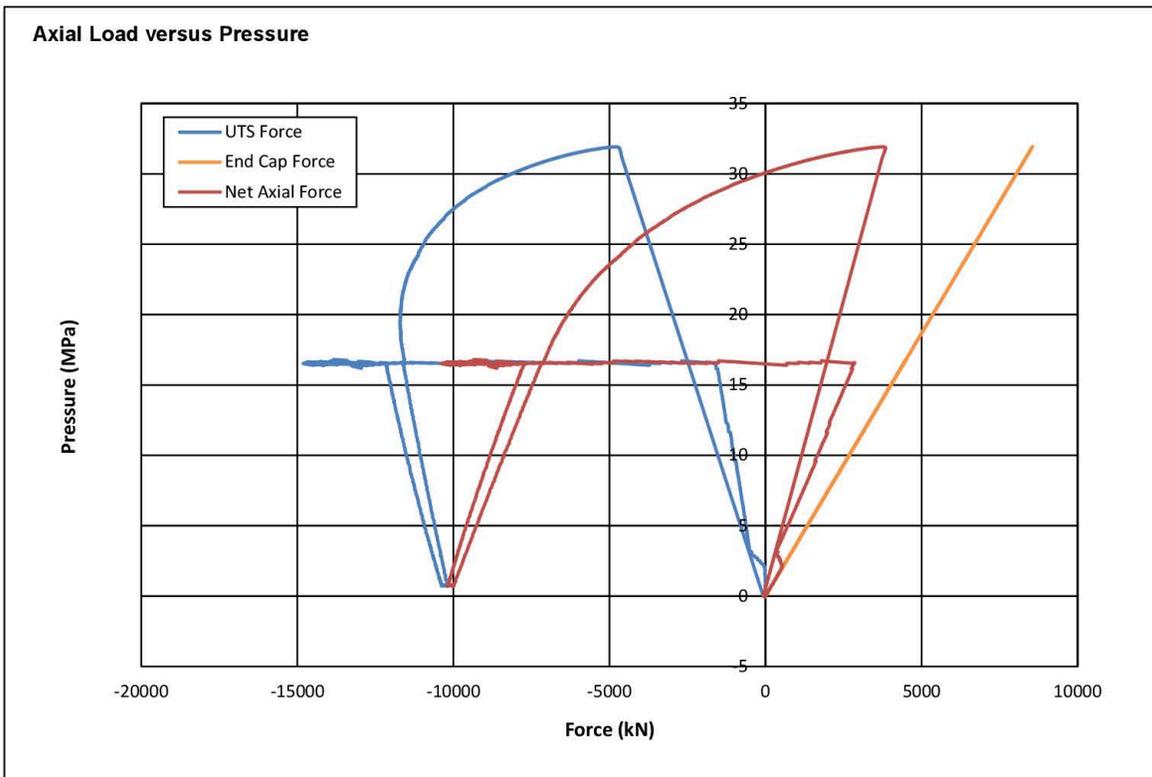
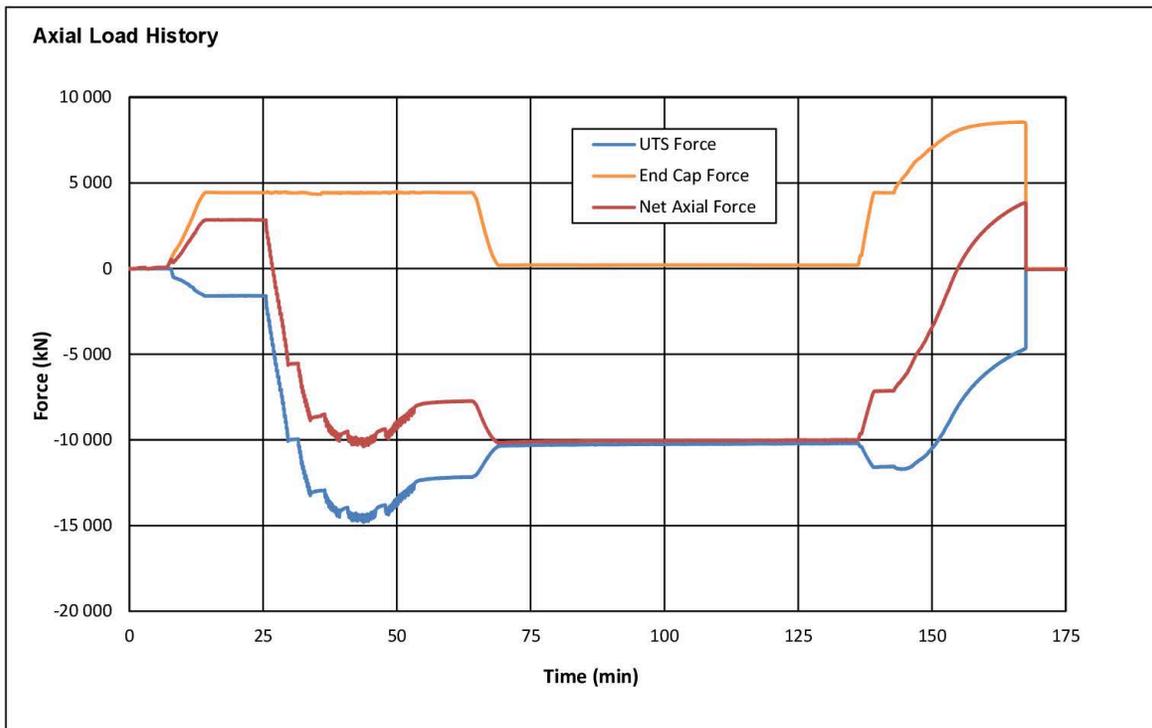
Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.b (Compression 2)	

### Strain Plots



Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.b (Compression 2)	

### Strain Plots



Compiled By: SLS	Date: 3-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.b (Compression 2)	

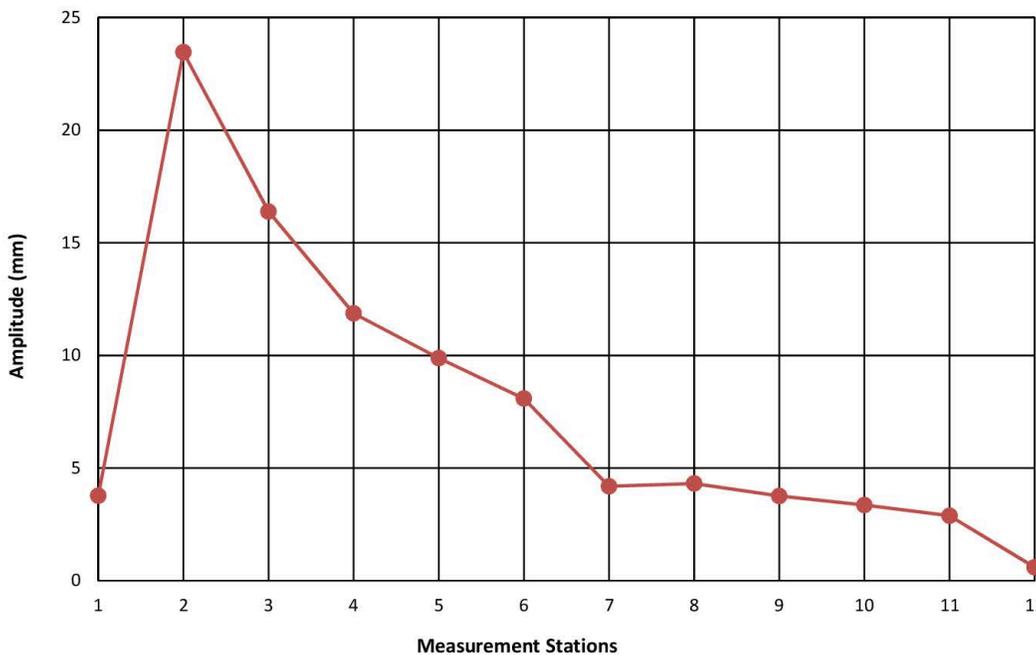
### Circumference Measurements

Station*	Pre-test		Post-test	
	Circumference (mm)	Circumference** (mm)	Bulge Amplitude (mm)	Calculated Average Hoop Strain (%)
1	1916	1940	3.8	1.2
2	1918	2065	23.5	7.7
3	1918	2021	16.4	5.4
4	1917	1992	11.9	3.9
5	1918	1980	9.9	3.2
6	1916	1967	8.1	2.7
7	1918	1944	4.2	1.4
8	1918	1945	4.3	1.4
9	1917	1941	3.8	1.2
10	1917	1938	3.4	1.1
11	1918	1936	2.9	0.9
12	1918	1922	0.6	0.2

