Evaluation of HDPE Pipelines Structural Performance

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November 2010

A Publication
As a Part of the Initiative on the Underground Structural Health Monitoring and Equipment Development

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SUMMARY

Structural performances of 191 HDPE pipelines throughout 10 different states throughout the nation were investigated. The sites were selected to cover diverse geographical locations. Qualitative and quantitative observations and measurements were performed using a pipeline inspection camera and a pipeline laser profiling unit. Several failure modes were identified for all the pipelines tested including: cracking/fracture, excessive deformation, joint displacement, inverse curvature and buckling. This study showed that 100% of the pipelines tested suffered from some or many of the aforementioned failure modes. In 68% of the pipes tested, the governing maximum deformations (Y, X, and/or ovality) of 5% was exceeded. A maximum value of 34% was observed for the maximum deformation and the average of maximum deformations was 7.6% among all pipelines inspected. This study indicates that structural health and integrity of the installed HDPE pipelines tested are generally below structurally acceptable levels of serviceability.

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1 – Introduction

High-Density Polyethylene (HDPE) pipes are commonly used in municipal, industrial, underwater, mining, landfill gas extraction, and agricultural applications. In contrary to its wide range of applications, there have been few studies to evaluate the behavior of buried HDPE pipes. This study is a part of a major initiation on health monitoring of underground structures in which a new state-of-the-art laser profiler is being developed. Thus, data is being collected from flexible pipe systems for comparative purposes. This report presents the initial results of video and laser inspections of HDPE pipelines in 61 site locations in 10 states throughout the nation. Different modes of structural failure are distinguished and analyzed both qualitatively and quantitatively throughout the study.

The project sites included inspection of more than 31,000 feet of HDPE pipeline sections. The detailed specifications of each states project sites are shown in Table 1. Figure 1 shows the locations of the sites.

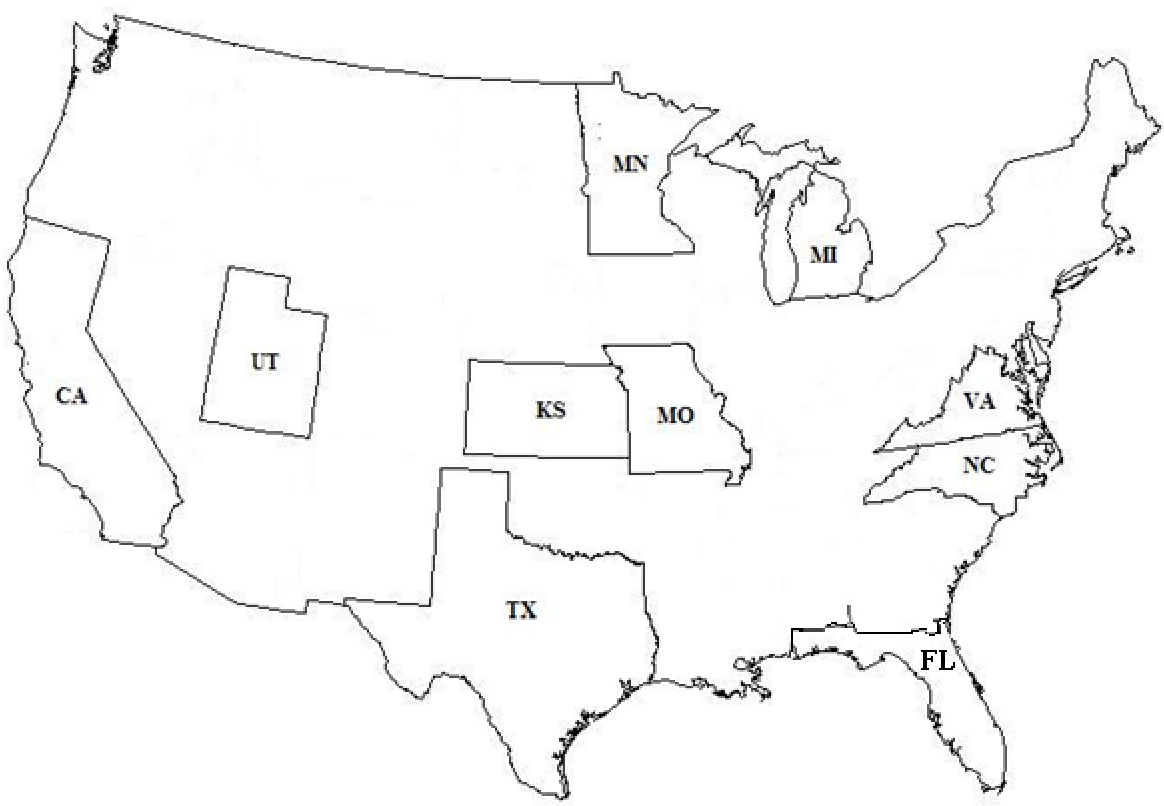


Figure 1 Layout of site numbers/locations

Table 1 Information of inspected sites and pipelines at each state

State	Number of site locations	Number of pipelines	Total length of the pipelines	
			(ft)	(m)
Texas	9	22	2,800	854
North Carolina	6	11	600	183
Virginia	8	21	3,000	915
Minnesota	9	31	8,700	2,652
Kansas	3	10	1,655	505
Missouri	4	13	1,400	427
California	2	29	2,545	776
Utah	2	10	1,525	465
Michigan	16	29	5,149	1,570
Florida	2	15	4,405	1,343
Total	61	191	31,779	9,689

2 – Framework of the study

At each site, detailed video inspections were performed on selected pipelines. This was done in three steps.

Step 1: Qualitative Video Inspection (Failure detection)

The first step was devoted to qualitative inspection of the pipelines which contained detailed video inspections using a high intensity lighting inspection camera (CUES OZ II). In this step, different failures and failure modes were observed and recorded accordingly. A view of the camera used for this study is shown in Figure 2.

a) Data Logger and Console

b) Video Camera

c) Laser Video Camera

Figure 2 Different instrumentations used in pipeline tests: a) CUES Inspector General instrumentation console, b) CUES rover with OZII Pan/Tilt/Zoom Camera Module (P/N CZ902), c) Ten-head laser ring and skid

Step 2: Quantitative Laser Video Inspection (obtaining maximum deformations)

The second step is devoted to quantitative evaluation of the behavior of the pipelines, which is the calculation of the percentage of deformation of the pipes using a pipeline laser profiling unit. In this technique, a ring of laser light is projected on the inside surface of the pipe. This ring is perpendicular to the longitudinal axis of the pipe. A view of the high-contrast laser profile under camera vision is shown in Figure 3. The laser profiling unit was placed at the far end of the pipeline and was pulled back to the beginning of the pipeline. Light was not allowed in the pipe to maximize the clarity of the ring. The laser profiling unit (Ten-head laser ring and skid) and other equipment are shown in Figure 2.

The acquired results were then processed using a special software provided with the laser profiling unit. A typical view of the Profiler software used for this purpose is shown in Figure 4.

In the post processing stage, the change in the pipe's diameter in vertical and horizontal directions or the deformation of the pipeline is calculated as a percentage variance from the expected internal diameter.

Typically, the maximum deformation of a given pipeline section occurs in the X or Y diameter; however, the pipeline may deform in a skew manner (racking behavior), so as to have the maximum deformation in the diagonal direction of the pipe (refer to Figure 1). In such a case, the maximum deformation is captured only by ovality graphs. Thus, the maximum of X and Y deformations, and the ovality of the pipe is considered as the maximum deformation of the pipeline in this study.

The ovality shows how oval or 'out of round' a pipe's cross-section has become due to deformation. This is displayed as a positive percentage, and the 0% represents a perfectly round pipe. The formula is based upon the American Society for Testing and Materials F1216 standards where it states:

$$\mathrm{O}vality = 100 \times \frac{\text{Maximum inside diameter} - \text{Mean inside diameter}}{\text{Mean inside diameter}}$$

in which q is the percentage of ovality of the original pipe. For obtaining mean inside diameter, the actual diameters are calculated over 90 different directions at each section.

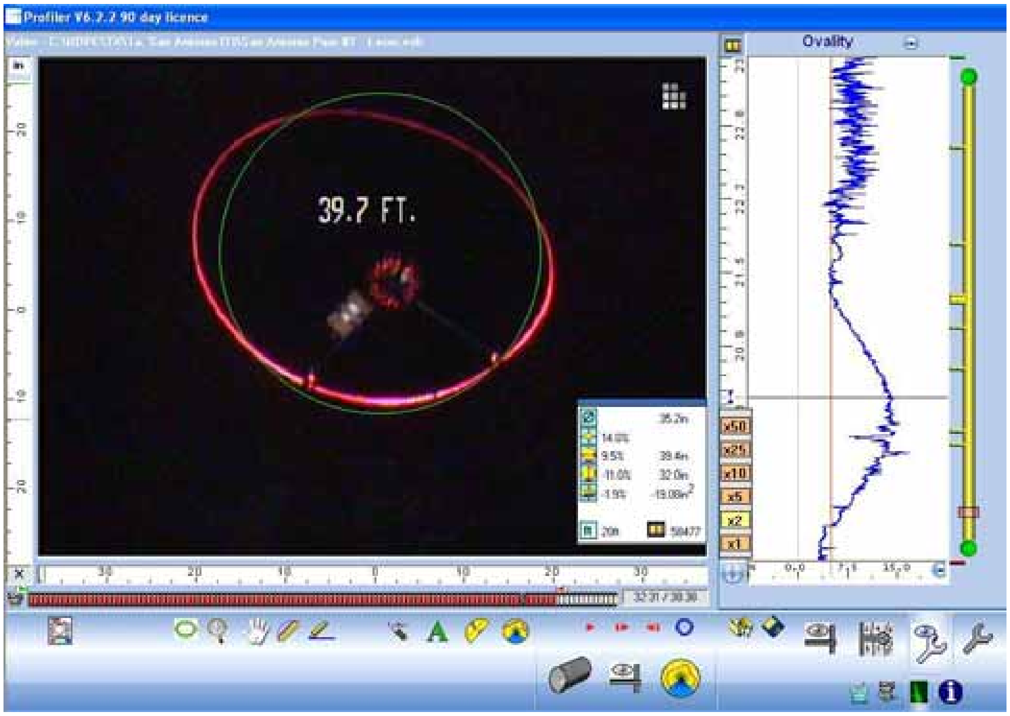


Figure 3 View of laser ring and skid under vision showing the laser ring profile and part of Ovality deformation graph for a sample pipeline in Texas State (pipeline No. 1 - Site No. 1: San Antonio – HW 1604 & 1560)

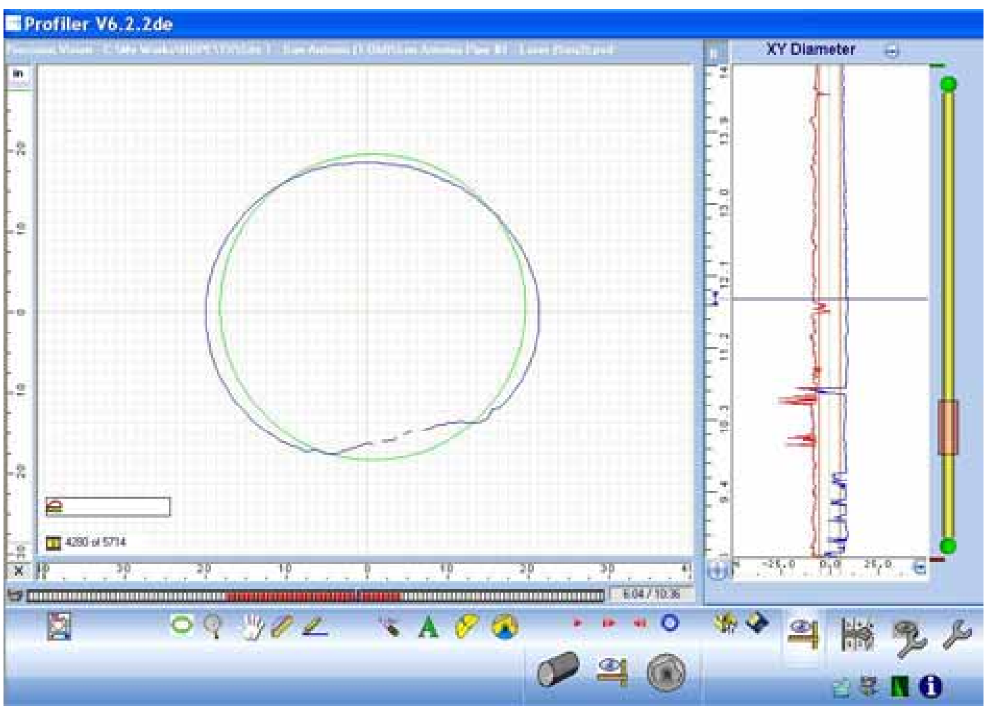
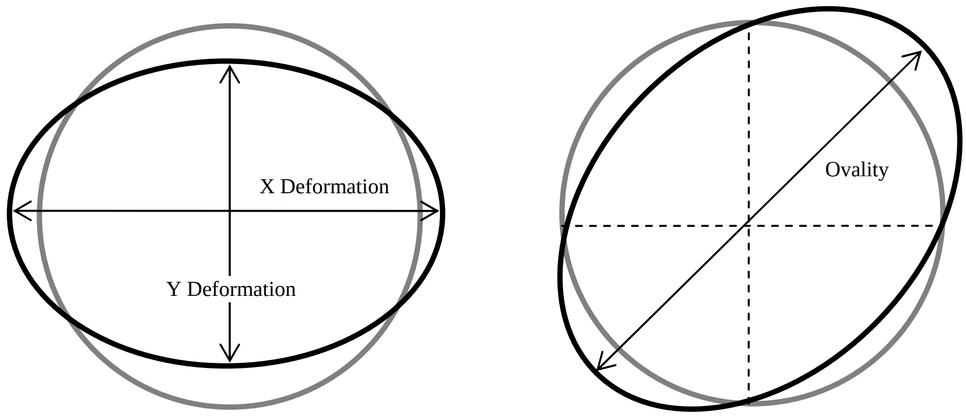


Figure 4 A view of analysis software showing the deformed ring (blue) and undeformed ring (green) of a single frame of the video for a sample pipeline in Texas State (pipeline No. 1 - Site No. 1: San Antonio – HW 1604 & 1560)



a) Symmetric Deformation b) Unsymmetrical Deformation

Figure 5 Different types of deformations observed by pipes

Step 3: Evaluations and Comparisons

In the third step, the results obtained in the previous steps are reported and specific results are described based on the observed behavior of the pipes. Tables mentioning different failures, maximum deformation graphs and snapshots of the observed failures are part of these evaluations. A summary of the results and comparison between the general behaviors of different pipes in different site locations are summarized in the last step for obtaining a comprehensive understanding of the behavior of the HDPE pipes throughout the study.

3 – Failure Modes

Based on the results taken from the laser and video inspections, seven different categories have been distinguished for the structural failure and failure of the HDPE culverts. These failure modes are: cracking/fracture, excessive deformation, inverse curvature, joint displacement, corrugation growth and buckling. They are defined and depicted in this section.

a) Cracking/Fracture

Cracking/fracture mode is defined as visible lines denoting material discontinuity. Fracture, rip and rupture are other terms used for this type of failure. The cracks can occur in either longitudinal, diagonal or radial directions. Different cases of major cracks are shown in Figure 6.

a)

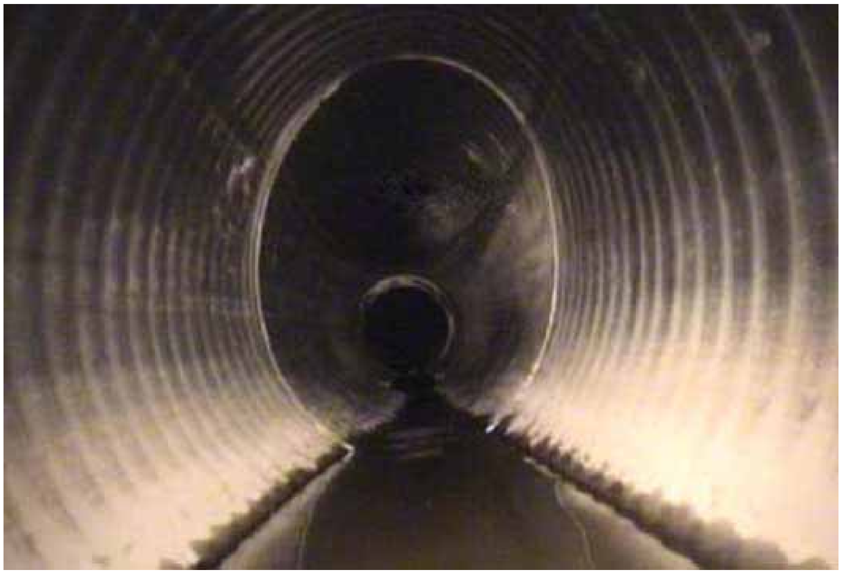
b)

Figure 6 Cracking/fracture failure; a) California State - Pipeline No. 20 (Site No. 2: Route 36), b) Texas State - (pipeline No. 19 (Segment 2) - Site No. 8: Houston - Fennell)

b) Excessive Deformation

Excessive deformation is defined as flattening or the change in the diameter of the pipe. This is particularly noticeable when the surface of the culvert displays a discernible circumferential change from a circular shape. Crown flattening and racking behavior are other cases of excessive deformation. The common limit of 5% is adopted for indicating excessive deformation. In some tests, large deformations of 20% are recorded. Different cases of excessive deformation are shown in Figure 7.

a)



b)

Figure 7 Excessive deformation failure; a) Texas State - pipeline No. 1 (Site No. 1: San Antonio – HW 1604 & 1560), b) Minnesota State - pipeline No. 18 (Site No. 6: Brooklyn Park - DuPont)

c) Inverse Curvature

Snap through (inverse curvature) is a buckling phenomenon which creates inverse curvature by deforming into reversed shapes by undergoing tensile instead of compressive deformation**.** This failure mode is known as the inward projection and bulging of the surface of a pipe surface due to excessive loads on the pipe. One case of inverse curvature failure mode is shown in Figure 8.

a)

b)

Figure 8 Inverse curvature deformation failure; a) Utah State - Pipeline No. 9 (Site No. 2: Silver Creek Parkway) b) Texas State - Pipeline No. 20 (Segment1) (Site No. 8: Houston – Fennel)

d) Joint Displacements

This failure mode is defined as the excessive joint displacement which causes a gap between the two adjacent pipes. The consequences permit the infiltration of embedment material and/or joint exfiltration. This case is shown in Figure 9.

a)

b)

Figure 9 Joint displacement failure; a) Virginia State -- pipeline No. 8 (Site No. 4: Mechanicsville), b) Texas State - pipeline No. 19 (Segment 1) (Site No. 8: Houston - Fennell)

e) Corrugation growth

Corrugation growth is defined as the occurrence of plastic deformation in the pipe's interior liner due to the transfer of stress from the outer corrugated wall to the inner liner. This phenomenon causes waviness in the interior pipe surface that affects its flow carrying characteristics. Two cases of typical pipe corrugation growth failure mode are shown in Figure 10.

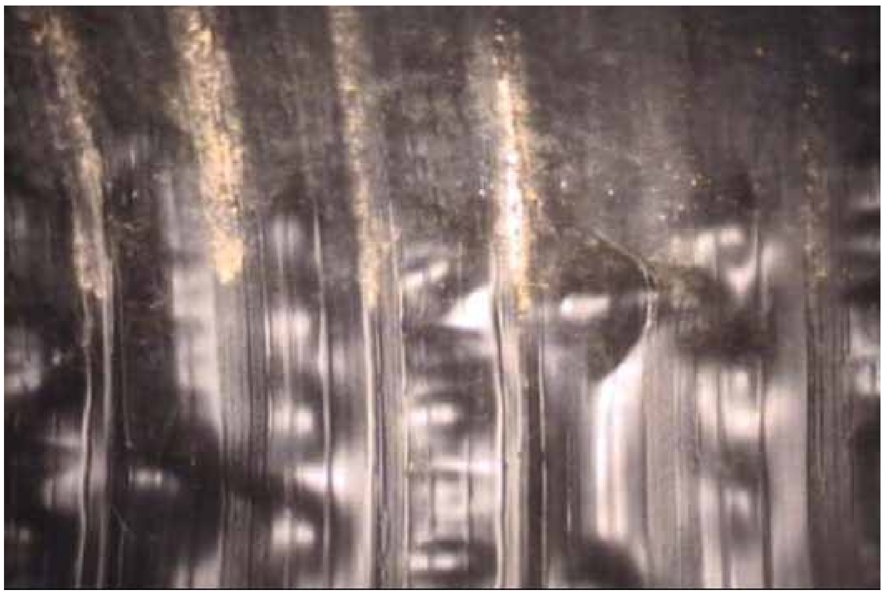
a)

b)

Figure 10 Corrugation failure; a) Kansas State - pipeline No. 7 (Site No. 2: Wichita), b) North Carolina State - pipeline No. 9 (Hickory-Oxford School Road)

f) Buckling

This failure mode is defined as the out of plane deformation due to large circumferential stresses which causes longitudinal and/or radial wavy surfaces of the pipe. This failure causes wavy appearance or dimpling on the surface of the pipe. Two cases of pipe surface buckling failure mode are shown in Figure 11.



a)

b)

Figure 11 Buckling deformation failure; a) North Carolina State - pipeline No. 11 (Rockingham-Love Lane) b) Utah State - pipeline No. 9 (Site No. 2: Silver Creek Parkway)

4 – Results

Laser and video inspections were performed on 191 pipelines having to total lengths of more than 31,000 feet. The raw data was processed and different failure modes and magnitudes of deformations were recorded. In this section these results are summarized. Statistical analyses are performed in order to find the average and maximum and percentages of observed failure modes in total and in each state. Detailed results pertaining to each state are found in appendices following the report.

Table 2 shows Percentage of experienced failure modes in total and in each state. This table shows that 69% of the pipes suffered from excessive deformation and 100% from corrugation growth. In addition, the 30%, 40%, 17% and 15% of the pipes suffered from the failure modes of joint displacement, cracking, buckling, and inverse curvature, respectively. It is acknowledged that the HDPE Type D is not in use currently.

Table 3 shows the maximum observed deformations and average of maximum deformations in total and in each state. This table shows that the maximum deformation for 69% of the pipelines was in the excess of the 5% limit specified by AASTHO Standards with the maximum and the average values of 34%, and 7.5%, respectively.

These results are also shown in Figure 12 to Figure 18 in bar column format for ease of comparison.

Table 2 Percentage of experienced failure modes in total and in each state

State	Excessive deforamtion	Cracking / Fracture	Inverse Curvature	Joint Displacement	Buckling	Corrugation Growth
Texas	38%	23%	18%	27%	18%	100%
North Carolina	75%	73%	0%	73%	27%	100%
Virginia	100%	26%	11%	32%	16%	100%
Minnesota	58%	26%	0%	26%	3%	100%
Kansas	70%	50%	30%	0%	20%	100%
Missouri	69%	20%	0%	0%	0%	100%
California	56%	69%	21%	7%	3%	100%
Utah	100%	40%	40%	20%	20%	100%
Michigan	82%	33%	10%	19%	23%	100%
Florida	73%	42%	17%	100%	42%	100%
Total	69%	40%	15%	30%	17%	100%

Table 3 Maximum observed deformation and average of maximum deformations in total and in each state

State	Number of site locations	Number of pipelines	Total length of the pipelines		Maximum deformation	Average of maximum deformation	Percentage of pipelines with excessive deformation (>5%)
			(ft)	(m)	(%)	(%)	(%)
Texas	9	22	2,800	854	22.5	6.8	38
North Carolina	6	11	600	183	10.4	6.3	75
Virginia	8	21	3,000	915	22.3	10.5	100
Minnesota	9	31	8,700	2,652	15	6.4	58
Kansas	3	10	1,655	505	10.4	6.8	70
Missouri	4	13	1,400	427	8.8	5	69
California	2	29	2,545	776	15.3	5.9	52
Utah	2	10	1,525	465	34	10.4	100
Michigan	16	29	5,149	1,570	23.1	10.5	82
Florida	2	15	4,405	1,343	10.3	6.3	73
Total	61	191	31,779	9,689	34	7.5	69

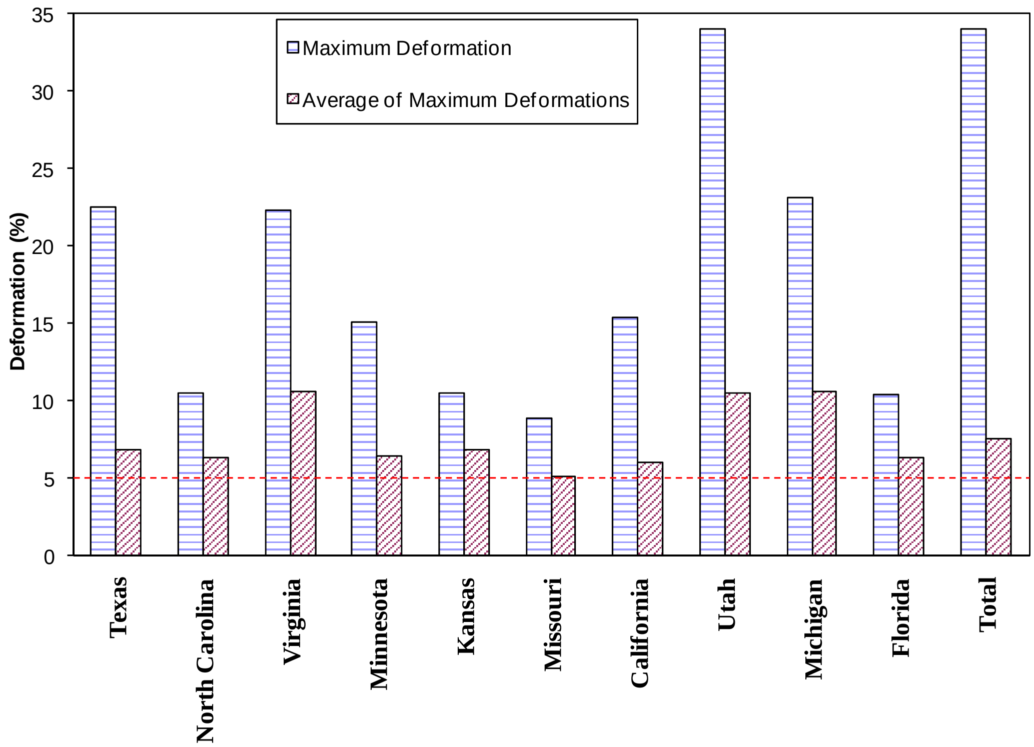


Figure 12 Maximum and average values for maximum deformations of pipelines inspected in each state and the average and maximum of the total pipes inspected.

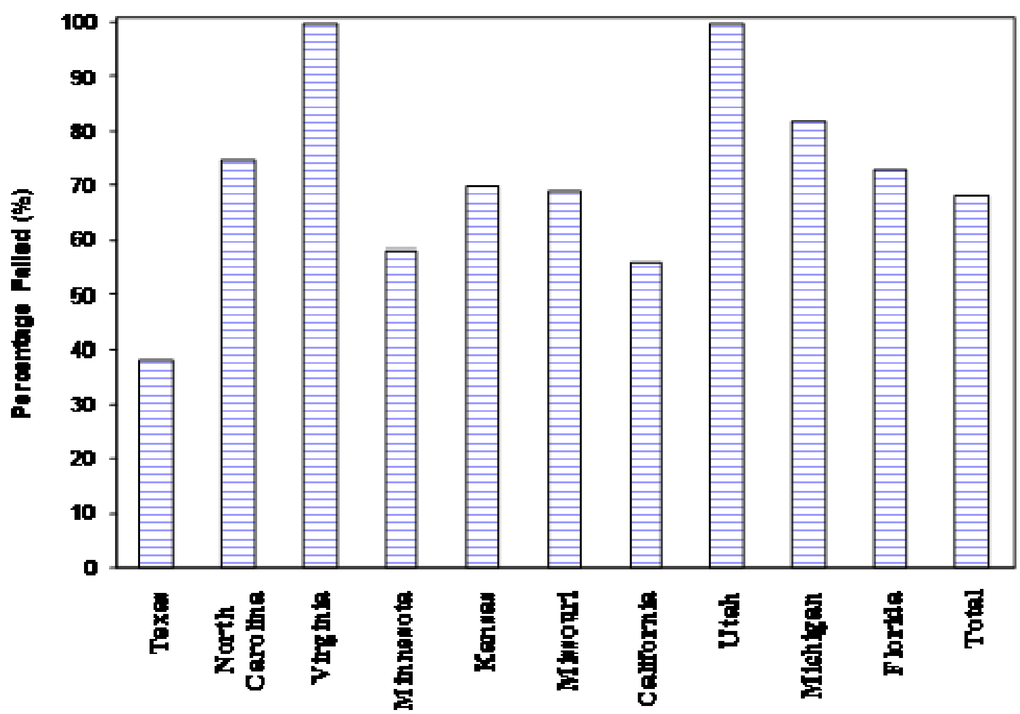


Figure 13 Percentage of pipelines failed by excessive deformation failure mode

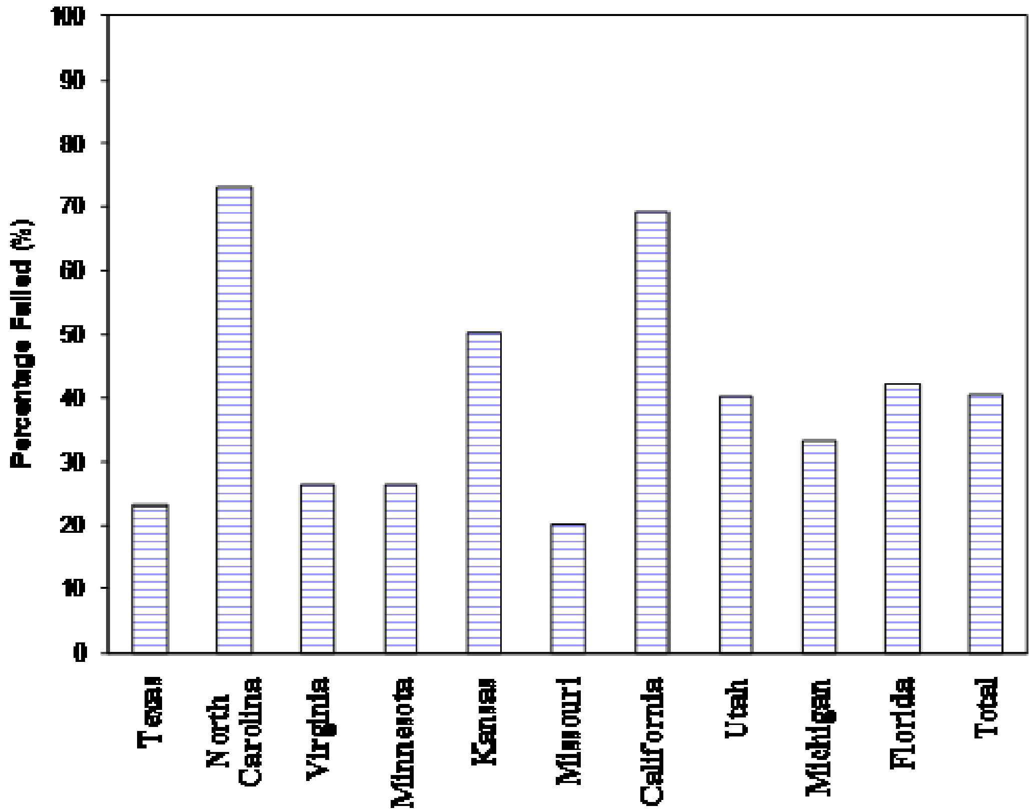


Figure 14 Percentage of pipelines failed by cracking/fracture failure mode

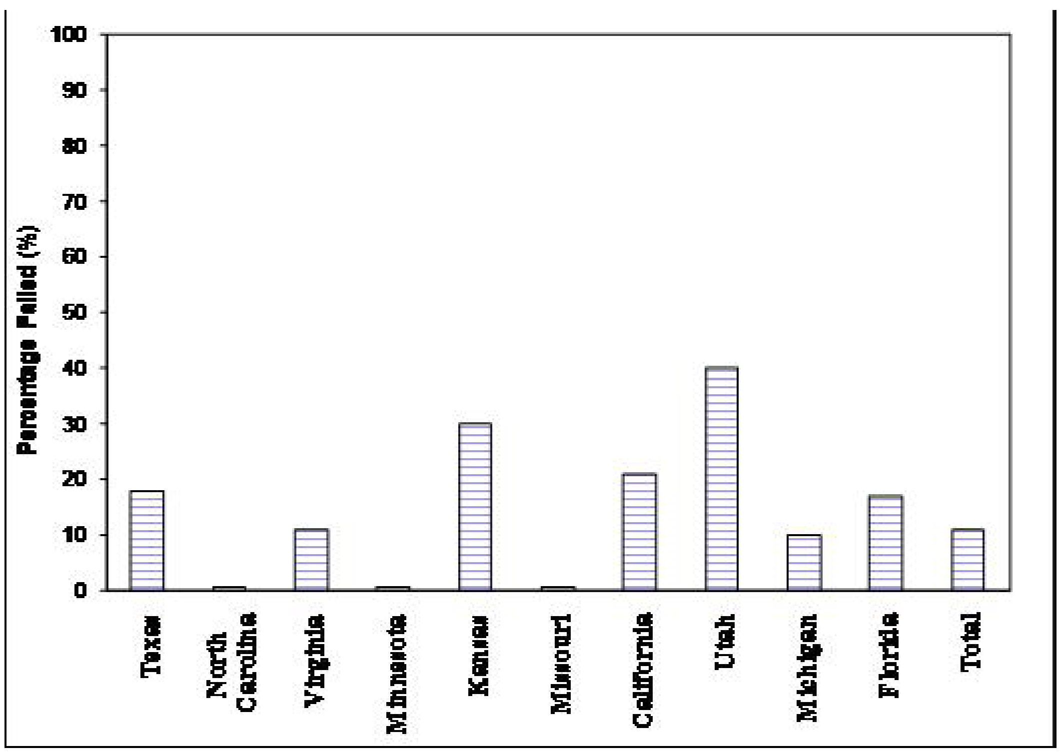


Figure 15 Percentage of pipelines failed by inverse curvature failure mode

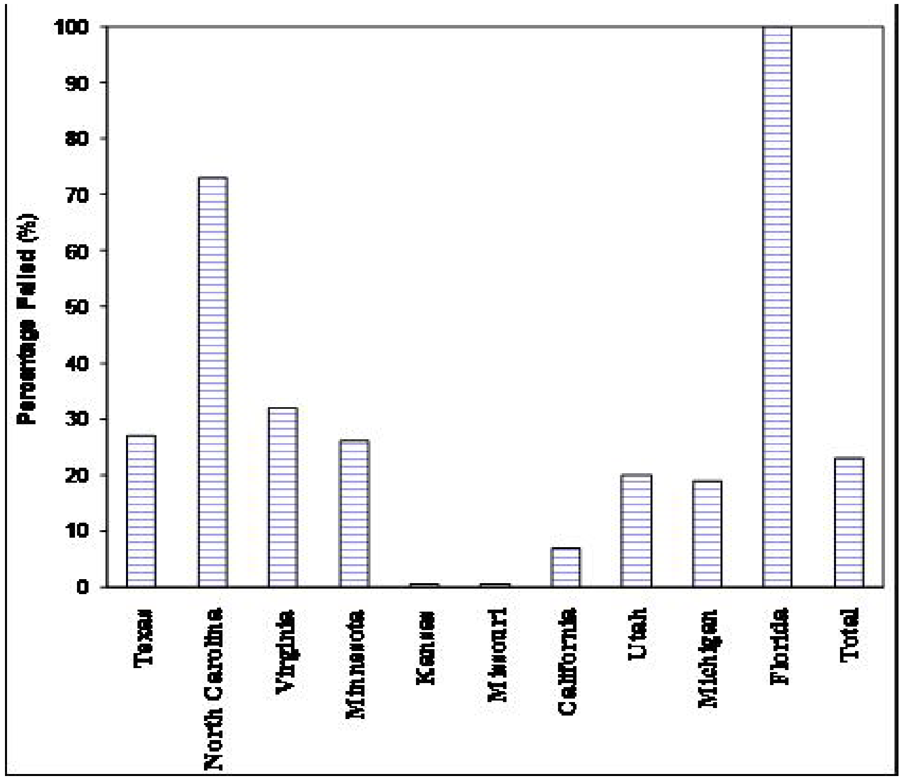


Figure 16 Percentage of pipelines failed by joint displacement failure mode

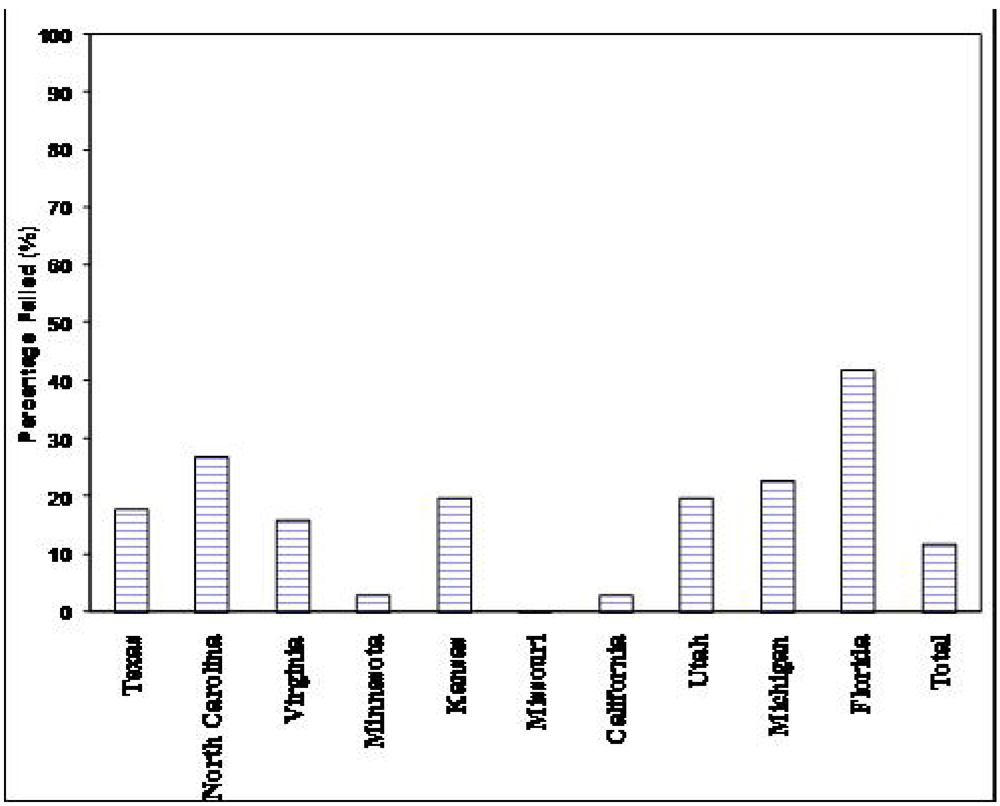


Figure 17 Percentage of pipelines failed by buckling failure mode

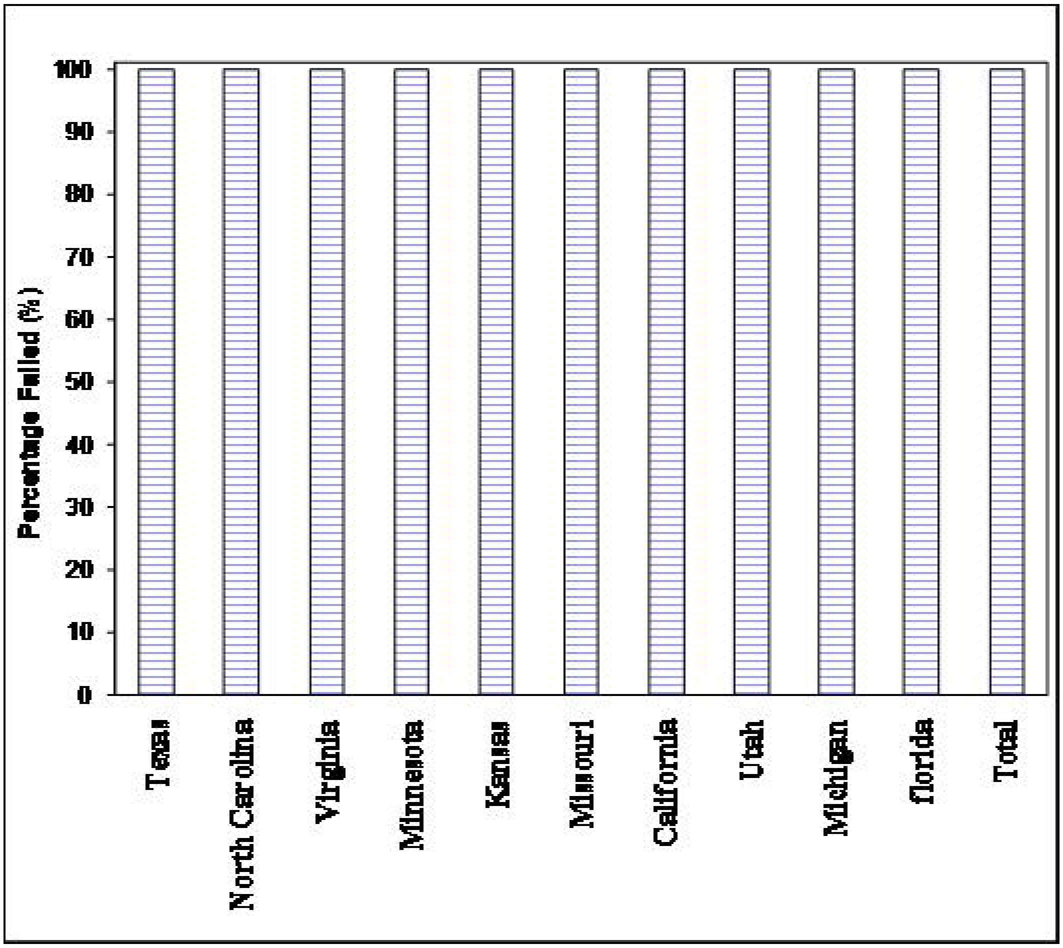


Figure 18 Percentage of pipelines failed by corrugation growth failure mode

5 – Summary, Conclusions, and Recommendations

Different pipelines in different site locations showed numerous failures throughout their lengths. By using a pipeline inspection camera, different failures of cracking/fracture, minor and major joint displacement, inverse curvature and buckling failure modes were observed and depicted in detail throughout the report.

Based on the findings of this study the following are the recommendations are noted:

1. Due to the different and multiple modes of failure experienced by the pipes identified in this study, it is evident that the knowledge of the long-term performance properties of HDPE pipes subjected to diverse service load is limited. Thus, further studies to identify the HDPE's long term properties are needed in order to avoid the unexpected failure such as those observed in this study.

2. Since 100% of the pipes experienced corrugation growth, it is recommended that a comprehensive study to be conducted to establish a post installation Mannings, n, due to the corrugation growth.

3. Since 69% of the pipes tested experienced an excessive deformation mode of failure (as high as 34%), it is recommended the long term stiffness properties of the HDPE pipes to be investigated.

4. It is recommended that the progressive failure characteristics of the HDPE pipes to be investigated in order to identify the cause of the multiple failure modes in a given pipeline which was inherent to most of the pipes investigated.

6 – Appendices

Details of deformation analyses and failure inspections for each pipeline inspected are presented in these appendices for all states. Pictures are extracted from the video camera for sections that have experienced important failure modes. Deformation along the length of the pipes in the horizontal and vertical directions is extracted from the laser video camera and is included for each pipeline evaluation when possible.

Appendix 1 – State of Texas

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Texas. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

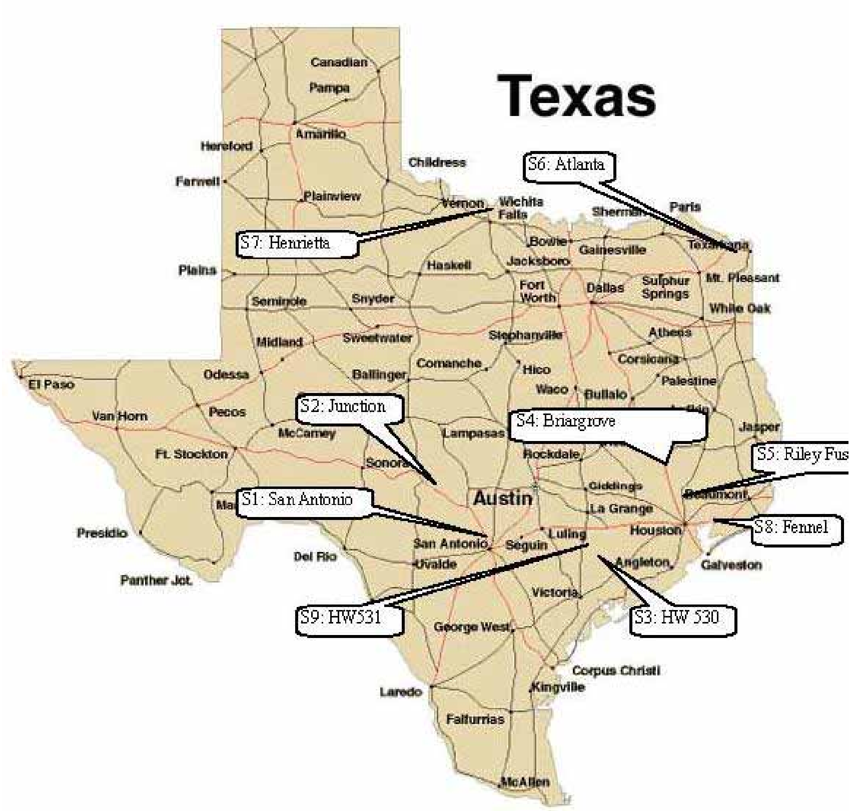


Figure 19 Layout of site numbers/locations

Table 4 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	San Antonio – HW 1604 & 1560	1	36	11/2/2006	418
		2	36	11/2/2006	195
		3	36	11/2/2006	200
2	Junction – HW 83	4	36	11/2/2006	160
3	Houston – HW 530	5	36	11/17/2006	40
		6*	42	11/17/2006	30
4	Houston – Briargrove MH-119	7	36	11/18/2006	340
		8	42	11/18/2006	380
5	Houston – Riley Fussel	9	36	11/18/2006	60
6	North Texas – Atlanta FM 997	10	36	11/29/2006	50
		11	36	11/29/2006	50
		12*	36	11/29/2006	50
		13*	42	11/29/2006	50
		14*	42	11/29/2006	50
7	North Texas - FM – 1197, Henrietta	15	48	1/22/2007	50
		16	48	1/22/2007	60
		17	48	1/22/2007	60
		18	48	1/22/2007	60
8	Houston – Fennell	19	36	2/8/2007	230
		20*	48	2/8/2007	230
9	Houston - HW 531	21	60	2/9/2007	30
		22	60	2/9/2007	30

* Laser video data was not collected

Table 5 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Joint Displacement	Corregation Growth	Buckling
1	San Antonio – HW 1604 & 1560	1	✓	✓	✓	✓	✓	✓
		2	✓	✓	✓	✓	✓	✓
		3	✓				✓	✓
2	Junction – HW 83	4					✓	
3	Houston – HW 530	5					✓	
		6		NA			✓	
4	Houston – Briargrove MH-119	7				✓	✓	
		8					✓	
5	Houston – Riley Fussel	9		✓			✓	
6	North Texas – Atlanta FM 997	10					✓	
		11					✓	
		12		NA			✓	
		13		NA			✓	
		14		NA		✓	✓	
7	North Texas - FM – 1197, Henrietta	15		✓			✓	
		16					✓	
		17					✓	
		18					✓	
8	Houston – Fennell	19 (Seg1)	✓	✓	✓	✓	✓	
		19 (Seg2)	✓	✓	✓	✓	✓	
		20 (Seg1)	✓	NA	✓	✓	✓	
		20 (Seg2)	✓	NA	✓	✓	✓	✓
9	Houston - HW 531	21					✓	
		22					✓	
Percentage of pipelines experiencing failure mode			32%	38%	27%	36%	100%	18%

NA: Laser video data was not collected

Table 6 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	San Antonio – HW 1604 & 1560	1	20.6	19.6	22.5	22.5
		2	14.5	18.4	19.5	19.5
		3	6.2	5.9	8.2	8.2
2	Junction – HW 83	4	1.4	1.7	1.7	1.7
3	Houston – HW 530	5	3.5	3.7	3.4	3.7
		6	NA	NA	NA	NA
4	Houston – Briargrove MH-119	7	1.4	2.1	2.6	2.6
		8	1.1	2	2.3	2.3
5	Houston – Riley Fussel	9	5.4	5.1	5.4	5.4
6	North Texas – Atlanta FM 997	10	3.5	4	4.2	4.2
		11	2.7	3.1	2.9	3.1
		12	NA	NA	NA	NA
		13	NA	NA	NA	NA
		14	NA	NA	NA	NA
7	North Texas - FM – 1197, Henrietta	15	4.4	4.5	5.2	5.2
		16	1.7	1.7	2.4	2.4
		17	3.5	3.5	3.9	3.9
		18	2.5	3.4	3.8	3.8
8	Houston – Fennell	19 - 1	5.1	7.1	6.2	7.1
		19 -2	10.7	18.6	15.6	18.6
		20	NA	NA	NA	NA
9	Houston - HW 531	21	2.7	4.6	3.8	4.6
		22	3.1	3	2.8	3.1
	Max		20.6	19.6	22.5	22.5
	Min		1.1	1.7	1.7	1.7
	Average		5.2	6.2	6.5	6.8

NA: Laser video data was not collected

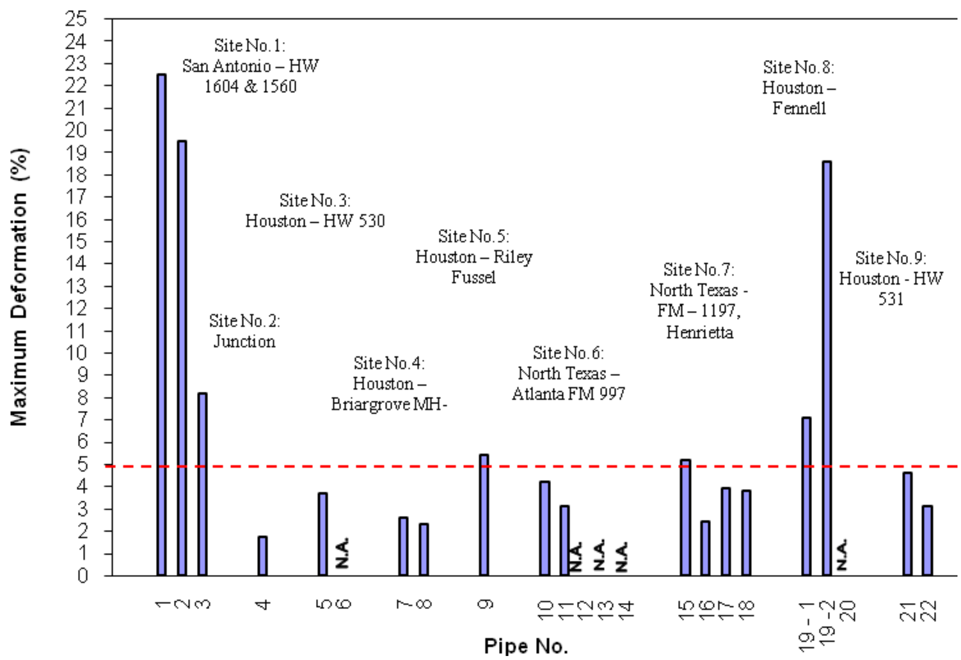
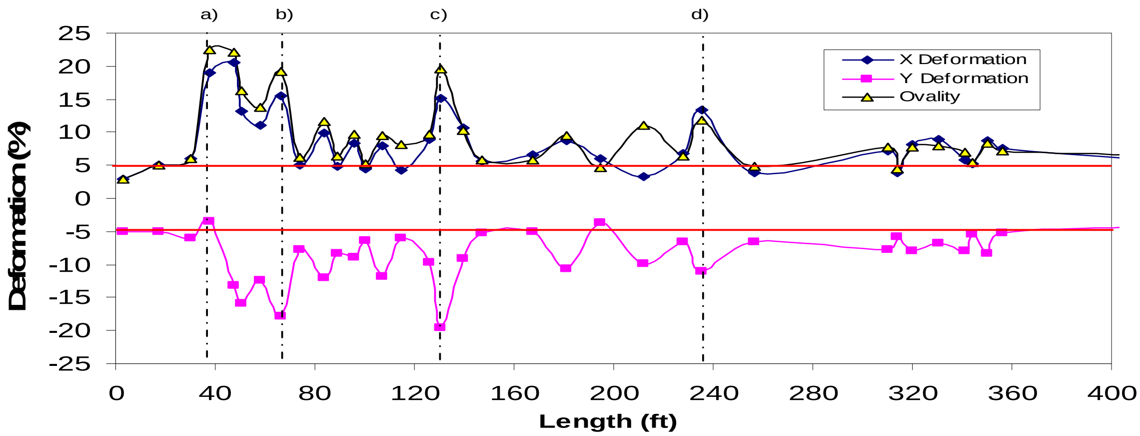
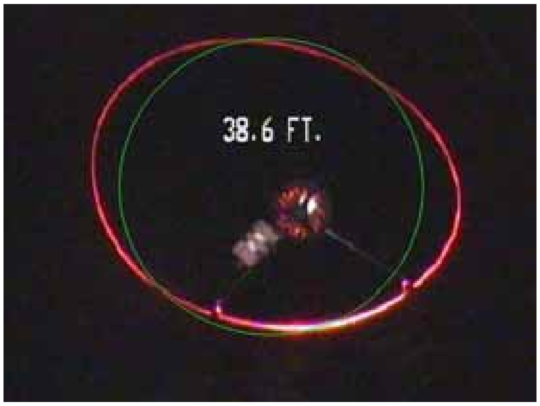


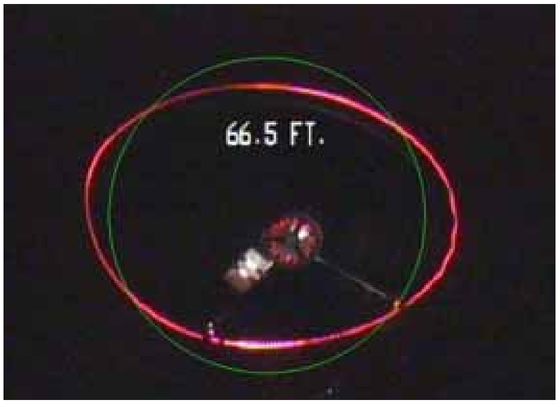
Figure 20 Comparison of Maximum deformations calculated for pipelines tested

Pipeline No. 1 (Site No. 1: San Antonio – HW 1604 & 1560)





a)



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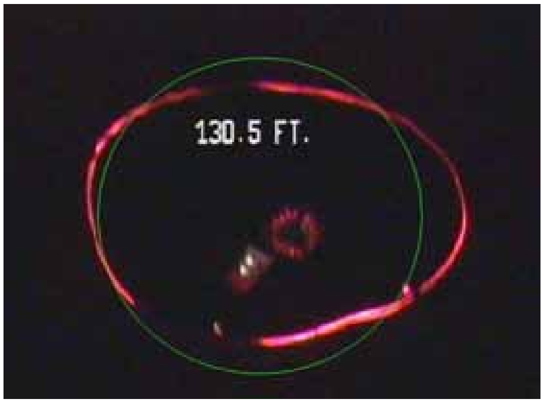

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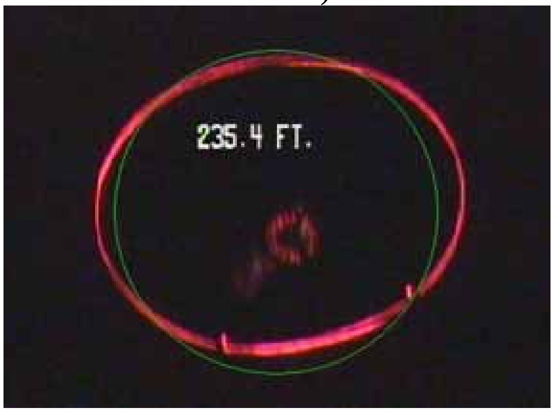


d)

Figure 21 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: San Antonio – HW 1604 & 1560)

Figure 22 Inverse curvature and corrugation growth failure modes for pipeline No. 1 (Site No. 1: San Antonio – HW 1604 & 1560)

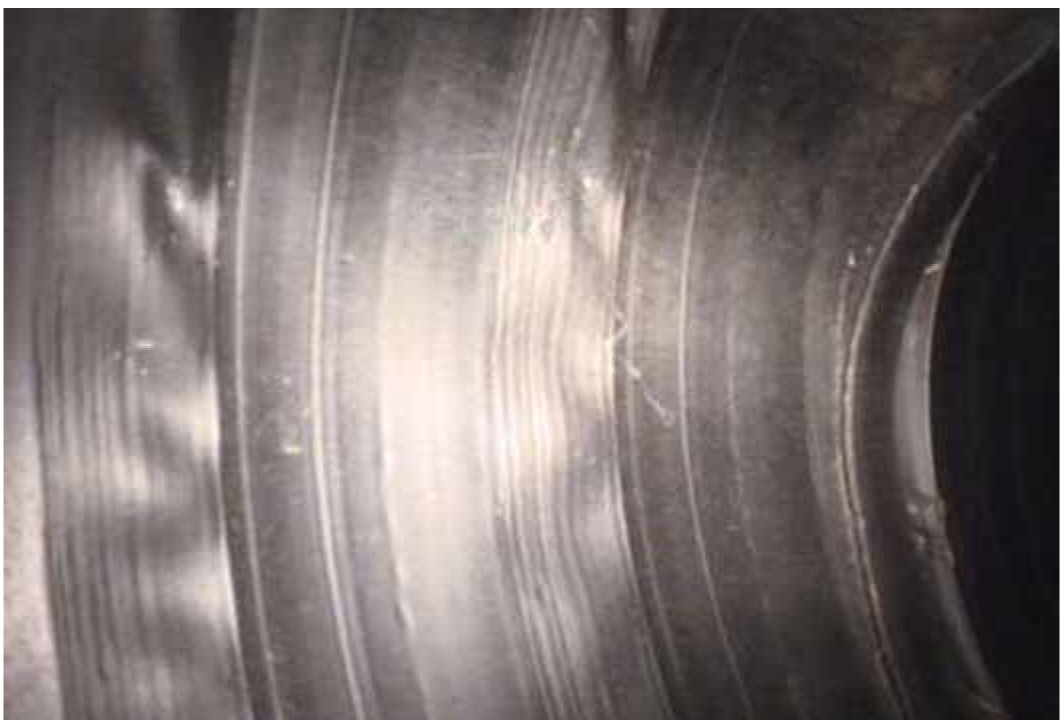
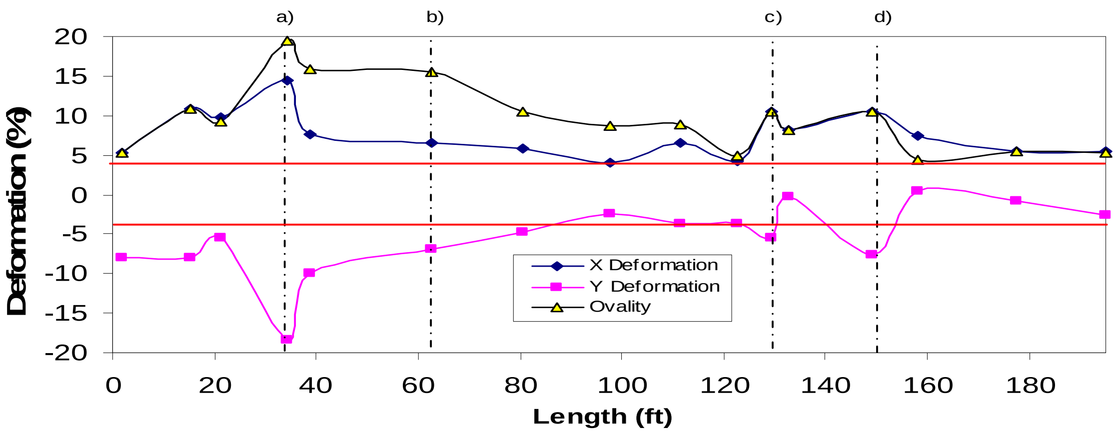


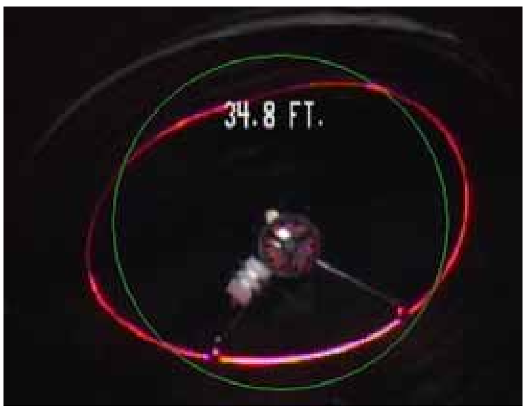
Figure 23 Buckling failure for pipeline No. 1 (Site No. 1: San Antonio - HW 1604 and 1560)

Figure 24 Cracking/fracture and buckling failures for pipeline No. 1 (Site No. 1: San Antonio - HW 1604 and 1560)

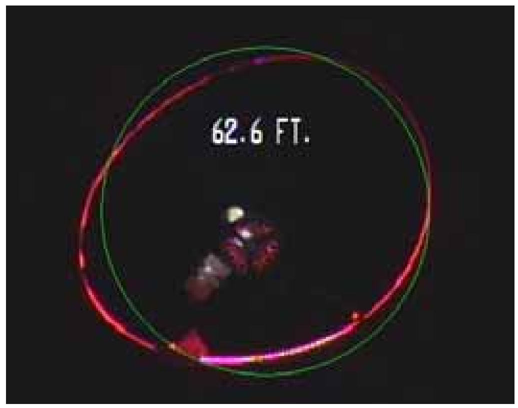
Figure 25 Excessive deformation and corrugation growth failure modes for pipeline No. 1 (Site No. 1: San Antonio - HW 1604 and 1560)

Pipeline No. 2 (Site No. 1: San Antonio – HW 1604 & 1560)





a)



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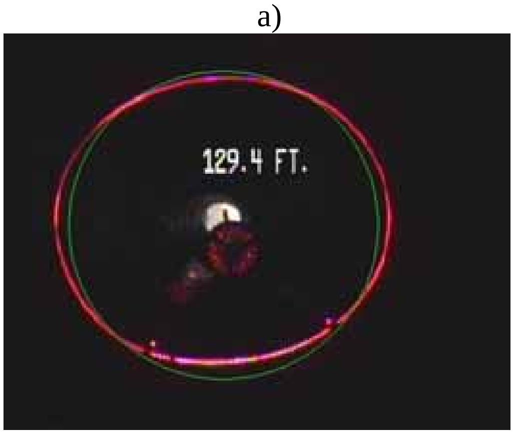
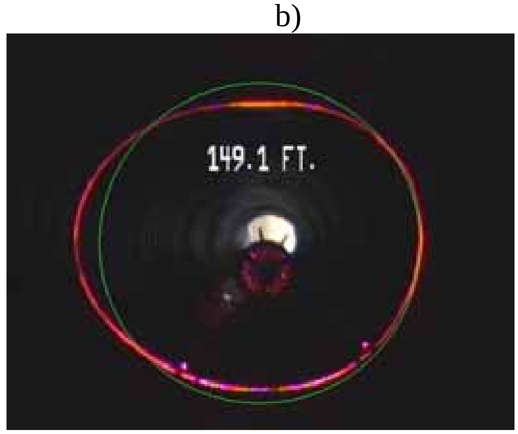


c)

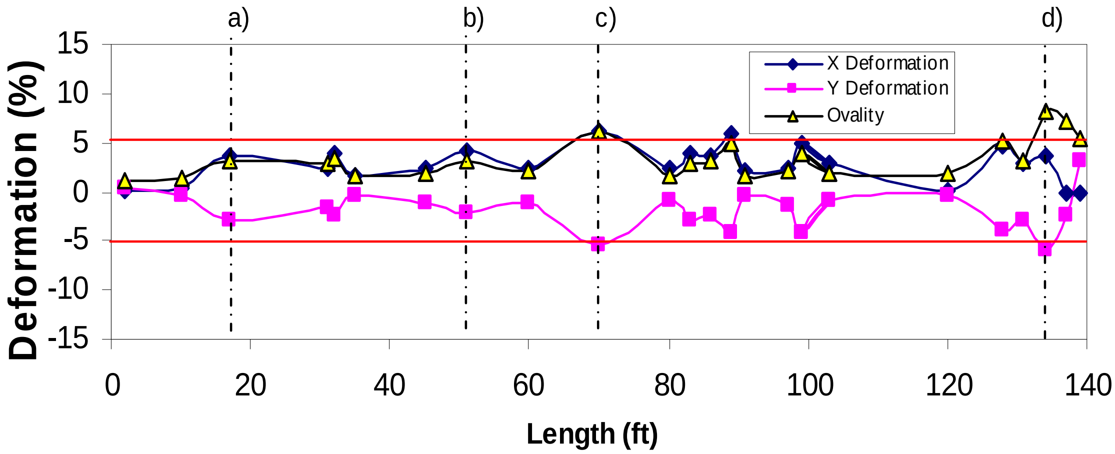


d)

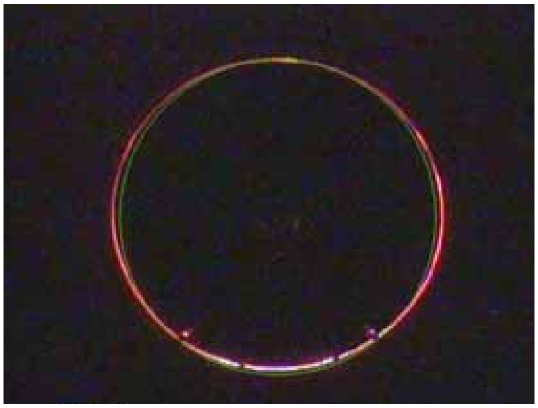
Figure 26 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: San Antonio – HW 1604 & 1560)

Figure 27 Buckling and excessive deformation failures for pipeline No. 2 (Site No. 1: San Antonio - HW 1604 and 1560)

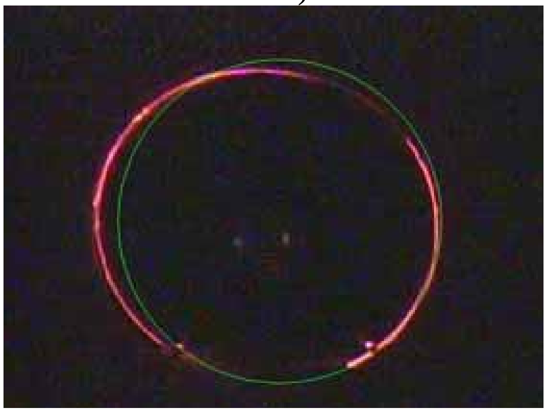
Pipeline No. 3 (Site No. 1: San Antonio – HW 1604 & 1560)



a)



b)



c)

d)

Figure 28 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: San Antonio – HW 1604 & 1560)

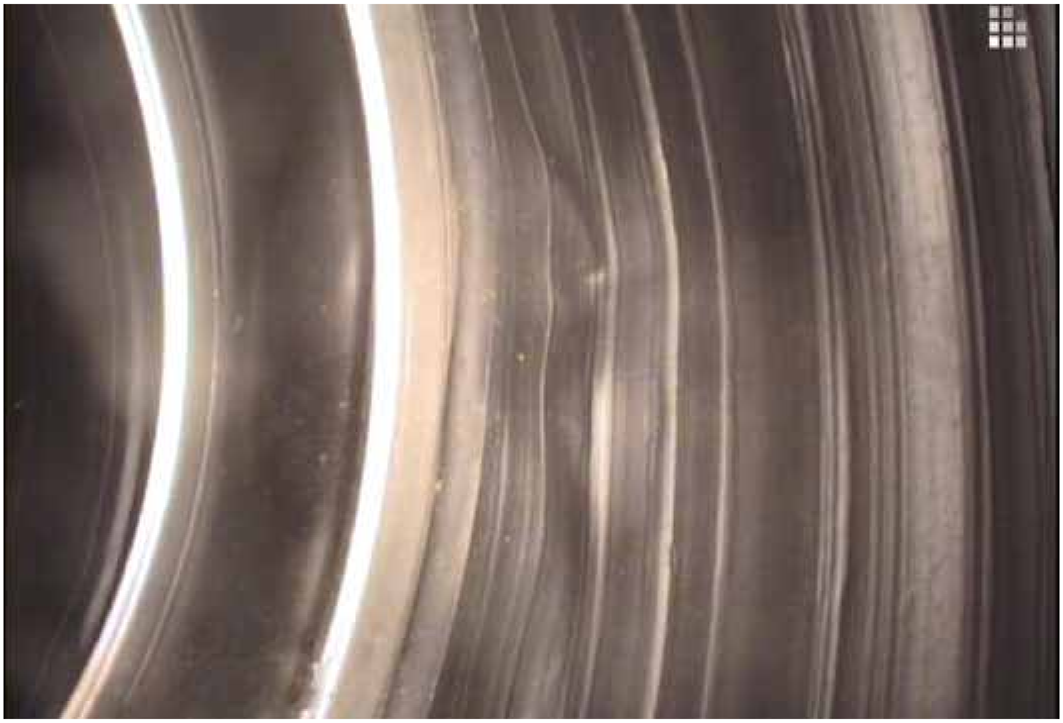
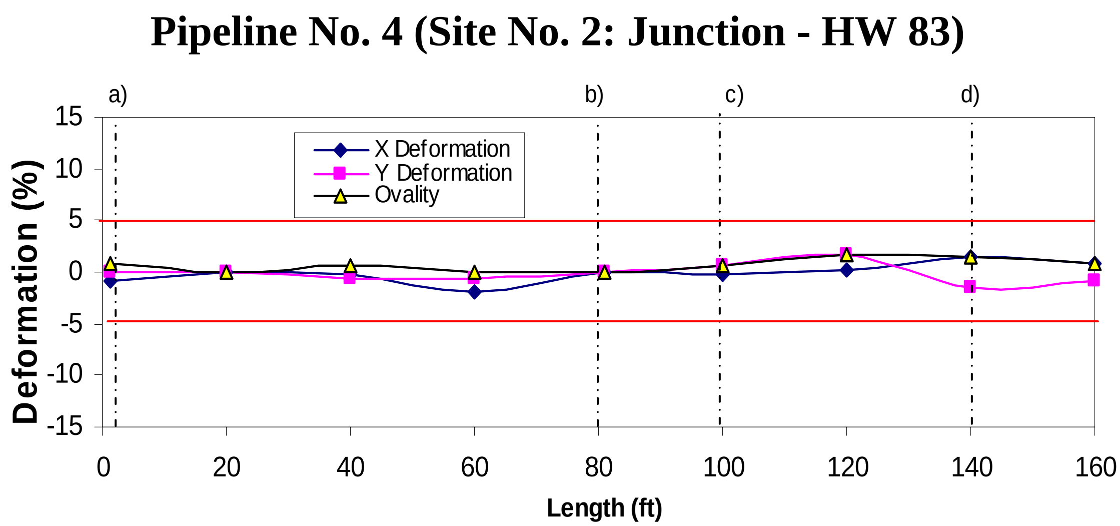
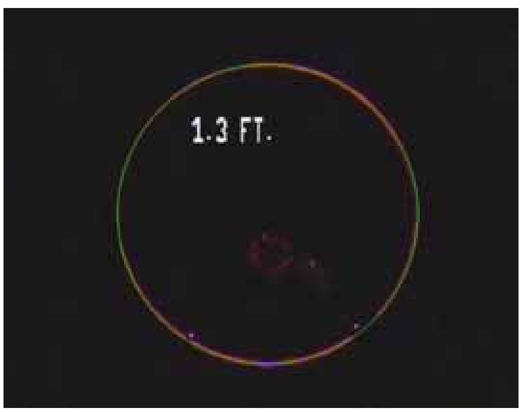


Figure 29 Buckling failure for pipeline No. 3 (Site No. 1: San Antonio - HW 1604 and 1560)

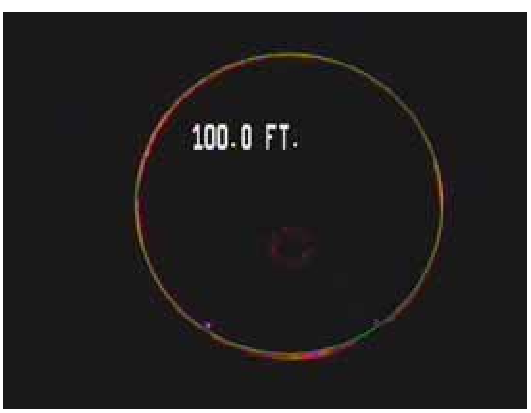
Figure 30 Corrugation growth and excessive deformation failures for pipeline No. 3 (Site No. 1: San Antonio - HW 1604 and 1560)





a)

b)

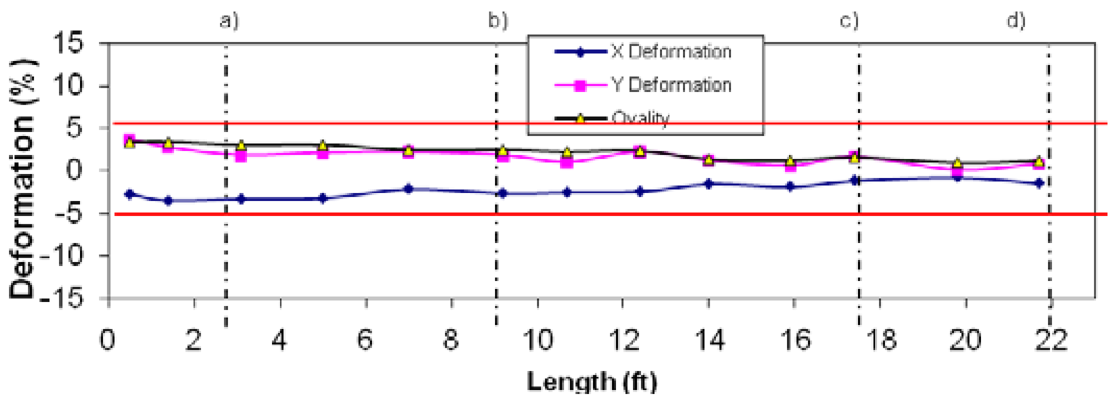


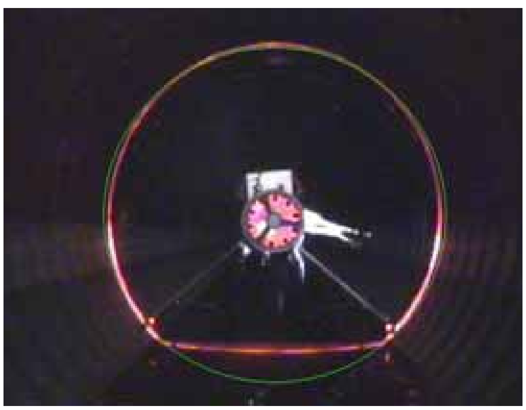
c)

d)

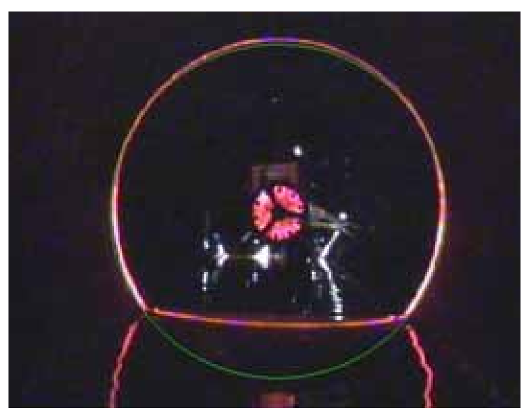
Figure 31 Horizontal and vertical deformation of the pipeline No. 4 (Site No. 2: Junction – HW 83)

Pipeline No. 5 (Site No. 3: Houston – HW 530)





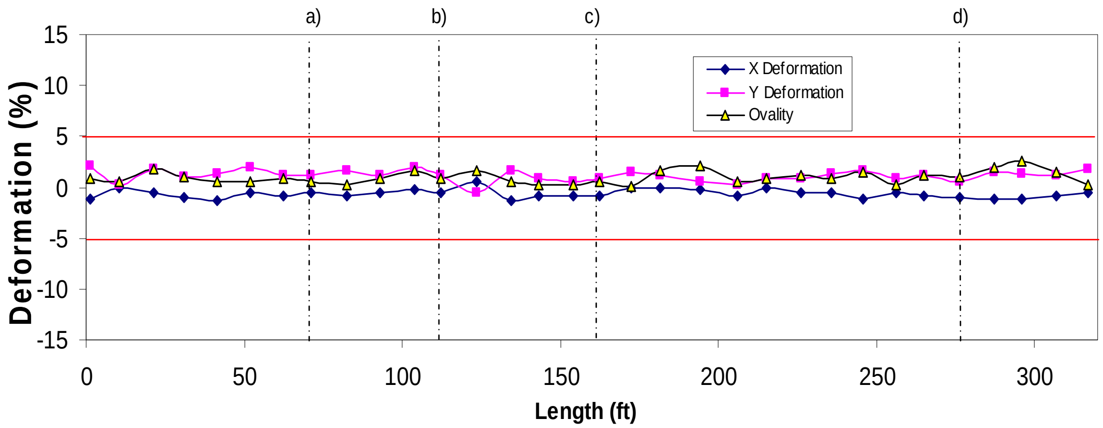

a) b)

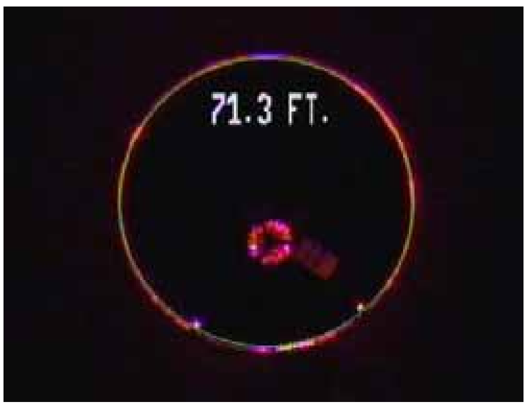



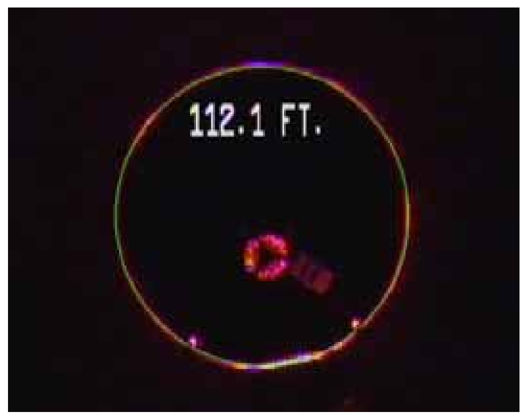
c.) d)

Figure 32 Horizontal and vertical deformation of the pipeline No. 5 (Site No. 3: Houston – HW 530)

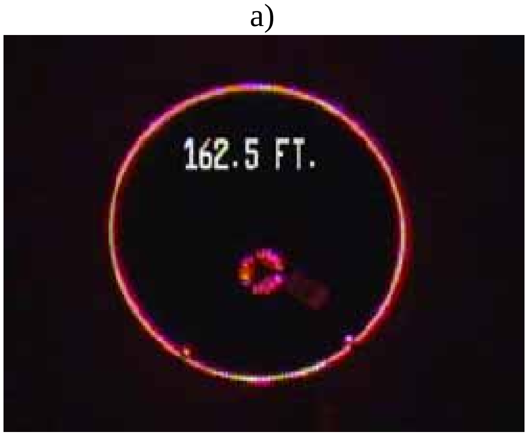
Pipeline No. 7 (Site No. 4: Houston - Briargrove - HW 119)

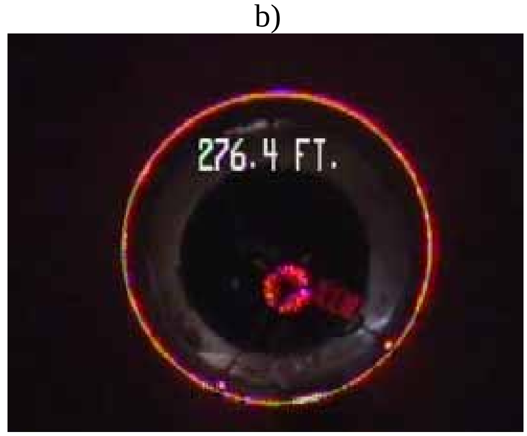






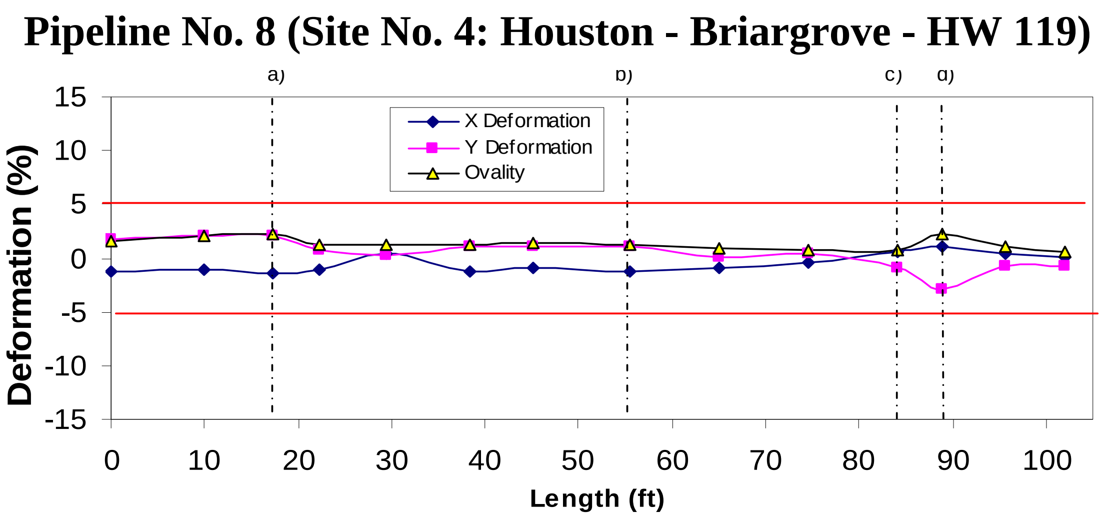
a) b)

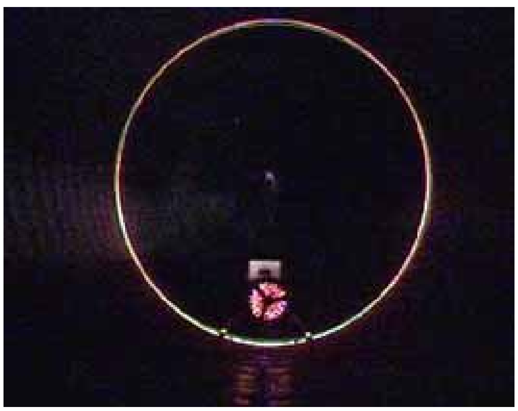




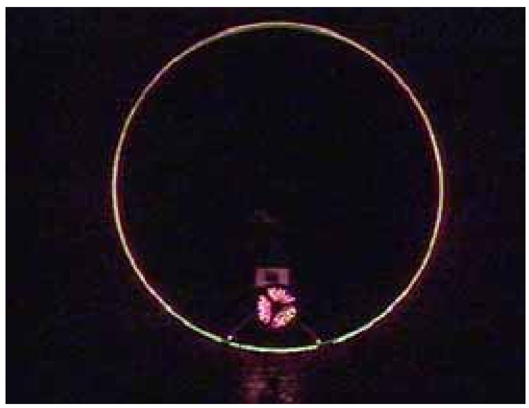
c) d)

Figure 33 Horizontal and vertical deformation of the pipeline No. 7 (Site No. 4: Houston - Briargrove - HW 119)

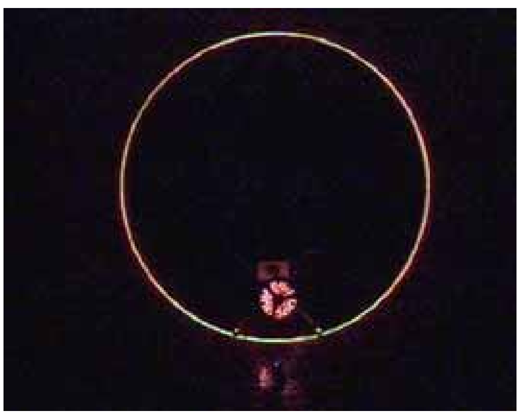




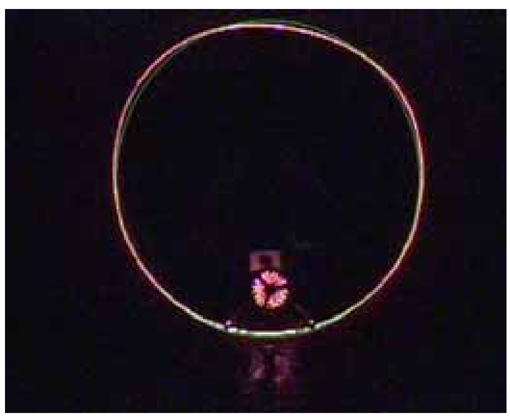
a)



b)



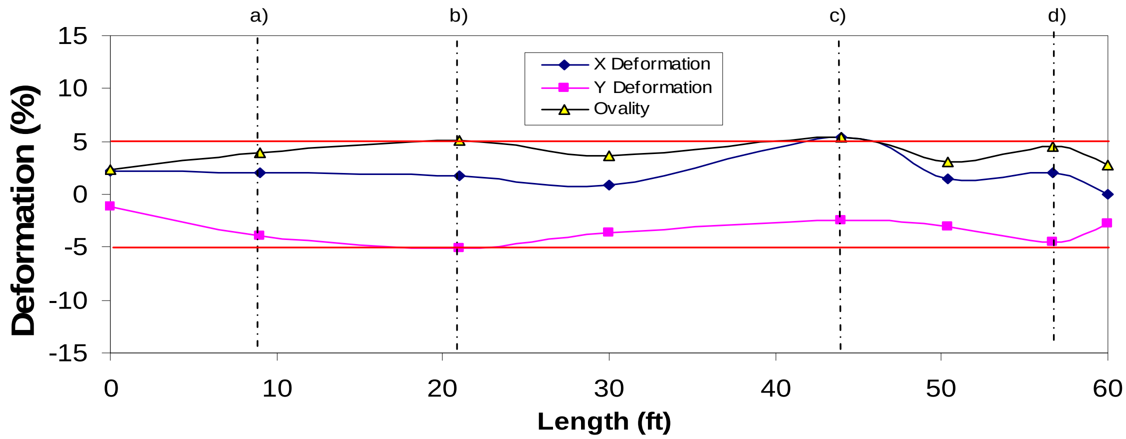
c)

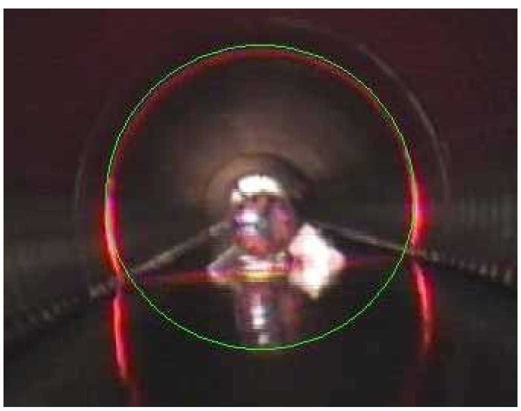
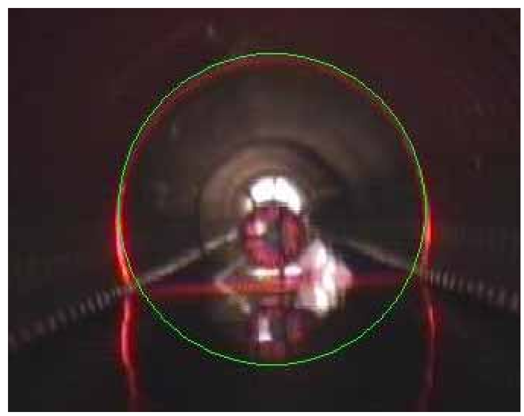


d)

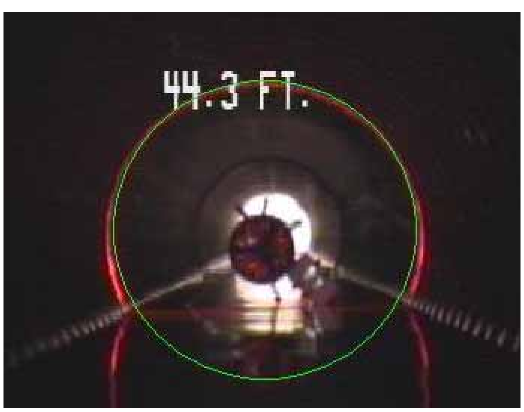
Figure 34 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 4: Houston - Briargrove - HW 119)

Pipeline No. 9 (Site No. 5: Houston – Riley Fussel)



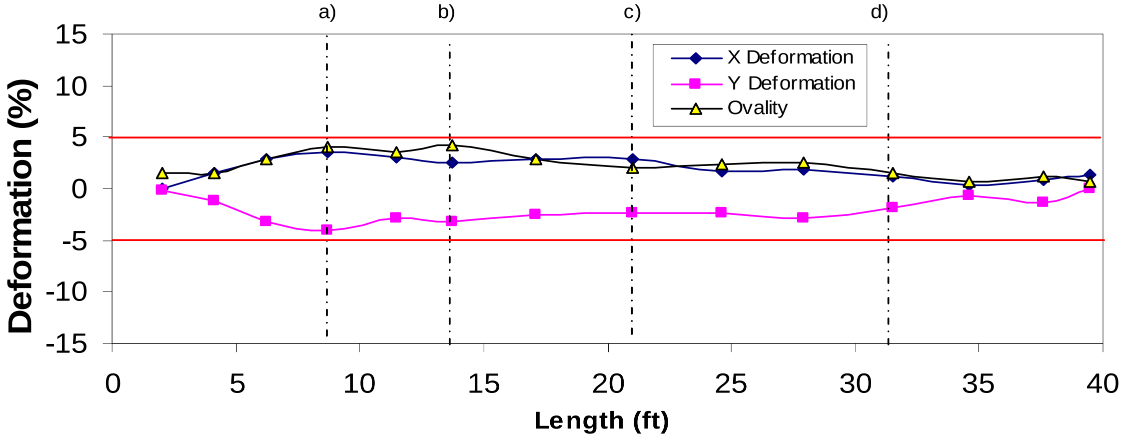
a) b)

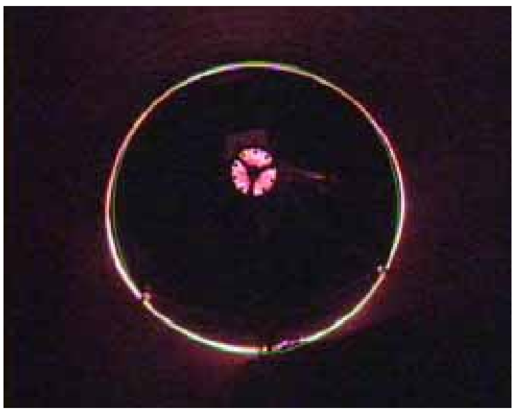


b) d)

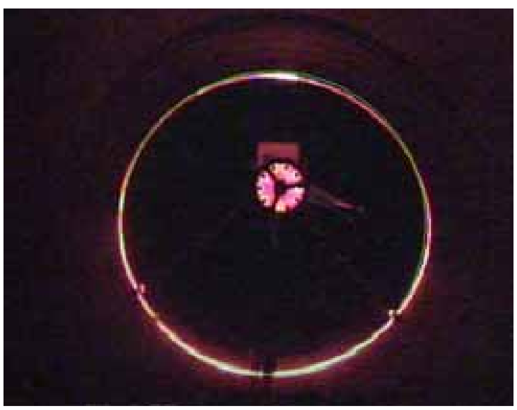
Figure 35 Horizontal and vertical deformation of the pipeline No. 9 (Site No. 5: Houston – Riley Fussel)

Pipeline No. 10 (Site No. 6: North Texas - Atlanta - FM 997)





a) b)

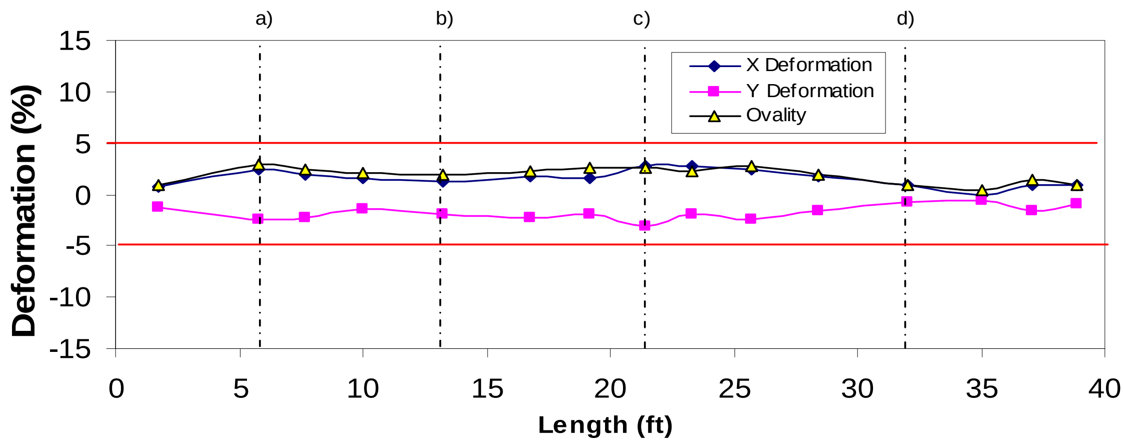


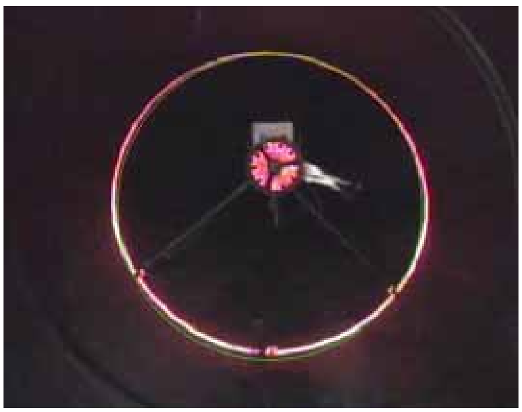
c)

d)

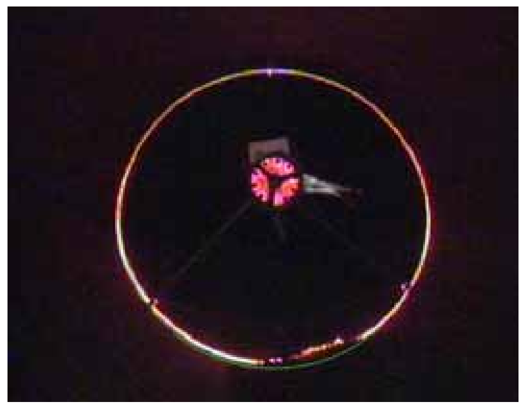
Figure 36 Horizontal and vertical deformation of the pipeline No. 10 (Site No. 6: North Texas - Atlanta - FM 997)

Pipeline No. 11 (Site No. 6: North Texas - Atlanta - FM 997)

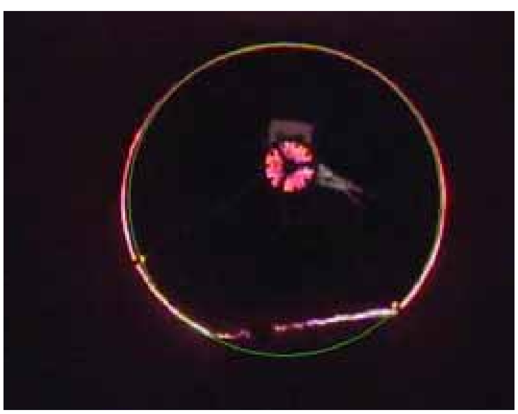




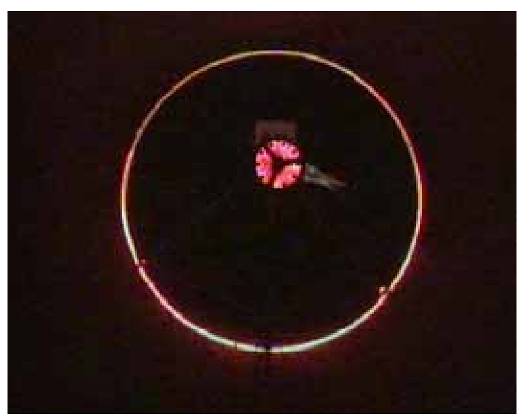
a)



b)



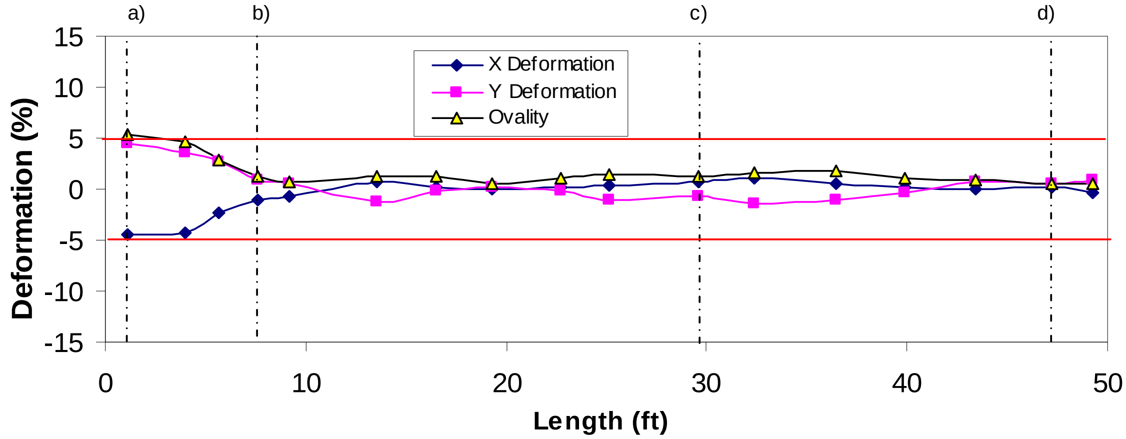
c.)



d)

Figure 37 Horizontal and vertical deformation of the pipeline No. 11 (Site No. 6: North Texas - Atlanta - FM 997)

Pipeline No. 15 (Site No. 7: North Texas - Henrietta - FM1197)



a)