\* refer to "Pipe Markings and Length" sheet

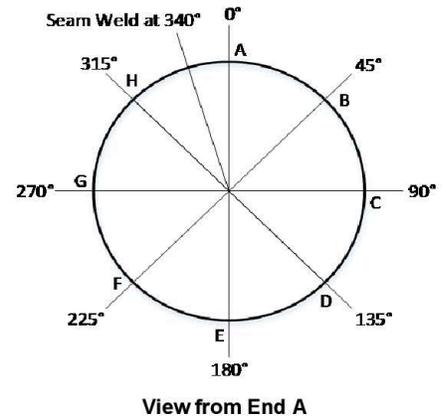
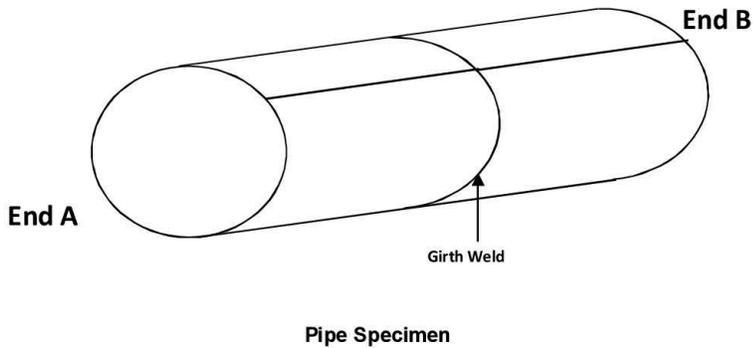
\*\* fracture opening width subtracted if present.

**Bulge Amplitude**



Compiled By: SEB	Date: 9-Apr-15	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.b (Compression 2)	

# Pipe Measurements



**Pre test Pup Lengths:**

End A to 1	<u>153</u>	mm
1 to 2	<u>305</u>	mm
2 to 3	<u>77</u>	mm
3 to 4	<u>77</u>	mm
4 to 5	<u>75</u>	mm
5 to 6	<u>79</u>	mm
6 to 7	<u>302</u>	mm
7 to 8	<u>76</u>	mm
8 to 9	<u>76</u>	mm
9 to 10	<u>76</u>	mm
10 to 11	<u>76</u>	mm
11 to 12	<u>309</u>	mm
12 to End B	<u>150</u>	mm

Total Length 1,831 mm

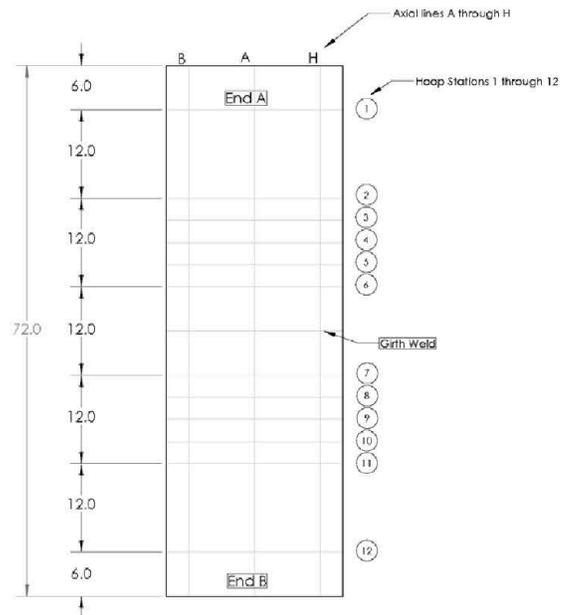
**Pre Test Pipe Lengths:**

Position B	<u>1831</u>	mm
Position D	<u>1831</u>	mm
Position F	<u>1829</u>	mm
Position H	<u>1832</u>	mm

Average 1,831 mm

**Post test Pup Lengths:**

End A to 1	<u>-</u>	mm
1 to 2	<u>298</u>	mm
2 to 3	<u>75</u>	mm
3 to 4	<u>72</u>	mm
4 to 5	<u>76</u>	mm
5 to 6	<u>77</u>	mm
6 to 7	<u>299</u>	mm
7 to 8	<u>77</u>	mm
8 to 9	<u>76</u>	mm
9 to 10	<u>74</u>	mm
10 to 11	<u>76</u>	mm
11 to 12	<u>306</u>	mm
12 to End B	<u>-</u>	mm



**Circumferences:**

End A measured circumference	<u>1918</u>	mm
End B measured circumference	<u>1918</u>	mm

Measurements Taken By: <b>SEB</b>	Date: <b>3-Mar-15</b>	Title: <b>Task 11 Compression Test</b>	
Measurements Approved By: <b>JHB</b>	Date: <b>3-Mar-15</b>	Specimen Identification: <b>11.b (Compression 2)</b>	Page 6 of 9

## Diameter Measurements

**Micrometer:** Mitutoyo 18-24" No 104-202

**Micrometer:** Mitutoyo 24-30" No 104-203

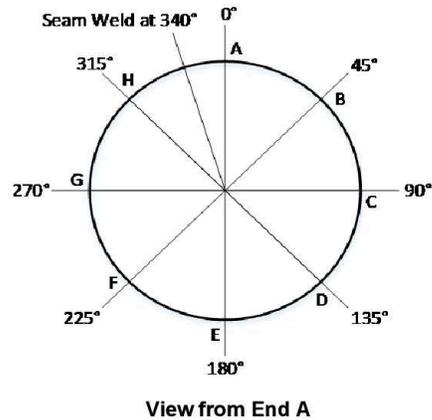
### 609.6 mm (24 in) Configuration (all spans) \*

584.2 mm Verification rod reading No.167-163: 584.25 mm  
609.6 mm Verification rod reading No. 167-164: 609.63 mm

### 609.6 mm (24 in) Configuration (select spans) \*

603.6 mm Verification rod reading No.167-163: 609.63 mm

Station	Spanned Positions (mm)			
	A-E	B-F	C-G	D-H
1	608.79	610.87	610.36	609.90
2	608.99	610.95	610.95	610.67
3	609.22	611.15	611.00	610.77
4	609.19	610.97	610.69	610.51
5	609.27	611.15	610.84	610.74
6	608.81	610.64	610.31	610.03
7	608.99	611.23	611.07	610.41
8	609.17	611.20	611.23	610.39
9	609.14	611.02	610.92	610.24
10	609.02	610.87	610.72	610.11
11	609.09	611.10	610.69	611.10
12	609.22	611.07	611.07	611.07



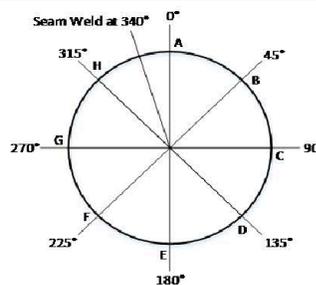
Station	Max. OD (mm)	@ Position	Min. OD (mm)	@ Position	Avg. OD (mm)	Stdev. (mm)	Ovality** (%)	Ovality incl. angle (°)
1	610.87	45	608.79	0	609.98	0.89	0.34	45
2	610.95	45	608.99	0	610.39	0.94	0.32	45
3	611.15	45	609.22	0	610.53	0.89	0.32	45
4	610.97	45	609.19	0	610.34	0.79	0.29	45
5	611.15	45	609.27	0	610.50	0.84	0.31	45
6	610.64	45	608.81	0	609.95	0.80	0.30	45
7	611.23	45	608.99	0	610.43	1.02	0.37	45
8	611.23	90	609.17	0	610.50	0.97	0.34	90
9	611.02	45	609.14	0	610.33	0.87	0.31	45
10	610.87	45	609.02	0	610.18	0.84	0.30	45
11	611.10	45	609.09	0	610.50	0.95	0.33	45
12	611.07	45	609.22	0	610.61	0.93	0.30	45