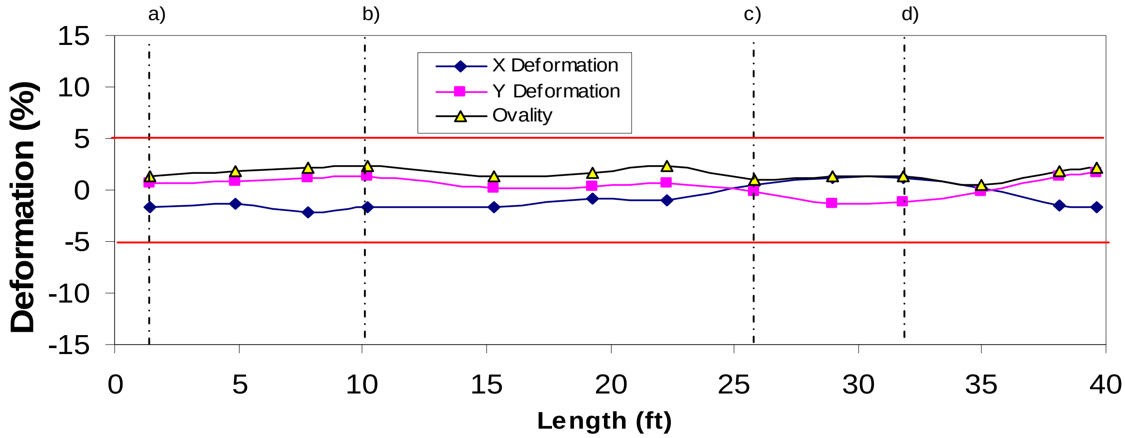
b)

c)

d)

Figure 38 Horizontal and vertical deformation of the pipeline No. 15 (Site No. 7: North Texas - Henrietta - FM1197)

Pipeline No. 16 (Site No. 7: North Texas - Henrietta - FM1197)

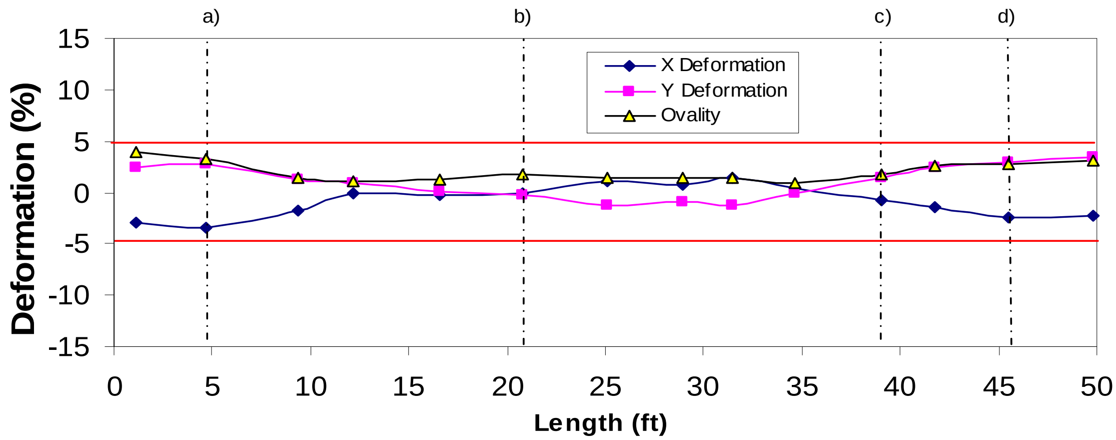


a) b)

b) d)

Figure 39 Horizontal and vertical deformation of the pipeline No. 16 (Site No. 7: North Texas - Henrietta - FM1197)

Pipeline No. 17 (Site No. 7: North Texas - Henrietta - FM1197)

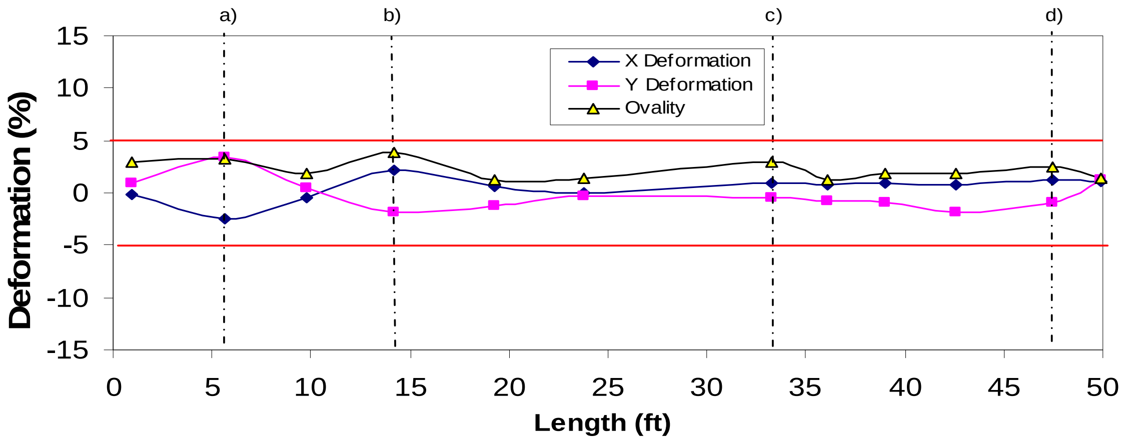


a) b)

b) d)

Figure 40 Horizontal and vertical deformation of the pipeline No. 17 (Site No. 7: North Texas - Henrietta - FM1197)

Pipeline No. 18 (Site No. 7: North Texas - Henrietta - FM1197)



a)

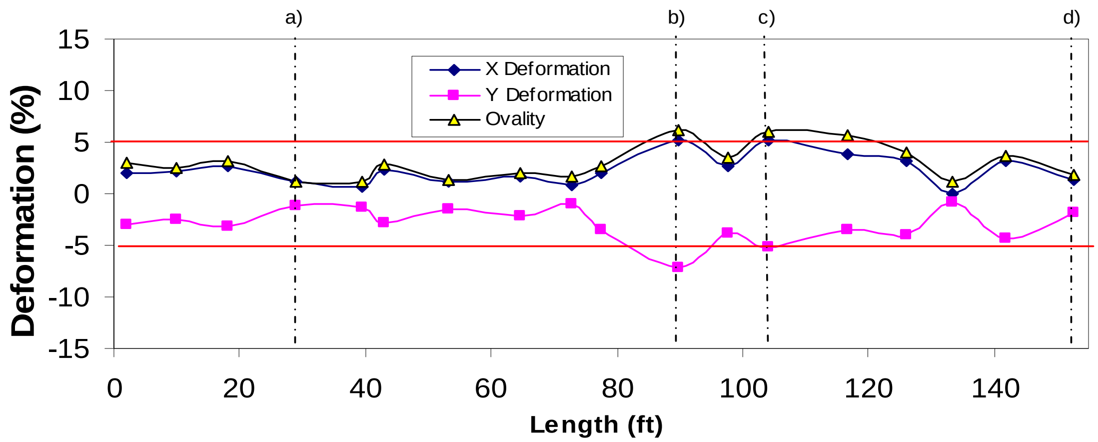
b)

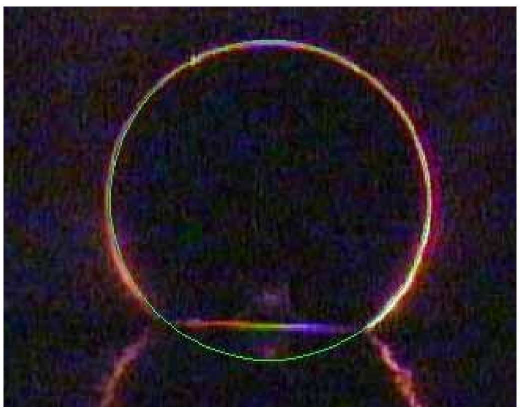
c)

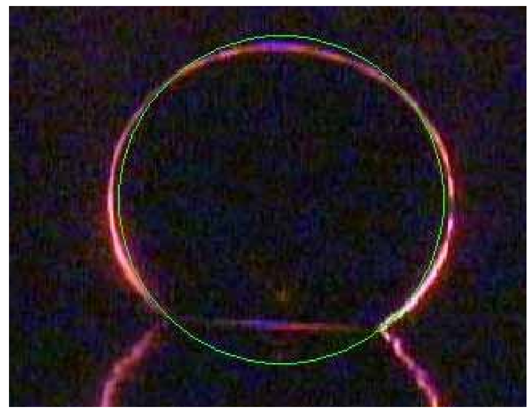
d)

Figure 41 Horizontal and vertical deformation of the pipeline No. 18 (Site No. 7: North Texas - Henrietta - FM1197)

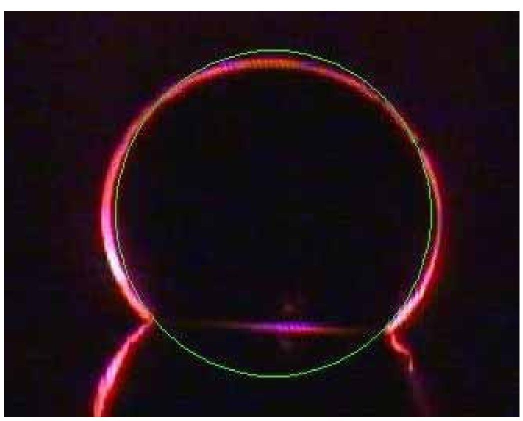
Pipeline No. 19 (Segment 1) (Site No. 8: Houston – Fennell)







a) b)



c) d)

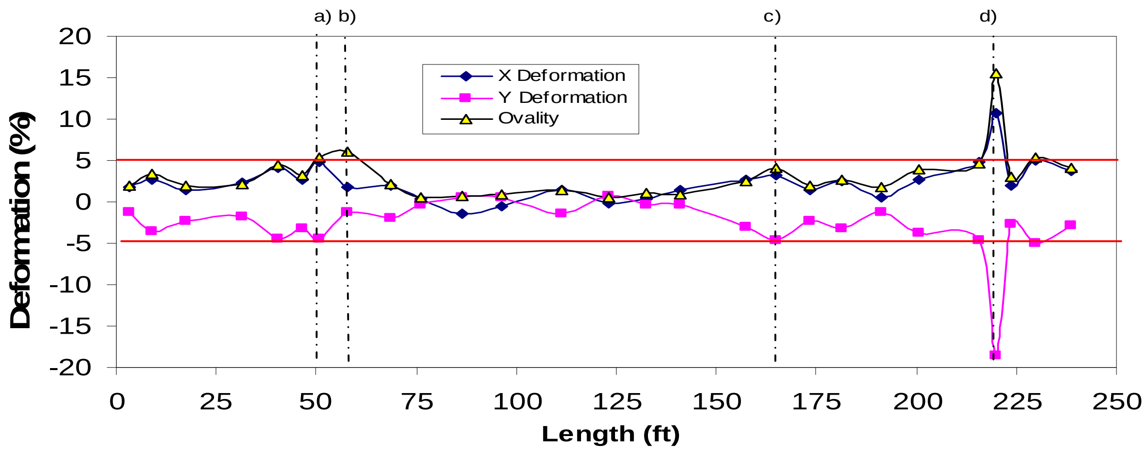
Figure 42 Horizontal and vertical deformation of the pipeline No. 19 (Segment 1) (Site No. 8: Houston – Fennell)

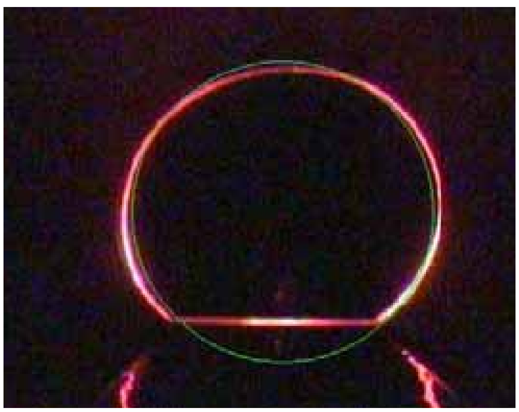
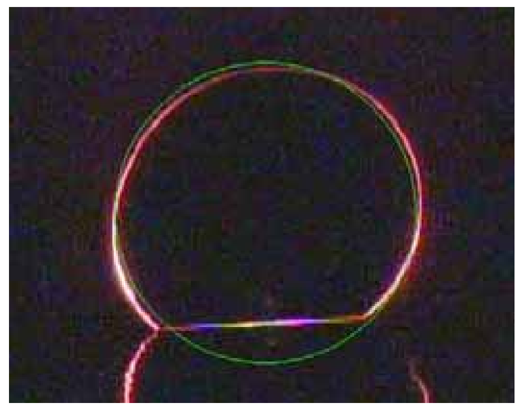
Figure 43 Excessive deformation and corrugation growth failures for pipeline No. 19 (Segment 1) (Site No. 8: Houston – Fennell)

Figure 44 Major joint displacement failure for pipeline No. 19 (Segment 1) (Site No. 8: Houston – Fennell)

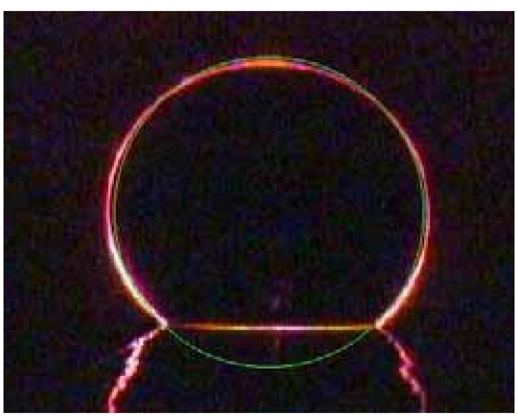
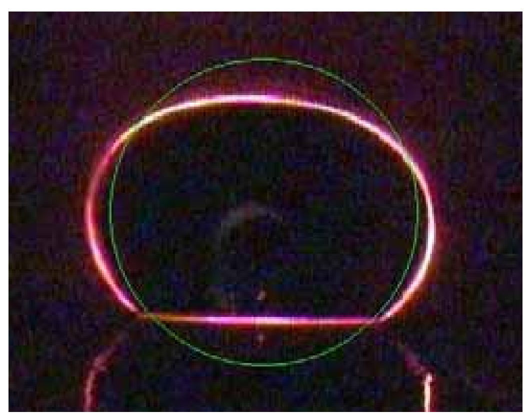
Figure 45 Excessive deformation and corrugation growth failures for pipeline No. 19 (Segment 1) (Site No. 8: Houston – Fennell)

Pipeline No. 19 (Segment 2) (Site No. 8: Houston – Fennell)



a) b)

b) d)

Figure 46 Horizontal and vertical deformation of the pipeline No. 19 (Segment 2) (Site No. 8: Houston – Fennell)

Figure 47 Major joint displacement, major cracking/fracture and inverse curvature failures for pipeline No. 19 (Segment 2) (Site No. 8: Houston – Fennell)

Figure 48 Major joint displacement and excessive deformation failures for pipeline No. 19 (Segment 2) (Site No. 8: Houston – Fennell)

Figure 49 Major joint displacement, minor cracking/fracture and inverse curvature failures for pipeline No. 19 (Segment 2) (Site No. 8: Houston – Fennell)

Pipeline No. 20 (Segment 1) (Site No. 8: Houston – Fennell)

Figure 50 Excessive deformation, inverse curvature, and cracking/fracture failures for pipeline No. 20 (Segment 1) (Site No. 8: Houston – Fennell)

Figure 51 Joint displacement, buckling and cracking/fracture failures for pipeline No. 20 (Segment 1) (Site No. 8: Houston – Fennell)

Figure 52 Major joint, inverse curvature and cracking/fracture failures for pipeline No. 20 (Segment 1) (Site No. 8: Houston – Fennell)

Figure 53 Cracking/fracture and inverse curvature failures for pipeline No. 20 (Segment 1) (Site No. 8: Houston – Fennell)

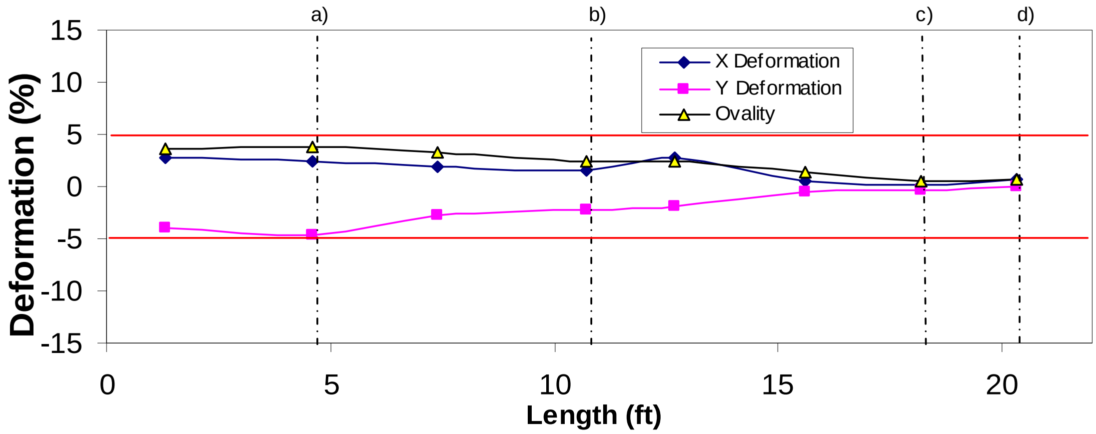
Pipeline No. 20 (Segment 2) (Site No. 8: Houston – Fennell)

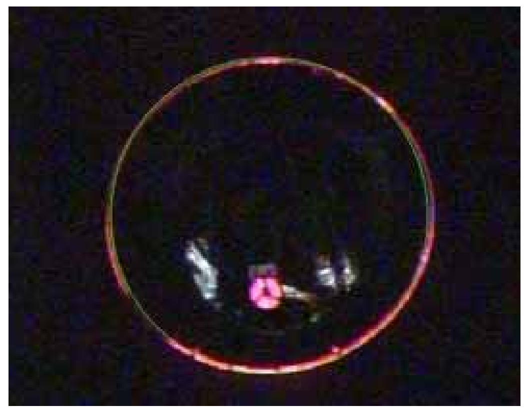
Figure 54 Cracking/fracture failure for pipeline No. 20 (Segment 2) (Site No. 8: Houston – Fennell)

Figure 55 Cracking/fracture and corrugation growth failure for pipeline No. 20 (Segment 2) (Site No. 8: Houston – Fennell)

Figure 56 Major cracking/fracture, minor cracking/fracture, and inverse curvature failures for pipeline No. 20 (Segment 2) (Site No. 8: Houston – Fennell)

Pipeline No. 21 (Site No. 9: Houston - HW 531)



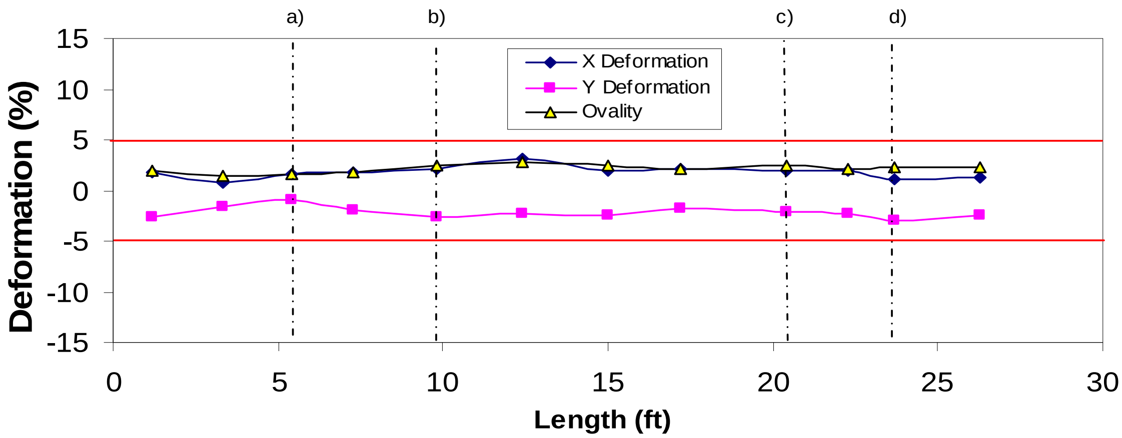



a) b)


c) d)

Figure 57 Horizontal and vertical deformation of the pipeline No. 21 (Site No. 9: Houston - HW 531)

Pipeline No. 22 (Site No. 9: Houston - HW 531)



a) b)

c) d)

Figure 58 Horizontal and vertical deformation of the pipeline No. 22 (Site No. 9: Houston - HW 531)

Appendix 2 – State of North Carolina

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of North Carolina. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

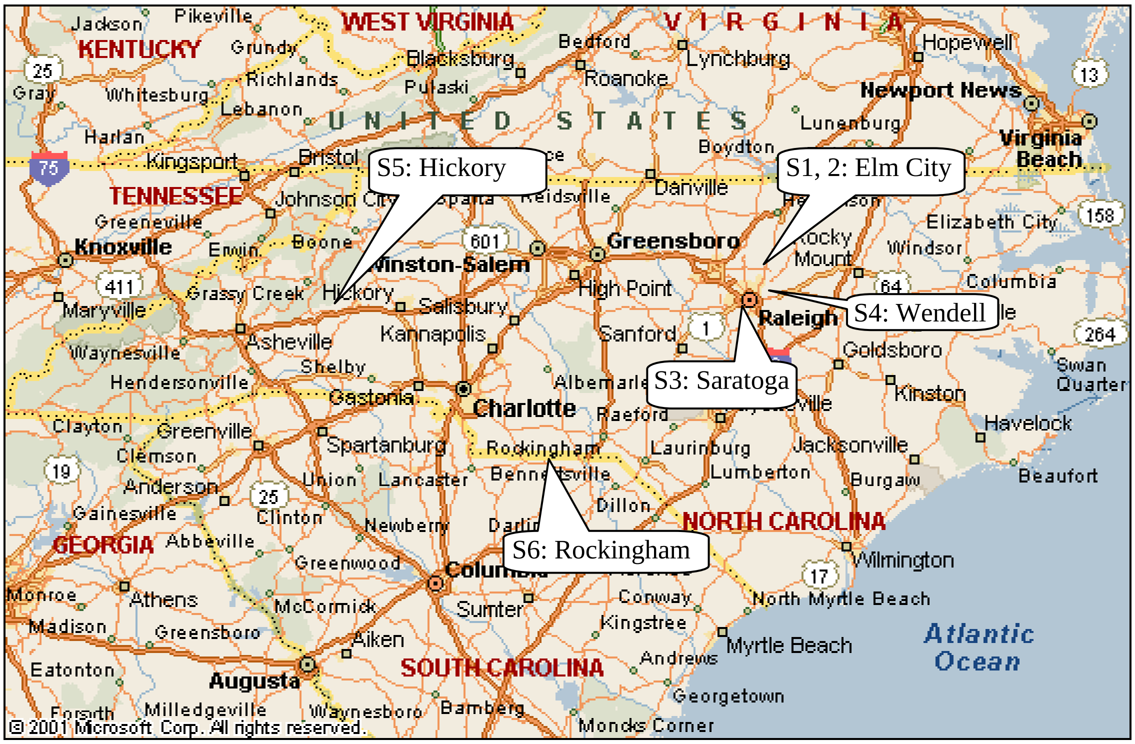


Figure 59 Layout of site locations

Table 7 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Diameter (in.)	Inspection date	Length (ft)
1	Elm City – Stagecoach Rd	1	24	4/4/2007	25
	Elm City – Stagecoach Rd	2	24	4/4/2007	25
	Elm City – Stagecoach Rd	3	24	4/4/2007	25
2	Elm City – Lake Wilson Rd	4*	36	4/4/2007	55
	Elm City – Lake Wilson Rd	5	36	4/4/2007	40
3	Saratoga – East Fork Rd	6*	48	4/4/2007	45
4	Wendell – Huntdell	7	42	4/5/2007	65
	Wendell – Huntdell	8	42	4/5/2007	65
5	Hickory – Oxford School Rd	9*	30	4/6/2007	110
6	Rockingham – Love Lane	10	48	4/6/2007	50
	Rockingham – Love Lane	11	48	4/6/2007	80

* Laser video data was not collected

Table 8 Summary of different observed damages for different pipes at different site locations

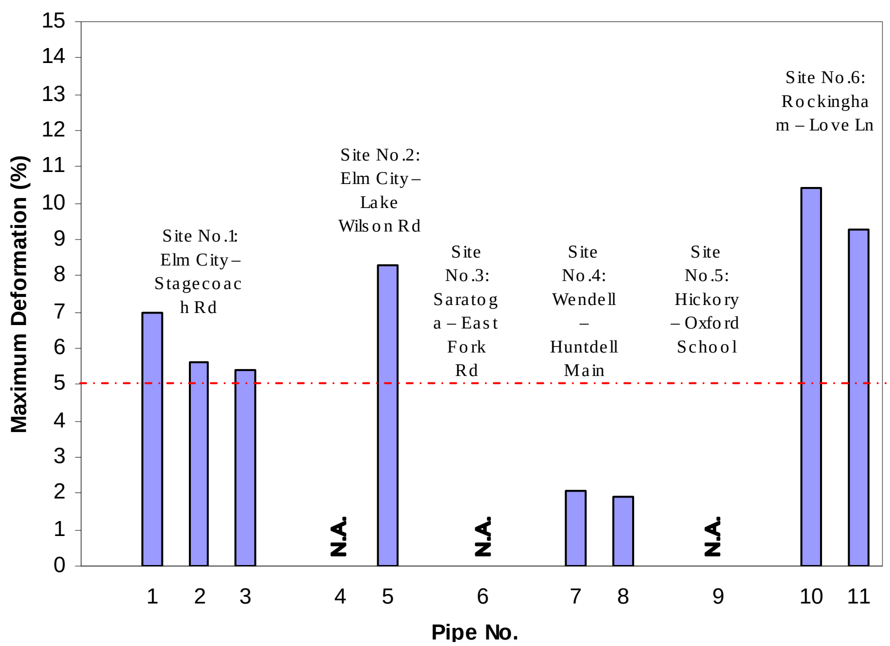
Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Joint Displacement	Corregation Growth	Buckling
1	Elm City - Stage Coach Road	1	✓	✓			✓	
		2		✓		✓	✓	
		3	✓	✓			✓	
2	Elm City - Lake Wilson Road	4		NA			✓	
		5	✓	✓		✓	✓	✓
3	Saratoga - East Fork Road	6	✓	NA		✓	✓	
4	Wendell - Huntdell Main Drive	7	✓			✓	✓	
		8	✓			✓	✓	
5	Hickory - Oxford School Road	9		NA		✓	✓	
6	Rockingham - Love Lane	10	✓	✓		✓	✓	✓
		11	✓	✓		✓	✓	✓
Percentage of pipelines experiencing failure mode			73%	75%	0%	73%	100%	27%

NA: Laser video data was not collected

Table 9 Comparison and Summary of Deformation of pipelines

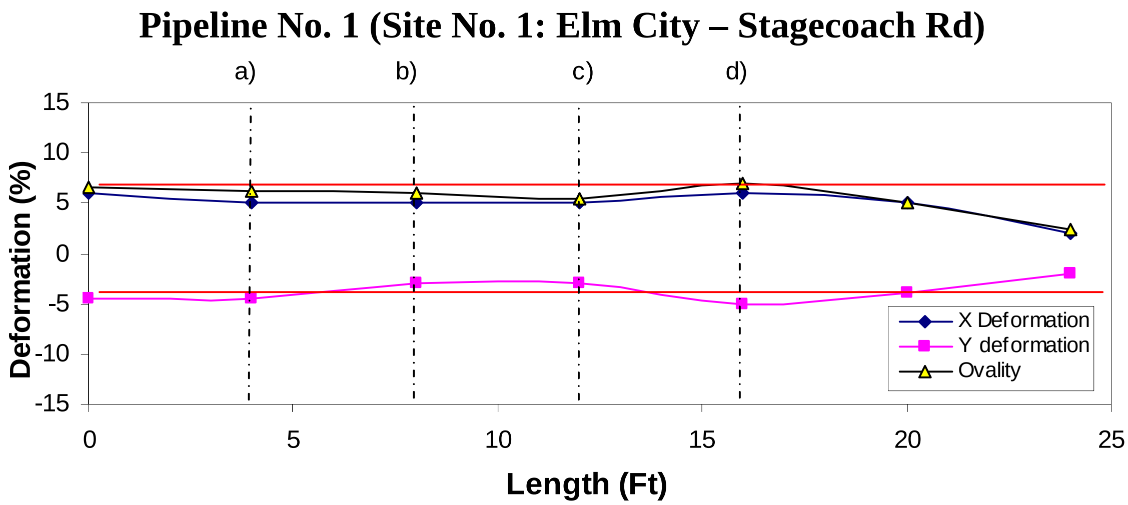
Site Numb	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Elm City - Stage Coach Road	1	6	5	7	7
		2	4.2	5.4	5.9	5.9
		3	3.7	5.4	5.4	5.4
2	Elm City - Lake Wilson Road	4	NA	NA	NA	NA
		5	6.1	8.3	8.3	8.3
3	Saratoga - East Fork Road	6	NA	NA	NA	NA
4	Wendell - Huntdell Main Drive	7	2.1	2.1	2.1	2.1
		8	1.9	2.1	2.1	2.1
5	Hickory - Oxford School Road	9	NA	NA	NA	NA
6	Rockingham - Love Lane	10	9.6	7.2	10.4	10.4
		11	9.3	6.7	9.3	9.3
	Maximum		9.6	8.3	10.4	10.4
	Minimum		1.9	2.1	2.1	2.1
	Average		5.4	5.3	6.3	6.3

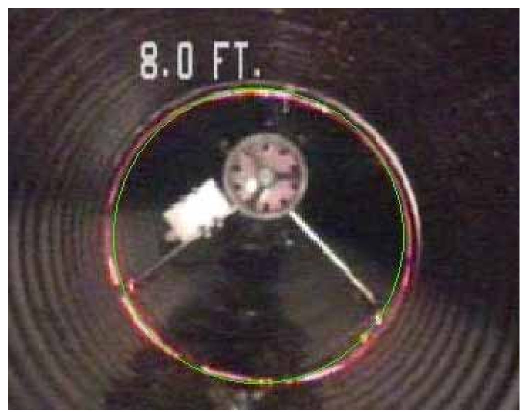
NA: Laser video data was not collected



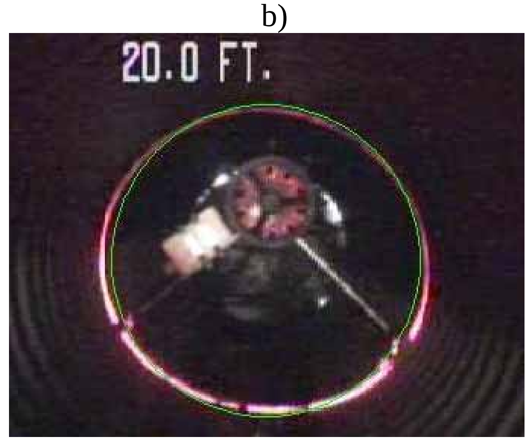
NA.: Data Not available due to excessive debris or the pipeline being full

Figure 60 Comparison of Maximum deformations calculated for pipelines tested in different site locations



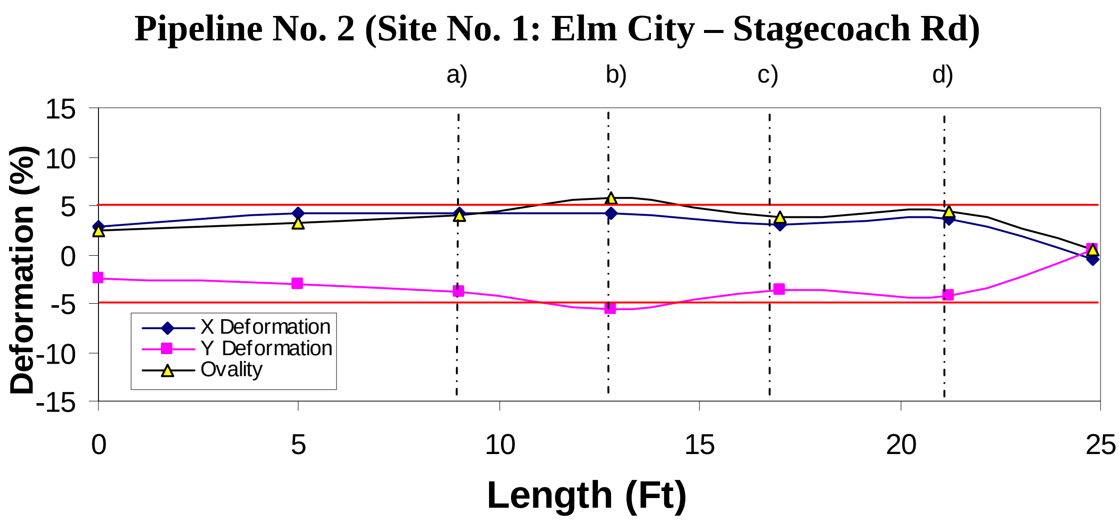


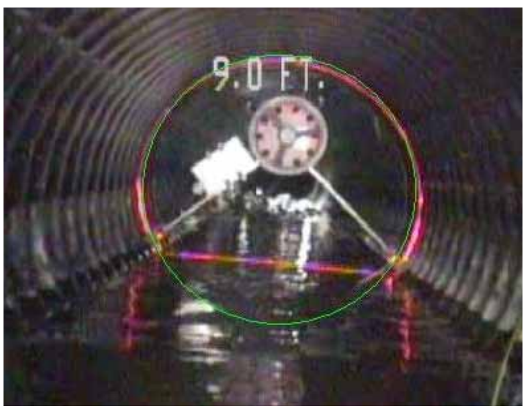
a) b)

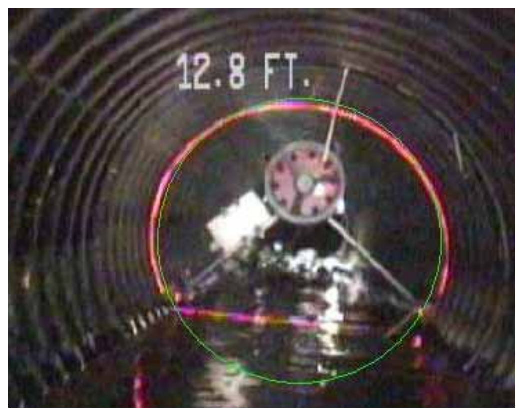


c) d)

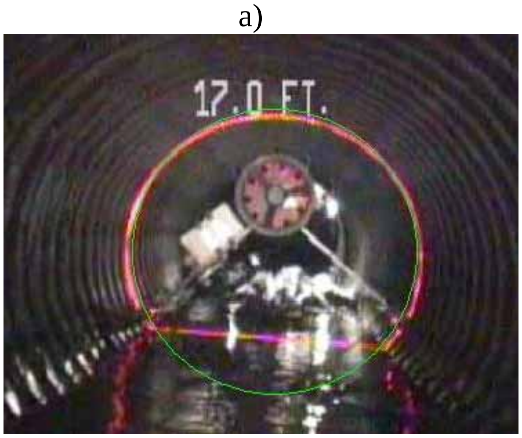
Figure 61 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: Elm City – Stagecoach Rd)

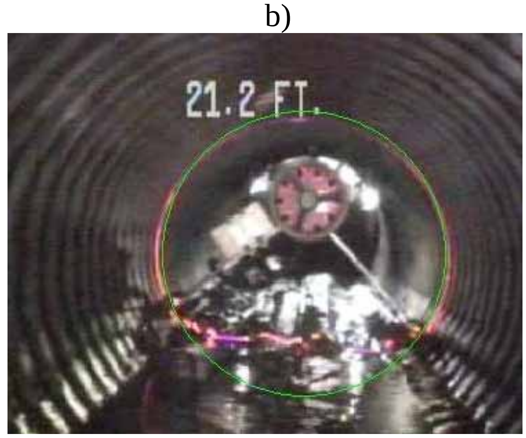






a) b)

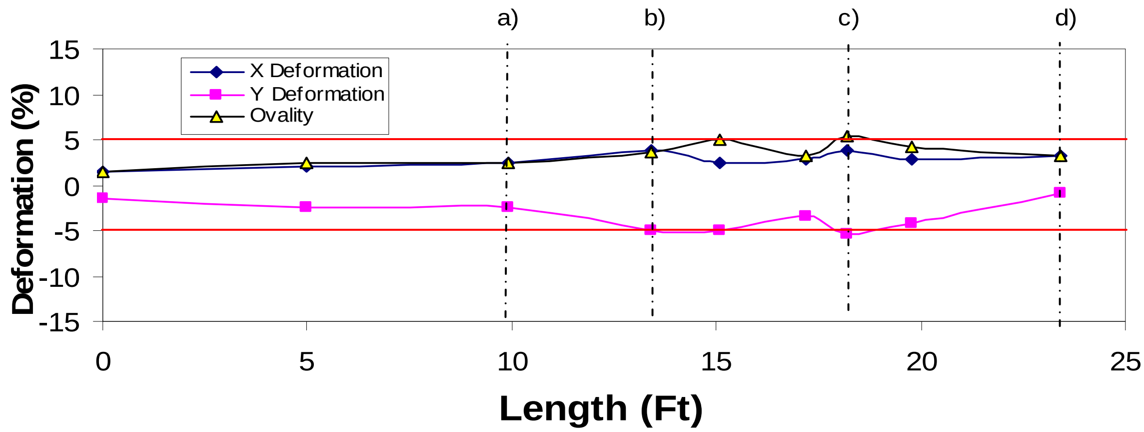


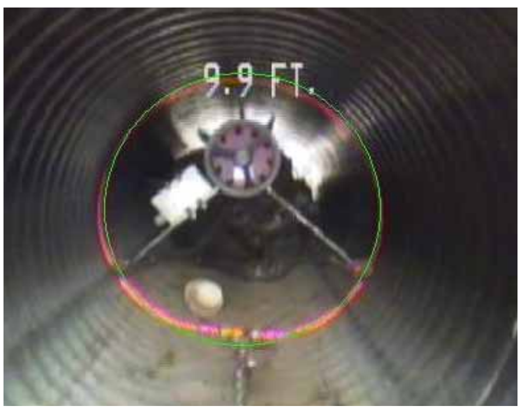


c) d)

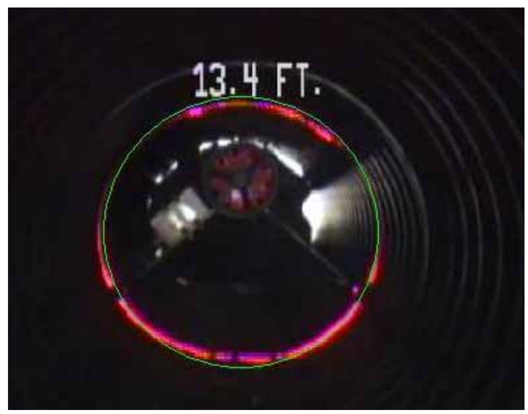
Figure 62 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: Elm City – Stagecoach Rd)

Pipeline No. 3 (Site No. 1: Elm City – Stagecoach Rd)

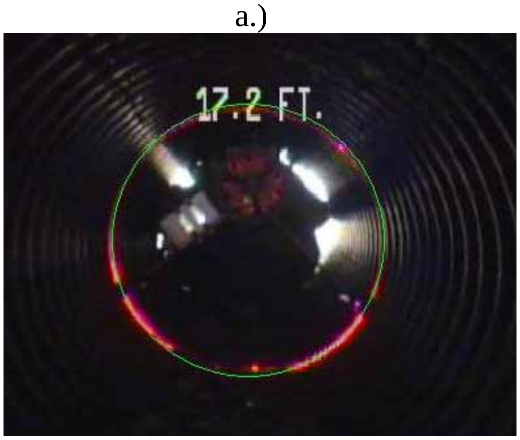




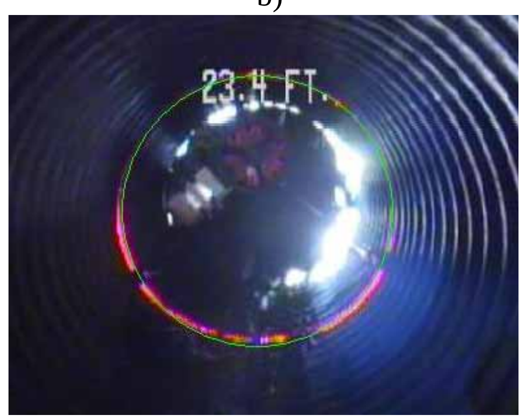
a.)



b)



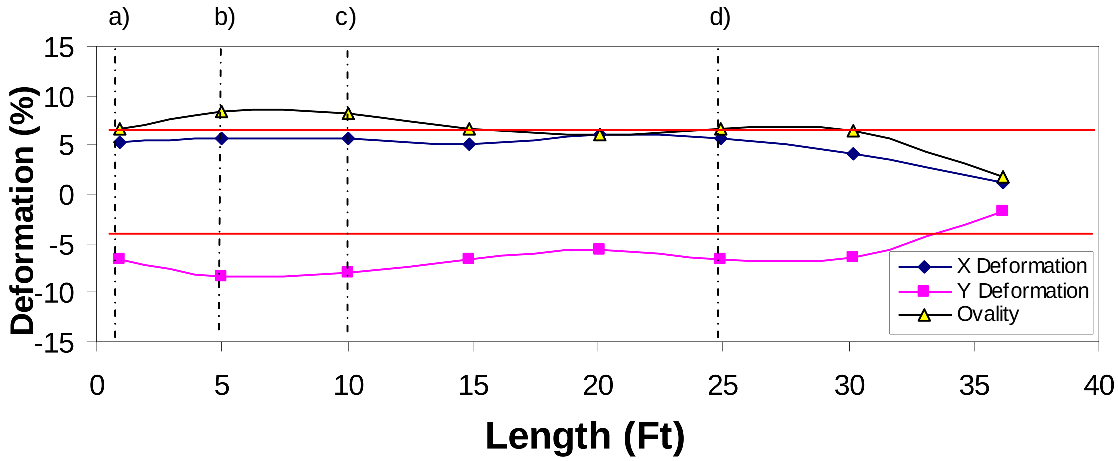
c)

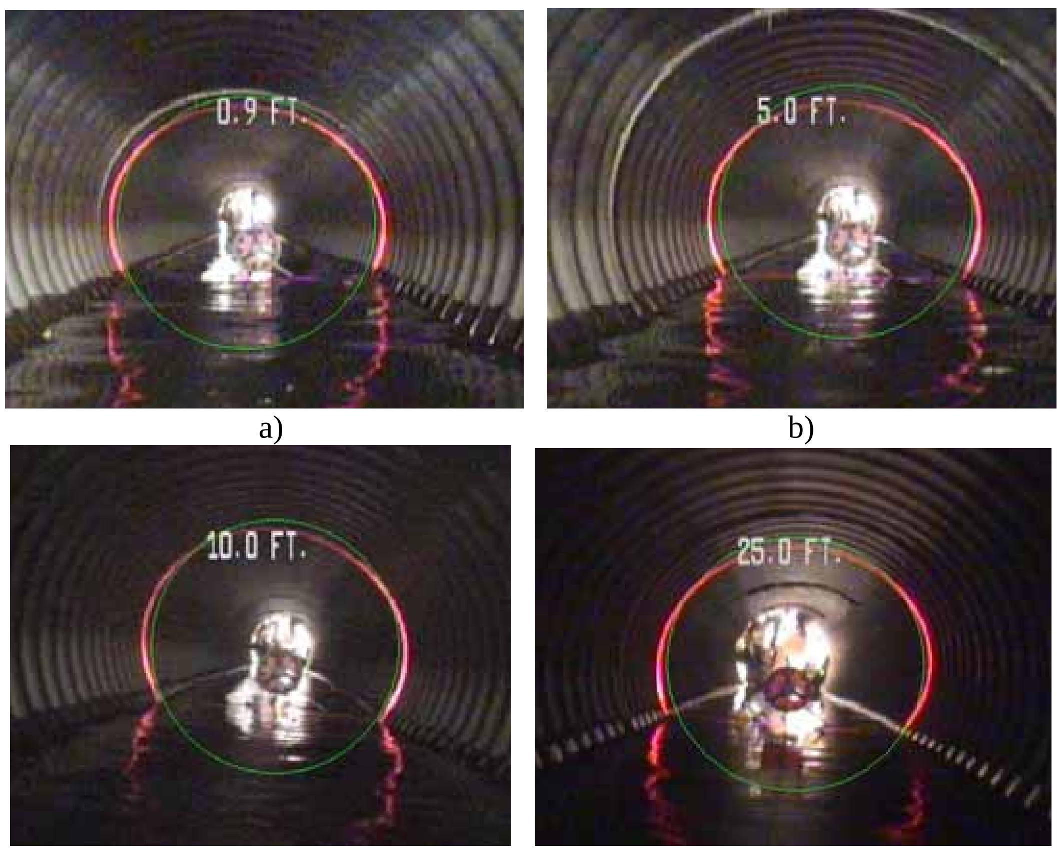


d)

Figure 63 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: Elm City – Stagecoach Rd)

Pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)





a) b)

c) d)

Figure 64 Horizontal deformation of the pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)

Figure 65 View of cracking failures for pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)

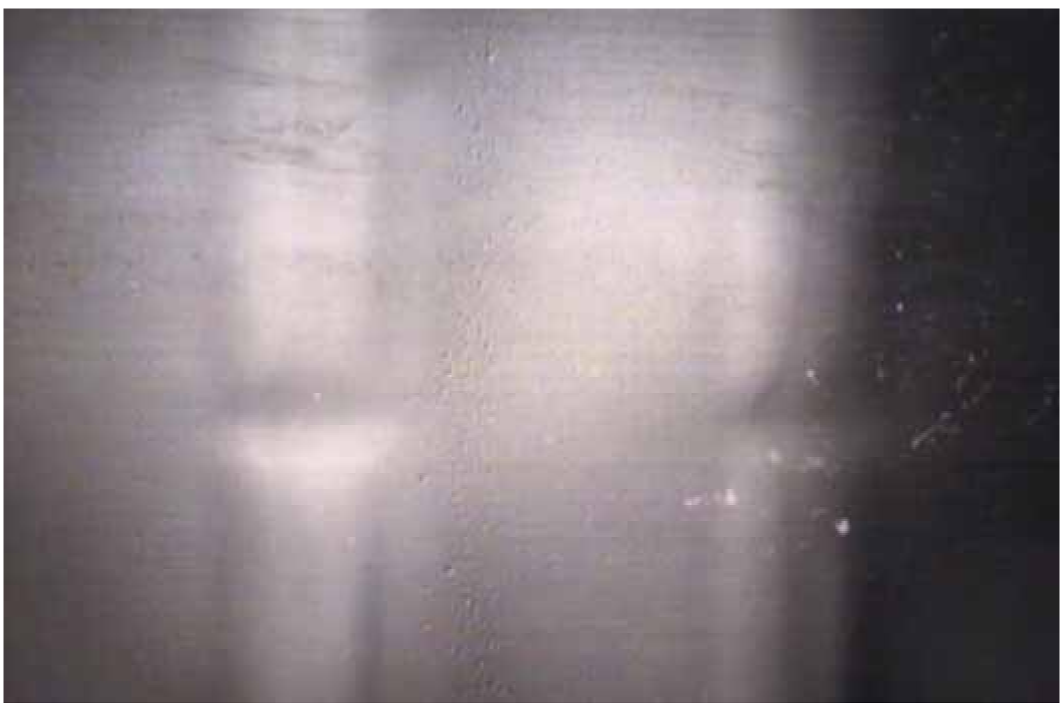


Figure 66 View of buckling failure for pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)

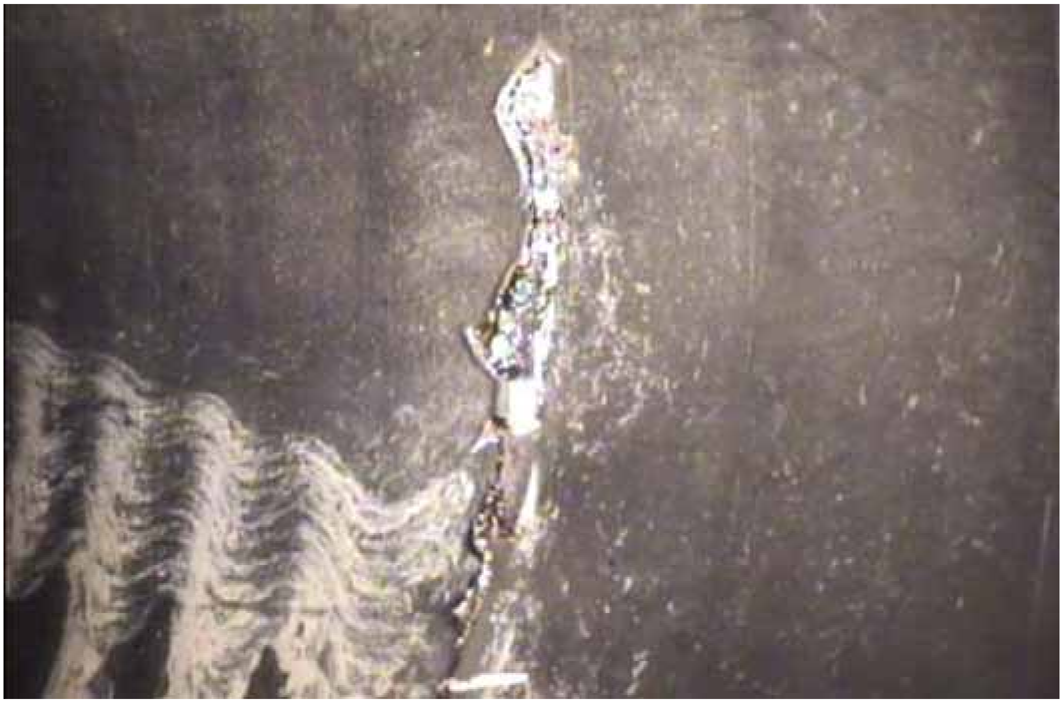


Figure 67 View of cracking failures for pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)

Figure 68 View of cracking failure for pipeline No. 5 (Site No. 2: Elm City – Lake Wilson Rd)

Pipeline No. 6 (Site No. 3: Saratoga – East Fork Rd)

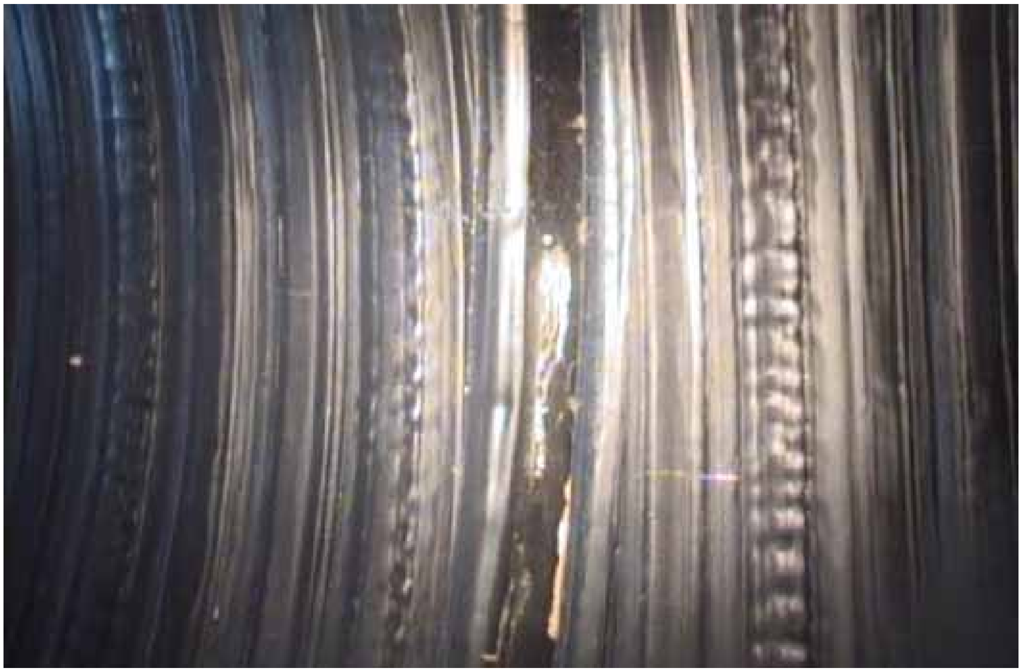


Figure 69 View of cracking failures for pipeline No. 6 (Site No. 3: Saratoga – East Fork Rd)

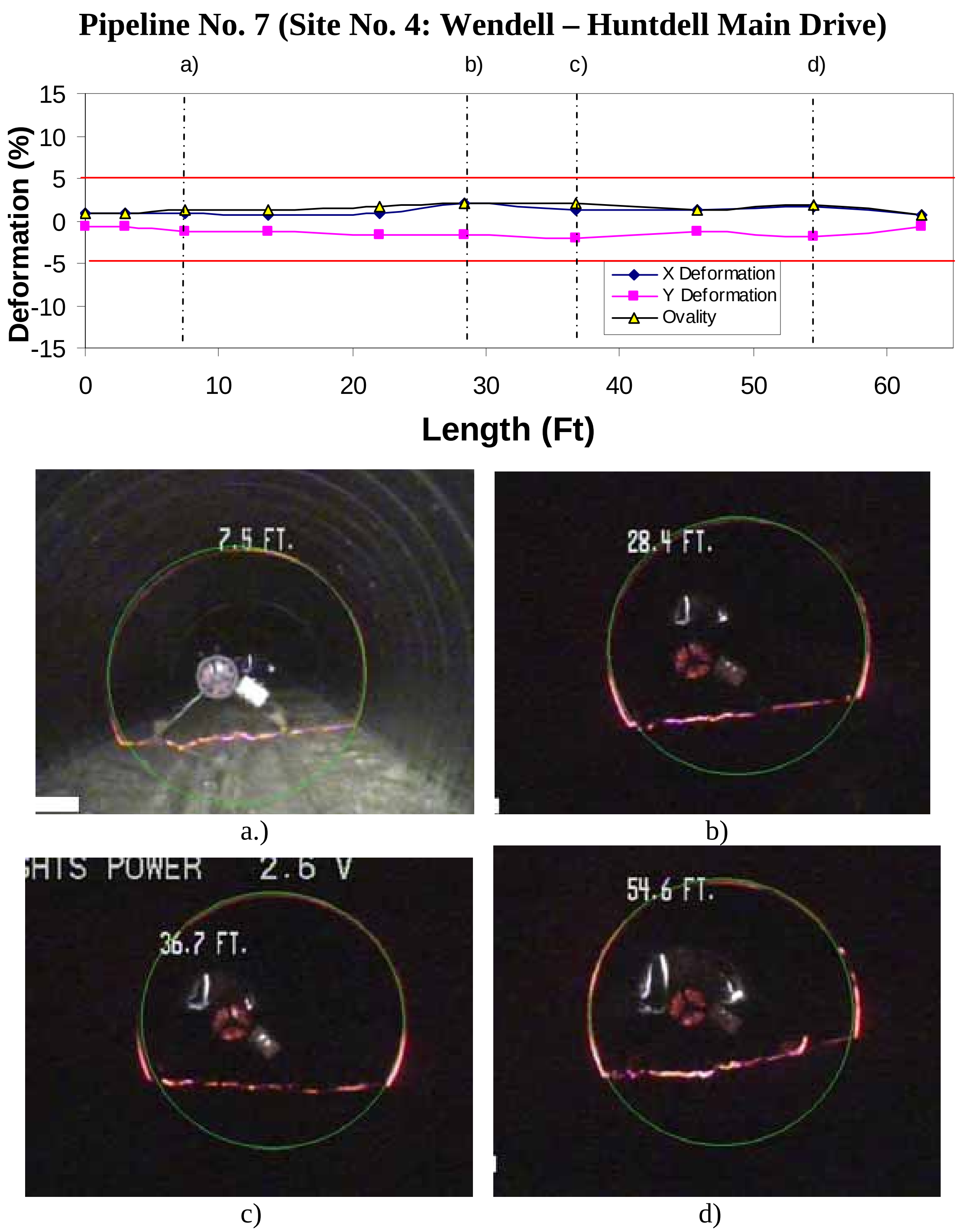


Figure 70 Horizontal deformation of the pipeline No. 7 (Site No. 4: Wendell – Huntdell Main Drive)

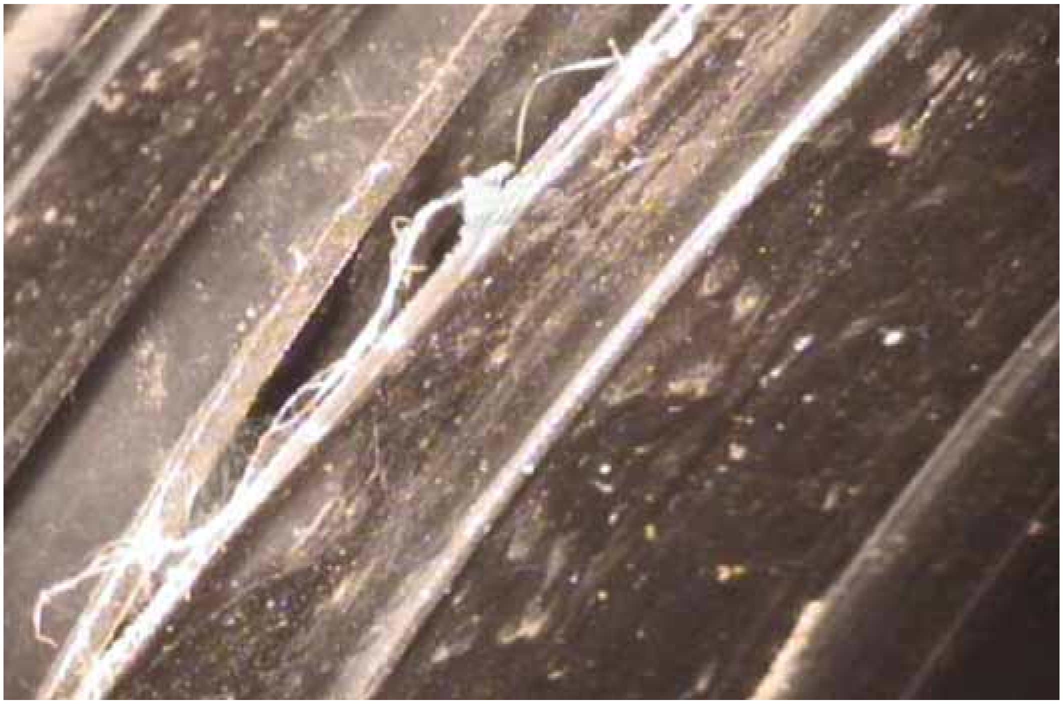


Figure 71 View of cracking failure for pipeline No. 7 (Site No. 4: Wendell – Huntdell Main Drive)

Figure 72 View of major joint displacement failures for pipeline No. 7 (Site No. 4: Wendell – Huntdell Main Drive)

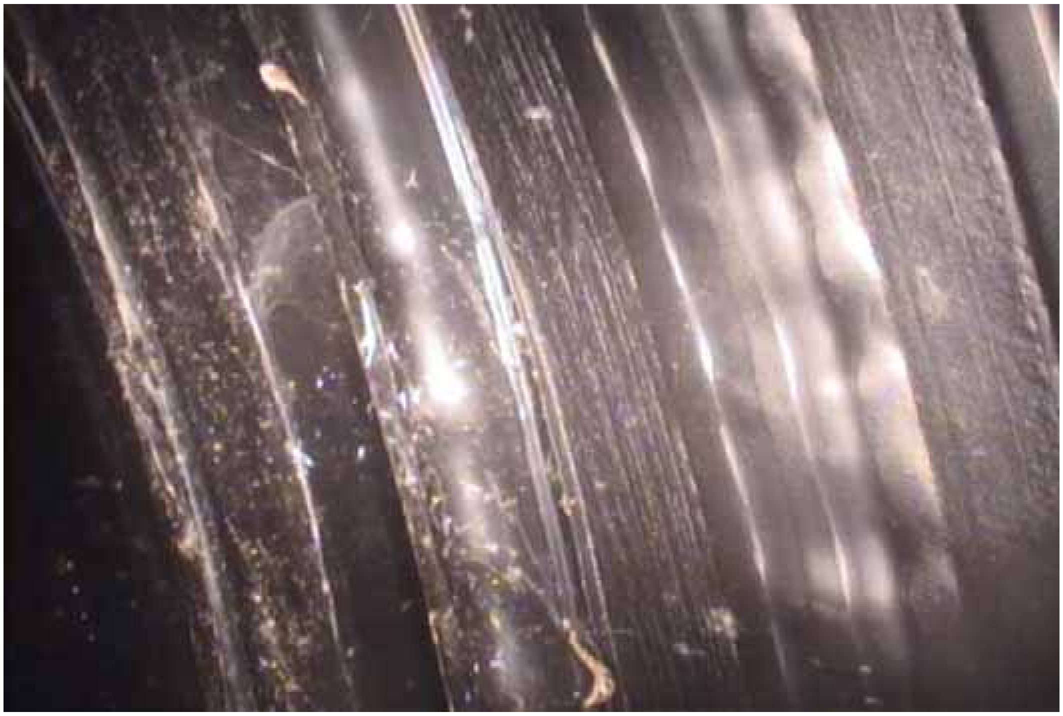
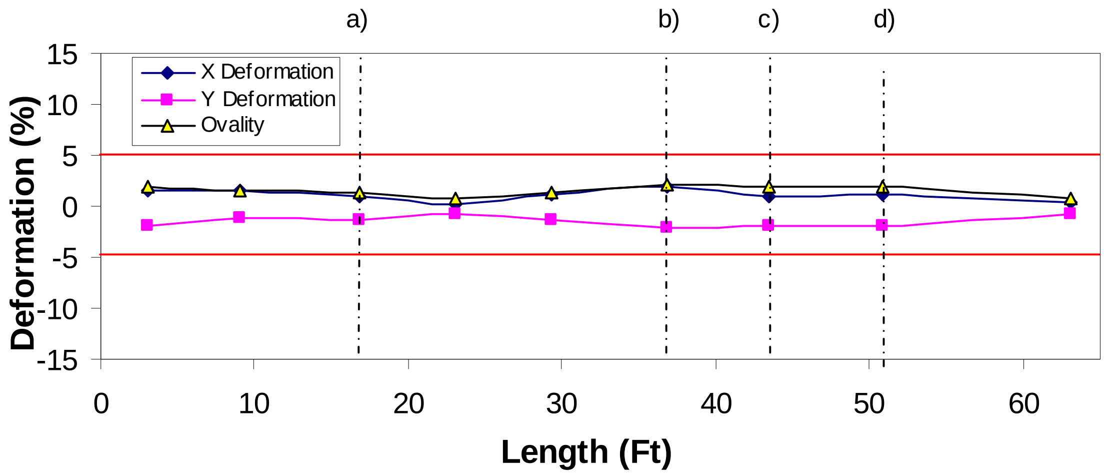
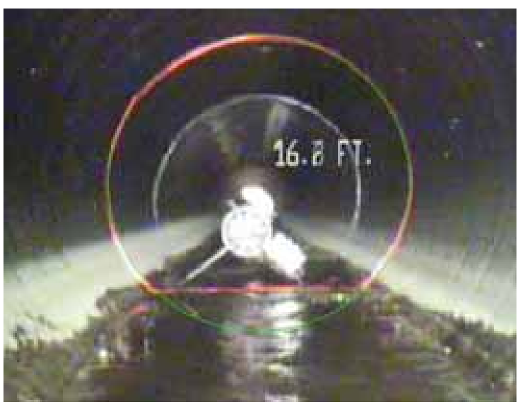
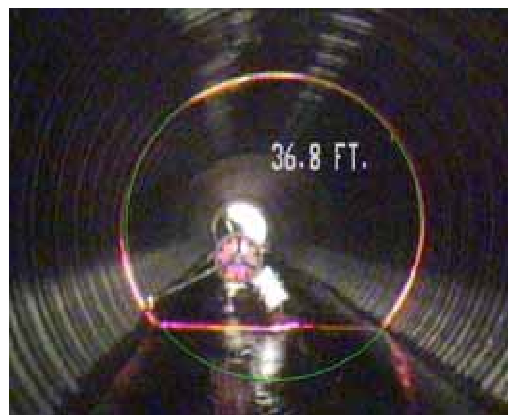


Figure 73 View of minor cracking failure for pipeline No. 7 (Site No. 4: Wendell – Huntdell Main Drive)

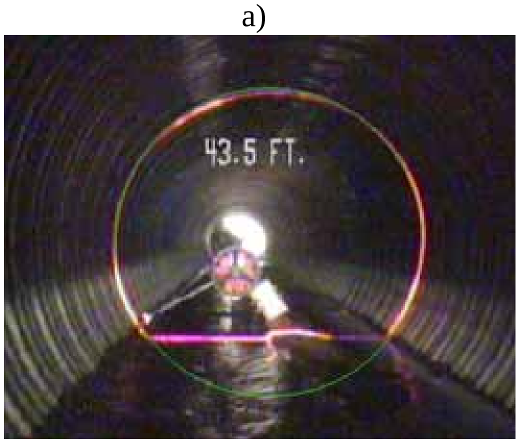
Pipeline No. 8 (Site No. 4: Wendell – Huntdell Main Drive)

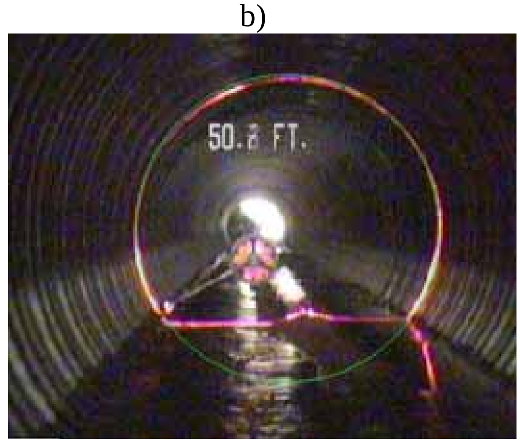






a) b)





c) d)

Figure 74 Horizontal deformation of the pipeline No. 8 (Site No. 4: Wendell – Huntdell Main Drive)

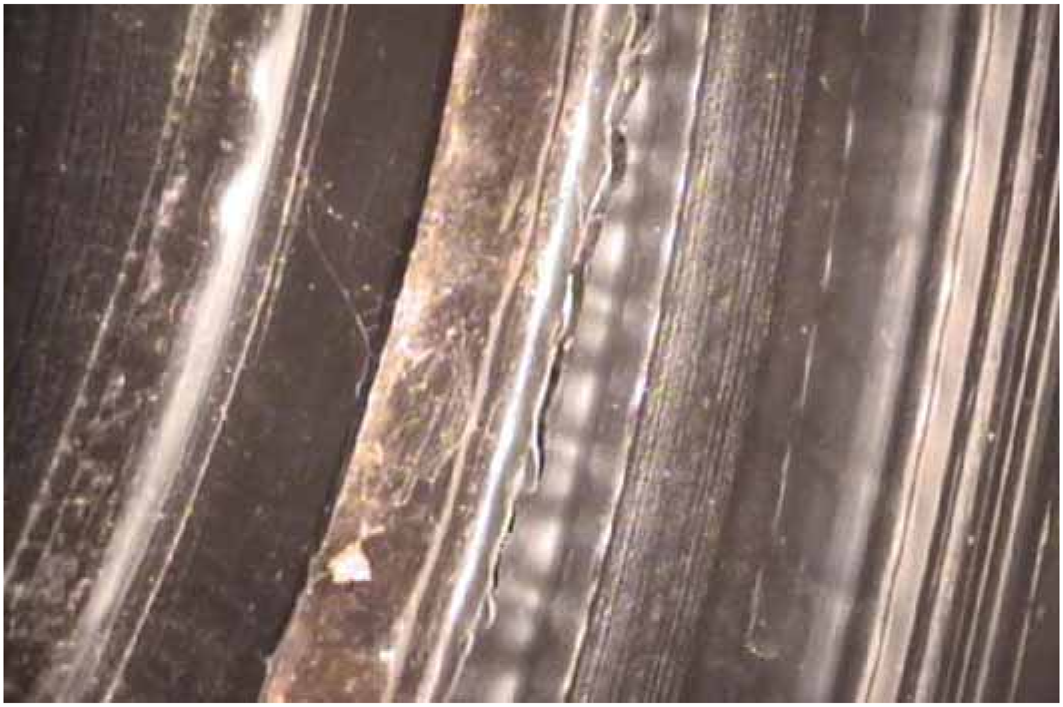


Figure 75 View of cracking failure for pipeline No. 8 (Site No. 4: Wendell – Huntdell Main Drive)

Figure 76 View of major joint displacement failure for pipeline No. 8 (Site No. 4: Wendell – Huntdell Main Drive)

Figure 77 View of and joint displacement failures for pipeline No. 8 (Site No. 4: Wendell – Huntdell Main Drive)

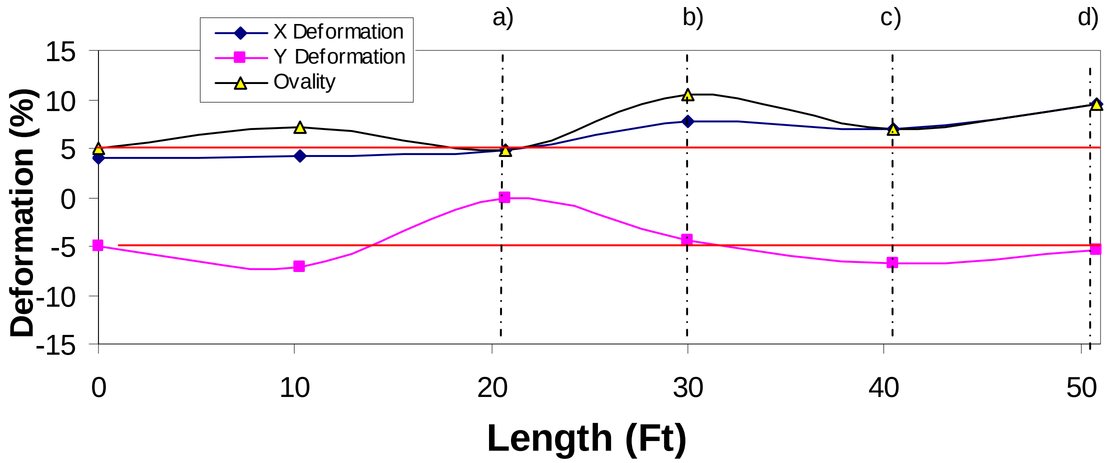
Pipeline No. 9 (Site No. 5: Hickory – Oxford School Rd)

Figure 78 View of joint displacement failure for pipeline No. 9 (Site No. 5: Hickory – Oxford School Rd)

Figure 79 View of corrugation growth failure for pipeline No. 9 (Site No. 5: Hickory – Oxford School Rd)

Figure 80 View of major joint displacement failure for pipeline No. 9 (Site No. 5: Hickory – Oxford School Rd)

Pipeline No. 10 (Site No. 6: Rockingham – Love Ln)



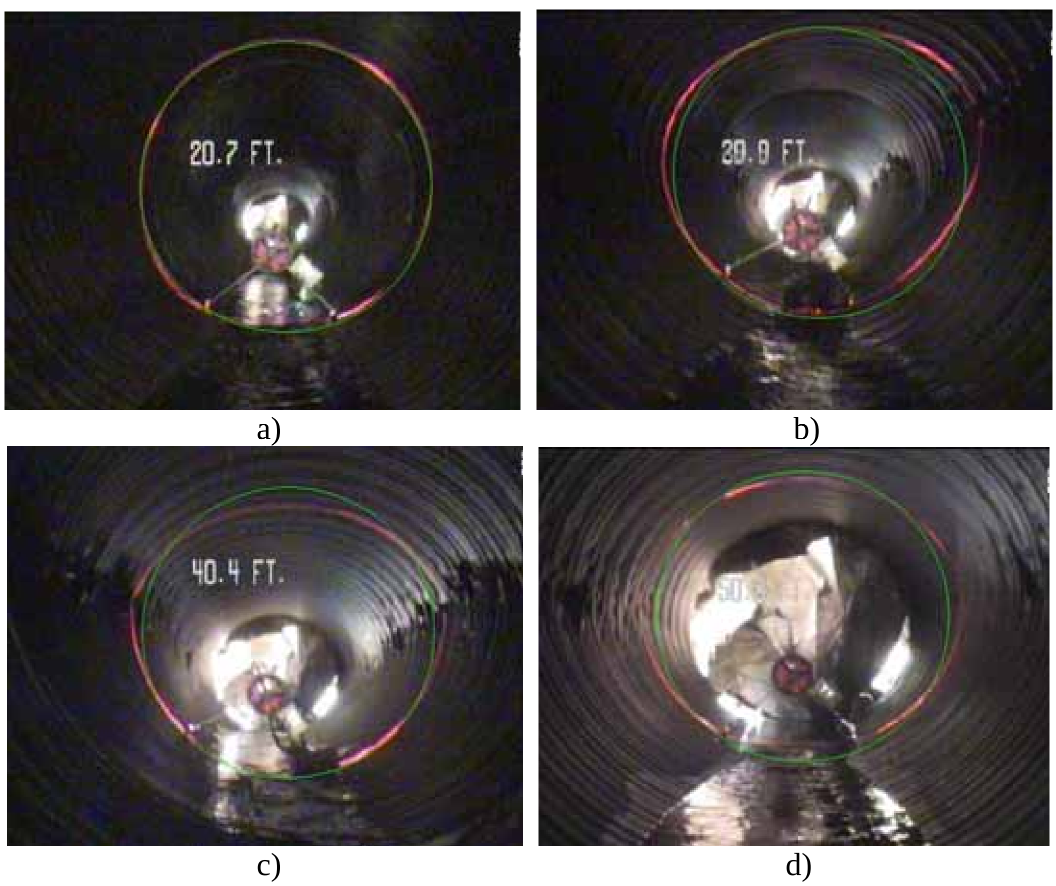


Figure 81 Horizontal deformation of the pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

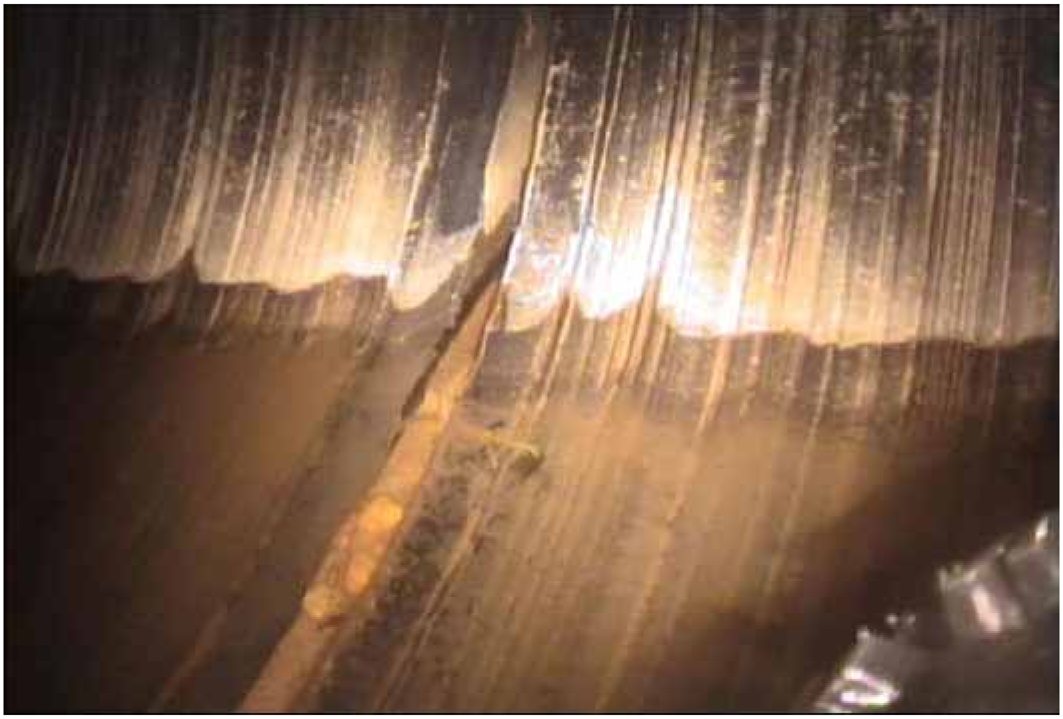


Figure 82 View of joint displacement failure for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

Figure 83 View of major joint displacement failure for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

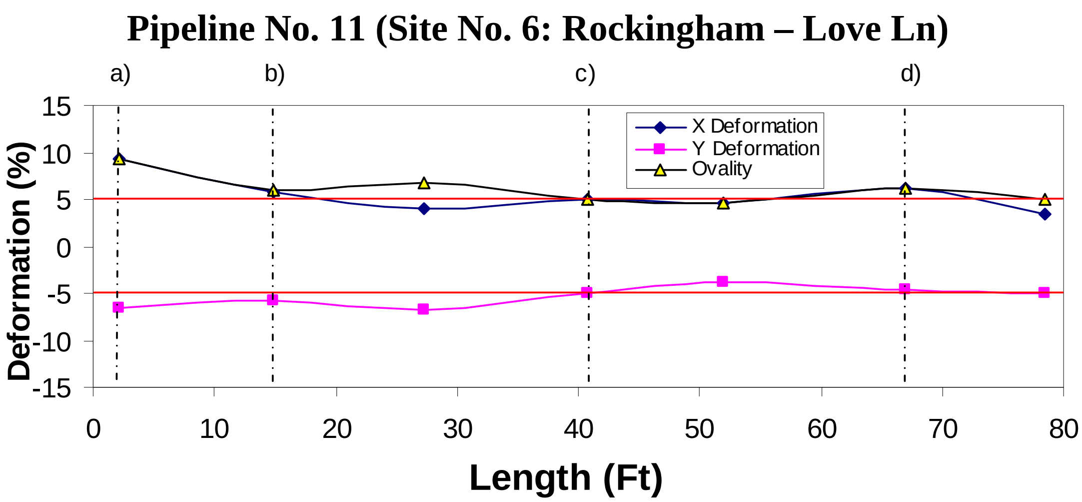
Figure 84 View of cracking failure for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

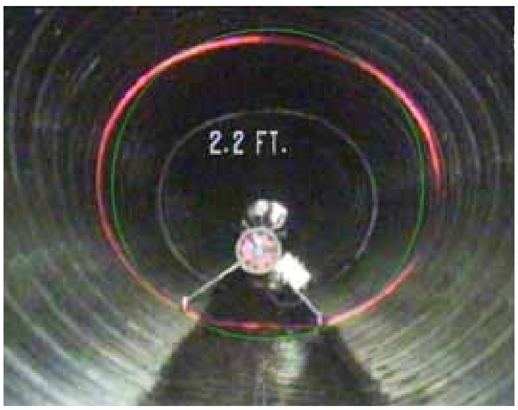
Figure 85 View of excessive deformation failure for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

Figure 86 View of buckling and cracking failures for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

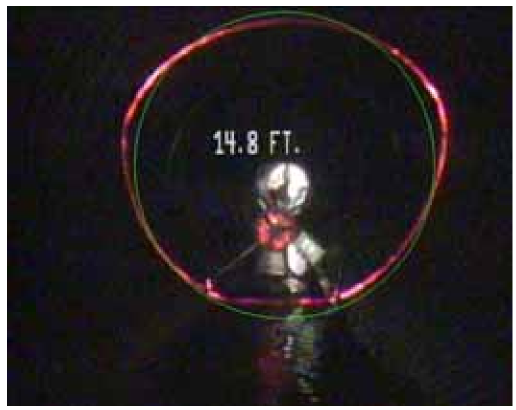
Figure 87 View of cracking failure for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

Figure 88 View of cracking and buckling failures for pipeline No. 10 (Site No. 6: Rockingham – Love Ln)

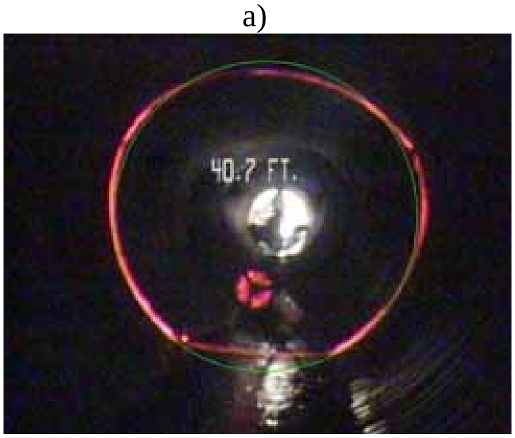




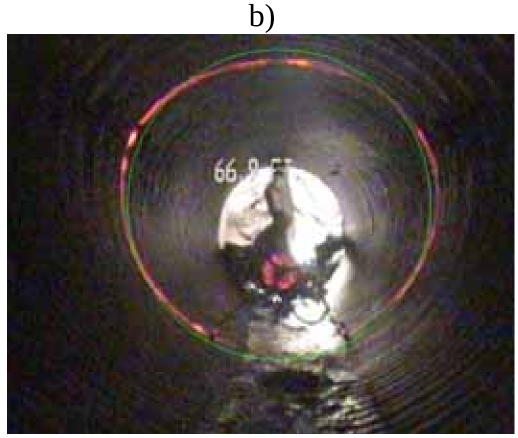
a)



b)



c)



d)

Figure 89 Horizontal deformation of the pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 90 View of excessive deformation failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

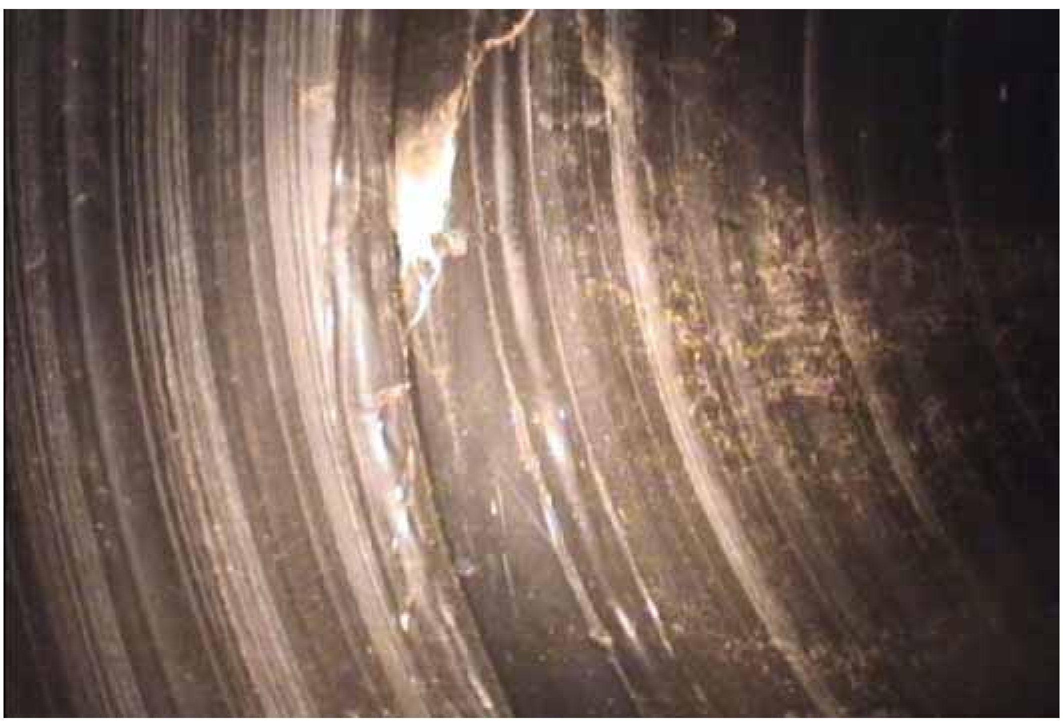


Figure 91 View of cracking failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

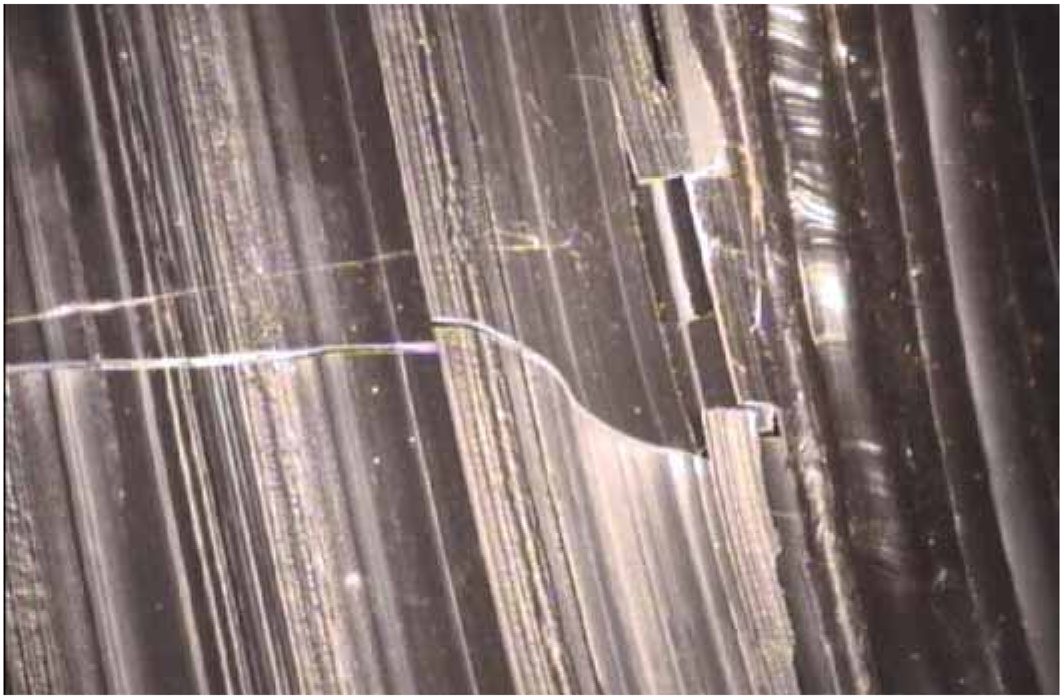


Figure 92 View of cracking failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 93 View of buckling and cracking failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

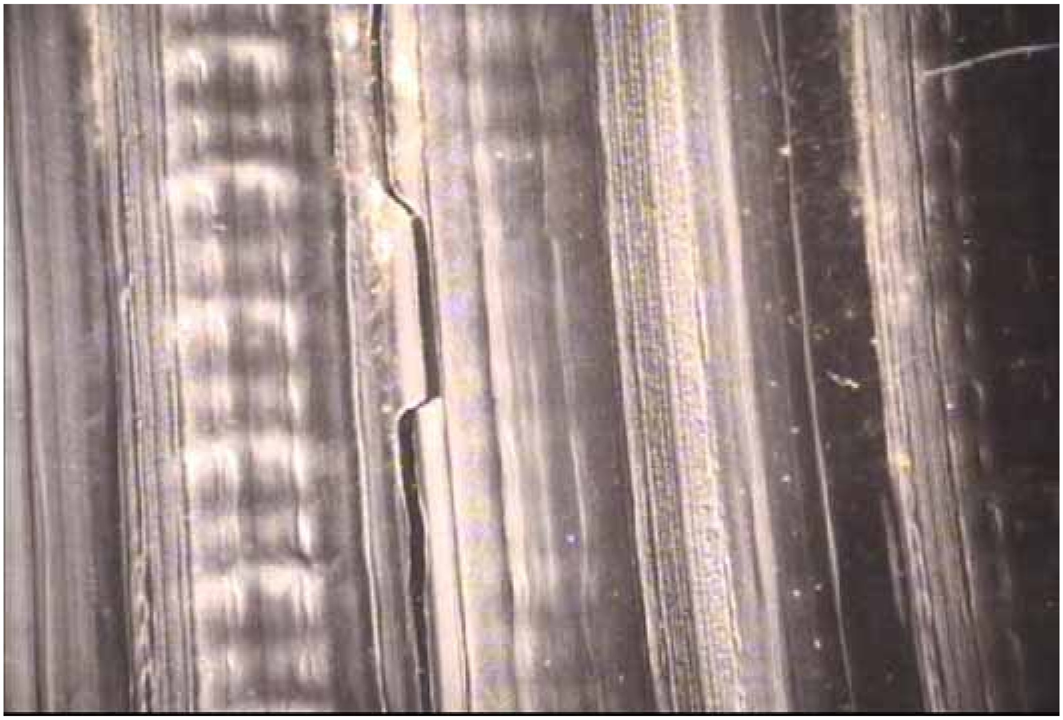


Figure 94 View of cracking failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

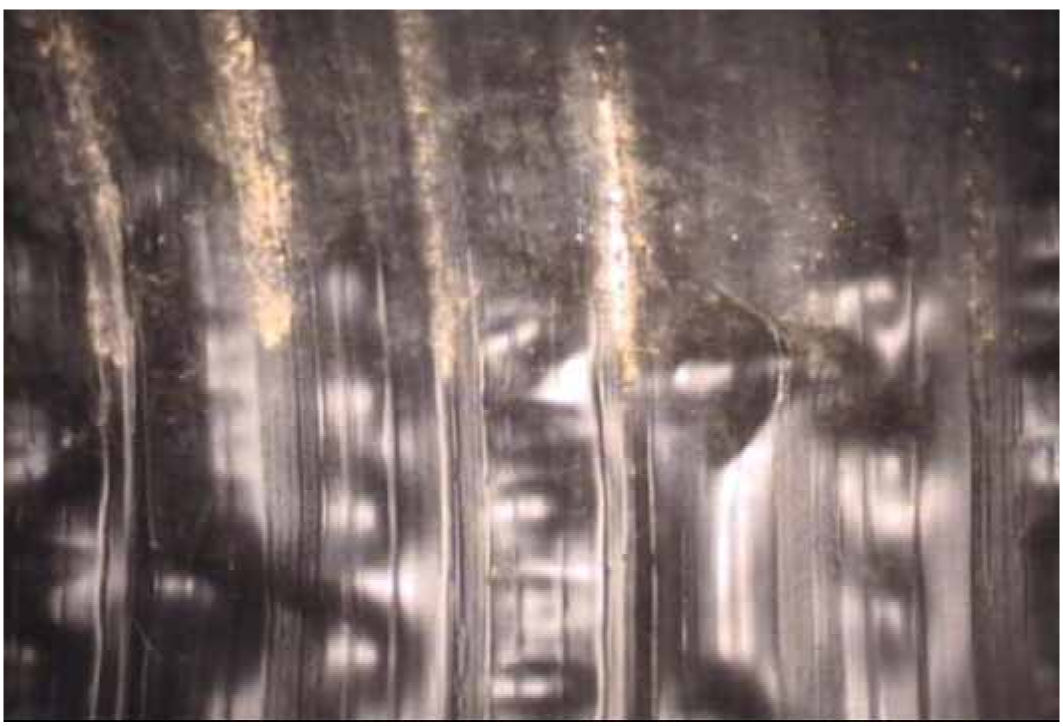


Figure 95 View of buckling failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

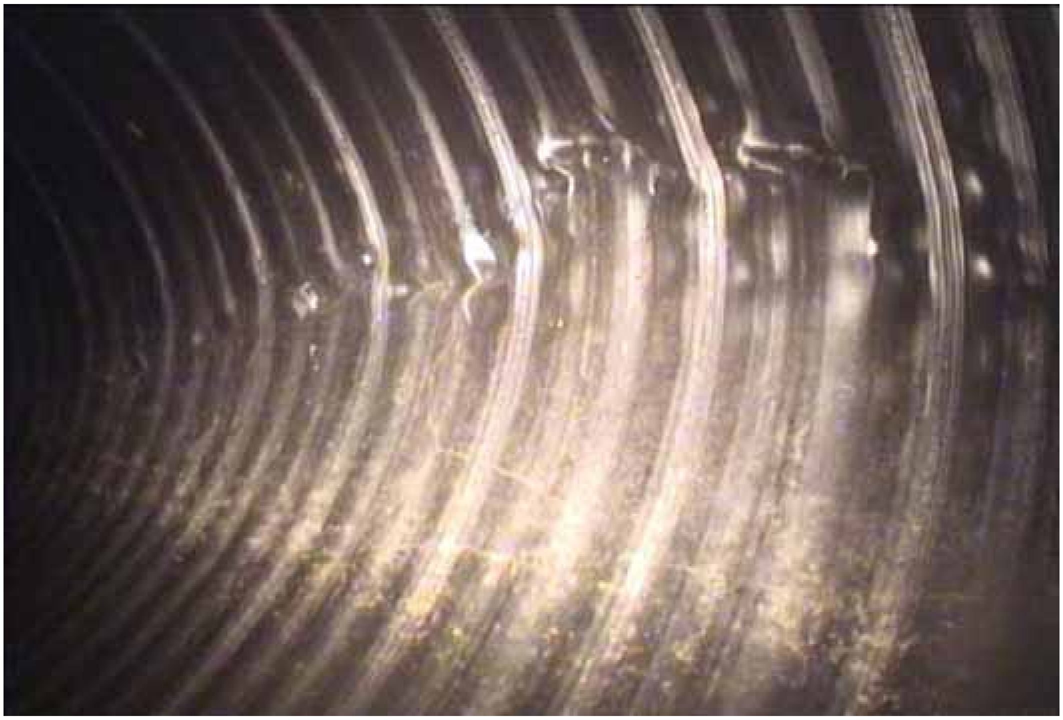


Figure 96 View of buckling and cracking failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

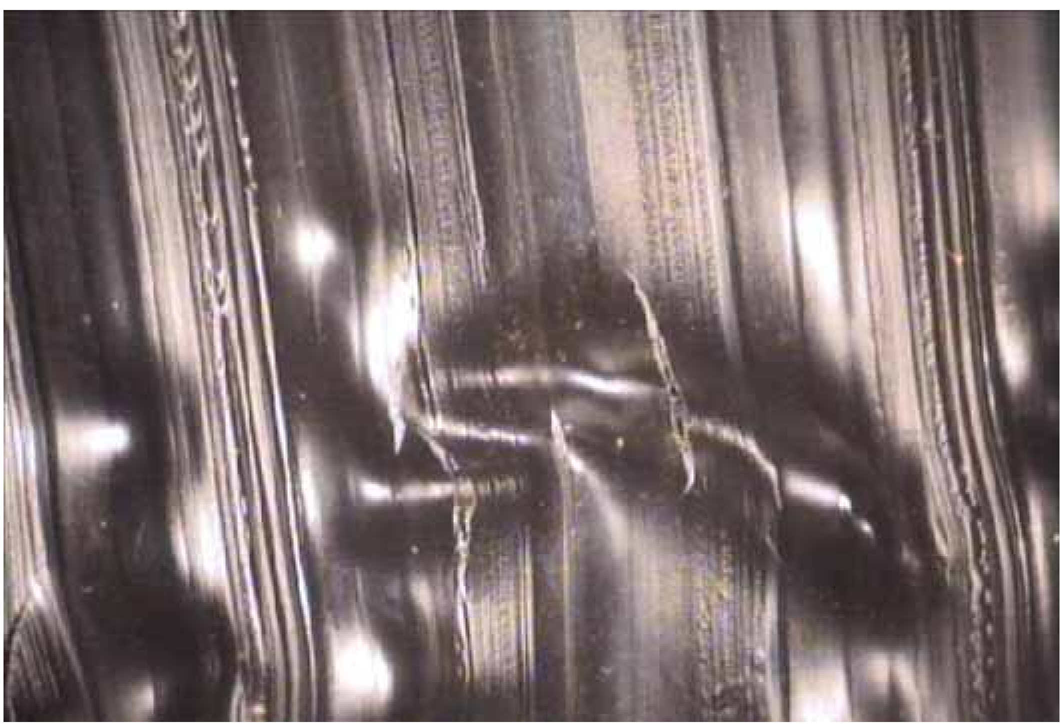


Figure 97 View of buckling and cracking failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 98 View of major joint displacement failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 99 View of cracking and major joint displacement failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

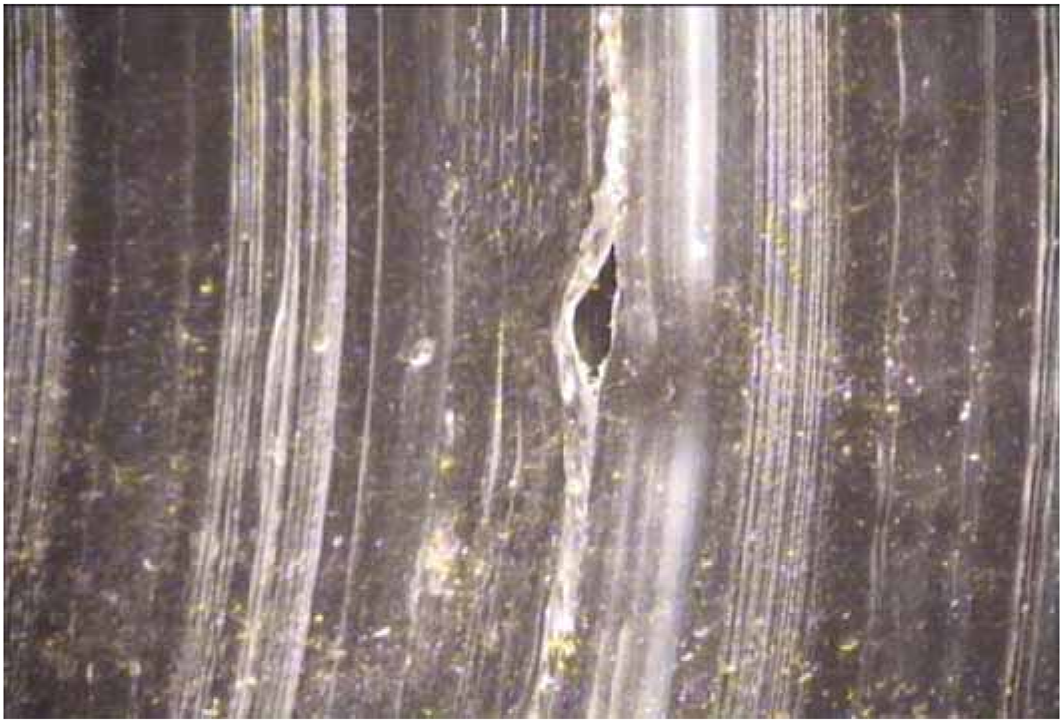


Figure 100 View of cracking failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