\* Imperial micrometer was used and measurements were converted.

$$** \text{Ovality} = \frac{(D_{\max} - D_{\min})}{(D_{\text{nom}})} * 100\%$$

Measurements Taken By: <b>SEB</b>	Date: <b>3-Mar-15</b>	Title: <b>Task 11 Compression Test</b>	<b>C-FER Technologies</b>
Measurements Approved By: <b>JHB</b>	Date: <b>3-Mar-15</b>	Specimen Identification: <b>11.b (Compression 2)</b>	

### Wall Thickness Measurements



### Micrometer Measurements

#### Pre-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	12.96	12.95
End A - Position D	12.82	12.83
End A - Position F	12.84	12.84
End A - Position H	12.93	12.94
End B - Position B	12.90	12.99
End B - Position D	12.78	12.79
End B - Position F	12.82	12.82
End B - Position H	12.87	12.87

**Micrometer ID:**

Mitutoyo 0-1"  
No. 293-180  
Calibration (1"): 1.00045"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX  
±0.001"  
Serial Number: 78000

#### Post-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	12.92	12.92
End A - Position D	12.87	12.84
End A - Position F	12.87	12.89
End A - Position H	12.99	12.97
End B - Position B	12.97	12.97
End B - Position D	12.91	12.92
End B - Position F	12.82	12.85
End B - Position H	13.00	13.00

**Micrometer ID:**

Mitutoyo 0-1"  
No. 293-180  
Calibration (1"): 1.00026"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX  
±0.001"  
Serial Number: 78000

### Ultrasonic Measurements

#### Pre-test Measurements

Station	Wall Thickness (mm)							
	Position							
	0	45	90	135	180	225	270	315
1	12.90	13.05	13.06	12.99	12.99	12.93	13.00	13.05
2	12.85	13.07	13.11	12.97	13.01	12.96	13.13	13.19
3	12.90	13.07	13.10	13.08	13.07	13.12	13.21	13.16
4	12.96	13.22	13.17	13.13	13.04	13.06	13.11	13.17
5	12.89	13.15	13.15	13.14	13.19	13.22	12.95	13.29
6	12.87	13.06	13.16	13.20	13.09	13.24	13.13	13.13
7	12.83	13.10	13.08	13.01	12.94	13.21	13.16	13.17
8	12.95	13.13	13.12	12.91	13.16	13.32	13.52	13.23
9	12.84	13.19	13.08	13.06	13.23	13.19	13.24	13.26
10	12.81	13.10	13.06	13.14	13.15	13.06	13.07	13.03
11	12.76	13.07	13.03	12.88	12.88	12.91	12.94	13.06
12	12.78	13.08	13.10	12.97	12.89	12.87	13.07	13.07

Average: 13.07  
Std. dev: 0.131

#### Post-test Measurements

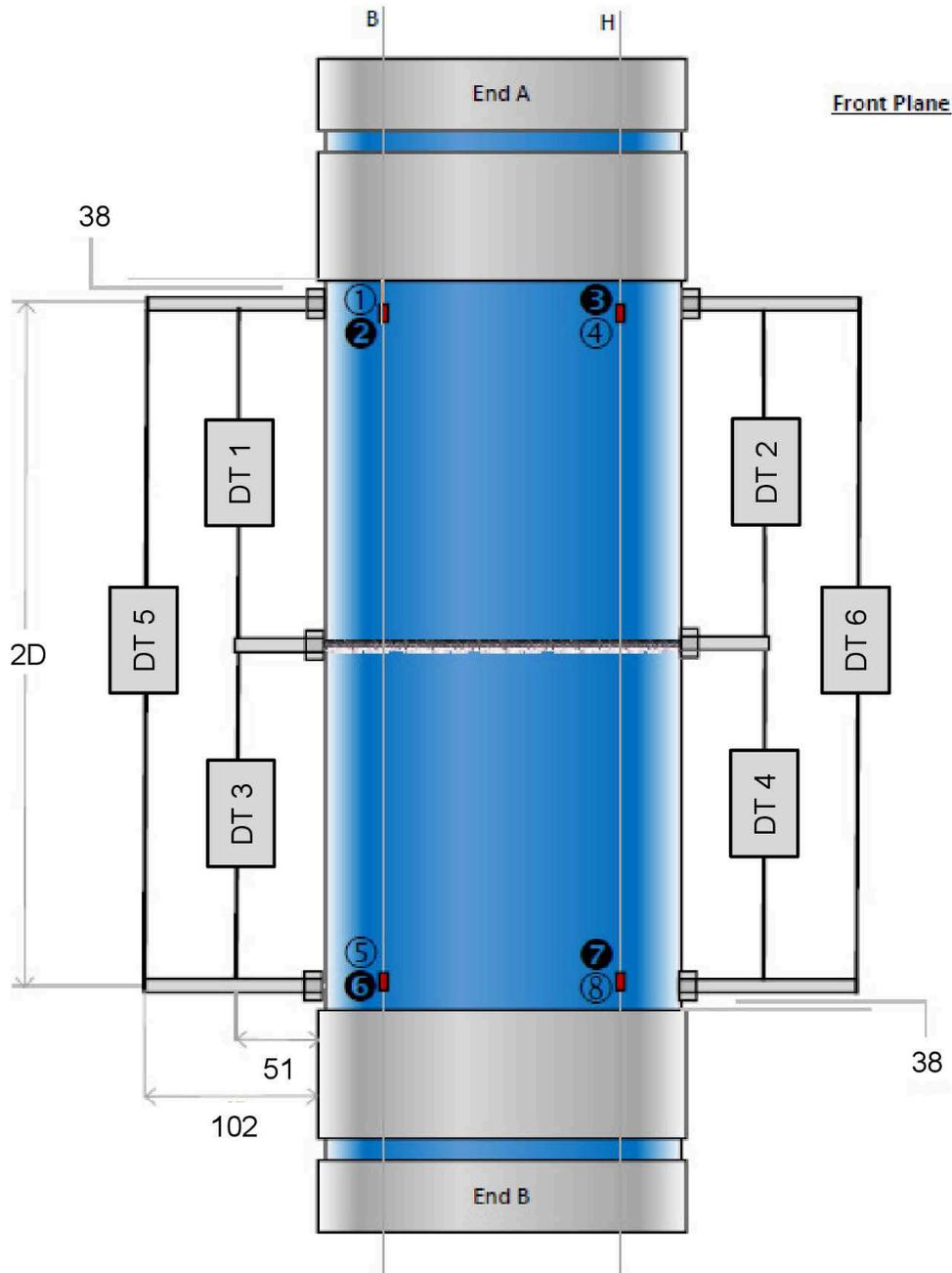
Station	Wall Thickness (mm)							
	Position							
	0	45	90	135	180	225	270	315
1	12.63	12.71	12.84	12.64	12.72	12.74	12.92	12.89
2	12.64	12.73	12.74	12.59	12.57	12.69	12.71	12.77
3	12.62	12.60	12.73	12.68	12.73	12.70	12.84	12.85
4	12.60	12.22	12.71	12.69	12.57	12.62	12.78	12.99
5	12.58	12.26	12.75	12.72	12.50	12.57	12.88	12.89
6	12.55	12.28	12.81	12.75	12.63	12.92	12.99	12.86
7	12.67	12.76	12.91	12.97	12.79	12.89	12.92	12.96
8	12.74	12.82	12.93	12.86	12.87	12.76	12.92	13.06
9	12.75	12.88	13.01	12.92	12.95	12.74	12.93	12.89
10	12.69	12.84	12.90	12.95	12.92	12.92	13.01	12.97
11	12.68	12.86	12.94	12.89	12.87	12.84	12.99	12.94
12	12.74	12.84	12.89	12.83	12.82	12.75	12.86	12.91

Average: 12.78  
Std. dev: 0.159

Pre-Test Measurements By: SEB	Date: 3-Mar-15	Approved By: JHB	Date: 3-Mar-15	Title: Task 11 Compression Test
Post-Test Measurements By: SLS	Date: 4-May-16	Approved By: CMJT	Date: 21-Apr-17	Specimen Identification: 11.b (Compression 2)



### Instrumentation Diagram



■ Uni-Axial Strain Gauge (2,3,4,6,7,8)

■ Bi-Axial Strain Gauge (1,5)

DT X Displacement Transducer

**Notes:**

Dimensions in mm

Two sets (pairs) of VIC cameras used. One set aimed at the front of the specimen and one at the rear.