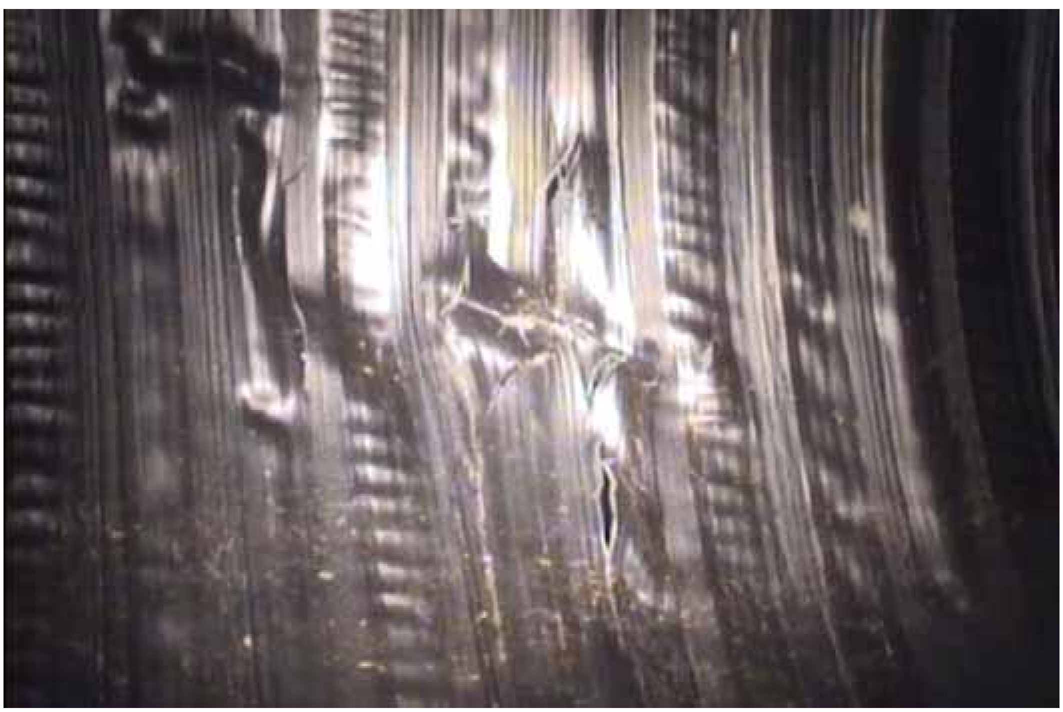


Figure 101 View of buckling and cracking failures for pipeline No. 11(Site No. 6: Rockingham – Love Ln)

Figure 102 View of major joint displacement failure for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 103 View of buckling and cracking failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 104 View of buckling and cracking failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Figure 105 View of cracking failures for pipeline No. 11 (Site No. 6: Rockingham – Love Ln)

Appendix 3 – State of Virginia

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Virginia. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

Figure 106 Layout of site locations

Table 10 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipeline Diameter (in.)	Inspection date	Length (ft)
1	Chesterfield – Commonwealth Pkwy	1*	60	8/22/2007	205
		2	60		245
2	Chesterfield – Bandermill	3	24	8/22/2007	320
3	Spotsylvania County	4	18	8/22/2007	210
		5*	18		20
4	Mechanicsville	6	30	8/21/2007	185
		7*	30		175
		8	18		165
		9*	18		290
5	Staunton	10	48	8/22/2007	160
		11*	48		50
		12	24		100
		13*	48		170
6	Winchester	14	18	8/27/2007	120
		15*	24		NA
		16	24		190
		17	30		60
		18	30		340
		19	42		NA

* Laser video data not collected

Table 11 Summary of different observed damages for different pipes at different site locations

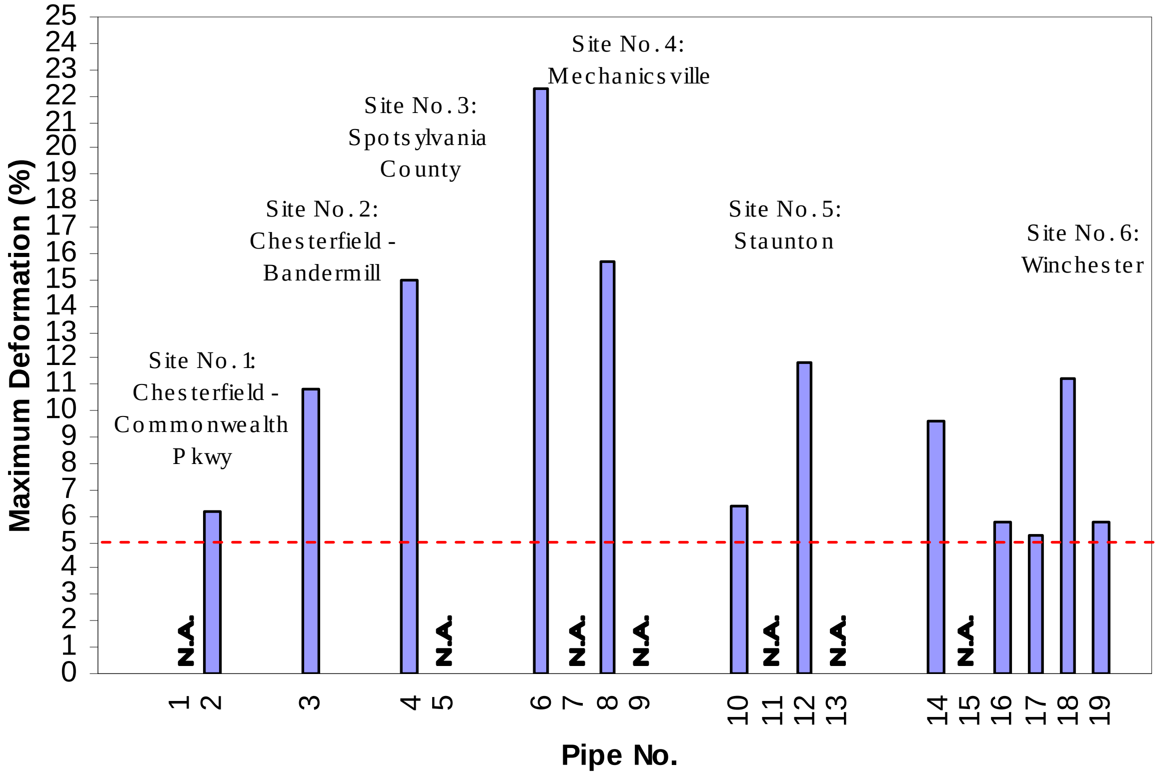
Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corregation Growth	Buckling
1	Chesterfield – Commonwealth Pkwy	1		NA			✓	
		2		✓			✓	
2	Chesterfield – Bandermill	3		✓		✓	✓	
3	Spotsylvania County	4	✓	P		✓	✓	✓
		5		NA			✓	
4	Mechanicsville	6	✓	✓	✓		✓	✓
		7		NA			✓	
		8		✓		✓	✓	
		9		NA			✓	
5	Staunton	10		✓			✓	
		11		NA			✓	
		12		✓			✓	
		13		NA			✓	
6	Winchester	14		✓		✓	✓	
		15	✓	✓			✓	
		16	✓	✓	✓	✓	✓	✓
		17		✓			✓	
		18	✓	✓		✓	✓	
		19		✓			✓	
Percentage of pipelines experiencing failure mode			26%	92%	11%	32%	100%	16%

NA: Laser video data not collected

Table 12 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Chesterfield – Commonwealth Pkwy	1	NA	NA	NA	NA
		2	4	6.2	5.2	6.2
2	Chesterfield – Bandermill	3	10.8	5.9	9.7	10.8
3	Spotsylvania County	4	11.7	13.9	15	15
		5	NA	NA	NA	NA
4	Mechanicsville	6	13	22.3	22.3	22.3
		7	NA	NA	NA	NA
		8	9.8	15.7	15.4	15.7
		9	NA	NA	NA	NA
5	Staunton	10	5	6.4	4.9	6.4
		11	NA	NA	NA	NA
		12	11.1	11.8	9.9	11.8
		13	NA	NA	NA	NA
6	Winchester	14	5.2	9.6	7.2	9.6
		15	NA	NA	NA	NA
		16	4.2	5.8	5.8	5.8
		17	5.3	3.5	4.4	5.3
		18	8.3	11.2	10.4	11.2
		19	3.1	5.8	3.9	5.8
	Max		13.0	22.3	22.3	22.3
	Min		3.1	3.5	3.9	5.3
	Average		7.6	9.8	9.5	10.5

NA: Laser video data not collected



NA.: Laser video data not collected

Figure 107 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Figure 108 View of the corrugation growth failure for pipeline No. 1 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Figure 109 View of the joint displacement failure for pipeline No. 1 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Pipeline No. 2 (Site No. 1: Chesterfield - Commonwealth Pkwy)

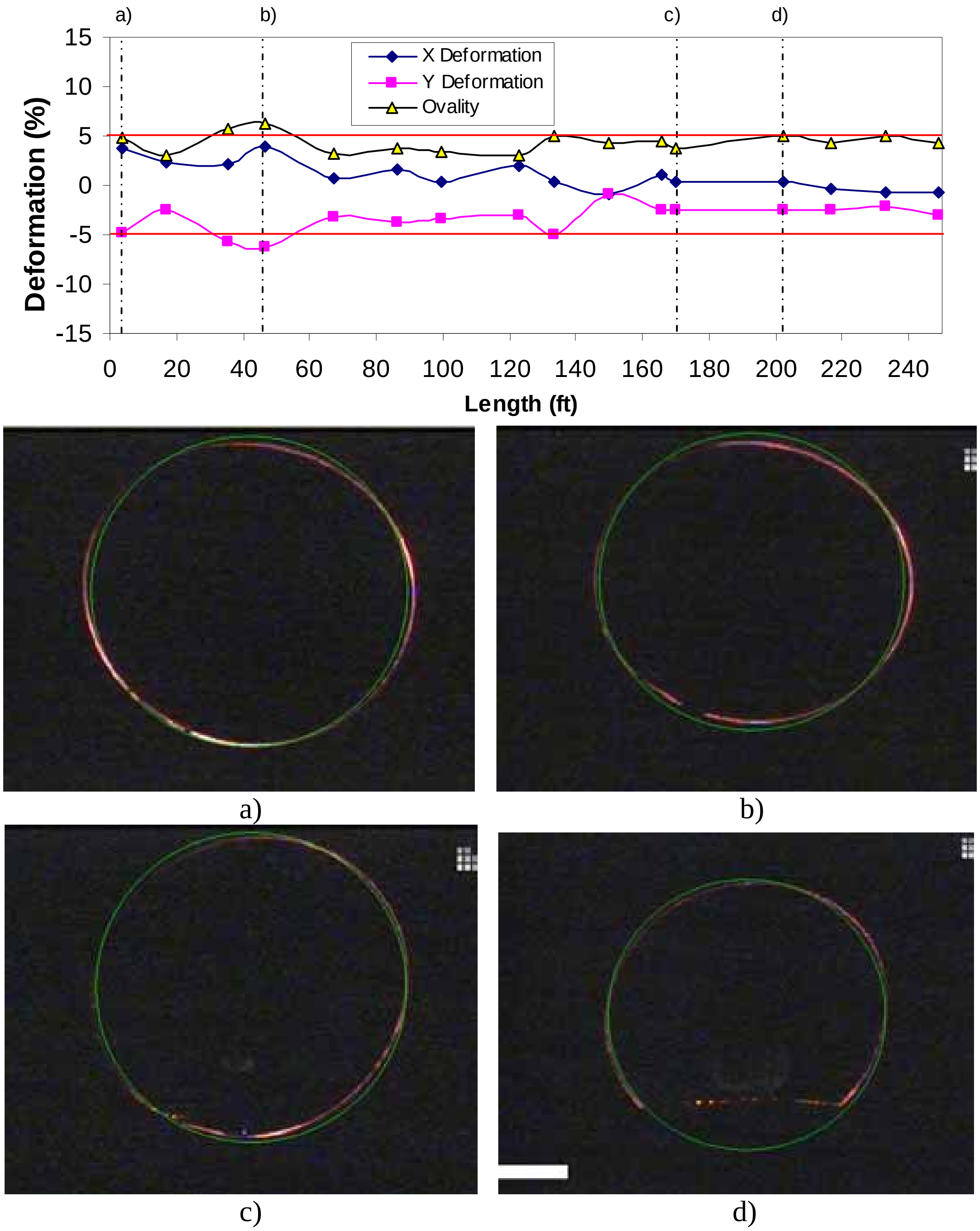
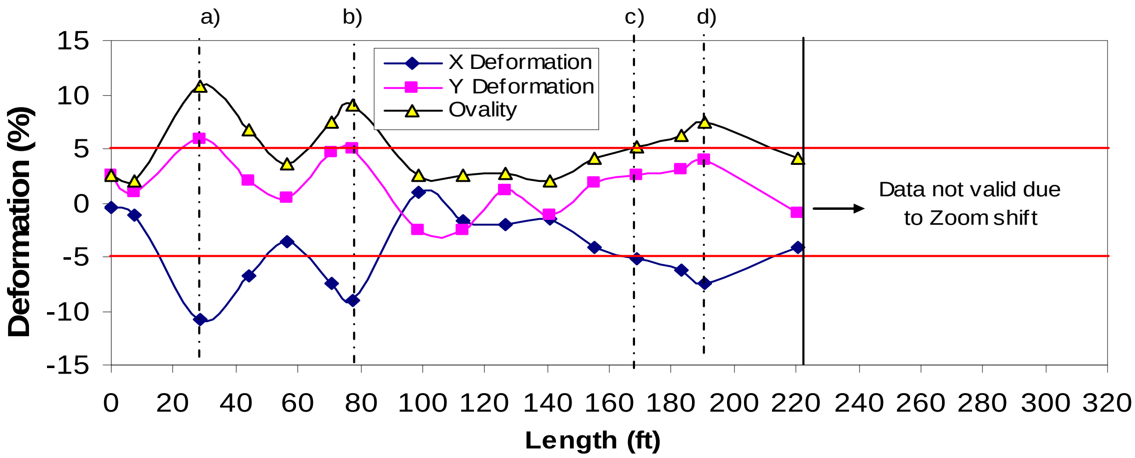


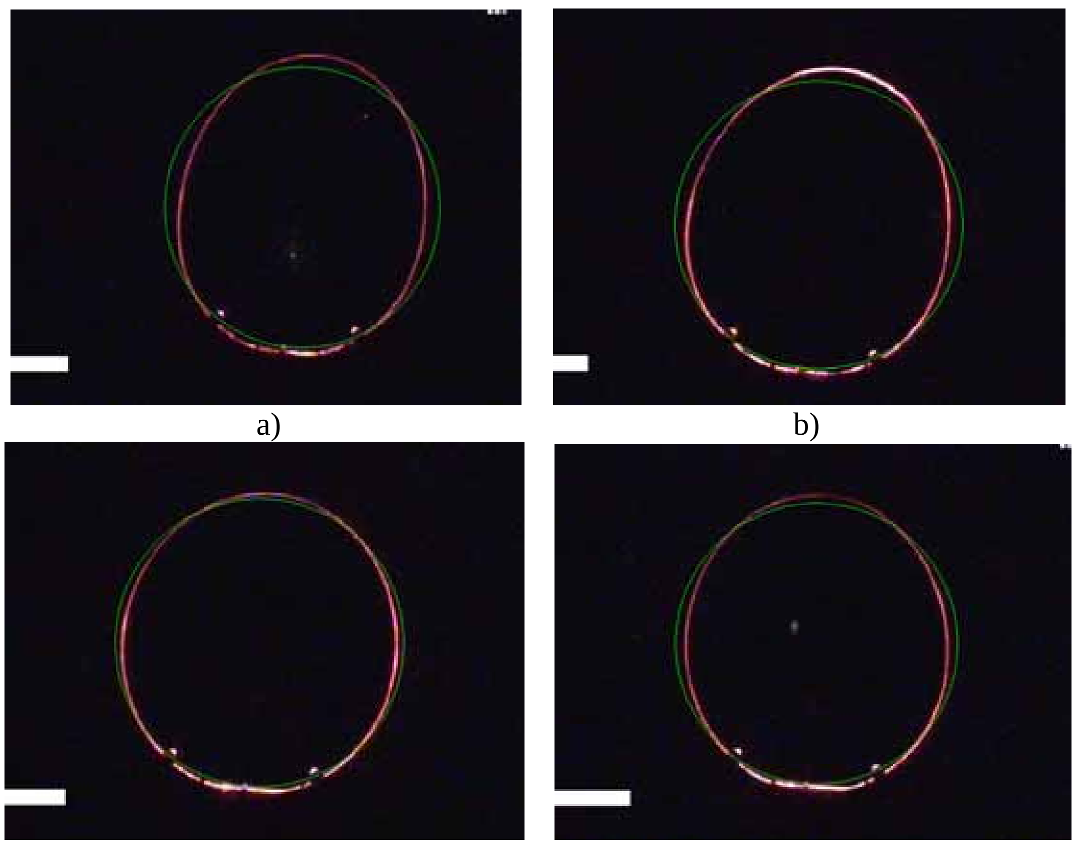
Figure 110 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Figure 111 View of opening of the pipe for pipeline No. 2 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Figure 112 View of the excessive deformation failure for pipeline No. 2 (Site No. 1: Chesterfield - Commonwealth Pkwy)

Pipeline No. 3 (Site No. 2: Chesterfield – Bandermill)





a) b)

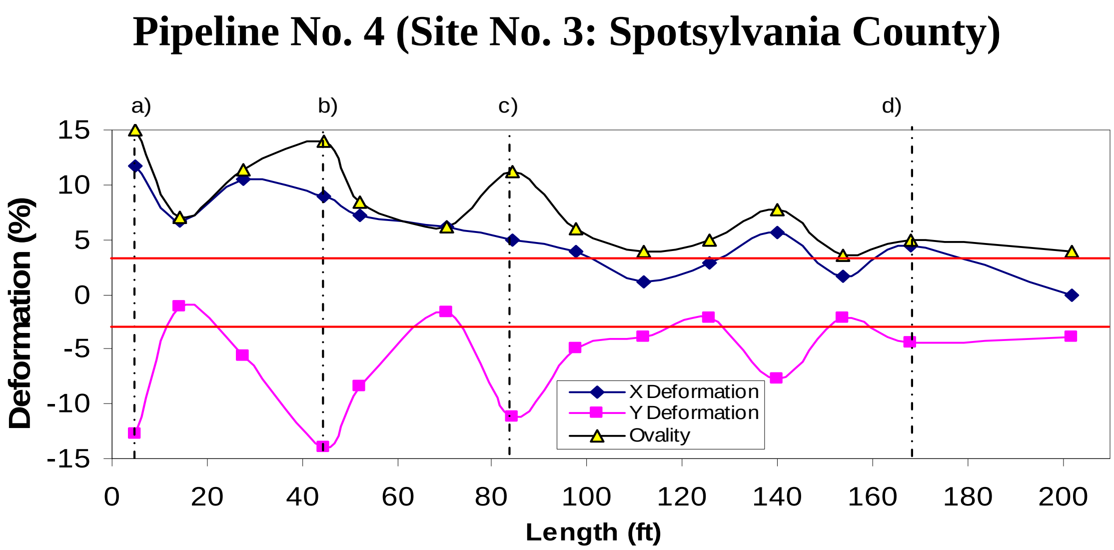
c) d)

Figure 113 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 2: Chesterfield – Bandermill)

Figure 114 View of major joint displacement failure for pipeline No. 3 (Site No. 2: Chesterfield – Bandermill)

Figure 115 View of cracking/fracture failure for pipeline No. 3 (Site No. 2: Chesterfield – Bandermill)

Figure 116 View of the excessive deformation failure for pipeline No. 3 (Site No. 2: Chesterfield – Bandermill)



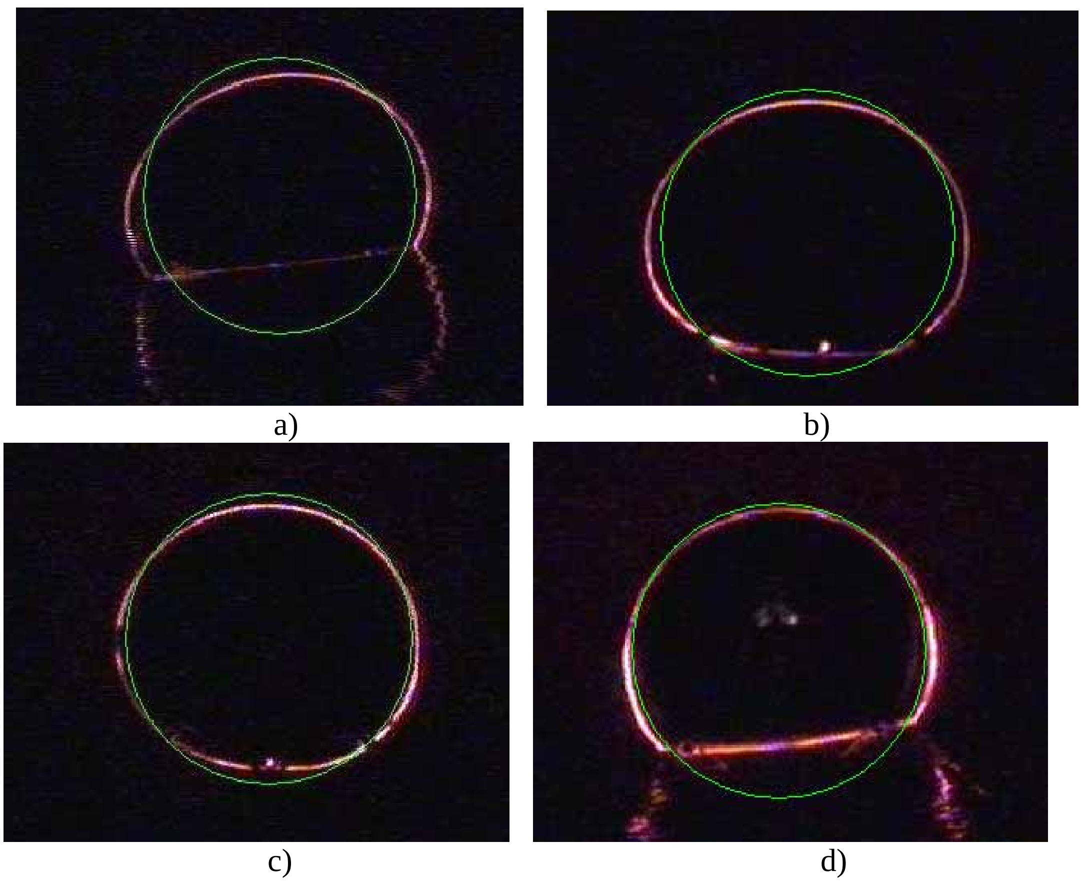


Figure 117 Horizontal and vertical deformation of the pipeline No. 4 (Site No. 3: Spotsylvania County)

Figure 118 View of buckling failure for pipeline No. 4 (Site No. 3: Spotsylvania County)

Figure 119 View of excessive deformation failure for pipeline No. 4 (Site No. 3: Spotsylvania County)

Figure 120 View of joint between two segments of the pipes for pipeline No. 4 (Site No. 3: Spotsylvania County)

Figure 121 View of joint between two segments of the pipes for pipeline No. 4 (Site No. 3: Spotsylvania County)

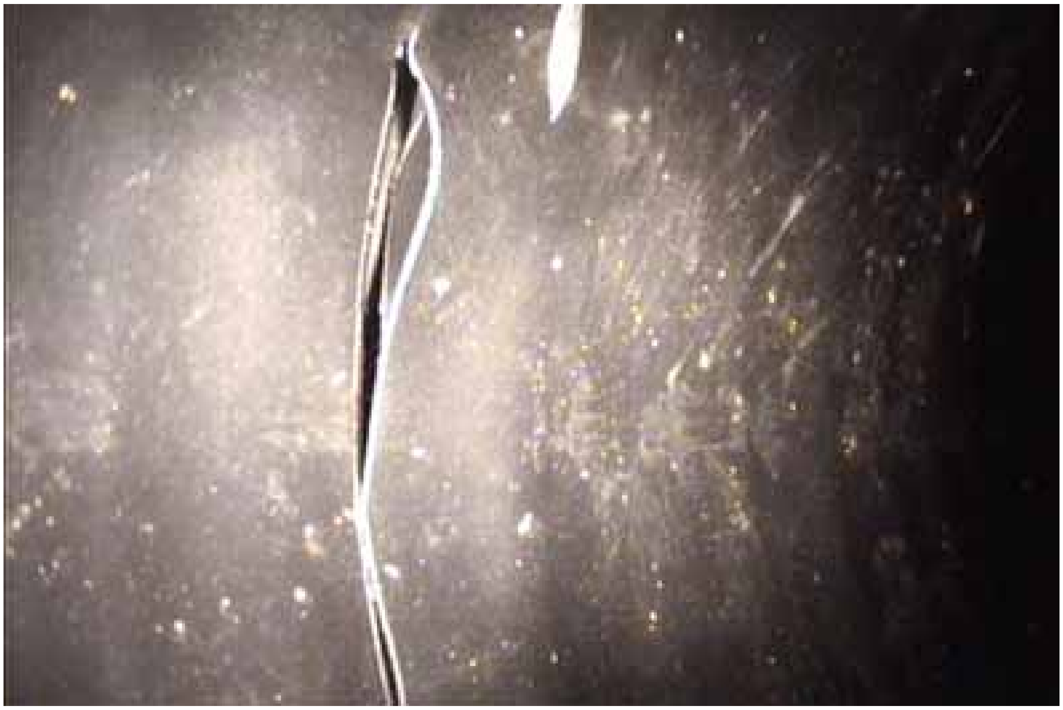
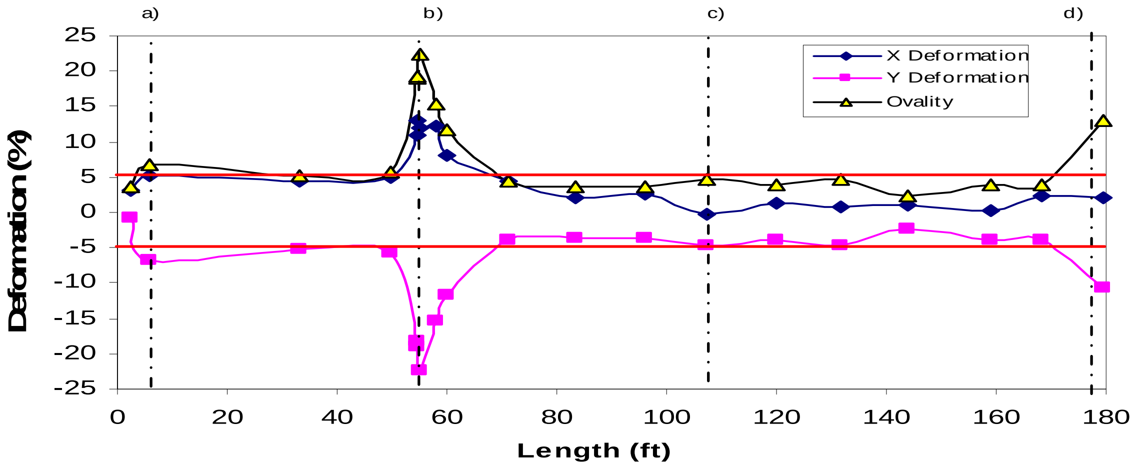


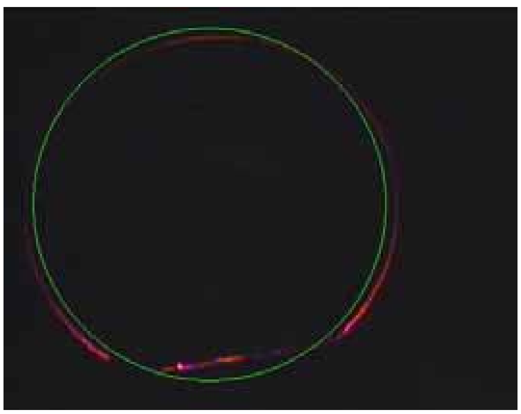
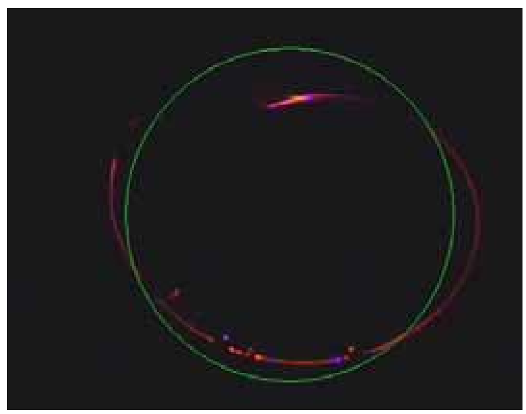
Figure 122 View of cracking/fracture failure for pipeline No. 4 (Site No. 3: Spotsylvania County)

Pipeline No. 5 (Site No. 3: Spotsylvania County)

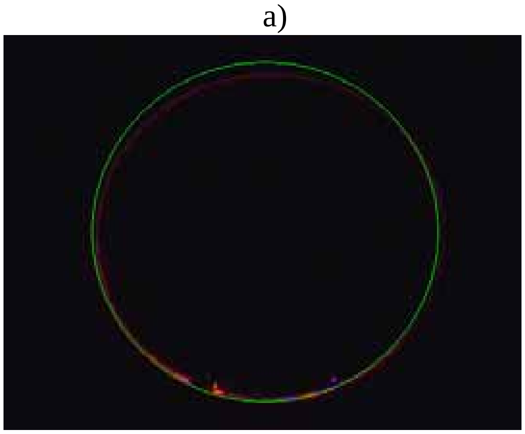
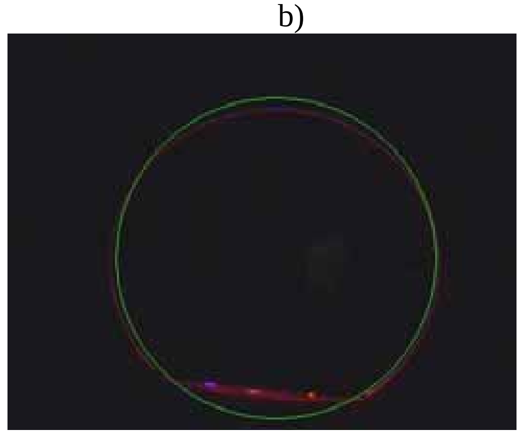
Figure 123 View of corrugation growth failure for pipeline No. 5 (Site No. 3: Spotsylvania County)

Pipeline No. 6 (Site No. 3: Spotsylvania County)



a) b)

c) d)

Figure 124 Horizontal and vertical deformation of the pipeline No. 6 (Site No. 4: Mechanicsville)

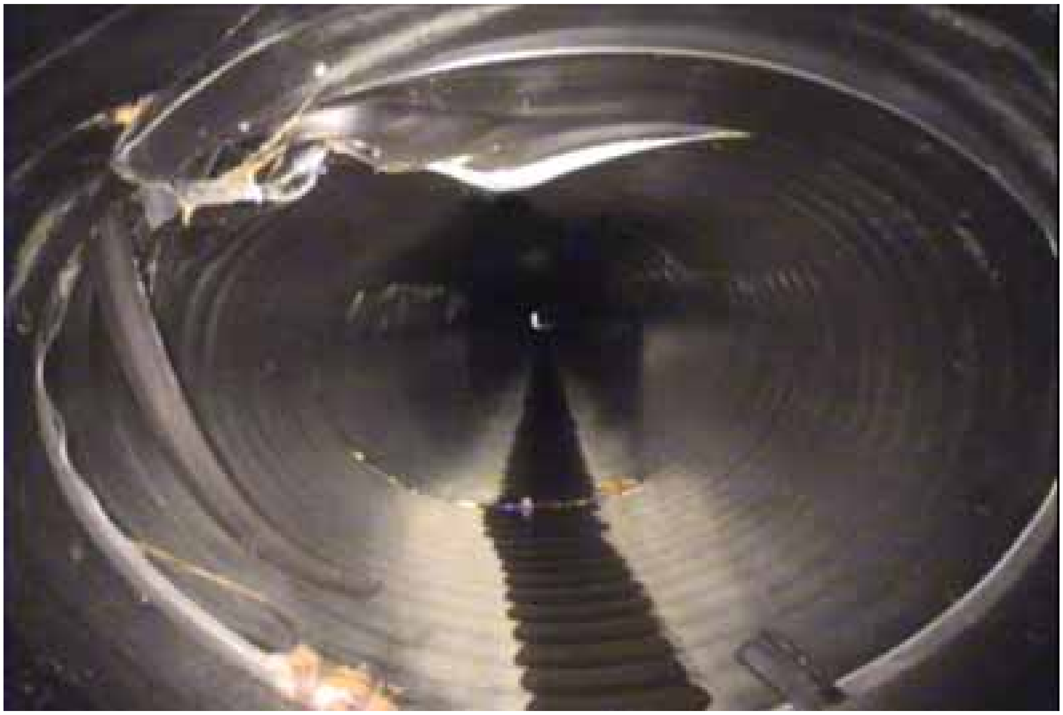


Figure 125 View of cracking/fracture failure for pipeline No. 6 (Site No. 4: Mechanicsville)

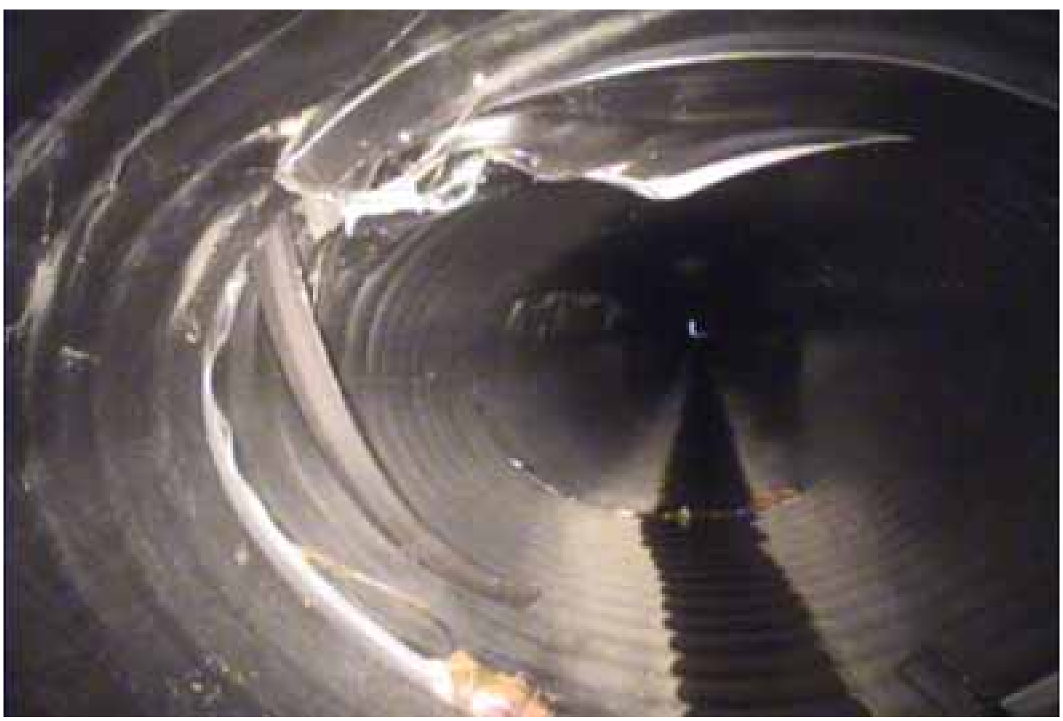


Figure 126 View of cracking/fracture and excessive deformation failures for pipeline No. 6 (Site No. 4: Mechanicsville)

Figure 127 View of cracking/fracture failure for pipeline No. 6 (Site No. 4: Mechanicsville)

Figure 128 View of cracking/fracture failure for pipeline No. 6 (Site No. 4: Mechanicsville)

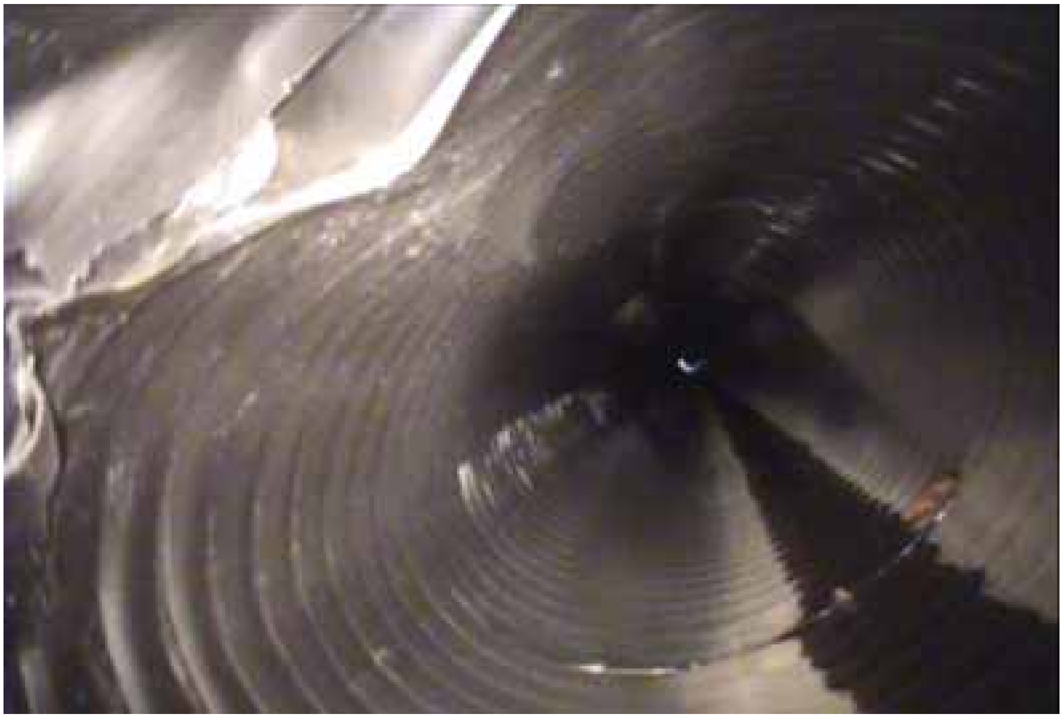
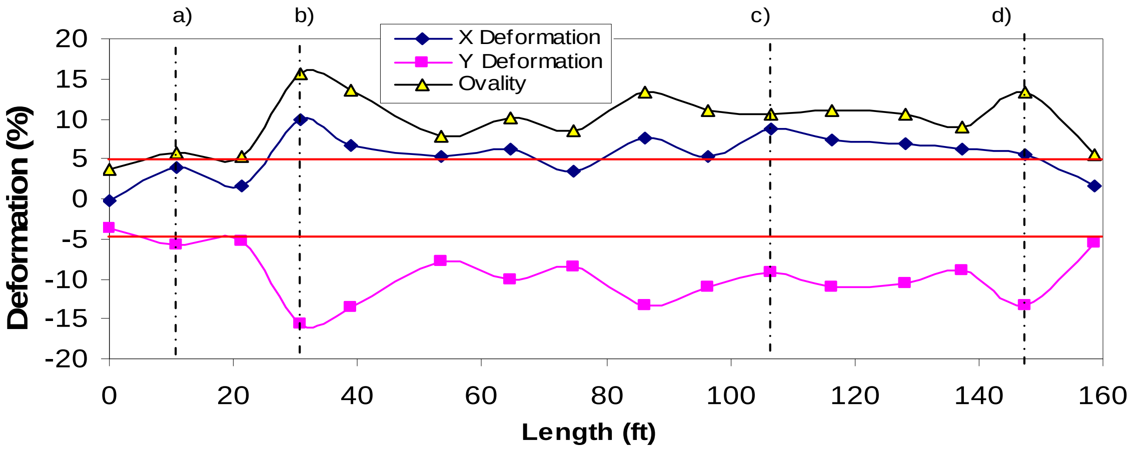


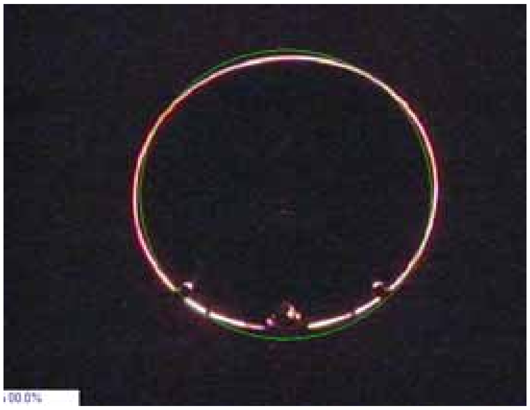
Figure 129 View of cracking/fracture failure for pipeline No. 6 (Site No. 4: Mechanicsville)

Pipeline No. 7 (Site No. 3: Spotsylvania County)

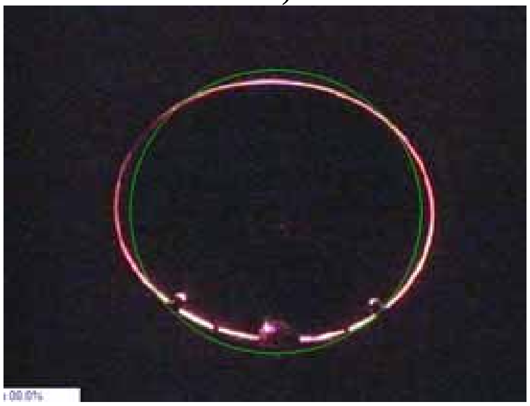
Figure 130 View of excessive deformation and corrugation growth failures for pipeline No. 7 (Site No. 4: Mechanicsville)

Pipeline No. 8 (Site No. 4: Mechanicsville)




a)


b)


c)

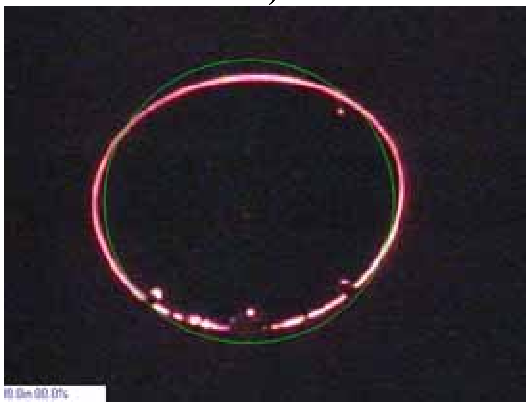

d)

Figure 131 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 4: Mechanicsville)

Figure 132 View of excessive deformation and corrugation growth failures for pipeline No. 8 (Site No. 4: Mechanicsville)

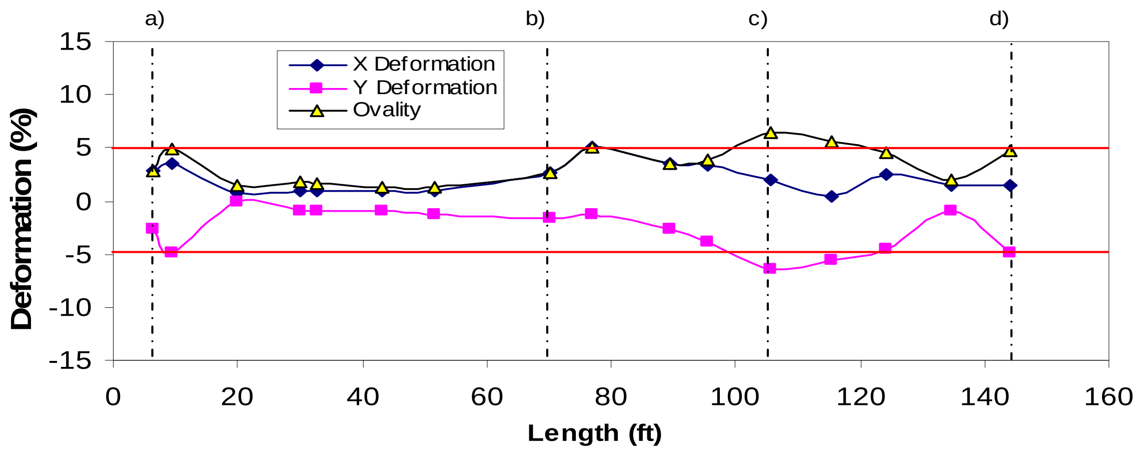
Figure 133 View of deformation of the pipe for pipeline No. 8 (Site No. 4: Mechanicsville)

Figure 134 View of major joint displacement failure for pipeline No. 8 (Site No. 4: Mechanicsville)

Pipeline No. 9 (Site No. 4: Mechanicsville)

Figure 135 View of excessive deformation failure for pipeline No. 9 (Site No. 4: Mechanicsville)

Pipeline No. 10 (Site No. 5: Staunton)



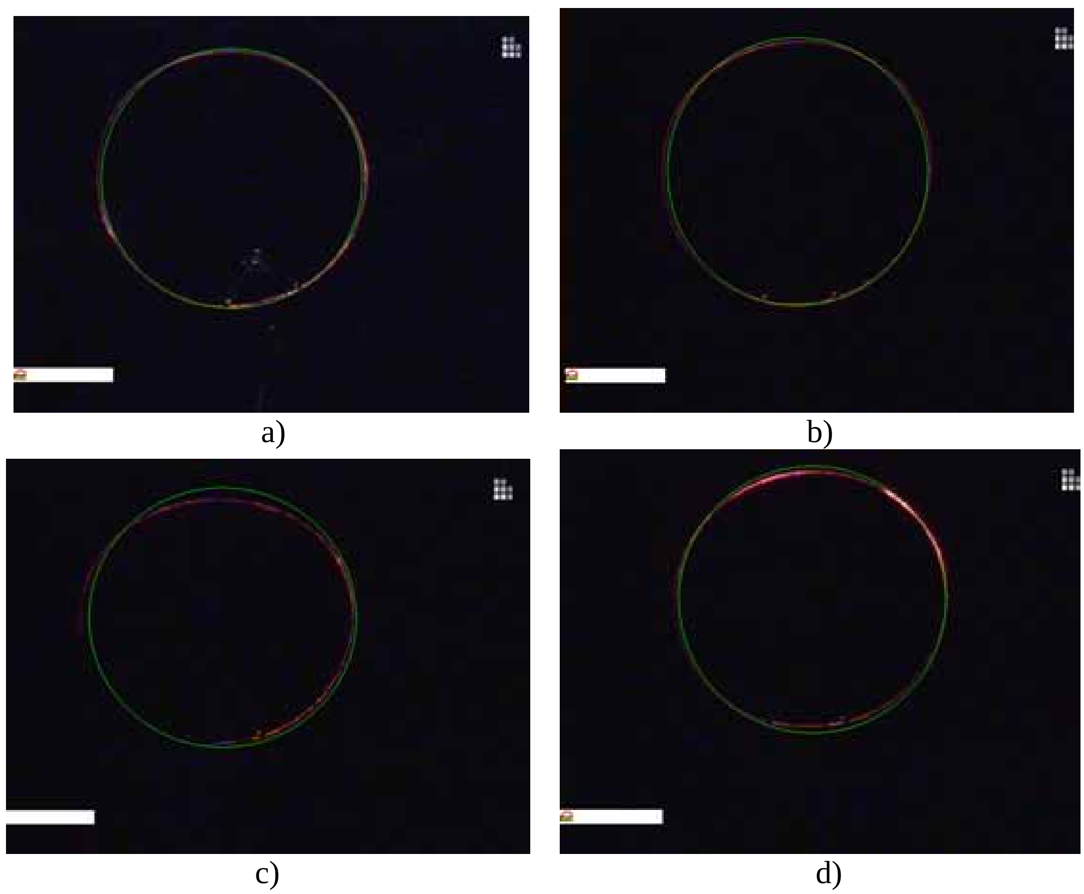
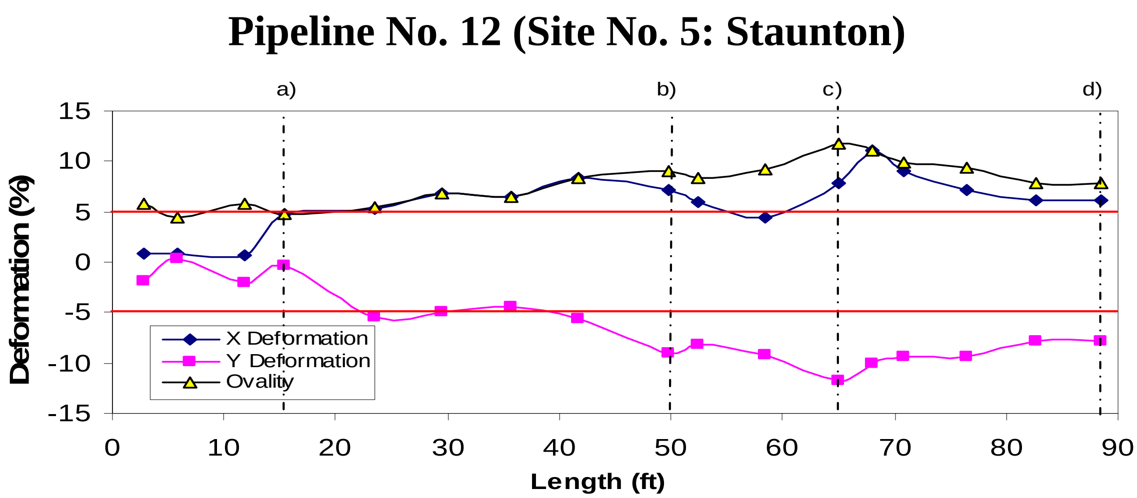


Figure 136 Horizontal and vertical deformation of the pipeline No. 10 (Site No. 5: Staunton)

Figure 137 View of excessive deformation failure for pipeline No. 10 (Site No. 5: Staunton)

Figure 138 View of excessive deformation failure for pipeline No. 11 (Site No. 5: Staunton)