Drawing Done By: SEB	Date: 13-Mar-15	Title: Task 11 Compression Test	
Drawing Approved By: CMJT	Date: 19-May-17	Specimen Identification: 11.b (Compression 2)	

# Task 11 Compression Test

Specimen Identification: 11.c (Compression 3)  
 C-FER Specimen Number: X80-DSAW-M5c

C-FER Test Summary: Rev. 4, June 23, 2017  
 Test Date: April 14, 2015

**Pipe Characteristics**

Nominal OD (mm) =	<u>609.6</u>
Average OD (mm) =	<u>610.4</u>
Nominal Wall Thickness (mm) =	<u>12.70</u>
Average Wall Thickness (mm) =	<u>12.97</u>
Specimen Length (mm) =	<u>1 834.3</u>
Length/OD =	<u>3.0</u>
SMYS (MPa) =	<u>552</u>
Target Pressure, 72% SMYS (MPa) =	<u>16.5</u>

**Test Loading Steps**

1. Specimen was pressurized at at rate of -2.8 MPa/min to 16.5 MPa.
2. Specimen was then compressed 219 mm while maintaining pressure.
3. Specimen was then pressurized to burst while the UTS Stroke (overall specimen length) was held constant.

**Internal Pressure History**

**General Test Data**

Net Compressive Load at Burst (kN) =	<u>-2096</u>
Maximum Net Compressive Load (kN) =	<u>-10 477</u>
Maximum Compressive Axial Stress (MPa) =	<u>-431</u>
Maximum Pressure (MPa) =	<u>28.2</u>
Max Top Hoop Strain from Circ. Meas. (%) =	<u>3.3</u>
Max Bottom Hoop Strain from Circ. Meas. (%) =	<u>31.4</u>
Hoop Strain at burst location from Circ. Meas. (%) =	<u>19.3</u>

**Displacement Transducers**

1D Top Strain After Step 2 (%) =	<u>-0.27</u>
1D Bottom Strain After Step 2 (%) =	<u>-34.4</u>
2D Strain After Step 2 (%) =	<u>-17.2</u>

**Strain Gauges**

Top Strain After Step 2 (%) =	<u>-0.41</u>
Bottom Strain After Step 2 (%) =	<u>-0.41</u>
Average Hoop Strain at Burst (%) =	<u>7.63</u>

**General Comments:**

Pressure was relieved several times to facilitate collar removal, specimen inspection, and instrument repositioning.

Primary buckle formed in the bottom section.

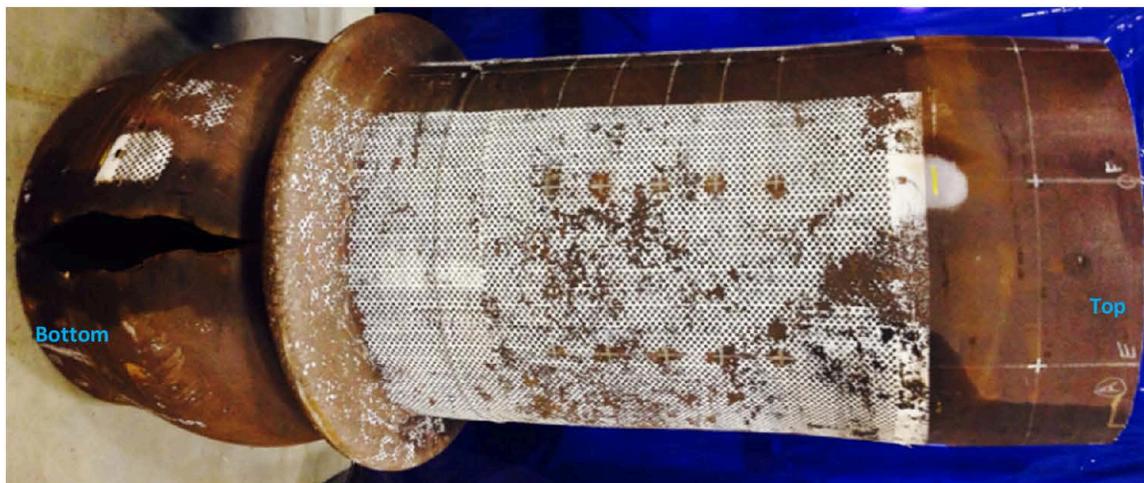
Secondary buckle formed in the top section.

Burst failure occurred below primary buckle.

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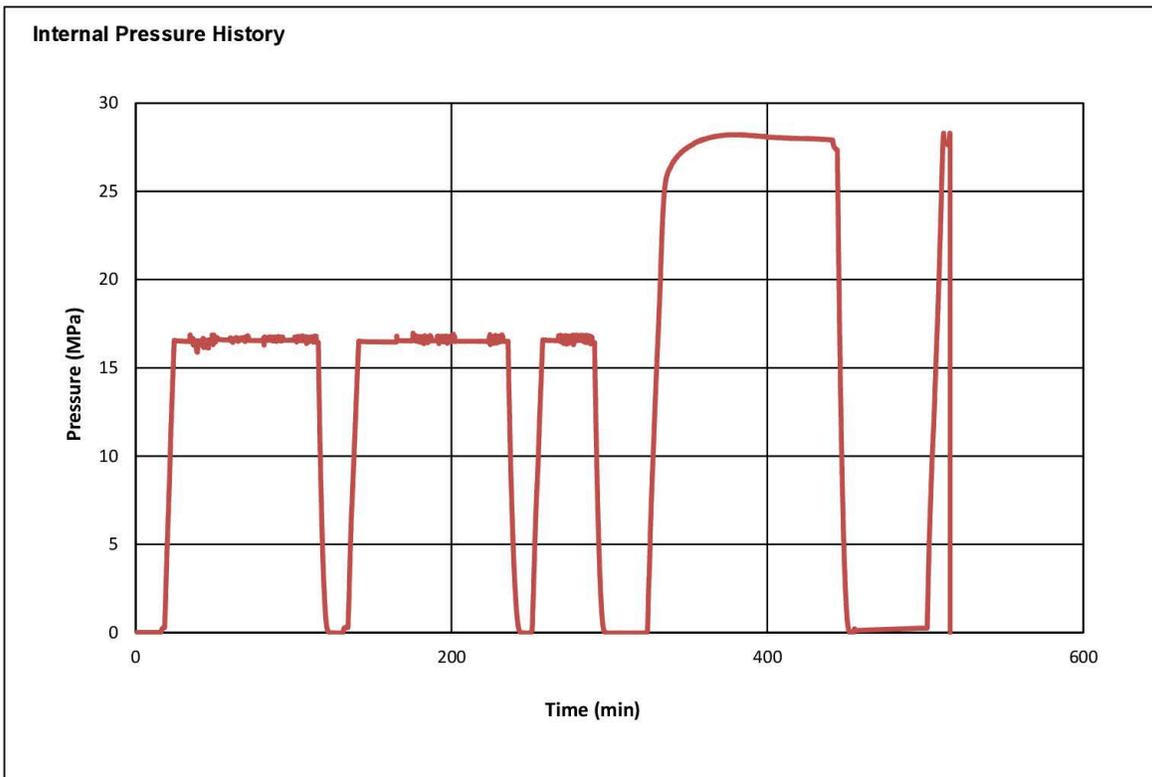
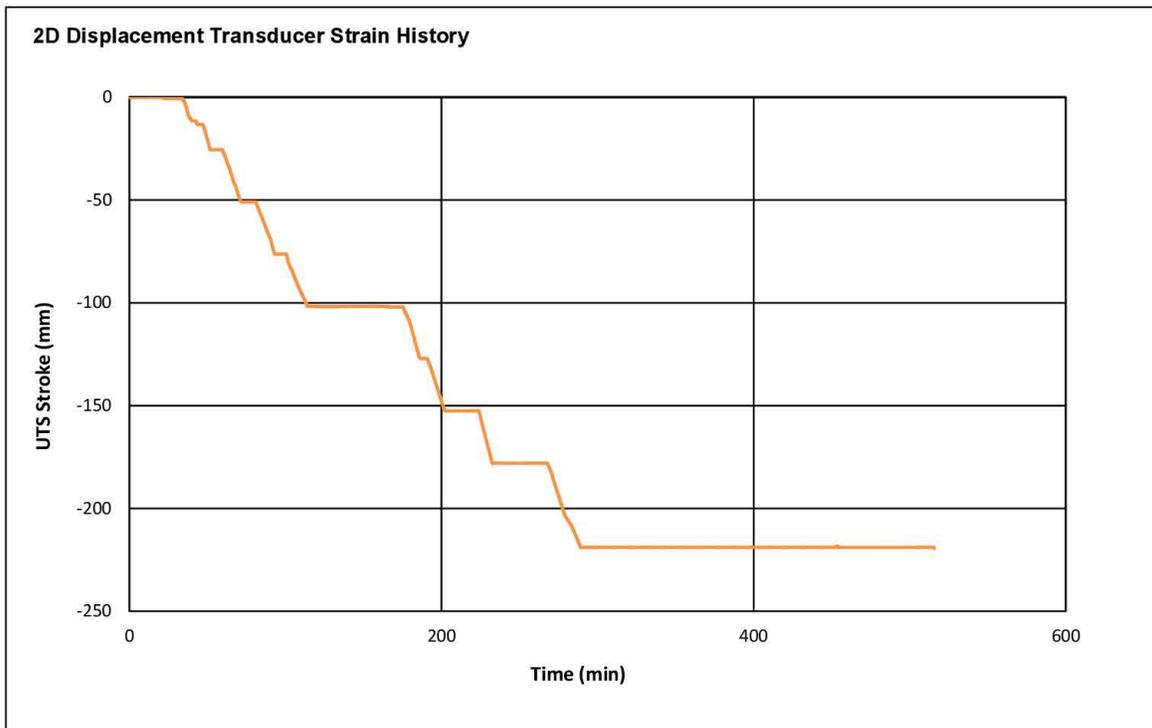
Strain Gauge 7 malfunctioned.