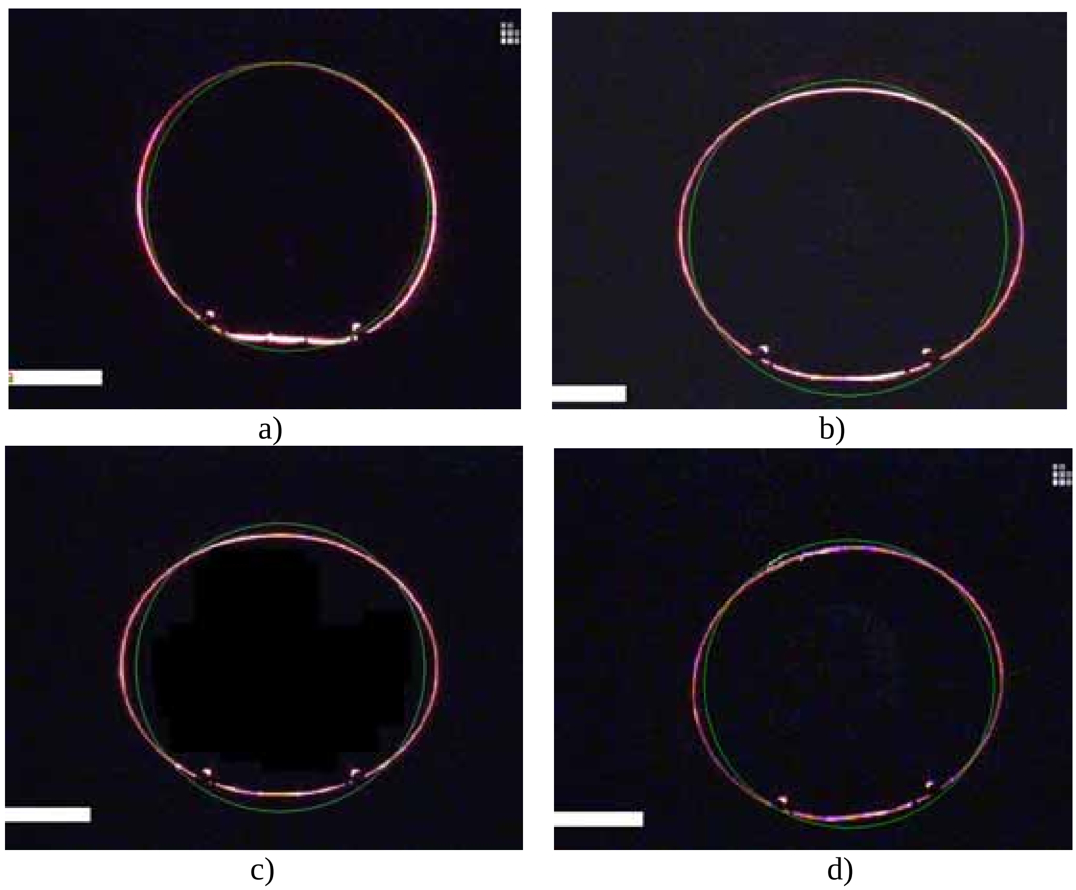
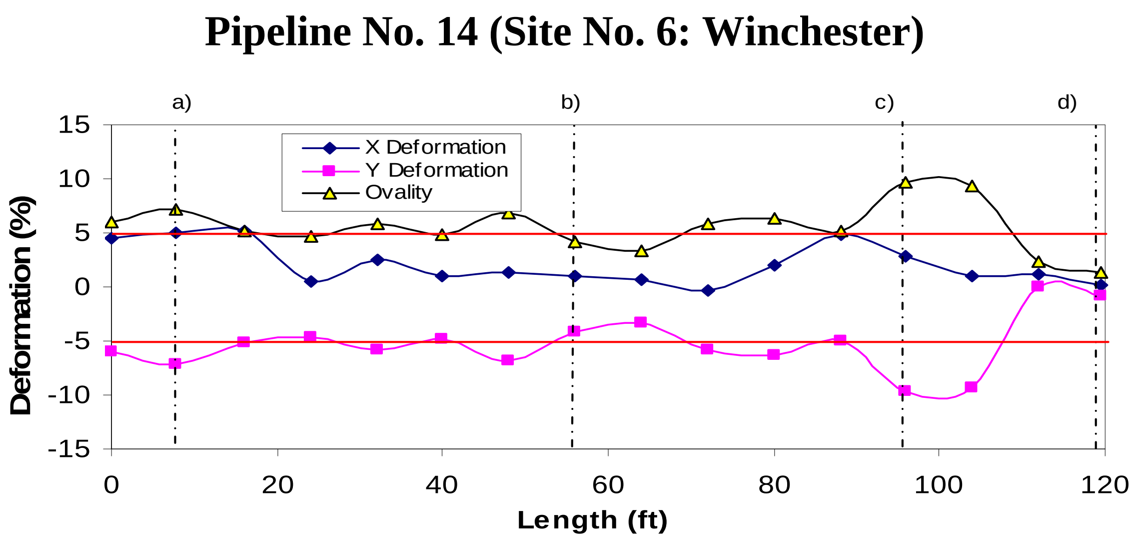
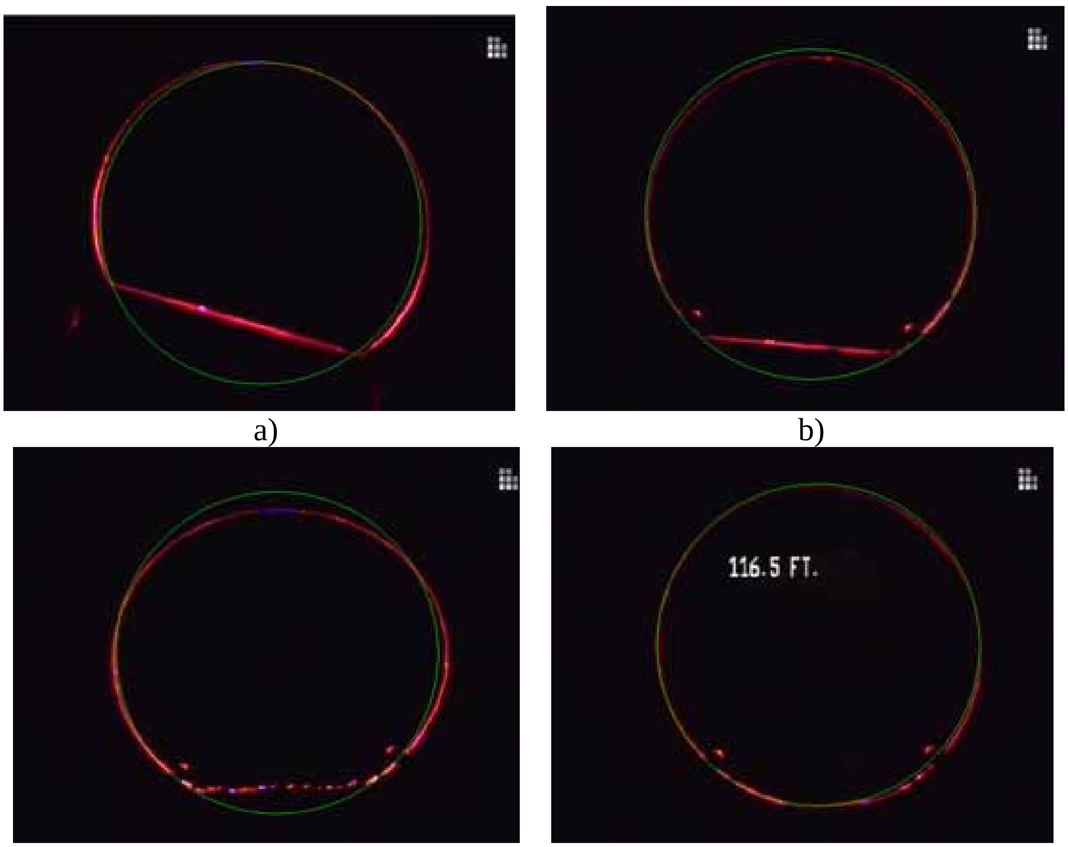


Figure 139 Horizontal and vertical deformation of the pipeline No. 12 (Site No. 5: Staunton)

Figure 140 View of excessive deformation failure for pipeline No. 12 (Site No. 5: Staunton)





a) b) c) d)

Figure 141 Horizontal and vertical deformation of the pipeline No. 14 (Site No. 6: Winchester)

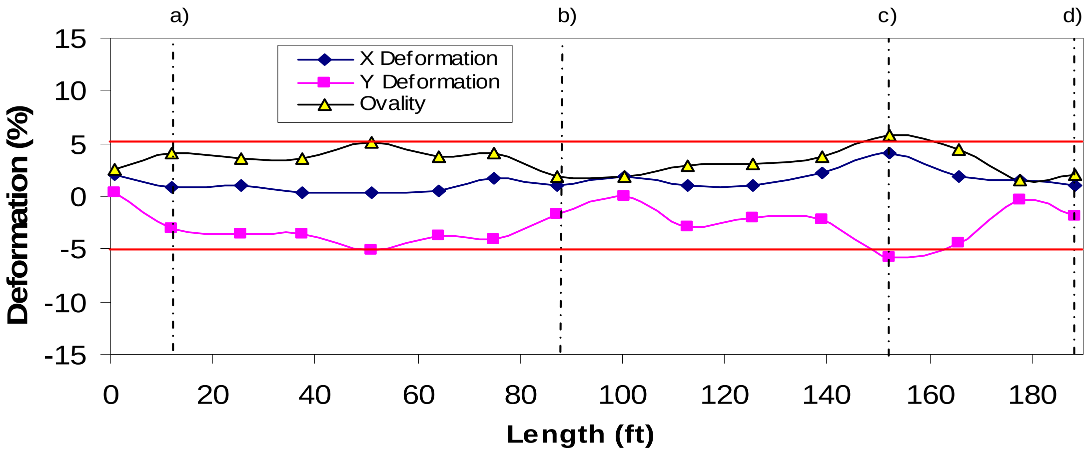
Figure 142 View of excessive deformation and major joint displacement failures for pipeline No. 14 (Site No. 6: Winchester)

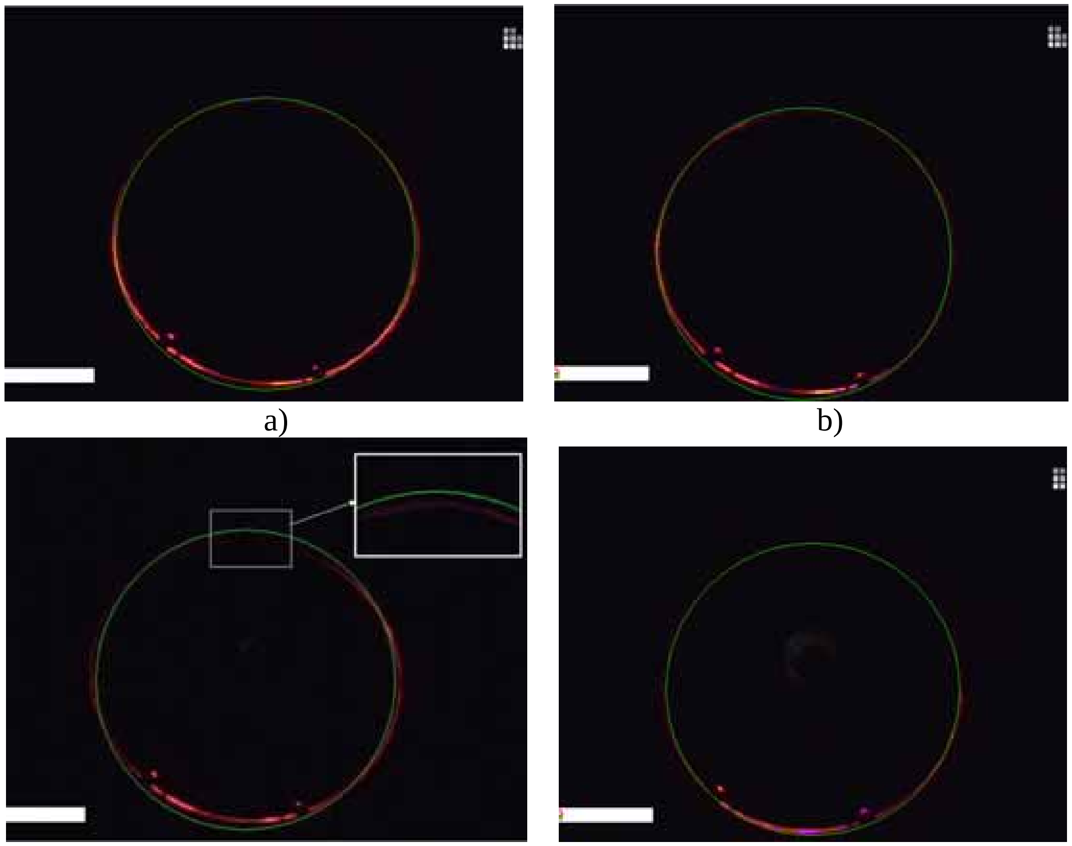
Pipeline No. 15 (Site No. 6: Winchester)

Figure 143 View of cracking/fracture failure for pipeline No. 15 (Site No. 6: Winchester)

Figure 144 View of cracking/fracture failure for pipeline No. 15 (Site No. 6: Winchester)

Pipeline No. 16 (Site No. 6: Winchester)





a) b)

c) d)

Figure 145 Horizontal and vertical deformation of the pipeline No. 16 (Site No. 6: Winchester)

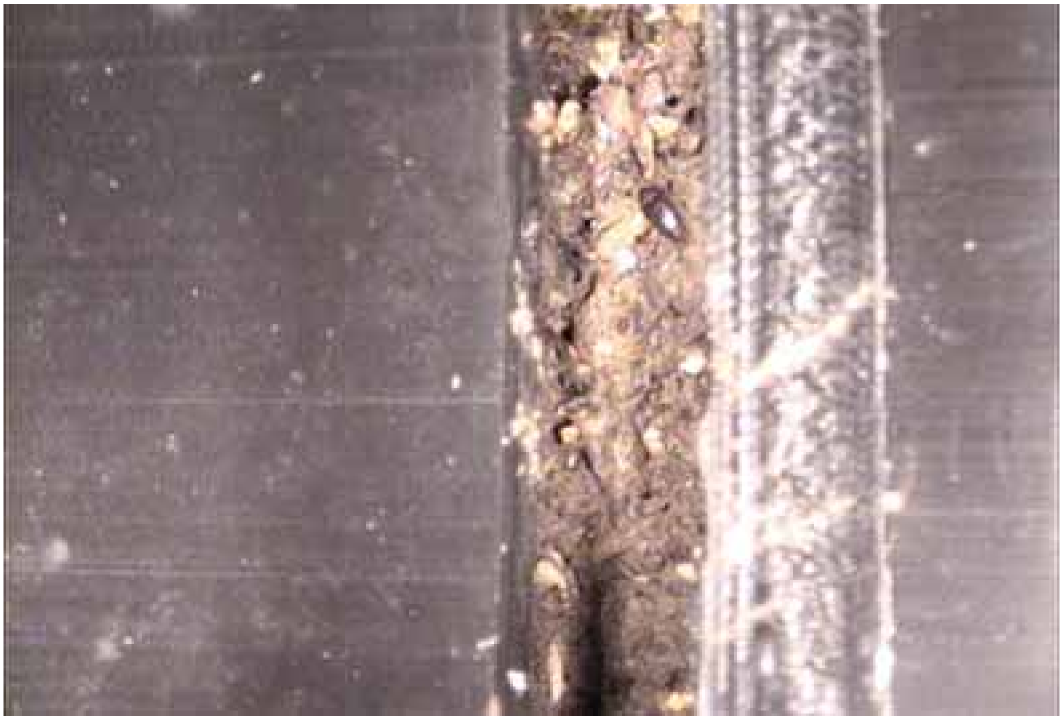


Figure 146 View of major joint displacement failure for pipeline No. 16 (Site No. 6: Winchester)

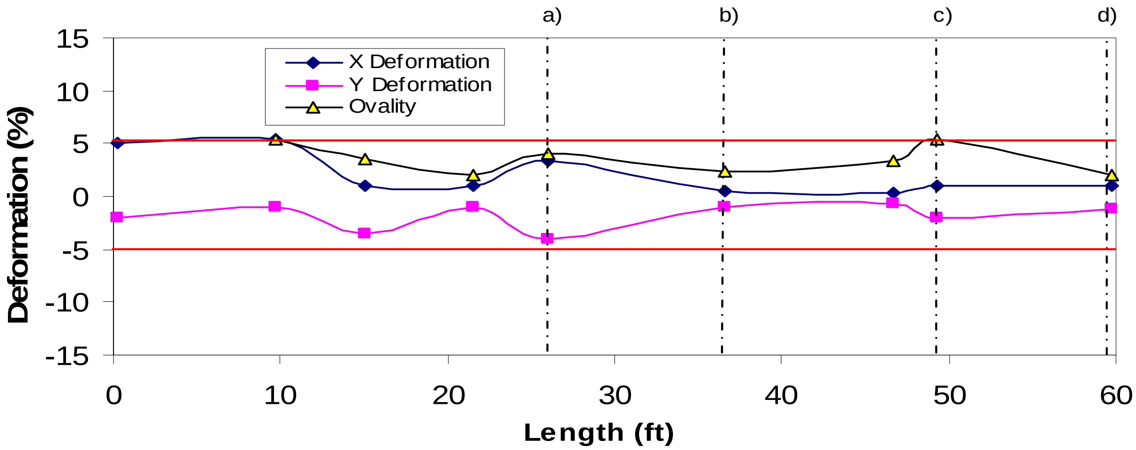
Figure 147 View of inverse curvature and corrugation growth failures for pipeline No. 16 (Site No. 6: Winchester)

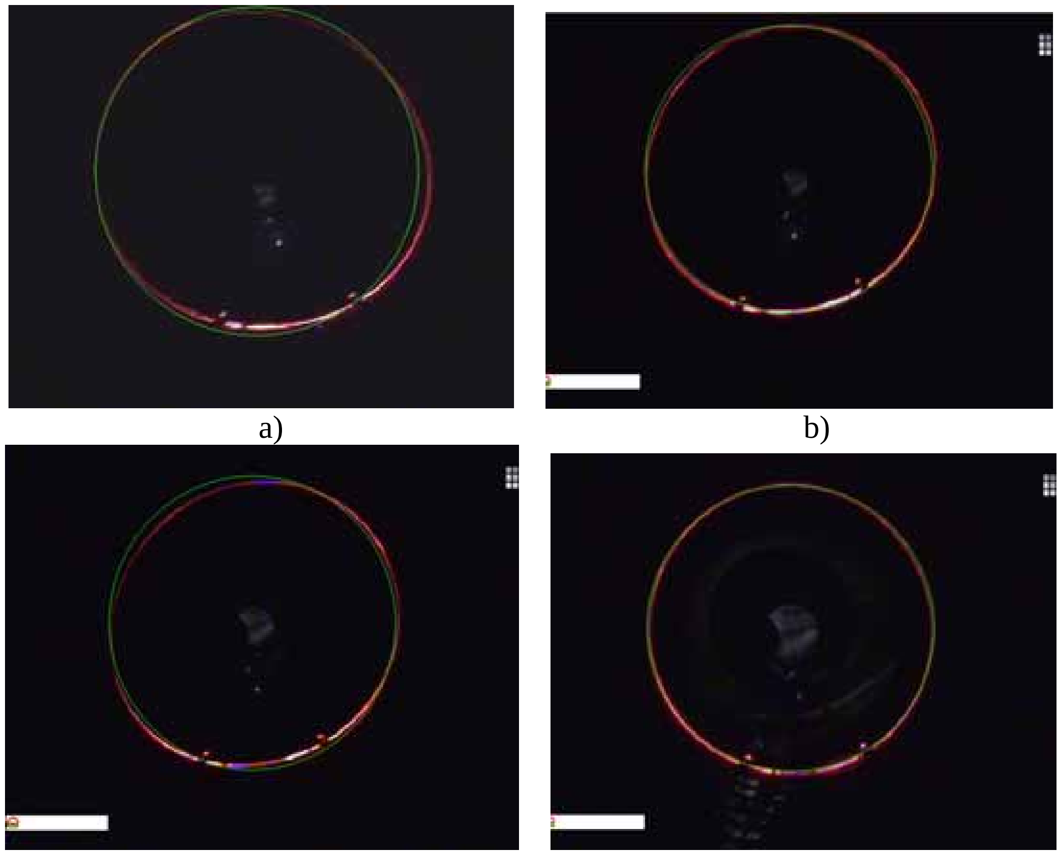
Figure 148 View of buckling and cracking/fracture failures for pipeline No. 16 (Site No. 6: Winchester)

Figure 149 View of cracking/fracture failure for pipeline No. 16 (Site No. 6: Winchester)

Figure 150 View of buckling failure for pipeline No. 16 (Site No. 6: Winchester)

Pipeline No. 17 (Site No. 6: Winchester)





a) b)

c) d)

Figure 151 Horizontal and vertical deformation of the pipeline No. 17 (Site No. 6: Winchester)

Pipeline No. 18 (Site No. 6: Winchester)

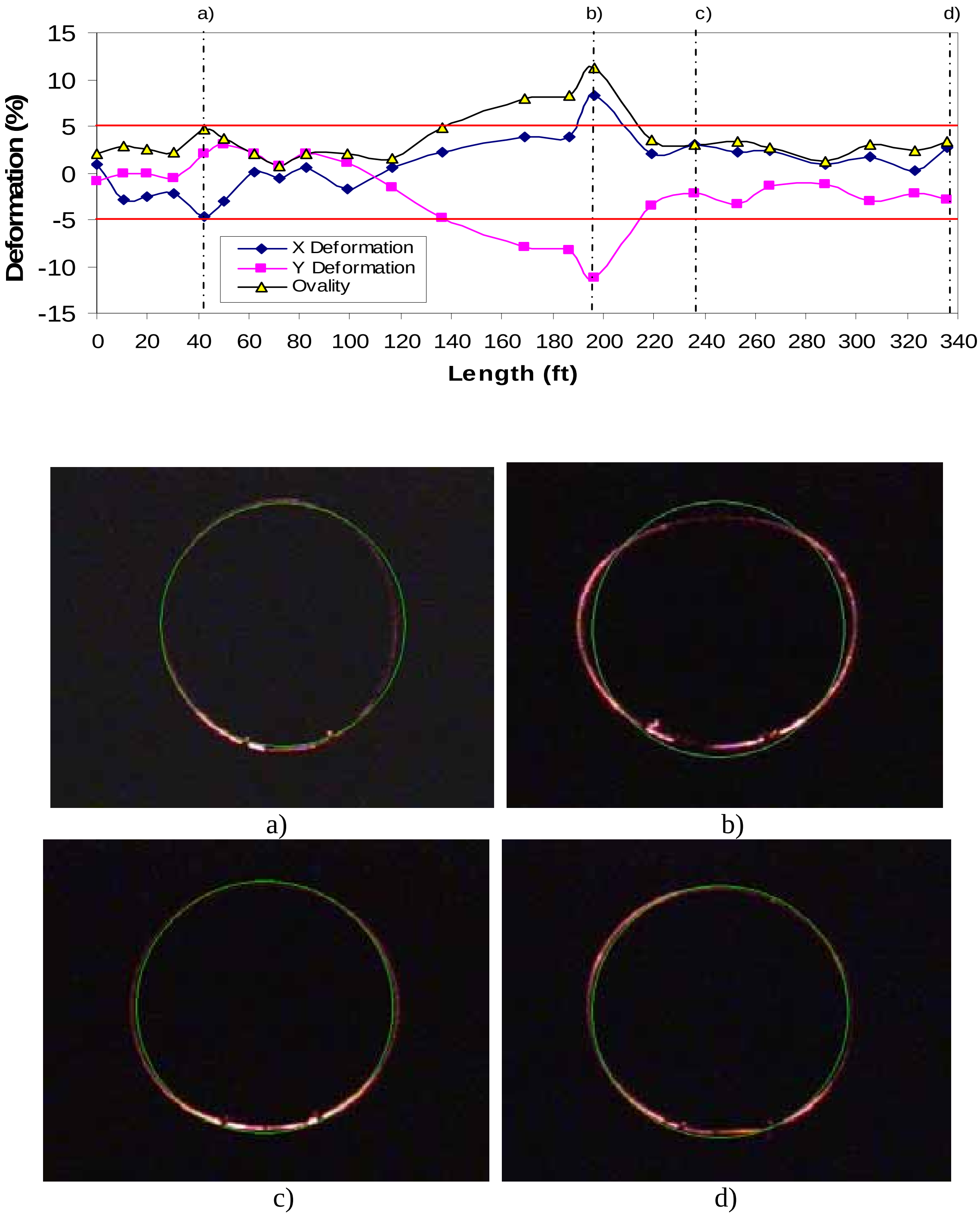
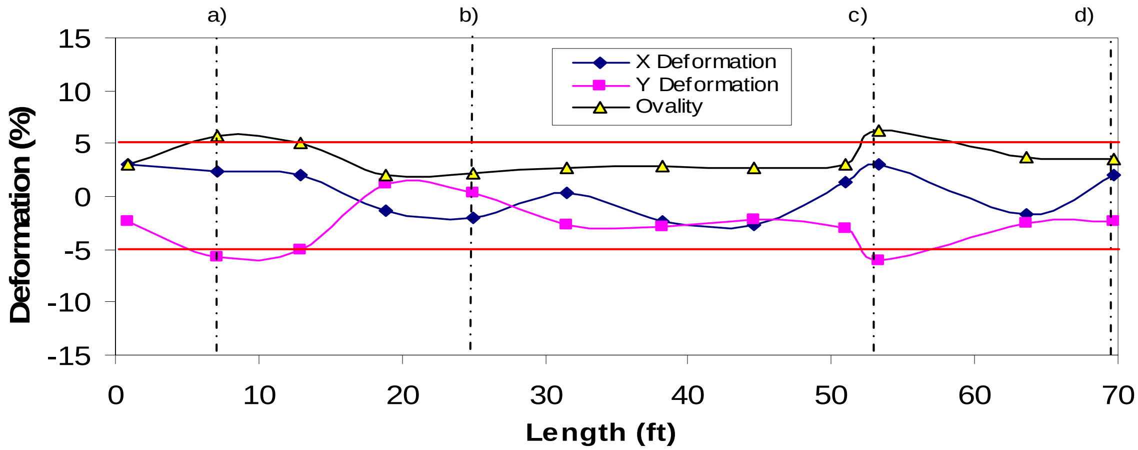
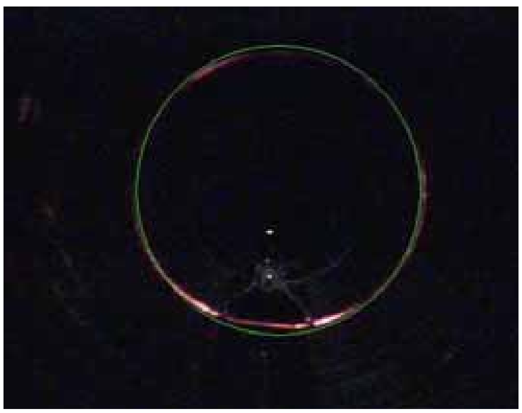


Figure 152 Horizontal and vertical deformation of the pipeline No. 18 (Site No. 6: Winchester)

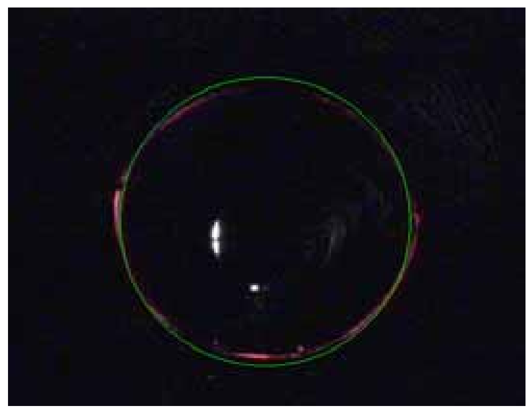
Figure 153 View of joint displacement failure for pipeline No. 18 (Site No. 6: Winchester)

Pipeline No. 19 (Site No. 6: Winchester)



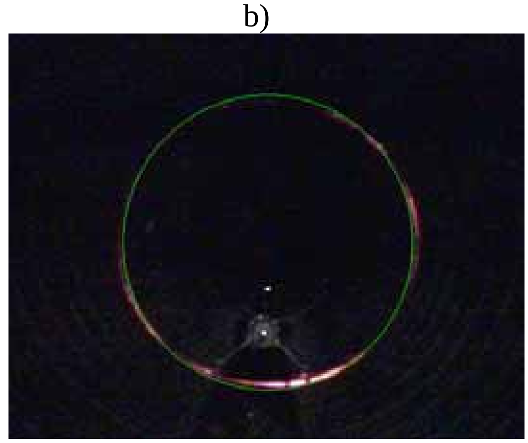


a)



b)

c)



d)

Figure 154 Horizontal and vertical deformation of the pipeline No. 19 (Site No. 6: Winchester)

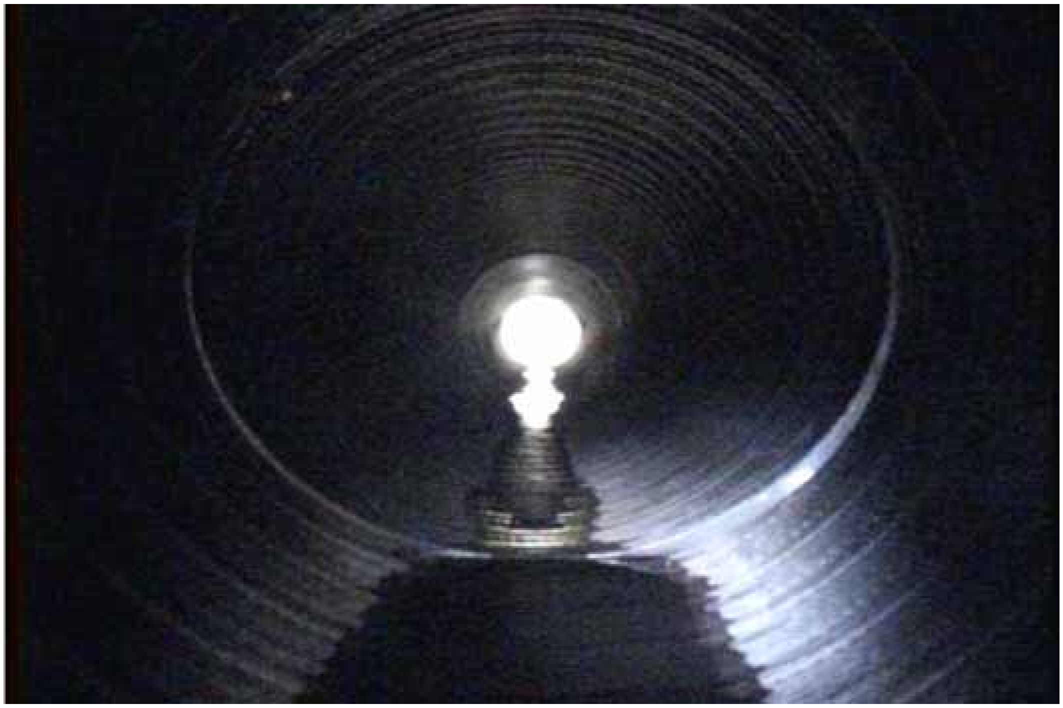


Figure 155 View of corrugation growth failure for pipeline No. 19 (Site No. 6: Winchester)

Appendix 4 – State of Minnesota

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Minnesota. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

Figure 156 Layout of site locations

Table 13 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	Brooklyn Park 64th Ave.	1	15	6/2/2008	20
		2	36	6/2/2008	190
		3	36	6/2/2008	155
2	Brooklyn Park 71st Ave	4	42	5/10/2007	250
		5	42		300
		6	42		150
		7	42	6/2/2008	310
		8	42	6/2/2008	315
3	Blaine – Xylite	9	24	5/11/2007	205
		10*	30		450
		11*	24		305
		12*	24		340
4	St Paul - Mounds View	13*	42	5/11/2007	125
		14*	48		180
5	McGregor	15	30	5/13/2007	80
6	Brooklyn Park - DuPont	16	30	5/12/2007	265
		17	24		295
		18	36		360
		19	36	5/13/2007	245
7	Mendota Heights	20	60	6/4/2008	125
		21	60	5/14/2007	415
		22	36		145
		23	48		465
		24	36	6/4/2008	200
		25	30	5/15/2007	455
		26	30		290
8	Fairmont	27	36	5/16/2007	470
		28	36	6/3/2008	480
		29	36		480
		30	30		420
9	Rochester	31	18	5/17/2007	375

* Laser video data was not collected.

Table 14 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Joint Displacement	Corregation Growth	Buckling
1	Brooklyn Park 64th Ave.	1					✓	
		2		✓			✓	
		3	✓	✓			✓	
2	Brooklyn Park 71st Ave	4					✓	
		5				✓	✓	
		6				✓	✓	
		7				✓	✓	
		8	✓	✓		✓	✓	
3	Blaine – Xylite	9	✓	✓			✓	
		10		NA		✓	✓	
		11		NA			✓	
		12	✓	NA			✓	
4	St Paul - Mounds View	13		NA			✓	
		14		NA			✓	
5	McGregor	15	✓	✓			✓	
6	Brooklyn Park - DuPont	16					✓	
		17		✓			✓	
		18		✓			✓	
		19	✓				✓	
7	Mendota Heights	20					✓	
		21					✓	
		22					✓	
		23		✓		✓	✓	
		24		✓			✓	
		25		✓			✓	
		26		✓			✓	
8	Fairmont	27	✓	✓		✓	✓	
		28					✓	
		29		✓			✓	✓
		30		✓			✓	
9	Rochester	31	✓	✓		✓	✓	
Percentage of pipelines experiencing failure mode			26%	58%	0%	26%	100%	3%

NA: Laser video data not collected.

Table 15 Comparison and Summary of Deformation of pipelines

Site No.	Site Location	Pipe No.	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Brooklyn Park 64th Ave.	1	3.4	4	4.1	4.1
		2	6.1	7.4	7.3	7.4
		3	10.9	8.9	11.3	11.3
2	Brooklyn Park 71st Ave	4	2.7	3.4	3	3.4
		5	1.3	1.7	2.1	2.1
		6	3.3	3.4	3.4	3.4
		7	2.7	2.9	3.5	3.5
		8	2.6	6.4	4.1	6.4
3	Blaine – Xylite	9	4.4	6.5	5.9	6.5
		10	NA	NA	NA	NA
		11	NA	NA	NA	NA
		12	NA	NA	NA	NA
4	St Paul - Mounds View	13	NA	NA	NA	NA
		14	NA	NA	NA	NA
5	McGregor	15	9.9	8.2	8.5	9.9
6	Brooklyn Park - DuPont	16	3.2	3.7	4.1	4.1
		17	6.4	5.1	6.3	6.4
		18	13.2	11.6	13.5	13.5
		19	3.1	3	4.5	4.5
7	Mendota Heights	20	1.1	3.4	3.6	3.6
		21	1.7	2.2	2.2	2.2
		22	2.9	2.4	2.9	2.9
		23	5.2	5	5.9	5.9
		24	6.9	7	7.6	7.6
		25	5.6	5.5	6.4	6.4
		26	9.1	12	15	15
8	Fairmont	27	8.8	9.8	10.2	10.2
		28	2.7	3.3	2.9	3.3
		29	9.8	11.1	11.2	11.2
		30	4.4	5.5	5.2	5.5
9	Rochester	31	6.7	5.8	5.5	6.7
	Max		13.2	12.0	15.0	15.0
	Min		1.1	1.7	2.1	2.1
	Average		5.3	5.7	6.2	6.4

NA.: Laser video data not collected

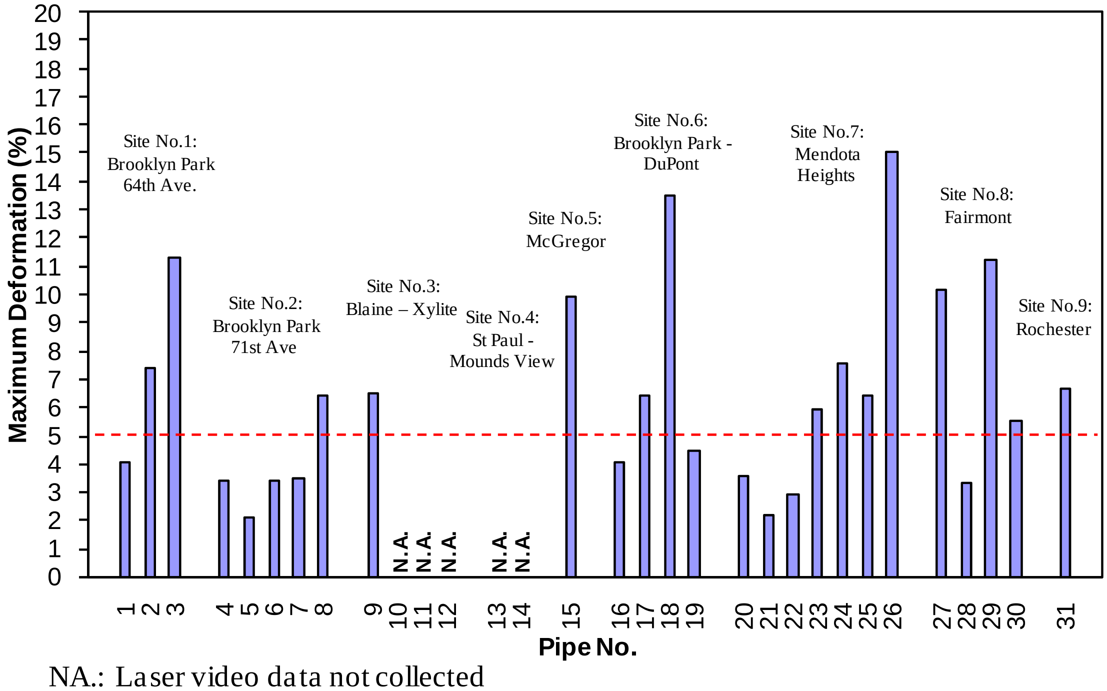
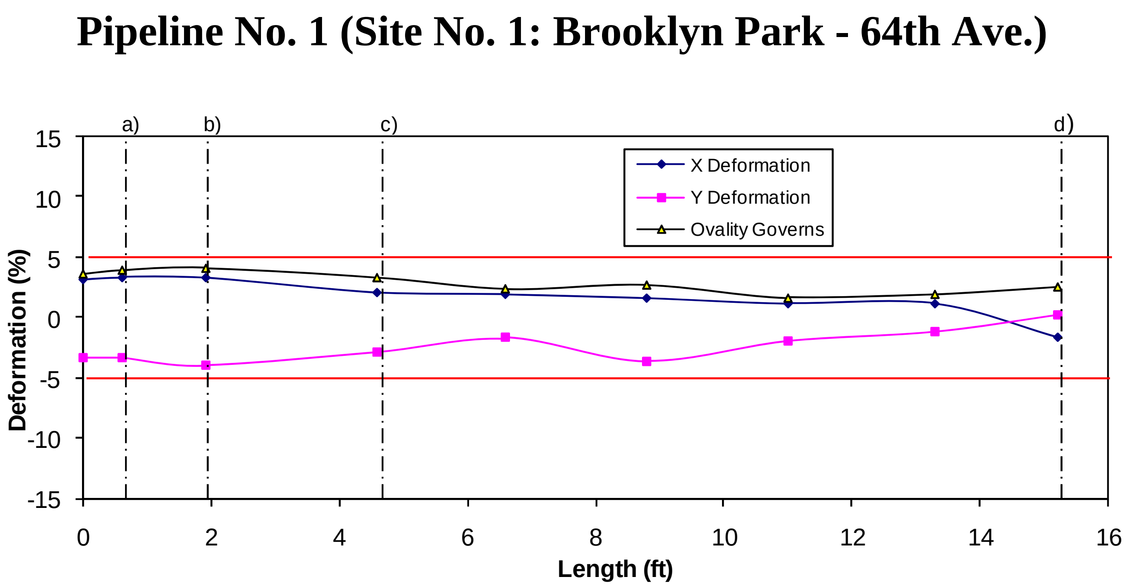
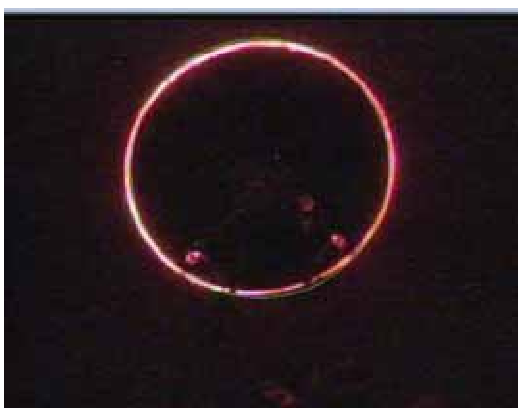


Figure 157 Comparison of Maximum deformations calculated for pipelines tested in different site locations

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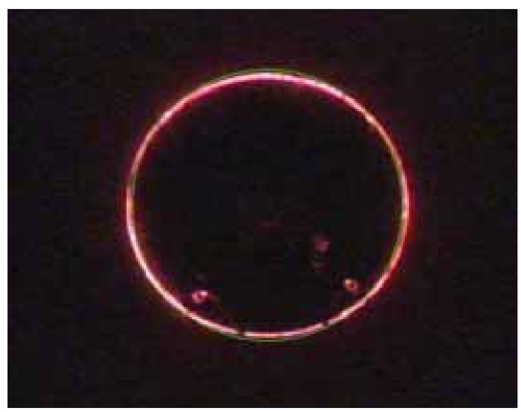
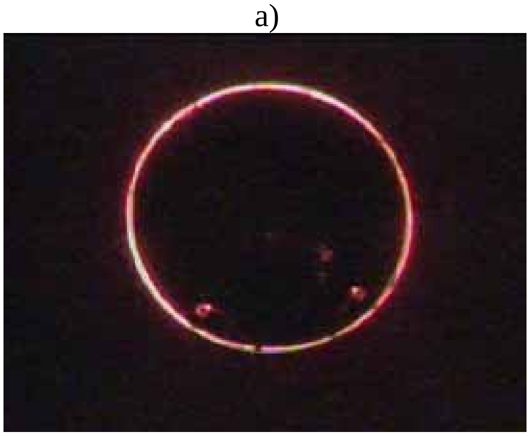

b)


c)

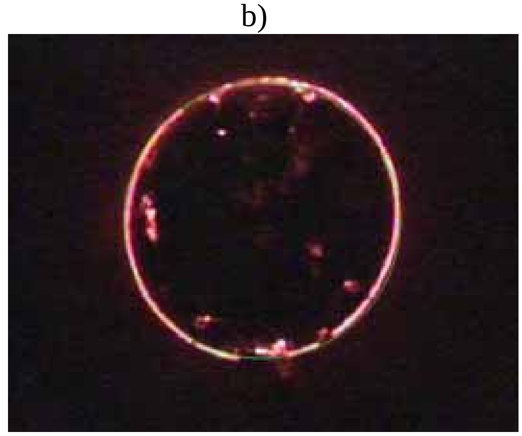
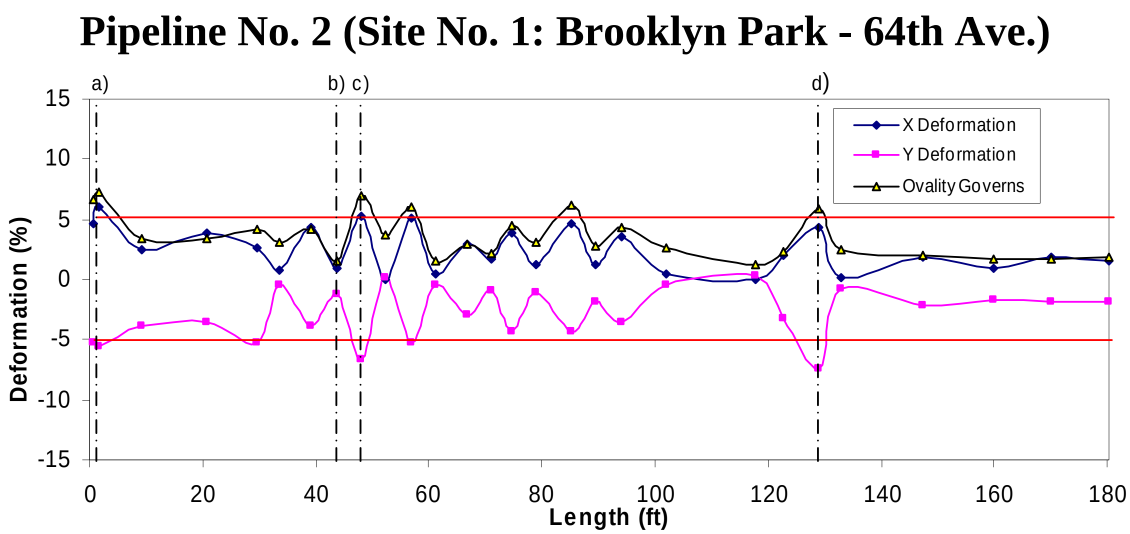
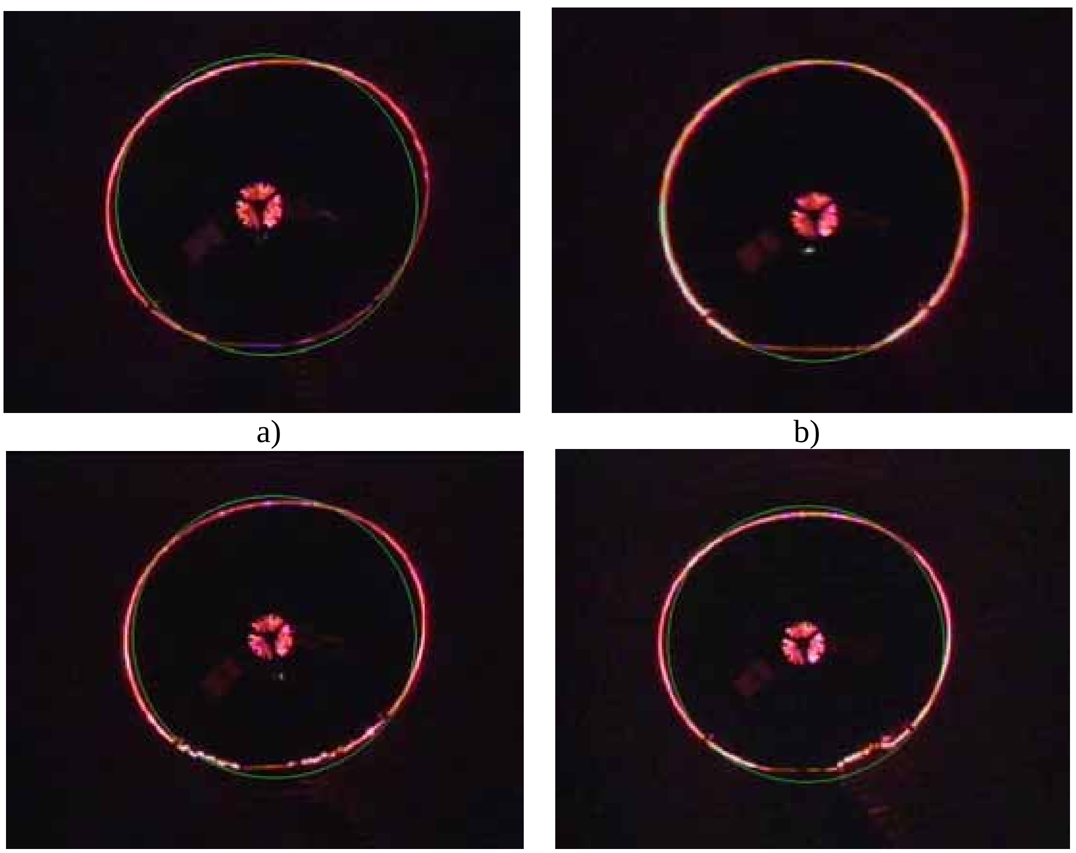

d)

Figure 158 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: Brooklyn Park – 64th Avenue)

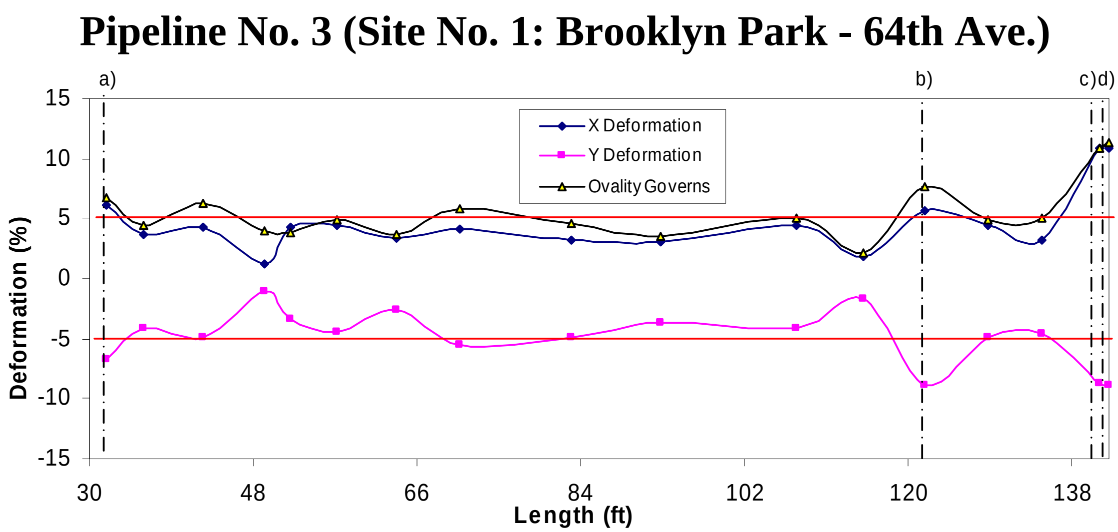


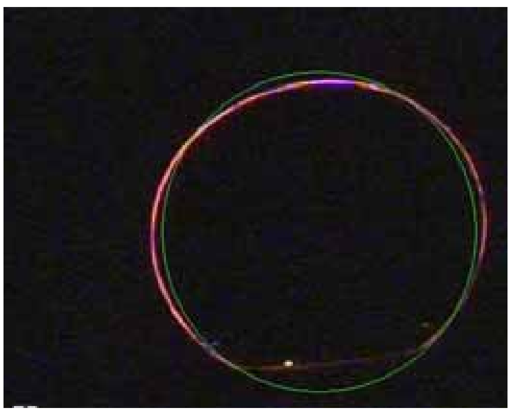


a) b)