Pipe after Testing:



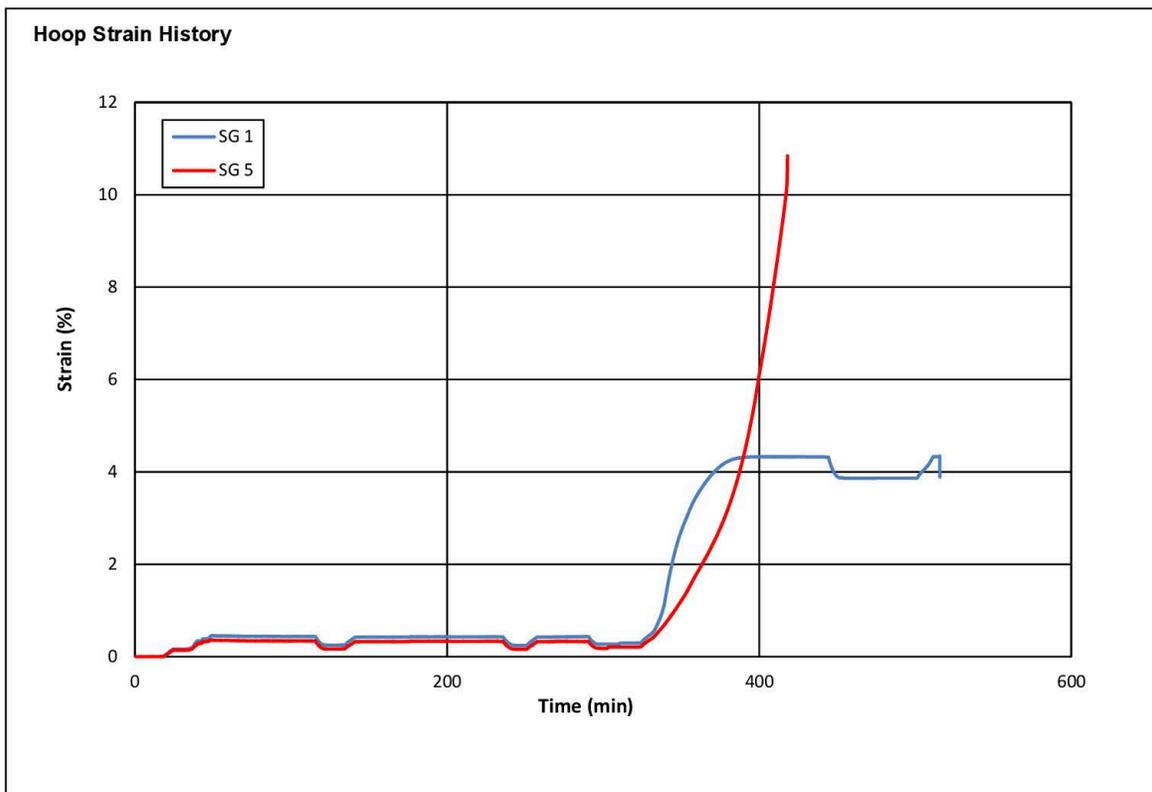
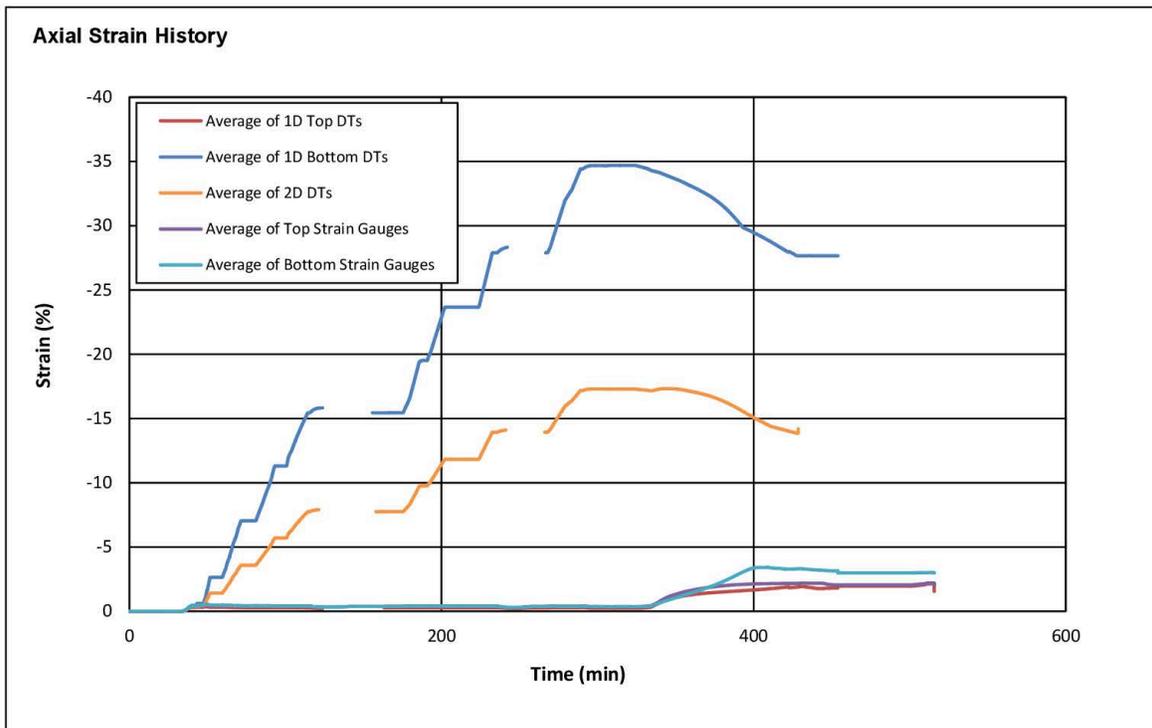
		Title: <b>Task 11 Compression Test</b>	
Complied By: <b>CMJT</b>	Date: <b>23-Jun-17</b>	Specimen Identification: <b>11.c (Compression 3)</b>	

### Test Control Plots



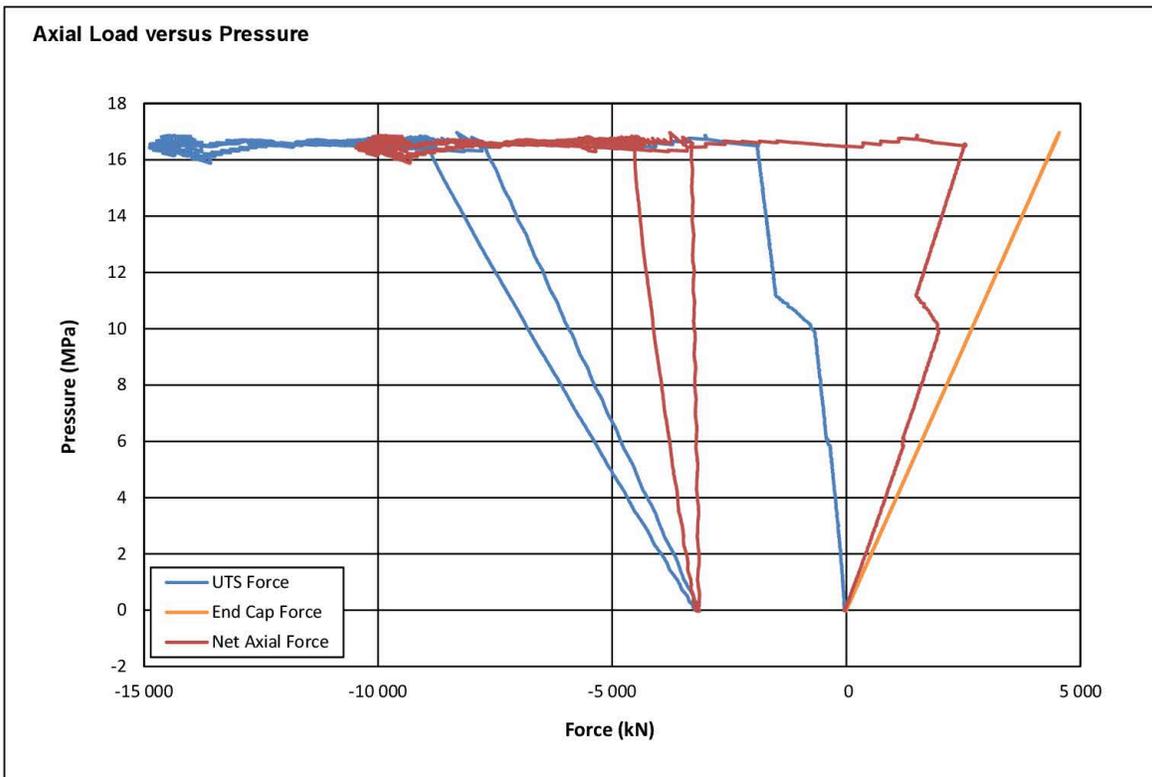
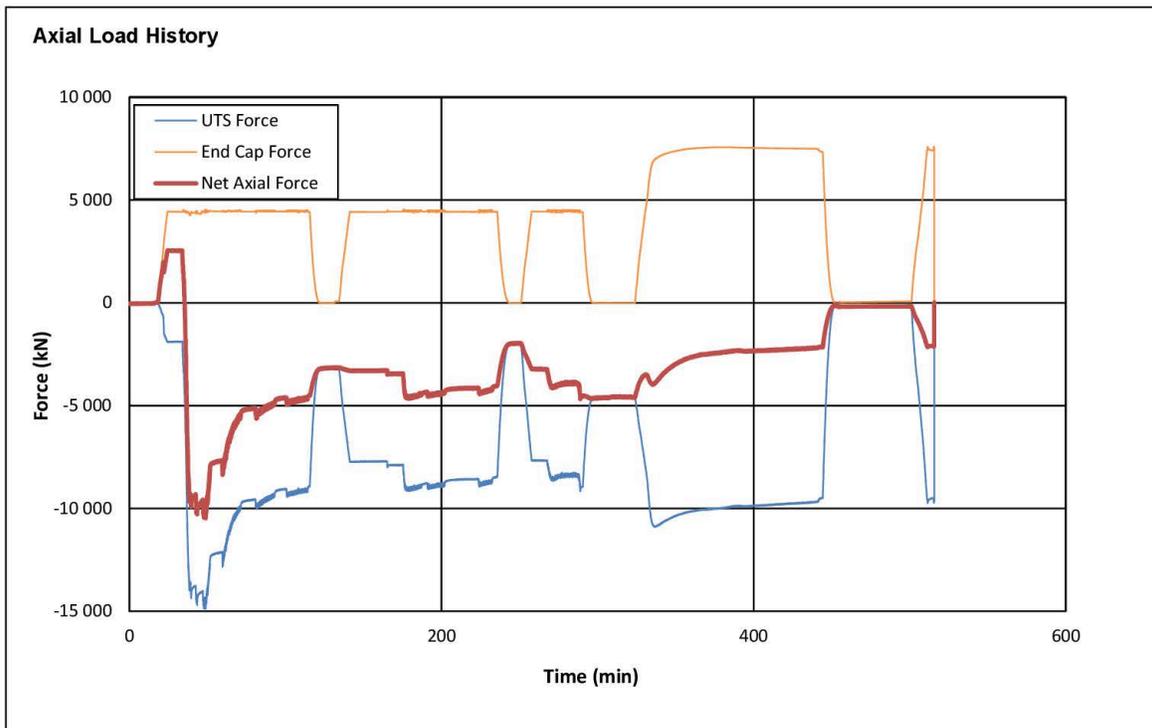
Compiled By: SLS	Date: 11-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.c (Compression 3)	

### Strain Plots



Compiled By: SLS	Date: 11-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.c (Compression 3)	

### Strain Plots



Compiled By: SLS	Date: 11-May-16	Title: Task 11 Compression Test	
Reviewed: CMJT	Date: 19-May-17	Specimen Identification: 11.c (Compression 3)	

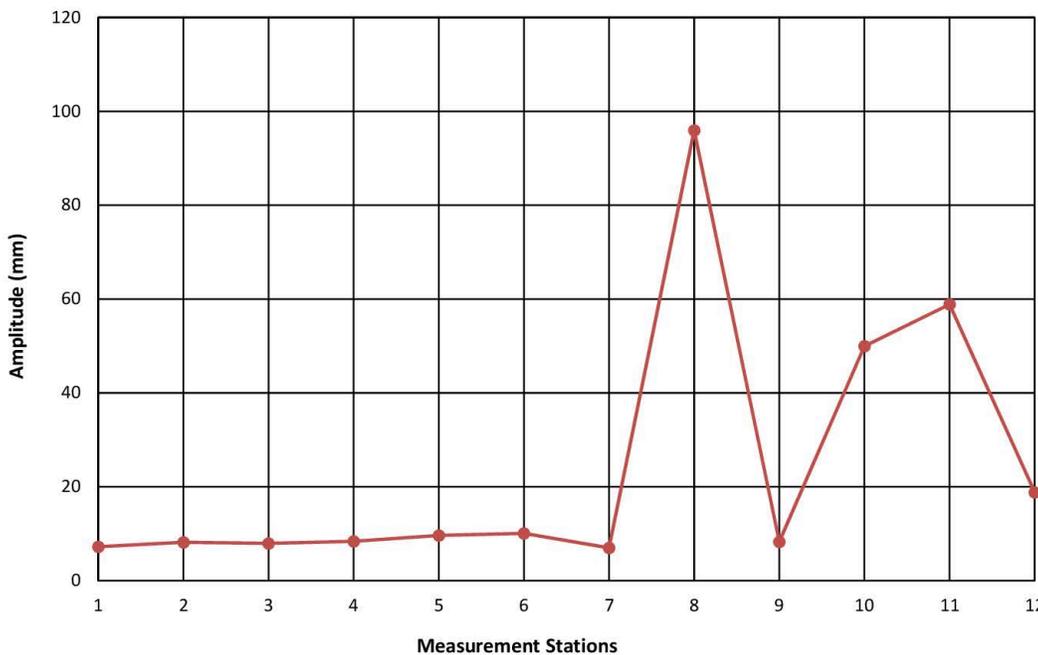
### Circumference Measurements

Station*	Pre-test	Circumference*	Post-test	
	Circumference (mm)		Bulge Amplitude (mm)	Hoop Strain (%)
1	1917	1962	7.2	2.4
2	1918	1969	8.1	2.7
3	1918	1968	7.9	2.6
4	1918	1970	8.3	2.7
5	1917	1977	9.6	3.1
6	1917	1980	10.0	3.3
7	1918	1962	7.0	2.3
8	1918	2521	95.9	31.4
9	1918	1970	8.2	2.7
10	1916	2230	49.9	16.4
11	1918	2288	58.9	19.3
12	1917	2035	18.8	6.2