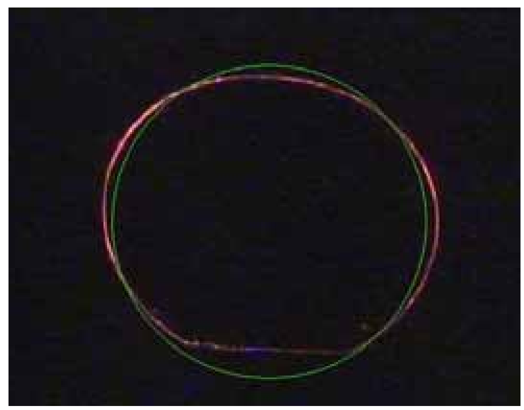
c) d)

Figure 159 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: Brooklyn Park – 64th Avenue)

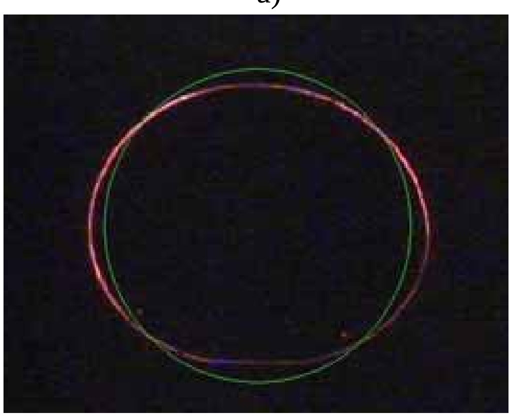




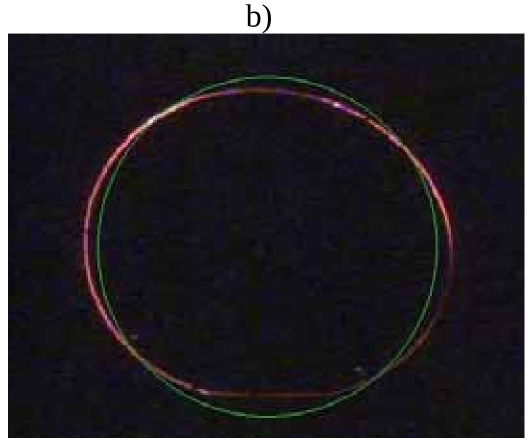
a)



b)



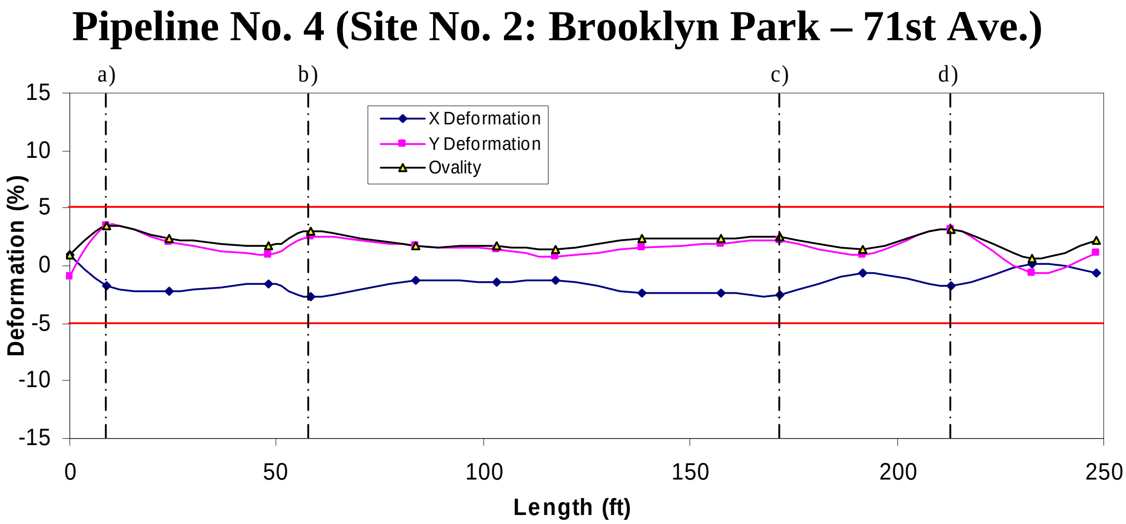
c)

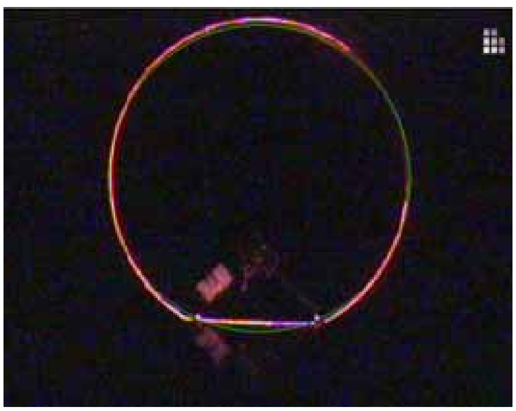


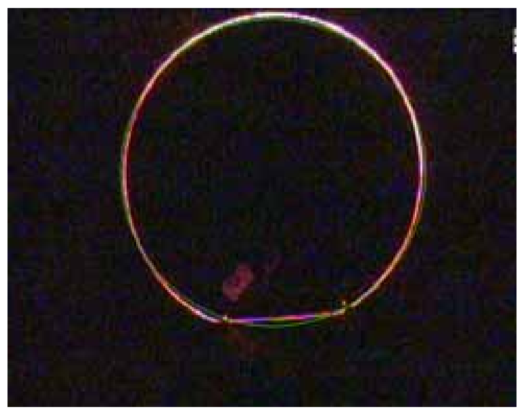
d)

Figure 160 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: Brooklyn Park – 64th Avenue)

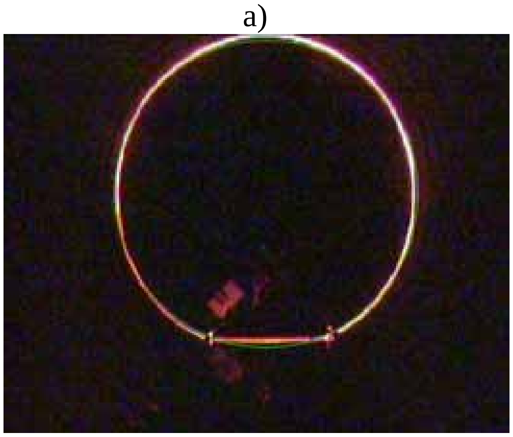
Figure 161 View of the cracking/fracture failure for pipeline No. 3 (Site No. 1: Brooklyn Park - 64th Ave)

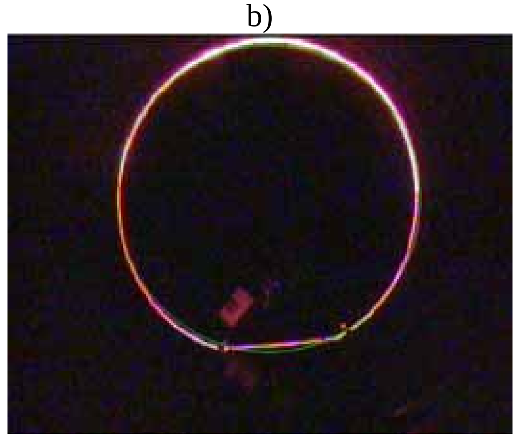






a) b)

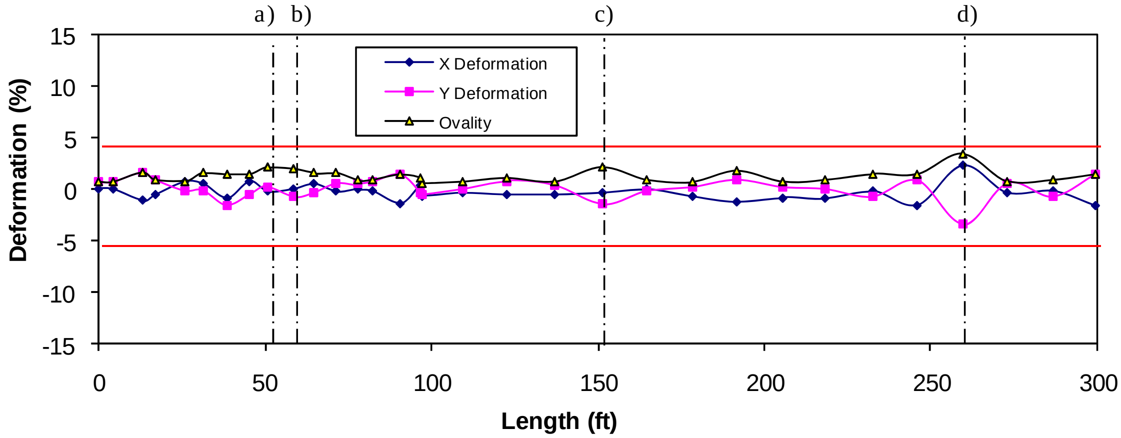




c) d)

Figure 162 Horizontal and vertical deformation of the pipeline No. 4 (Site No. 2: Brooklyn Park - 71st Ave)

Pipeline No. 5 (Site No. 2: Brooklyn Park – 71st Ave.)



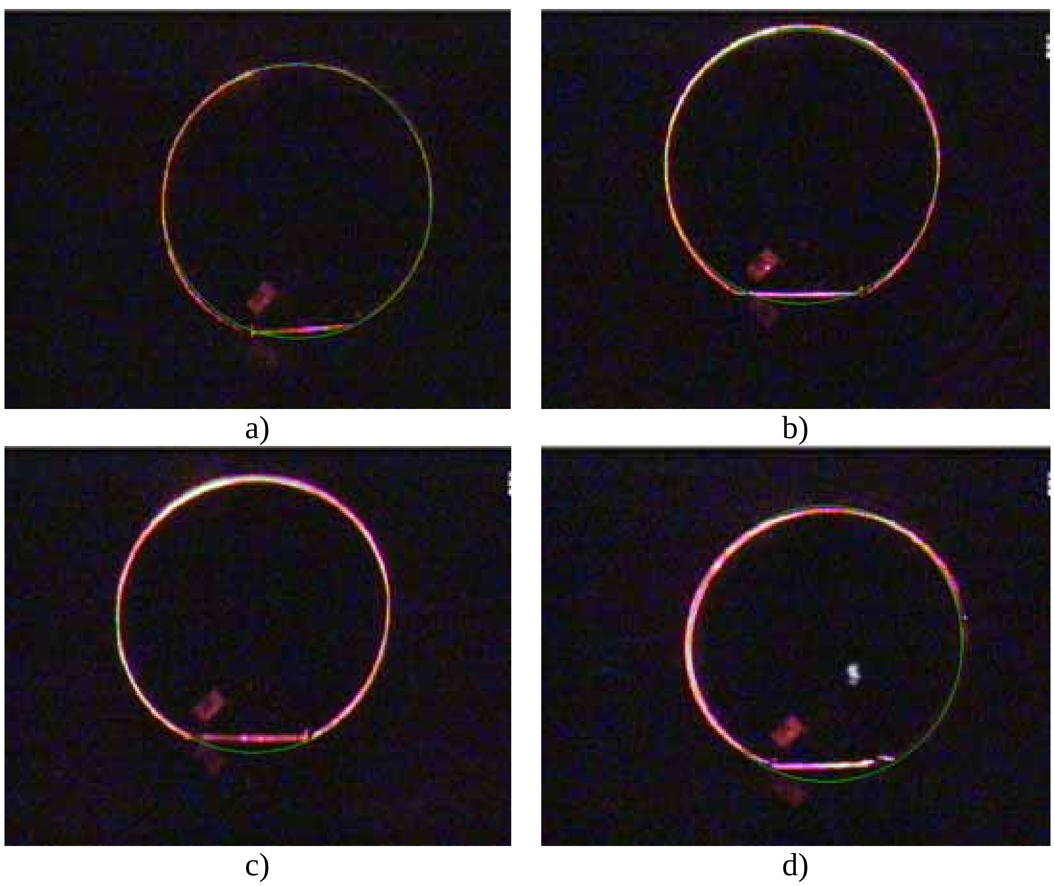
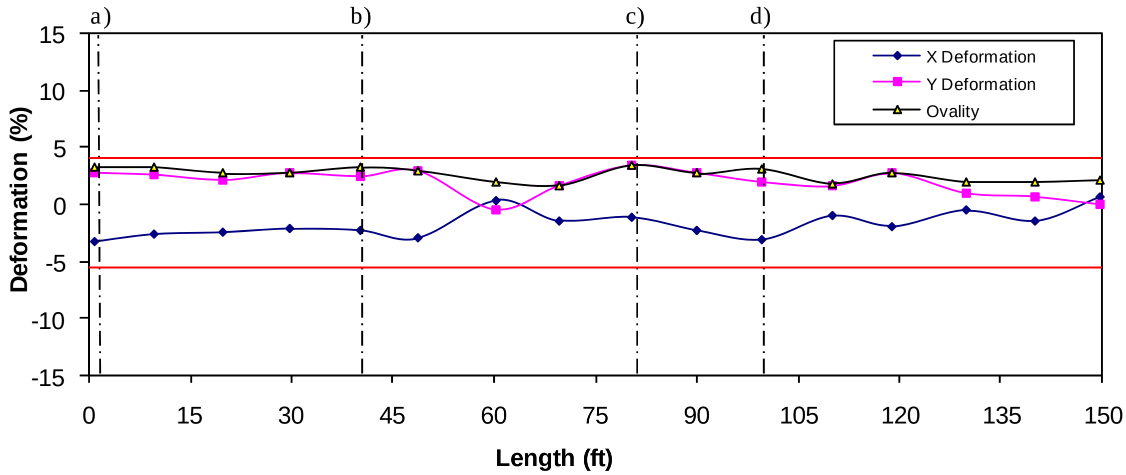


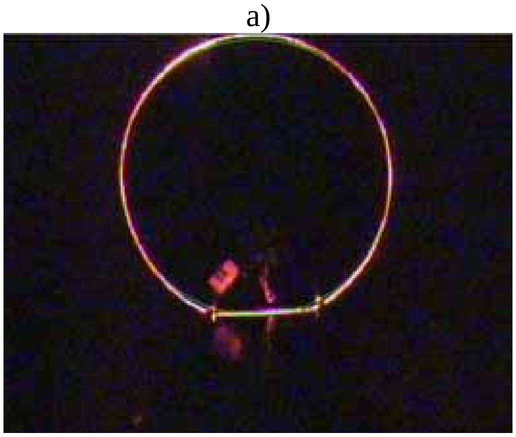
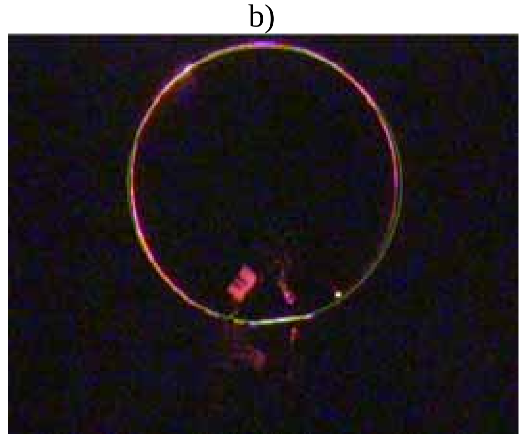
Figure 163 Horizontal and vertical deformation of the pipeline No. 5 (Site No. 2: Brooklyn Park - 71st Ave)

Figure 164 View of the major joint displacement failure for pipeline No. 5 (Site No. 2: Brooklyn Park - 71st Ave)

Pipeline No. 6 (Site No. 2: Brooklyn Park – 71st Ave.)



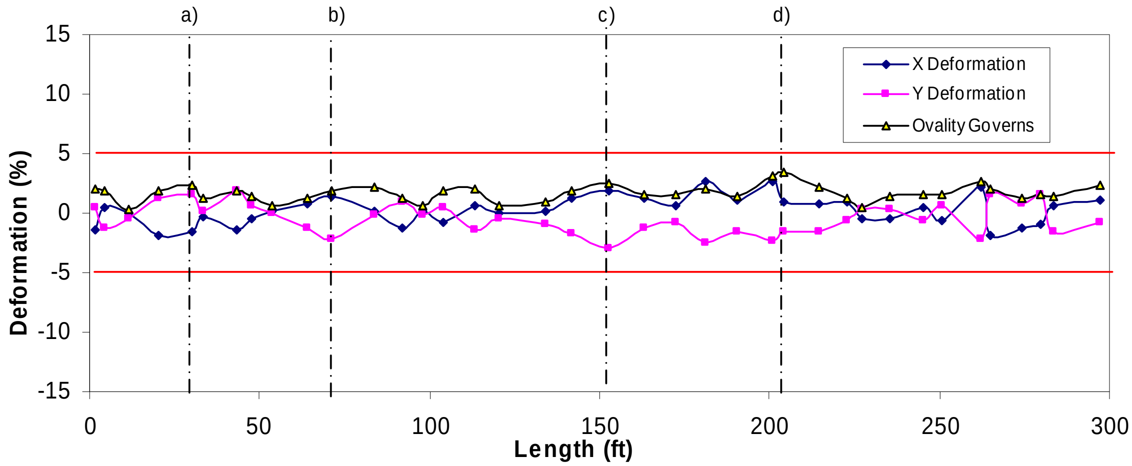

a) b)

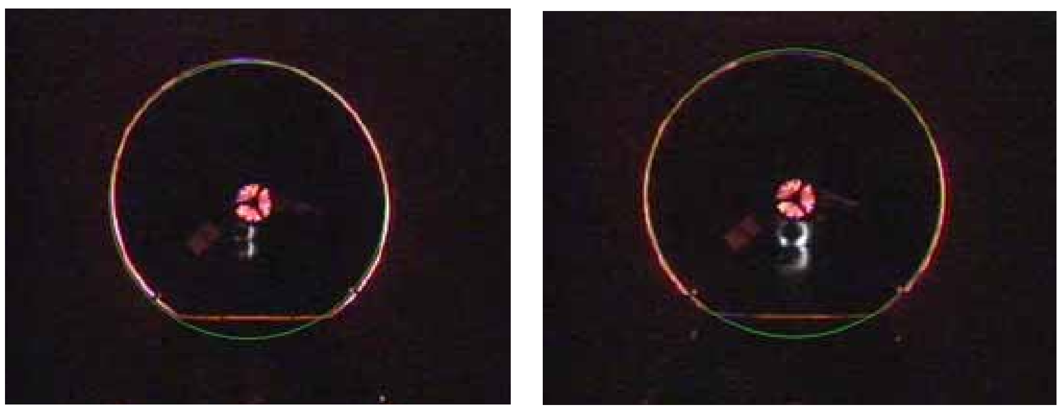



c) d)

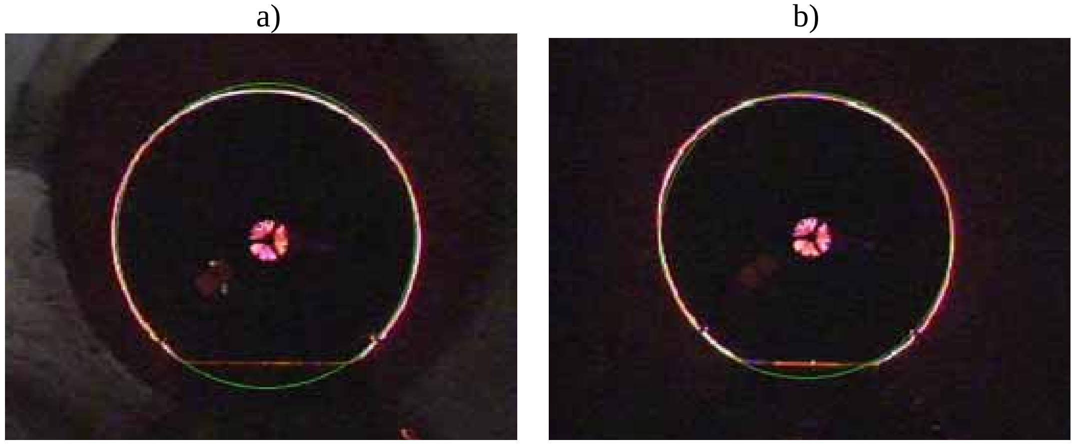
Figure 165 Horizontal and vertical deformation of the pipeline No. 6 (Site No. 2: Brooklyn Park - 71st Ave)

Pipeline No. 7 (Site No. 2: Brooklyn Park – 71st Ave.)



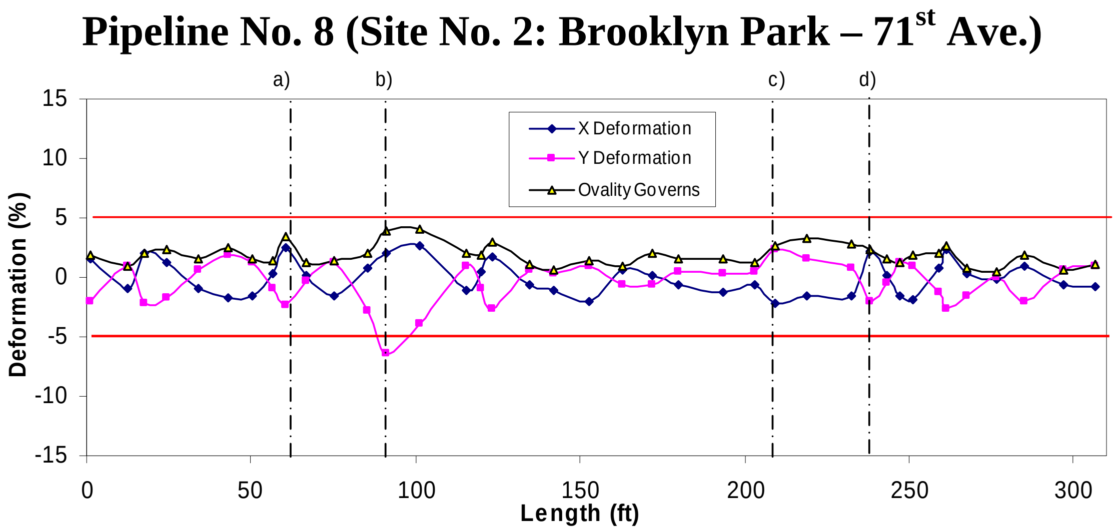


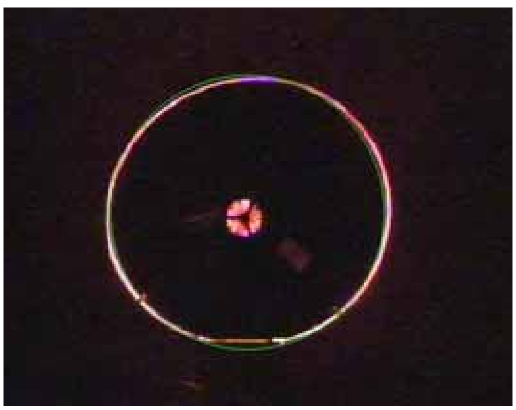
a) b)



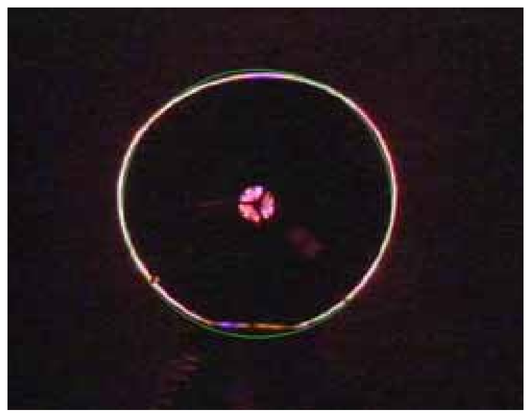
c) d)

Figure 166 Horizontal and vertical deformation of the pipeline No. 7 (Site No. 2: Brooklyn Park - 71st Ave)

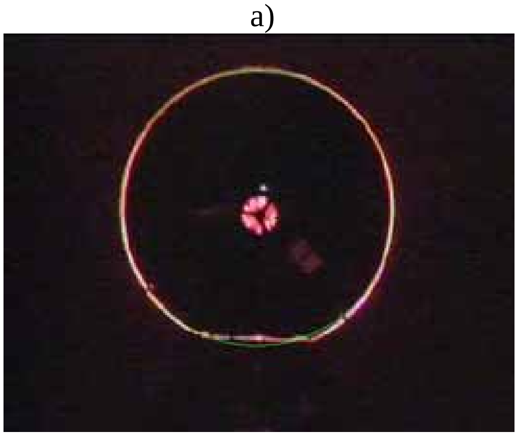




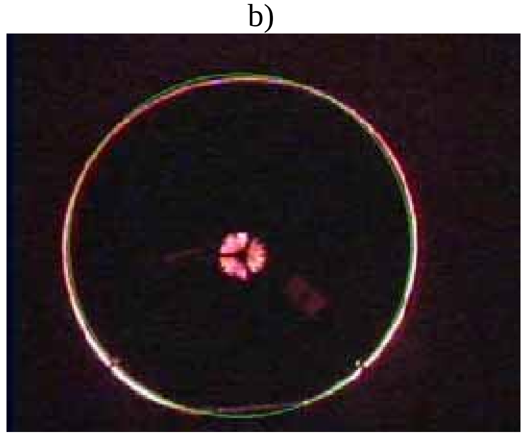
a)



b)

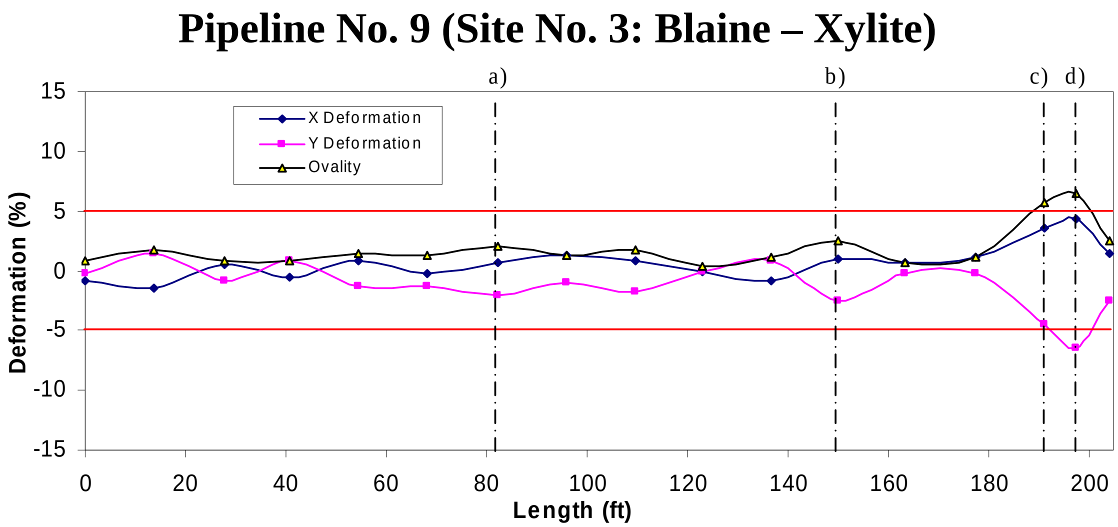


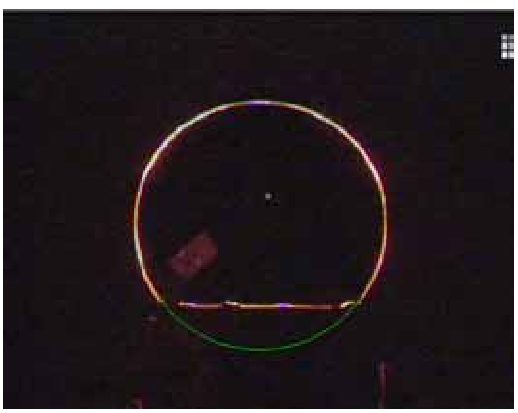
c)

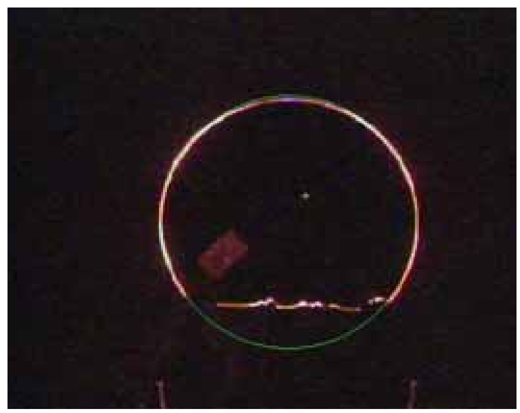


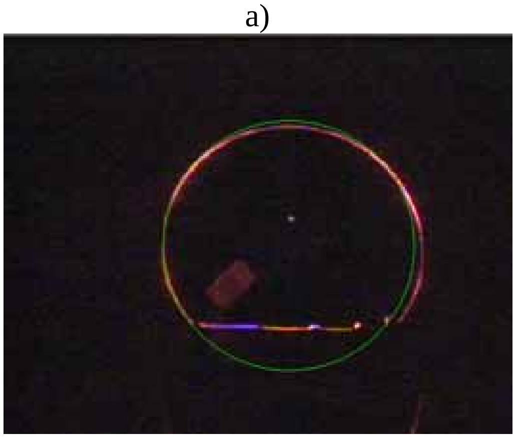
d)

Figure 167 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 2: Brooklyn Park - 71st Ave)




a)


b)


c)

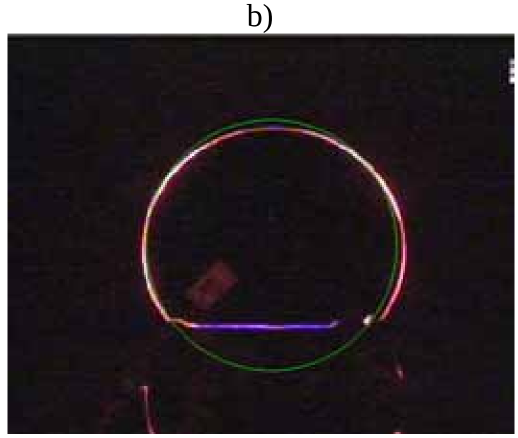

d)

Figure 168 Horizontal and vertical deformation of the pipeline No. 9 (Site No. 3: Blaine - Xylite)

Figure 169 View of cracking/fracture failure for pipeline No. 9 (Site No. 3: Blaine - Xylite)

Pipeline No. 12 (Site No. 3: Blaine – Xylite)

Figure 170 View of cracking failure for pipeline No. 12 (Site No. 3: Blaine - Xylite)

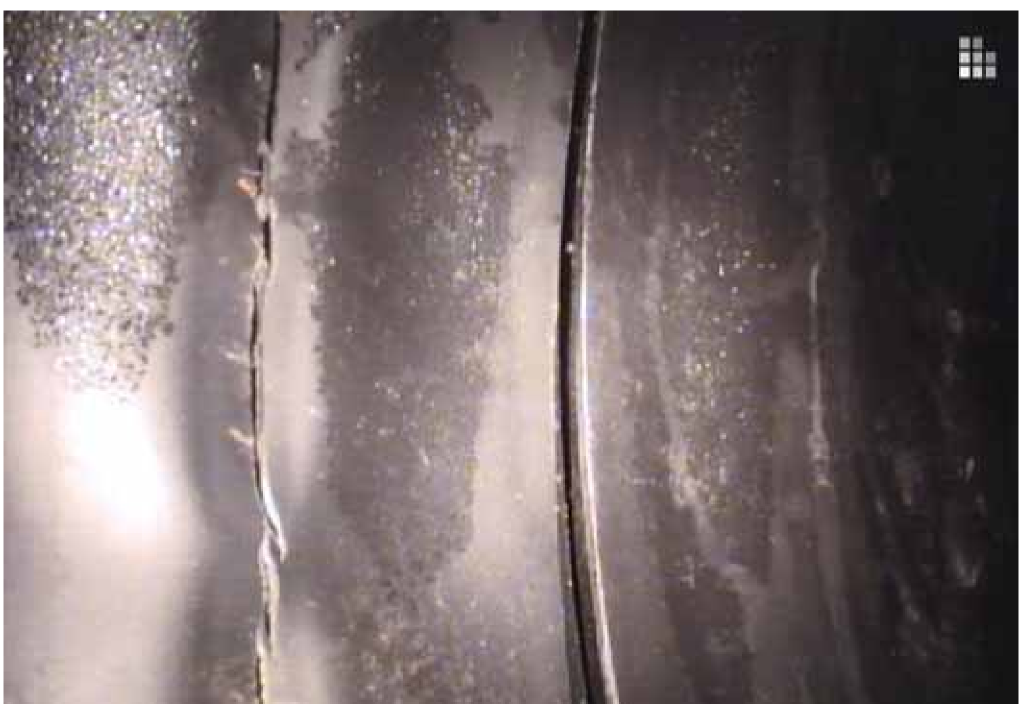
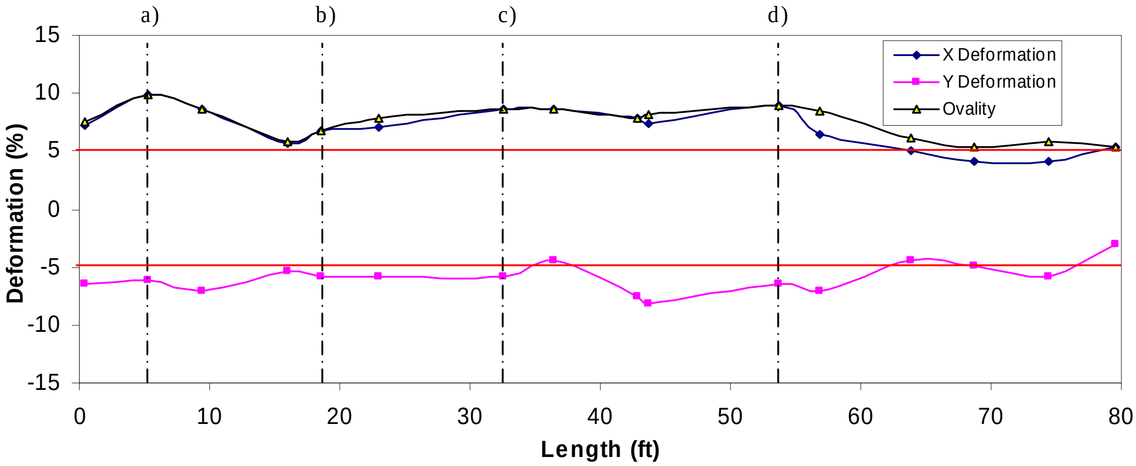
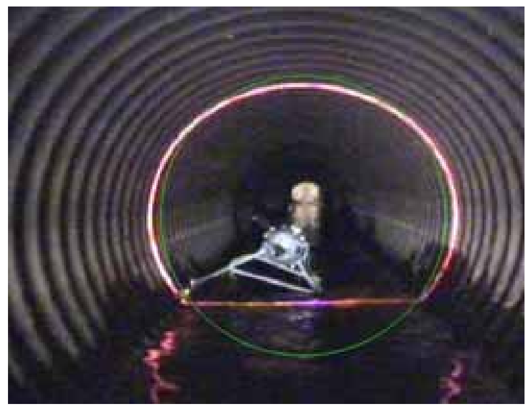


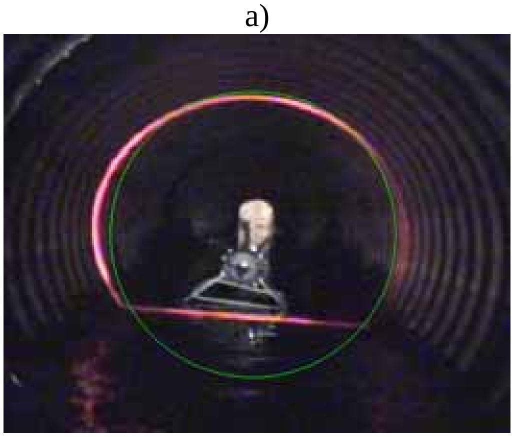
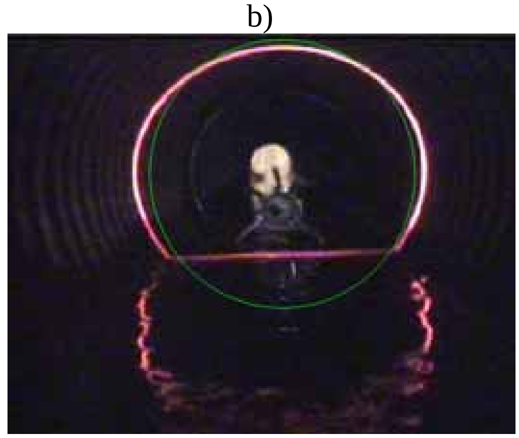
Figure 171 View of cracking failure for pipeline No. 12 (Site No. 3: Blaine - Xylite)

Pipeline No. 15 (Site No. 5: McGregor)



a) b)

c) d)

Figure 172 Horizontal and vertical deformation of the pipeline No. 15 (Site No. 5: McGregor)

Figure 173 View of cracking/fracture failure for pipeline No. 15 (Site No. 5: McGregor)

Figure 174 View of corrugation growth and excessive deformation failures for pipeline No. 15 (Site No. 5: McGregor)

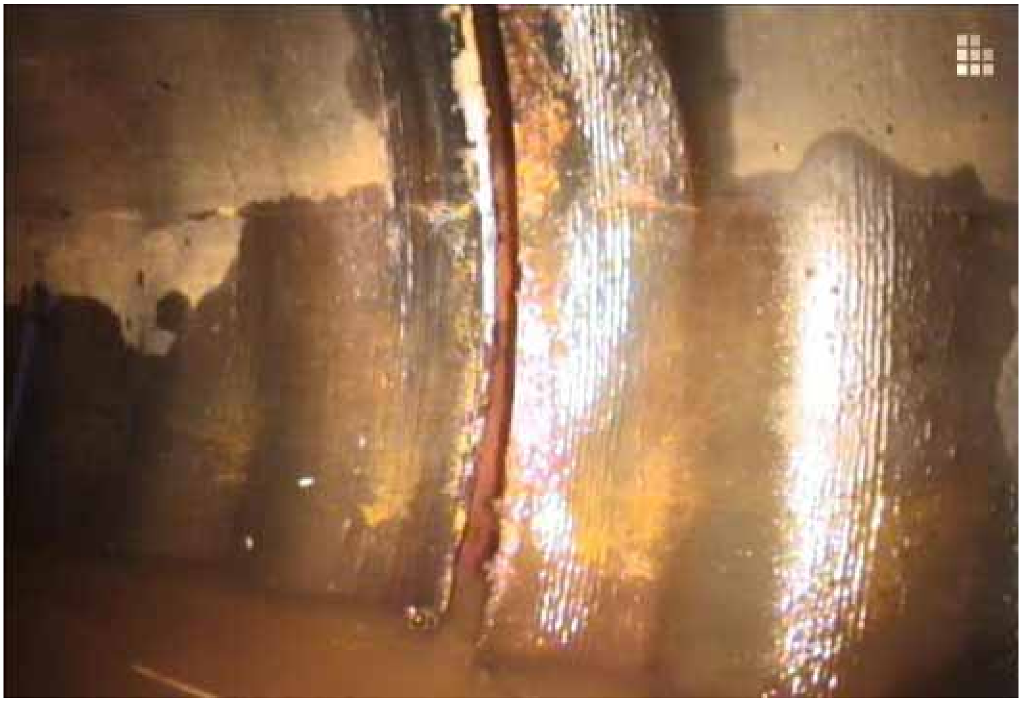
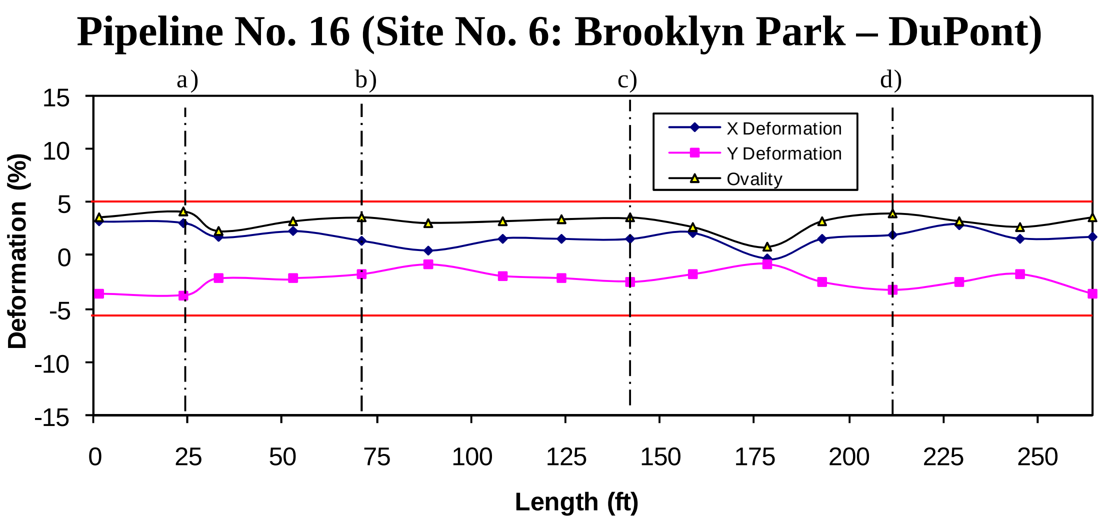
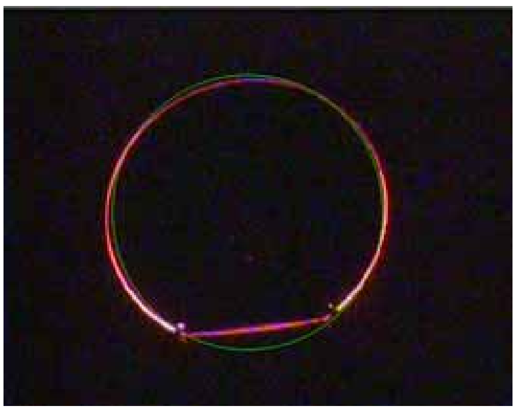
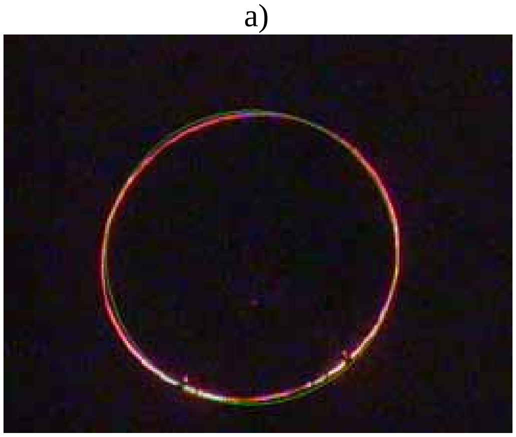


Figure 175 View of joint displacement failure for pipeline No. 15 (Site No. 5: McGregor)




a)


b)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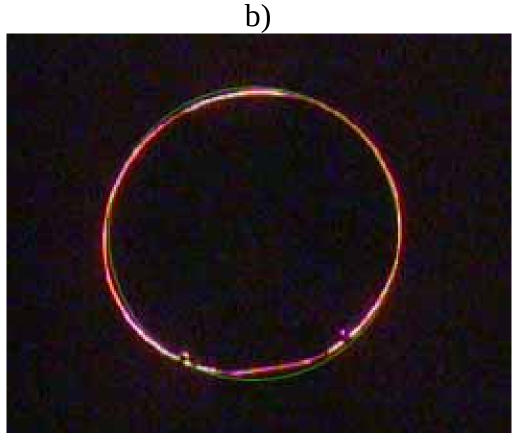

d)

Figure 176 Horizontal and vertical deformation of the pipeline No. 16 (Site No. 6: Brooklyn Park - DuPont)

Pipeline No. 17 (Site No. 6: Brooklyn Park – DuPont)

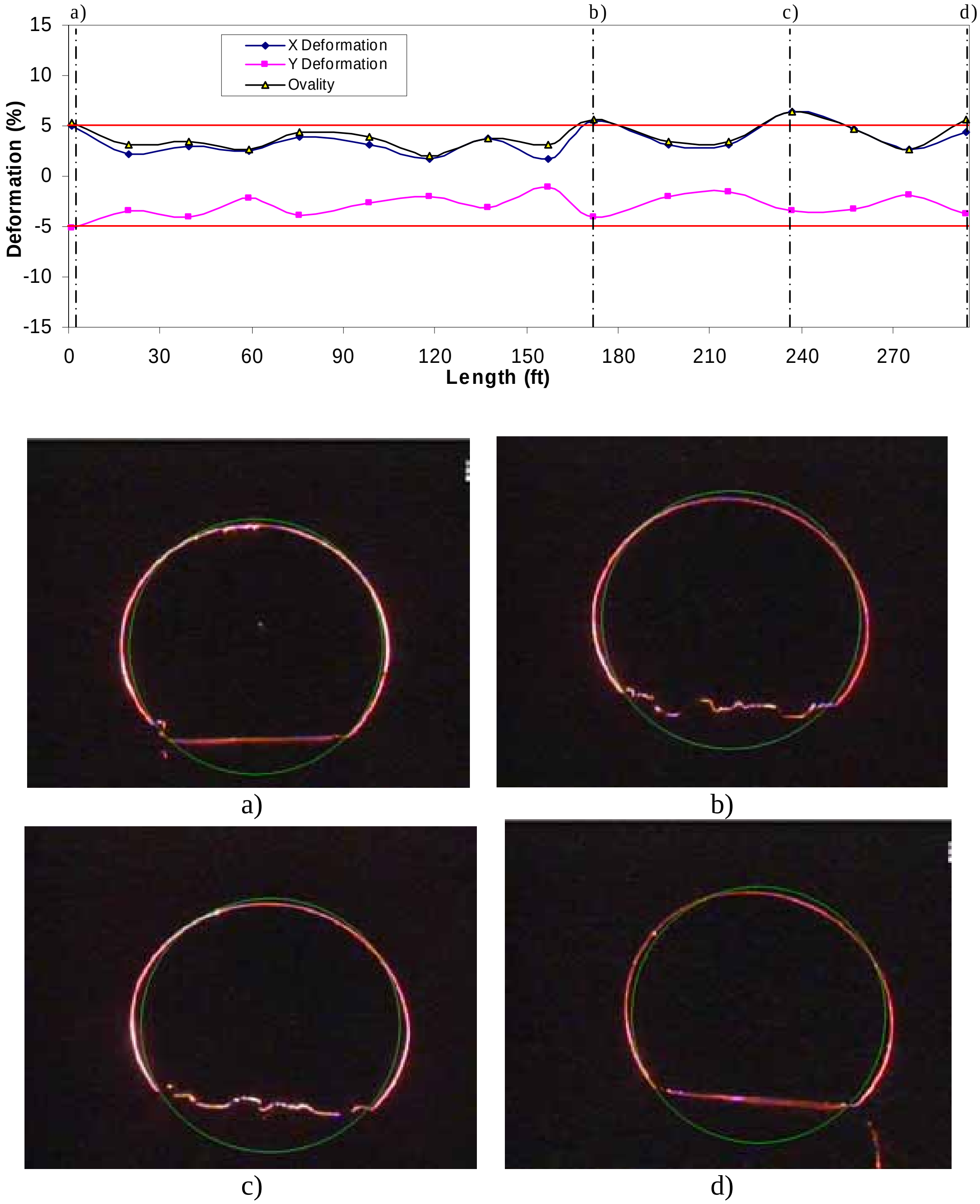
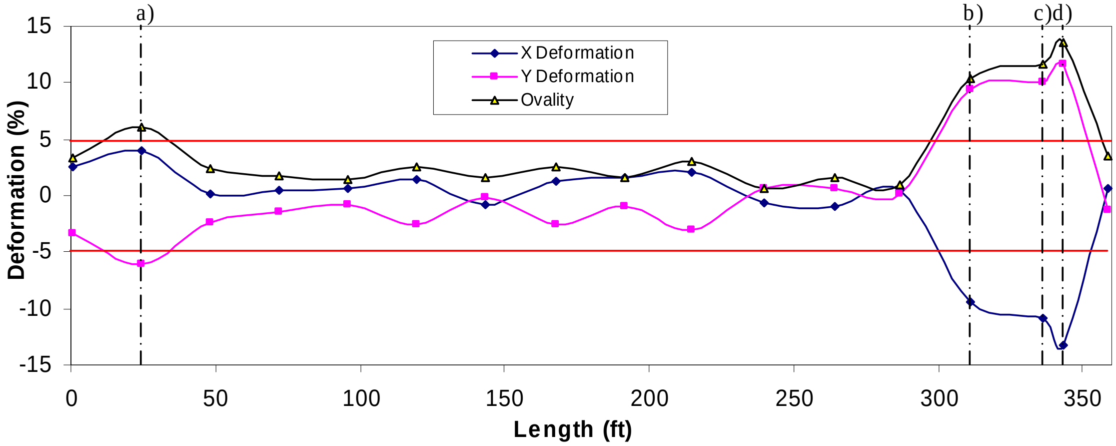
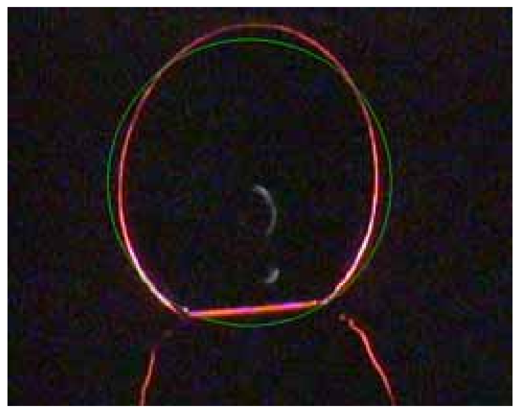


Figure 177 Horizontal and vertical deformation of the pipeline No. 17 (Site No. 6: Brooklyn Park - DuPont)