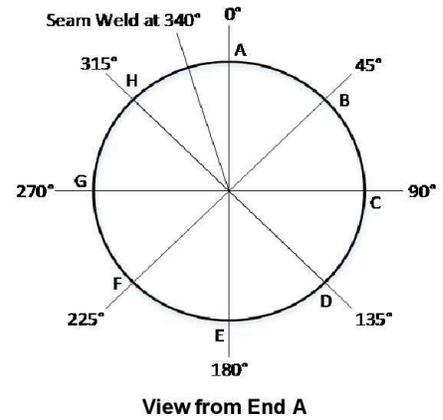
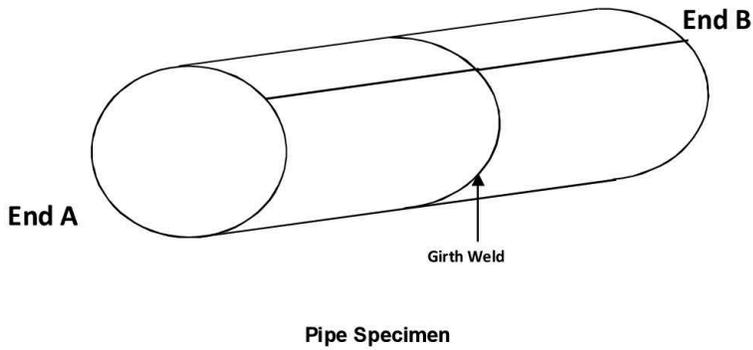
\* refer to "Pipe Markings and Length" sheet

\*\* fracture opening width subtracted if present.

**Bulge Amplitude**



### Pipe Measurements



**Pre test Pup Lengths:**

End A to 1	<u>155</u>	mm
1 to 2	<u>299</u>	mm
2 to 3	<u>82</u>	mm
3 to 4	<u>74</u>	mm
4 to 5	<u>79</u>	mm
5 to 6	<u>75</u>	mm
6 to 7	<u>304</u>	mm
7 to 8	<u>76</u>	mm
8 to 9	<u>75</u>	mm
9 to 10	<u>78</u>	mm
10 to 11	<u>77</u>	mm
11 to 12	<u>303</u>	mm
12 to End B	<u>157</u>	mm

Total Length 1 834 mm

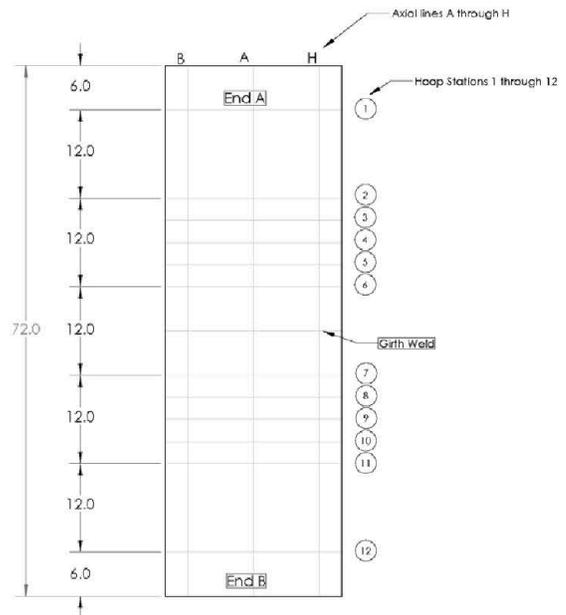
**Pre Test Pipe Lengths:**

Position B	<u>1 834</u>	mm
Position D	<u>1 833</u>	mm
Position F	<u>1 834</u>	mm
Position H	<u>1 836</u>	mm

Average 1 834 mm

**Post test Pup Lengths:**

End A to 1	<u>-</u>	mm
1 to 2	<u>300</u>	mm
2 to 3	<u>77</u>	mm
3 to 4	<u>74</u>	mm
4 to 5	<u>74</u>	mm
5 to 6	<u>75</u>	mm
6 to 7	<u>-</u>	mm
7 to 8	<u>-</u>	mm
8 to 9	<u>-</u>	mm
9 to 10	<u>-</u>	mm
10 to 11	<u>-</u>	mm
11 to 12	<u>-</u>	mm
12 to End B	<u>-</u>	mm



**Circumferences:**

End A measured circumference	<u>1 918</u>	mm
End B measured circumference	<u>1 919</u>	mm

Measurements Taken By: <b>SEB</b>	Date: <b>3-Mar-15</b>	Title: <b>Task 11 Compression Test</b>	
Measurements Approved By: <b>JHB</b>	Date: <b>3-Mar-15</b>	Specimen Identification: <b>11.c (Compression 3)</b>	Page 6 of 9

## Diameter Measurements

**Micrometer:** Mitutoyo 18-24" No 104-202

**Micrometer:** Mitutoyo 24-30" No 104-203

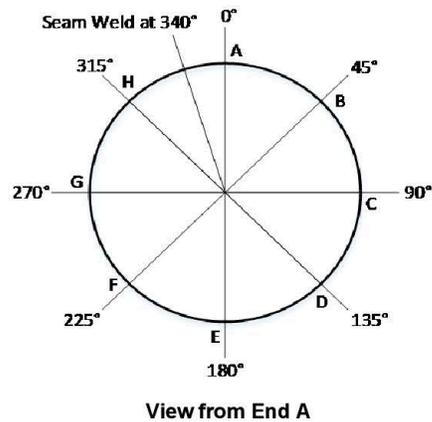
### 609.6 mm (24 in) Configuration (all spans) \*

584.2 mm Verification rod reading No.167-163: 584.23 mm  
609.6 mm Verification rod reading No. 167-164: 609.63 mm

### 609.6 mm (24 in) Configuration (select spans) \*

603.6 mm Verification rod reading No.167-163: 609.63 mm

Station	Spanned Positions (mm)			
	A-E	B-F	C-G	D-H
1	609.45	610.95	611.05	609.17
2	609.98	610.79	611.20	609.93
3	610.13	610.90	611.33	609.98
4	609.88	610.84	611.20	609.57
5	609.63	610.77	610.90	609.14
6	609.68	610.95	610.92	609.14
7	609.90	611.10	611.58	609.75
8	610.03	611.00	611.48	609.88
9	609.83	611.05	611.51	609.93
10	608.99	610.57	610.77	609.42
11	608.99	610.59	610.69	611.89
12	609.24	610.77	611.35	609.22



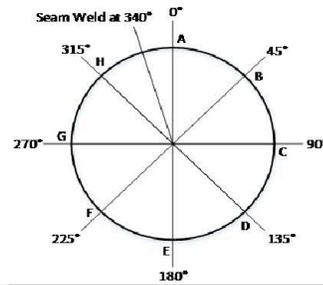
Station	Max. OD (mm)	@ Position	Min. OD (mm)	@ Position	Avg. OD (mm)	Stdev. (mm)	Ovality** (%)	Ovality incl. angle (°)
1	611.05	90	609.17	135	610.15	0.98	0.31	45
2	611.20	90	609.93	135	610.48	0.62	0.21	45
3	611.33	90	609.98	135	610.58	0.64	0.22	45
4	611.20	90	609.57	135	610.37	0.77	0.27	45
5	610.90	90	609.14	135	610.11	0.86	0.29	45
6	610.95	45	609.14	135	610.17	0.91	0.30	90
7	611.58	90	609.75	135	610.58	0.90	0.30	45
8	611.48	90	609.88	135	610.60	0.77	0.26	45
9	611.51	90	609.83	0	610.58	0.83	0.28	90
10	610.77	90	608.99	0	609.94	0.87	0.29	90
11	611.89	135	608.99	0	610.54	1.19	0.48	135
12	611.35	90	609.22	135	610.15	1.08	0.35	45

\* Imperial micrometer was used and measurements were converted.

$$** \text{Ovality} = \frac{(D_{\max} - D_{\min})}{(D_{\text{nom}})} * 100\%$$

Measurements Taken By: <b>SEB</b>	Date: <b>3-Mar-15</b>	Title: <b>Task 11 Compression Test</b>	
Measurements Approved By: <b>JHB</b>	Date: <b>3-Mar-15</b>	Specimen Identification: <b>11.c (Compression 3)</b>	

# Wall Thickness Measurements



## Micrometer Measurements

### Pre-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	12.94	12.97
End A - Position D	12.93	12.94
End A - Position F	13.03	13.03
End A - Position H	12.94	12.93
End B - Position B	12.87	12.89
End B - Position D	12.84	12.84
End B - Position F	12.93	12.92
End B - Position H	12.80	12.81

**Micrometer ID:**

Mitutoyo 0-1"

No. 293-180

Calibration (1"): 1.00045"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX

±0.001"

Serial Number: 78000

### Post-test Pipe Ring Verification

	Micrometer (mm)	Ultrasonic probe (mm)
End A - Position B	13.01	13.01
End A - Position D	12.96	12.96
End A - Position F	13.01	12.99
End A - Position H	12.90	12.87
End B - Position B	12.87	12.84
End B - Position D	12.86	12.85
End B - Position F	12.66	12.63
End B - Position H	12.85	12.82

**Micrometer ID:**

Mitutoyo 0-1"

No. 293-180

Calibration (1"): 1.00026"

**Ultrasonic Probe ID:**

Dakota Ultrasonics MVX

±0.001"

Serial Number: 78000

## Ultrasonic Measurements

### Pre-test Measurements

Station	Wall Thickness (mm)							
	0	45	90	135	180	225	270	315
1	12.90	13.00	12.88	12.99	12.93	13.05	12.95	12.83
2	12.83	13.02	12.86	12.89	12.83	12.97	13.00	12.91
3	12.85	12.99	12.95	13.01	12.90	13.01	12.99	12.90
4	12.95	13.04	13.10	13.02	12.93	13.00	13.10	12.96
5	12.93	13.01	13.11	12.84	12.99	13.20	13.13	13.04
6	12.92	12.98	12.99	13.03	12.84	13.14	13.11	12.92
7	12.92	12.99	13.18	13.03	12.87	13.24	13.22	13.01
8	12.93	13.06	13.04	12.95	13.06	13.02	13.20	13.10
9	12.80	12.97	13.07	13.14	12.92	13.13	13.14	12.92
10	12.81	12.94	12.89	12.94	12.89	12.96	12.99	12.82
11	12.79	12.90	12.85	12.91	12.85	12.96	12.98	12.83
12	12.75	12.86	12.88	12.88	12.84	12.87	12.99	12.82

Average: 12.97  
Std. dev: 0.106

### Post-test Measurements

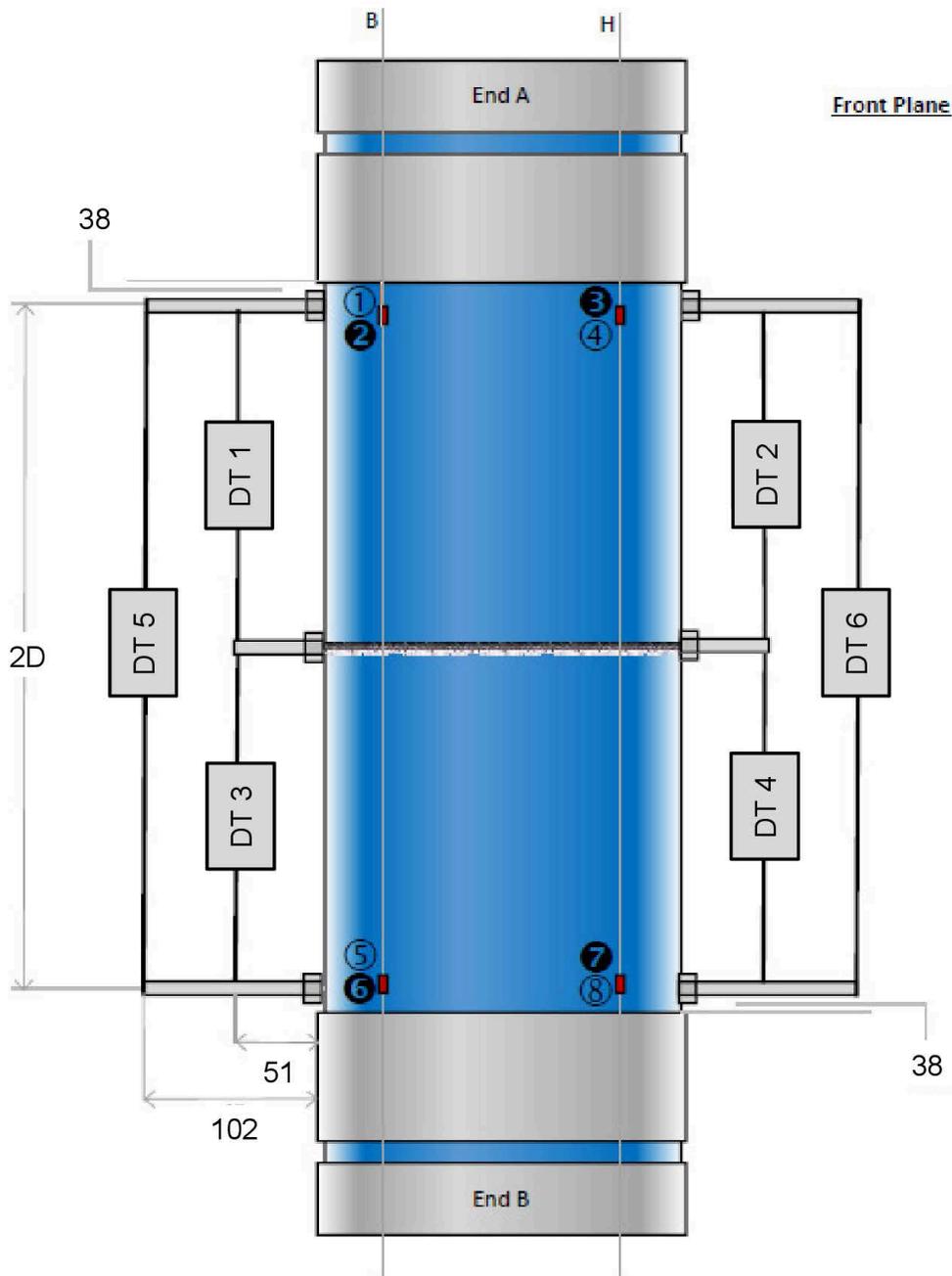
Station	Wall Thickness (mm)							
	0	45	90	135	180	225	270	315
1	12.77	12.87	12.81	12.86	12.68	12.81	12.9	12.75
2	12.68	12.78	12.76	12.8	12.57	12.81	12.86	12.88
3	12.71	12.78	12.84	12.72	12.64	12.8	12.88	12.8
4	12.73	12.93	12.79	12.69	12.66	12.9	12.98	12.79
5	12.75	12.78	12.82	12.62	12.51	12.79	12.88	12.86
6	12.7	12.76	12.86	12.64	12.57	12.8	12.93	12.77
7	Buckled Region							
8								
9								
10								
11							11.99	
12	12.5	12.67	12.59	12.48	12.5	12.2	12.75	12.59

Average: 12.73  
Std. dev: 0.170

Pre-Test Measurements By: SEB	Date: 3-Mar-15	Approved By: JHB	Date: 3-Mar-15	Title: Task 11 Compression Test
Post-Test Measurements By: SLS	Date: 4-May-16	Approved By: CMJT	Date: 25-Apr-17	Specimen Identification: 11.c (Compression 3)



### Instrumentation Diagram



■ Uni-Axial Strain Gauge (2,3,4,6,7,8)

■ Bi-Axial Strain Gauge (1,5)

DT X Displacement Transducer

**Notes:**

Dimensions in mm

Two sets (pairs) of VIC cameras used. One set aimed at the front of the specimen and one at the rear.

Drawing Done By: SEB	Date: 13-Mar-15	Title: Task 11 Compression Test	
Drawing Approved By: CMJT	Date: 19-May-17	Specimen Identification: 11.c (Compression 3)	