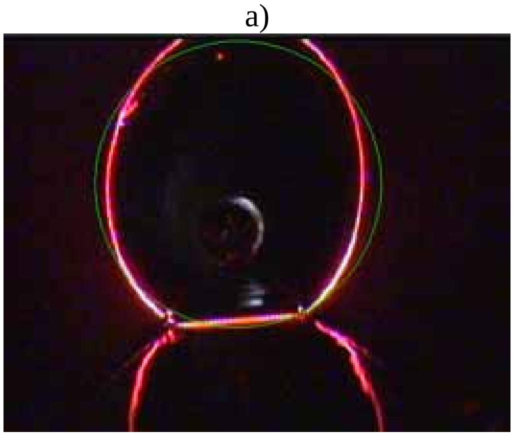
Pipeline No. 18 (Site No. 6: Brooklyn Park – DuPont)



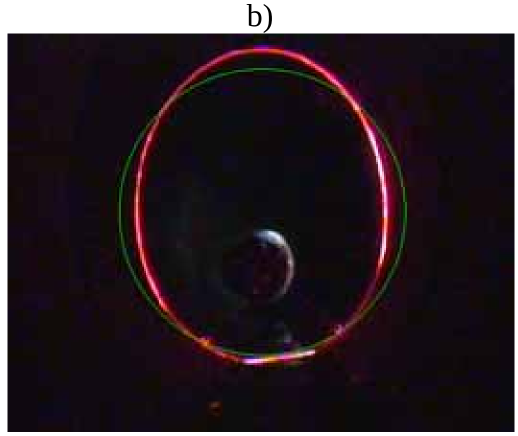
a)



b)



c)



d)

Figure 178 Horizontal and vertical deformation of the pipeline No. 18 (Site No. 6: Brooklyn Park - DuPont)

Figure 179 View of joint displacement failure for pipeline No. 18 (Site No. 6: Brooklyn Park - DuPont)

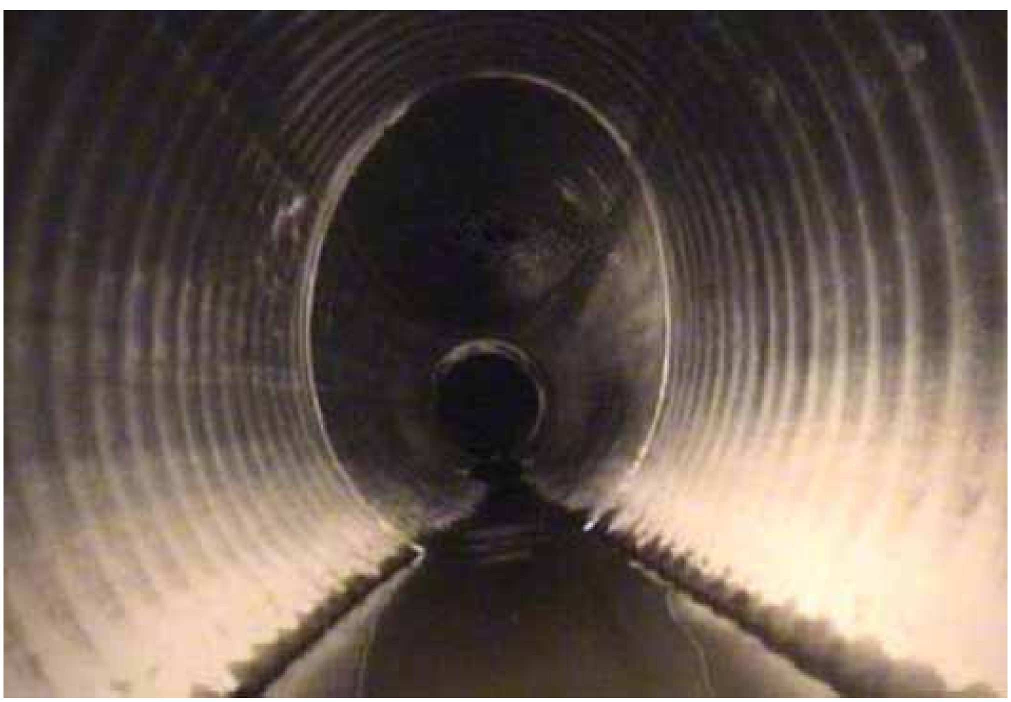
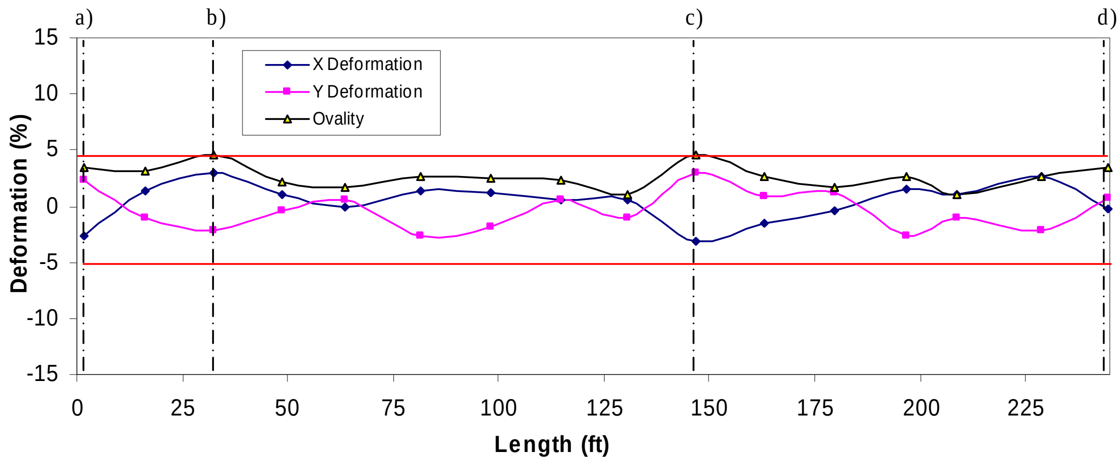
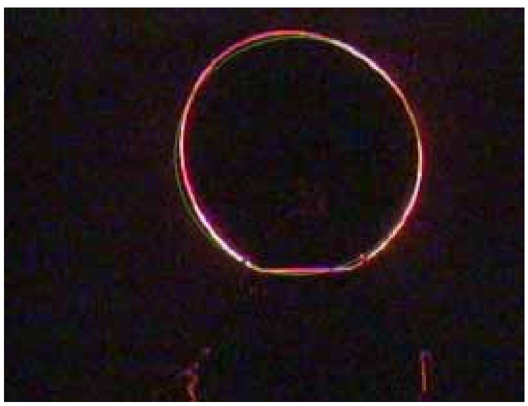


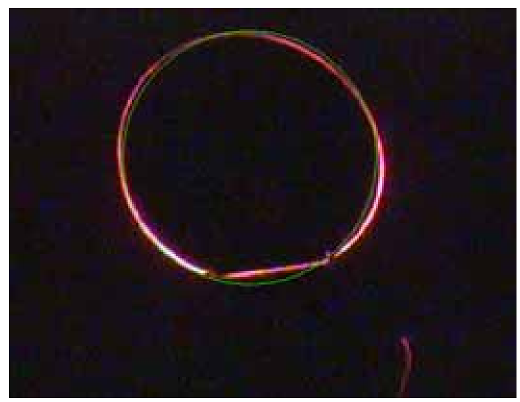
Figure 180 View of corrugation growth and excessive deformation failures for pipeline No. 18 (Site No. 6: Brooklyn Park - DuPont)

Pipeline No. 19 (Site No. 6: Brooklyn Park – DuPont)

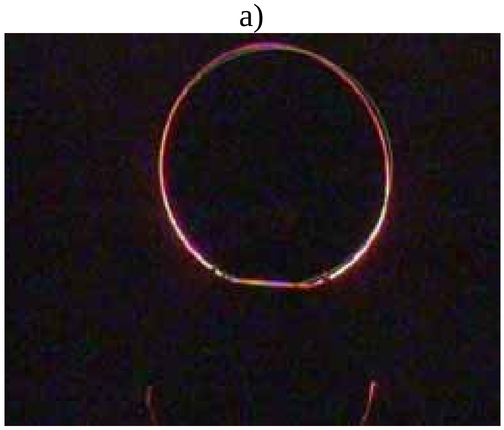




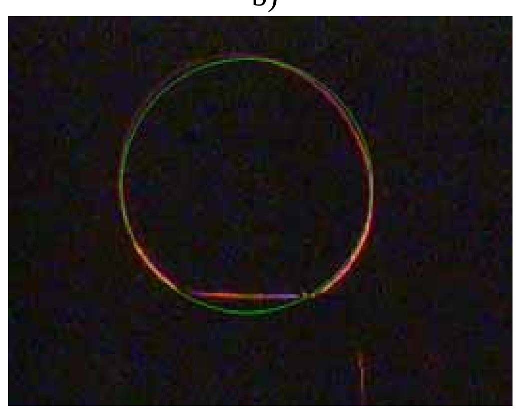
a)



b)



c)



d)

Figure 181 Horizontal and vertical deformation of the pipeline No. 19 (Site No. 6: Brooklyn Park - DuPont)

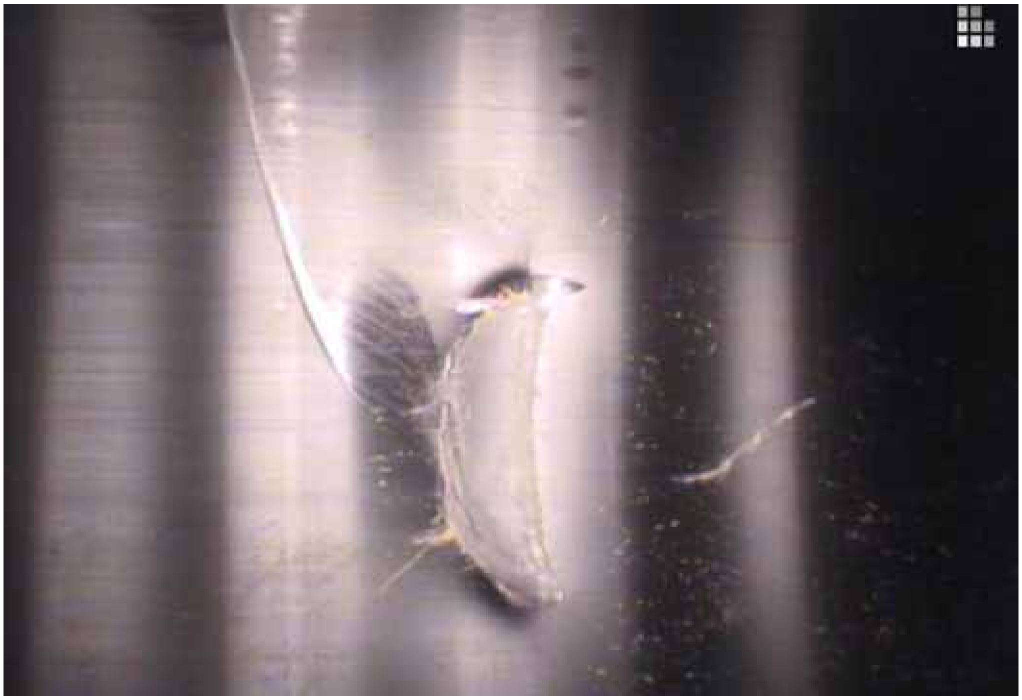
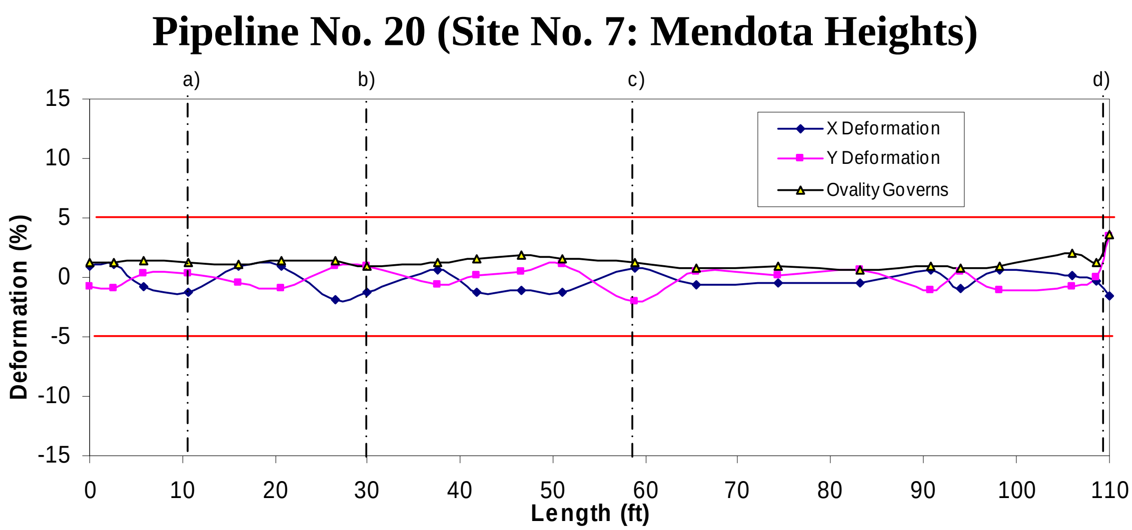
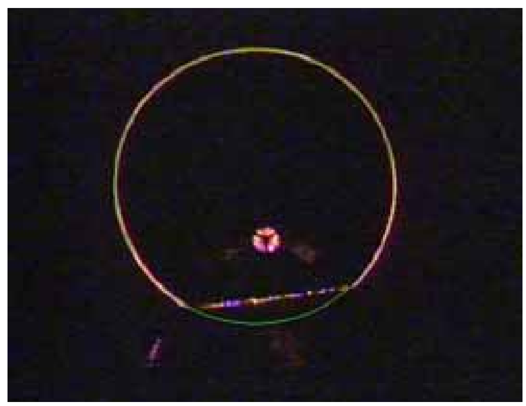


Figure 182 View of cracking/fracture failure for pipeline No. 19 (Site No. 6: Brooklyn Park - DuPont)



a)



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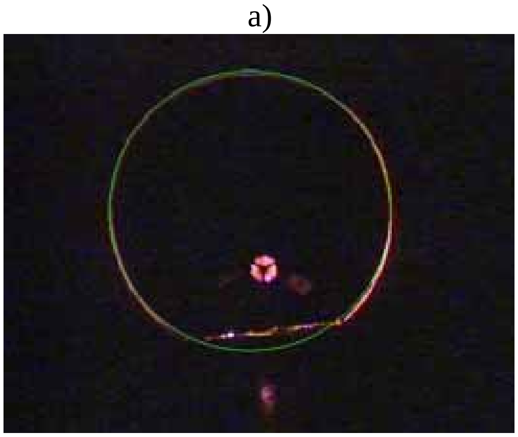
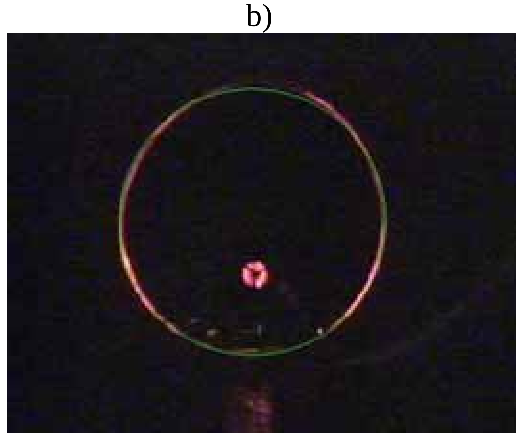
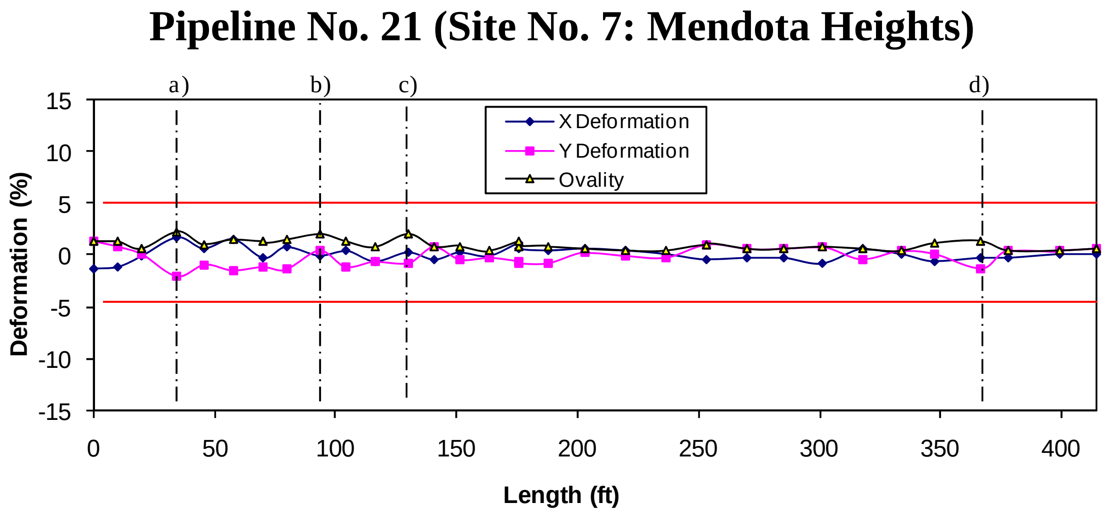


c)



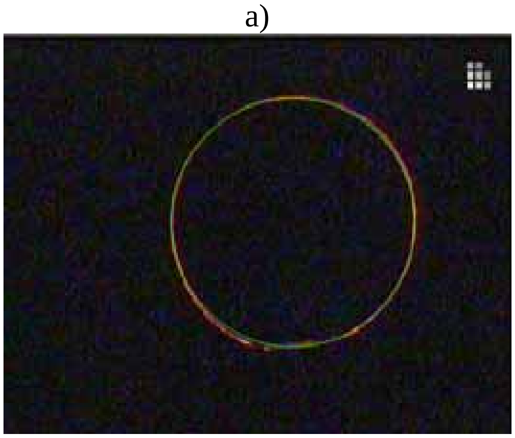
d)

Figure 183 Horizontal and vertical deformation of the pipeline No. 20 (Site No. 7: Mendota Heights)




a)


b)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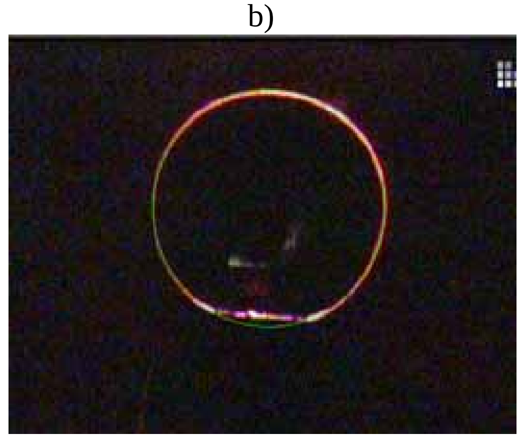
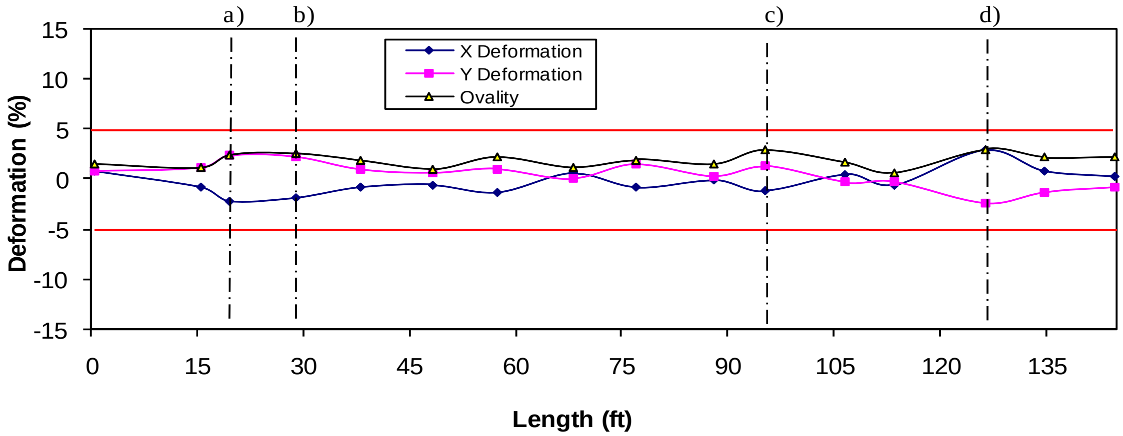
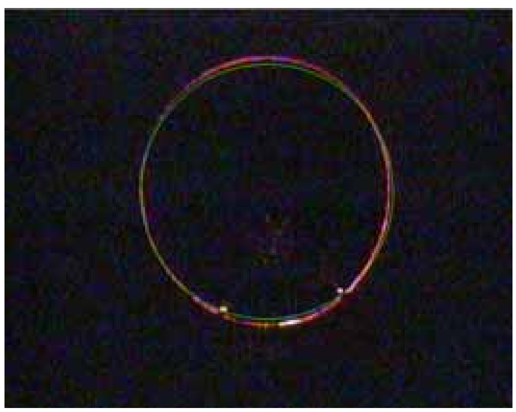

d)

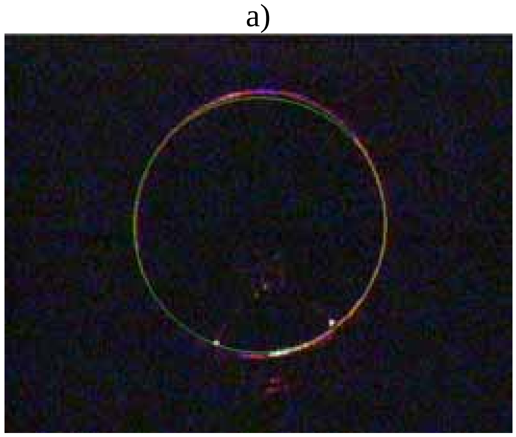
Figure 184 Horizontal and vertical deformation of the pipeline No. 21 (Site No. 7: Mendota Heights)

Pipeline No. 22 (Site No. 7: Mendota Heights)




a)


b)


b)

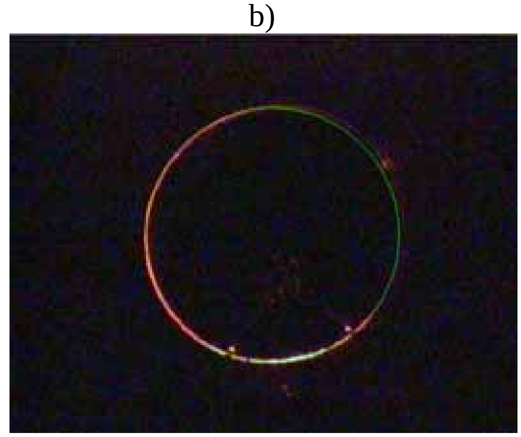
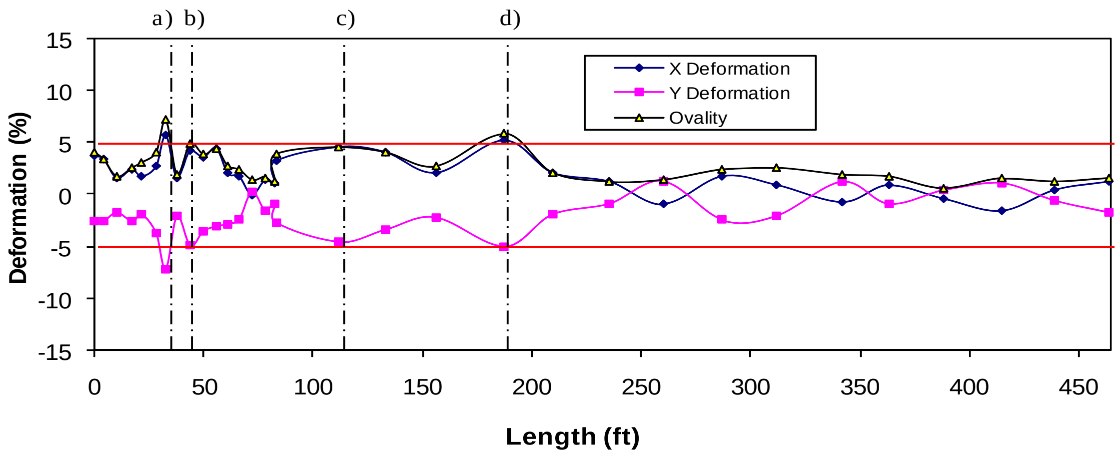

d)

Figure 185 Horizontal and vertical deformation of the pipeline No. 22 (Site No. 7: Mendota Heights)

Pipeline No. 23 (Site No. 7: Mendota Heights)




a)


b)


c)

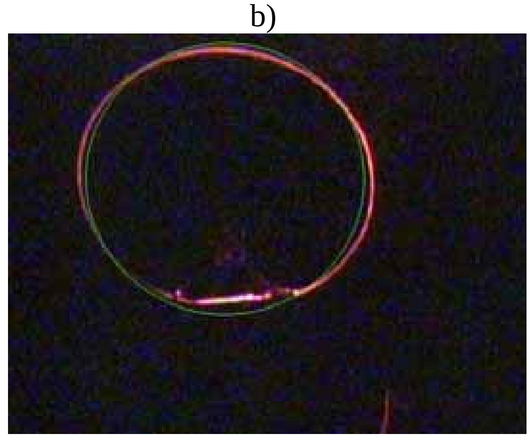
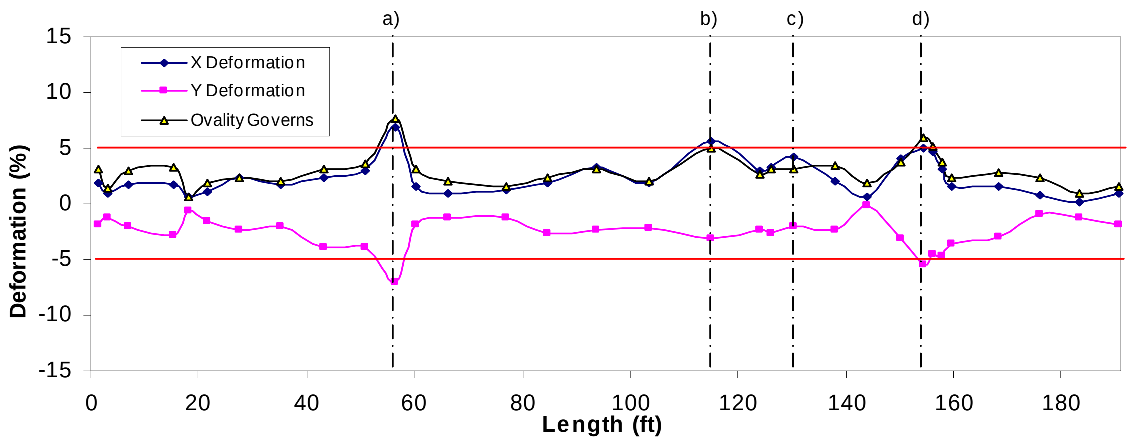
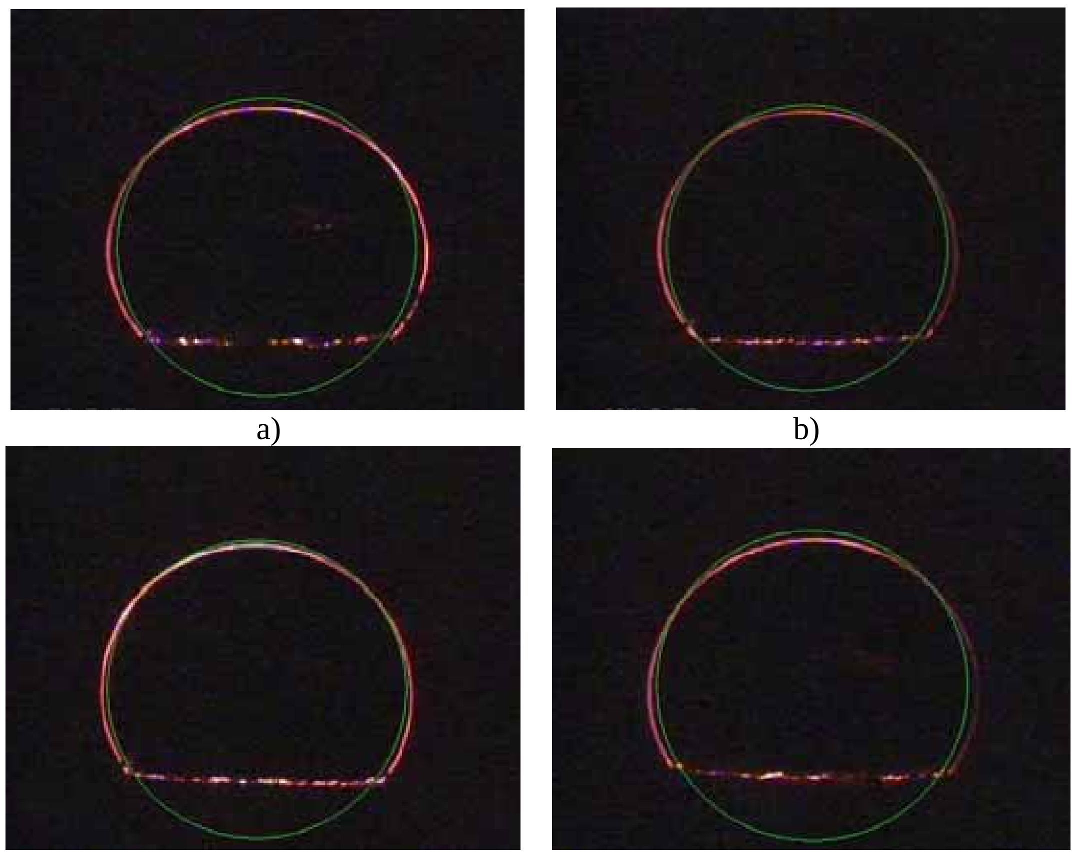

d)

Figure 186 Horizontal and vertical deformation of the pipeline No. 23 (Site No. 7: Mendota Heights)

Pipeline No. 24 (Site No. 7: Mendota Heights)



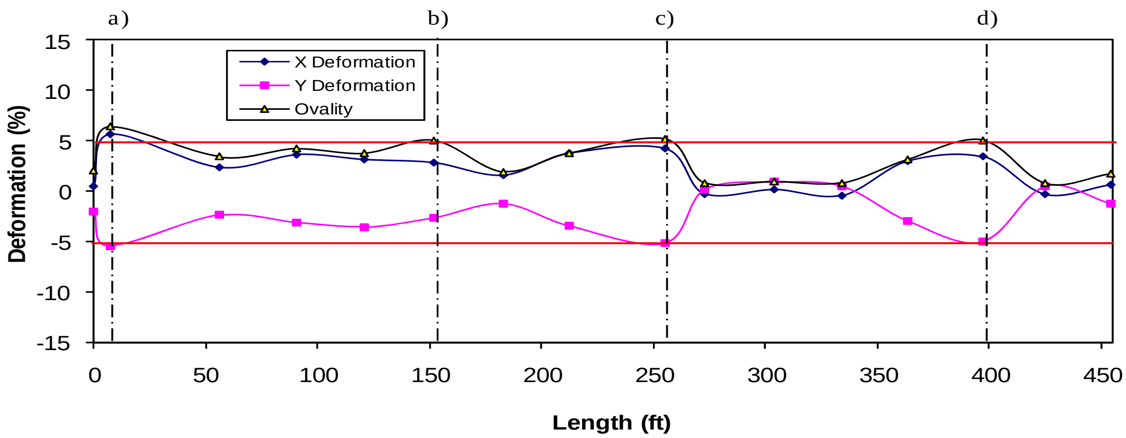


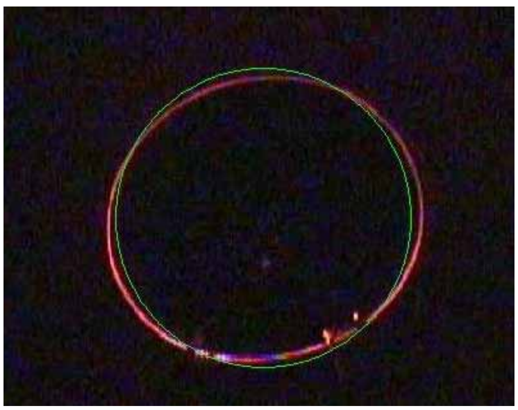
a) b)

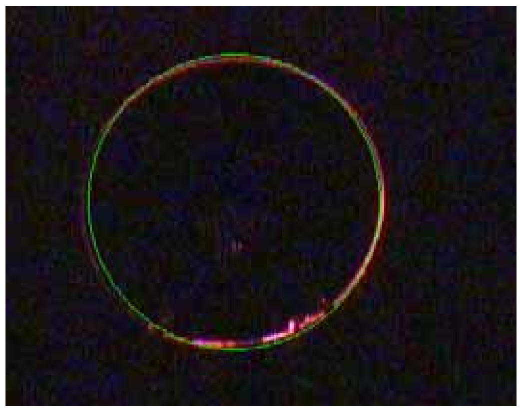
c) d)

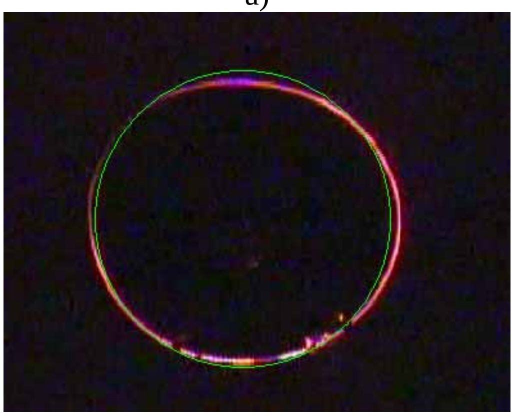
Figure 187 Horizontal and vertical deformation of the pipeline No. 24 (Site No. 7: Mendota Heights)

Pipeline No. 25 (Site No. 7: Mendota Heights)



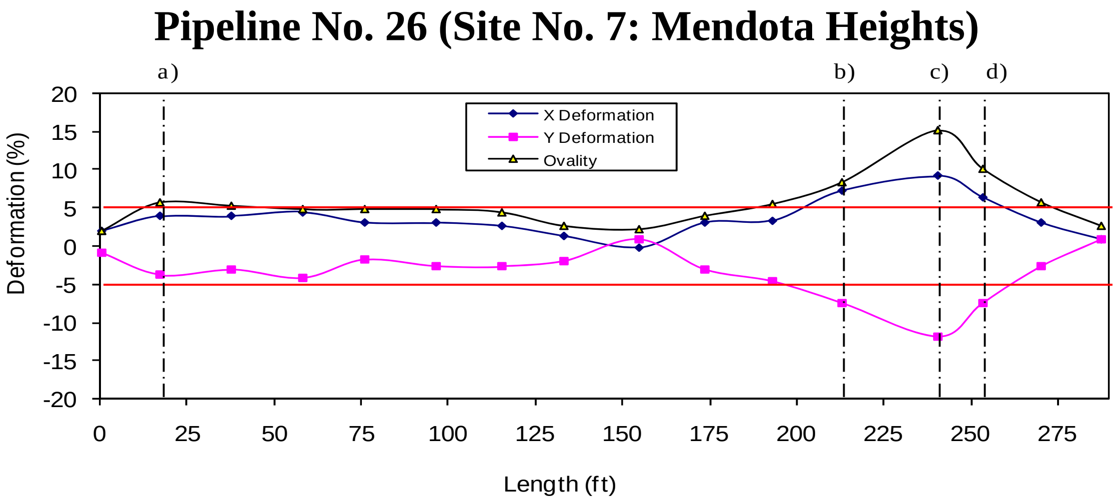

a)

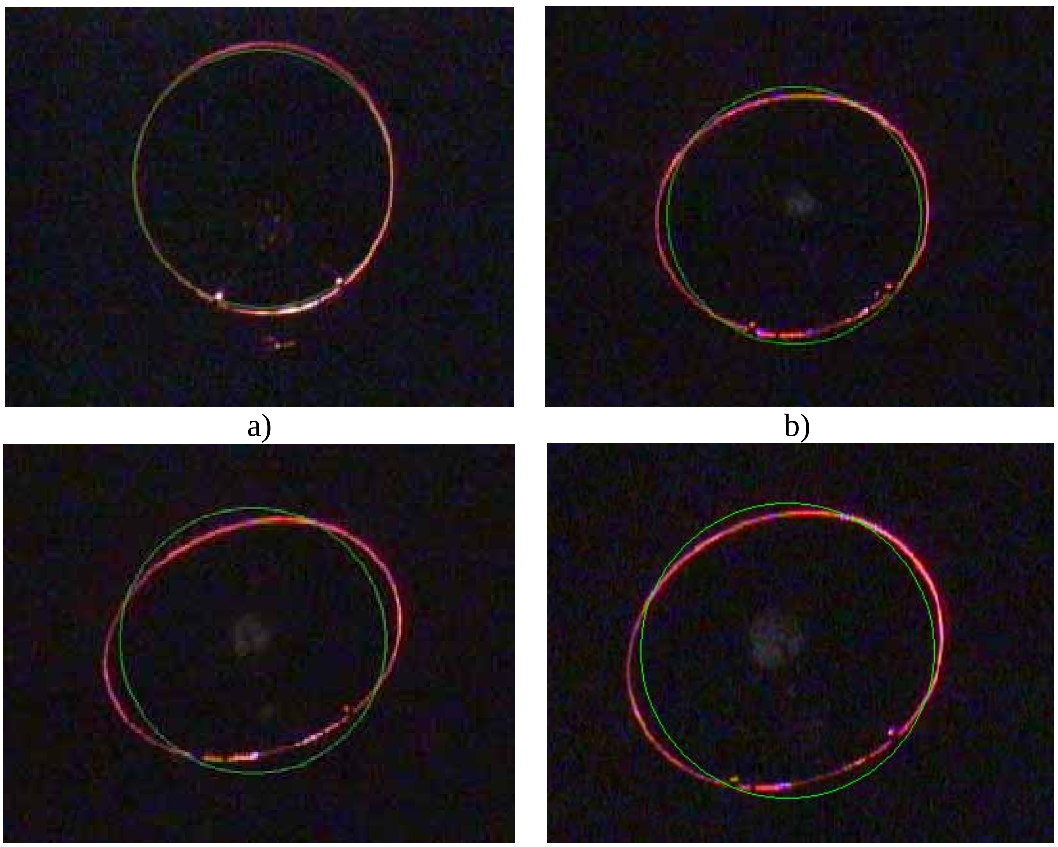

b)


c)


d)

Figure 188 Horizontal and vertical deformation of the pipeline No. 25 (Site No. 7: Mendota Heights)





a)

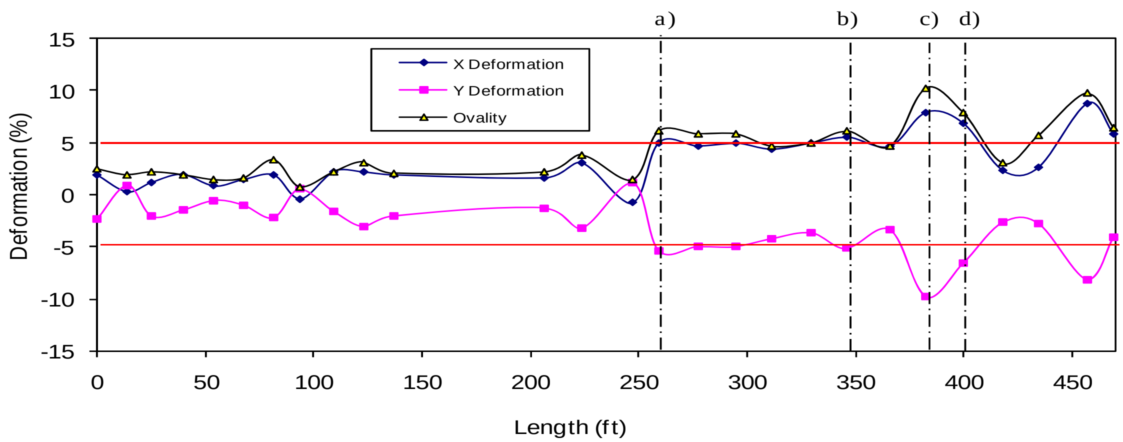
b)

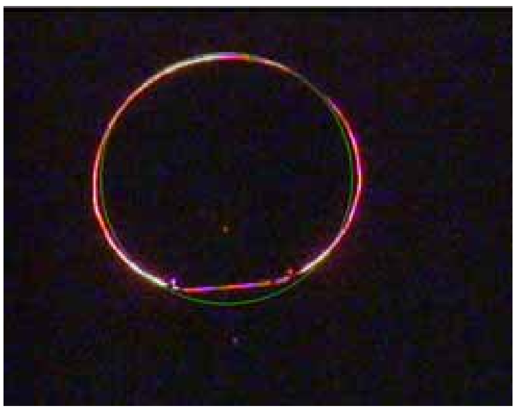
c)

d)

Figure 189 Horizontal and vertical deformation of the pipeline No. 26 (Site No. 7: Mendota Heights)

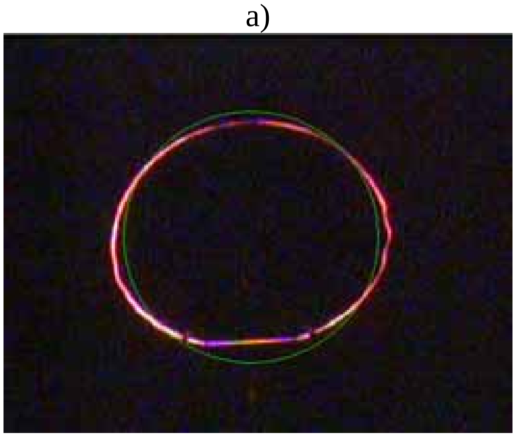
Pipeline No. 27 (Site No. 8: Fairmont)





a)

b)



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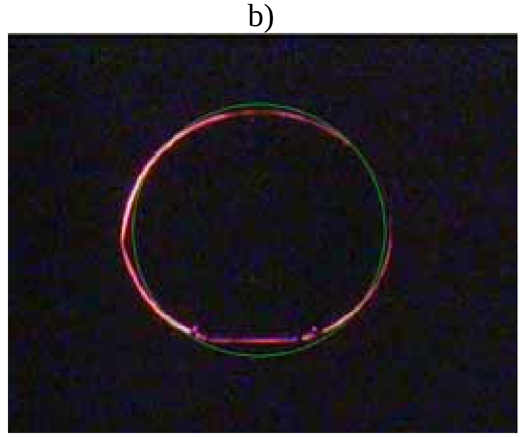


d)

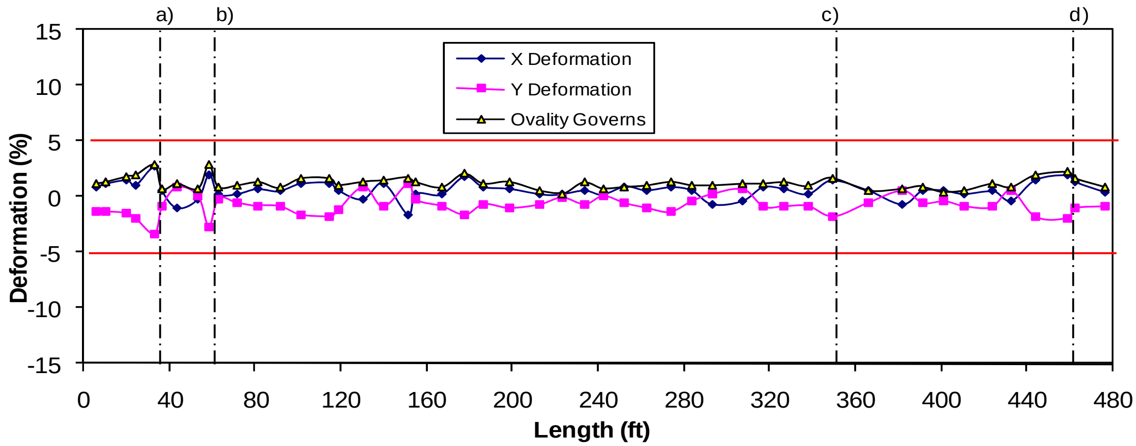
Figure 190 Horizontal and vertical deformation of the pipeline No. 27 (Site No. 8: Fairmont)

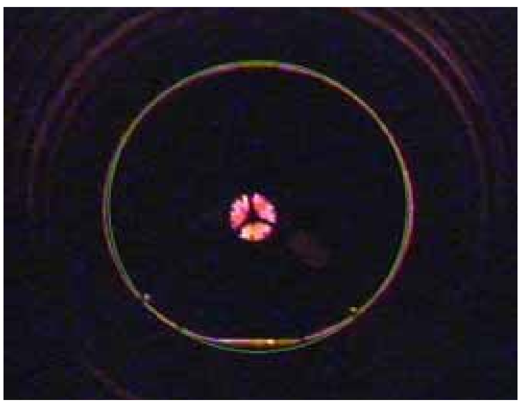
Figure 191 View of cracking/fracture failure for pipeline No. 27 (Site No. 8: Fairmont)

Figure 192 View of joint displacement failure for pipeline No. 27 (Site No. 8: Fairmont)

Figure 193 View of excessive deformation failure for pipeline No. 27 (Site No. 8: Fairmont)

Pipeline No. 28 (Site No. 7: Mendota Heights)





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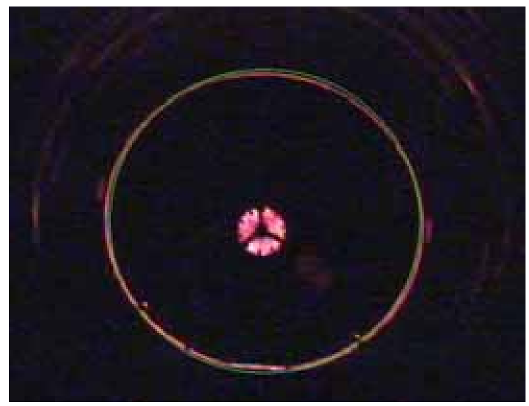
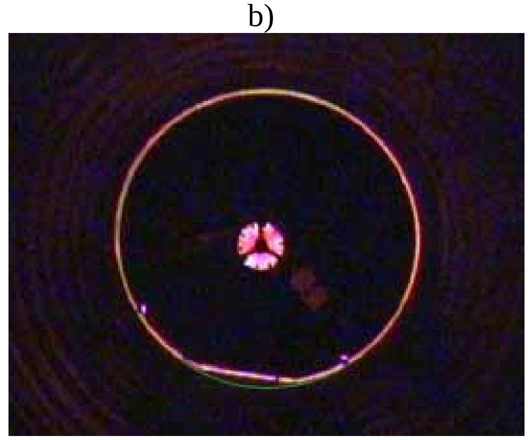


b)

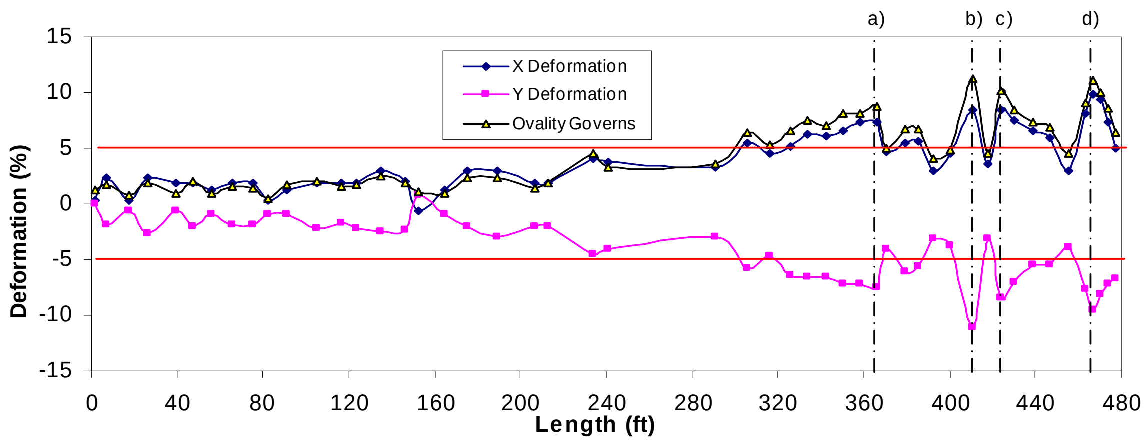
c)

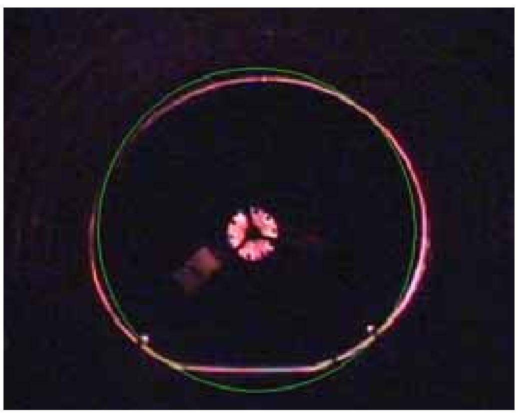


d)

Figure 194 Horizontal and vertical deformation of the pipeline No. 28 (Site No. 8: Fairmont)

Pipeline No. 29 (Site No. 7: Mendota Heights)

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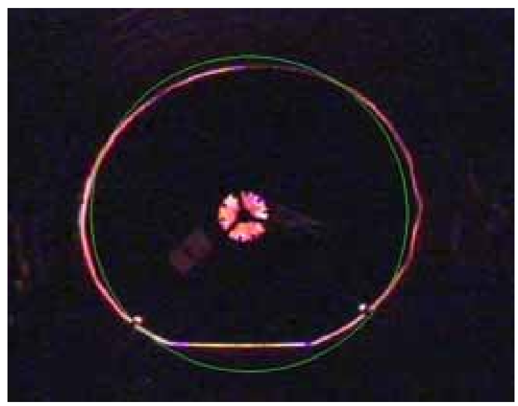
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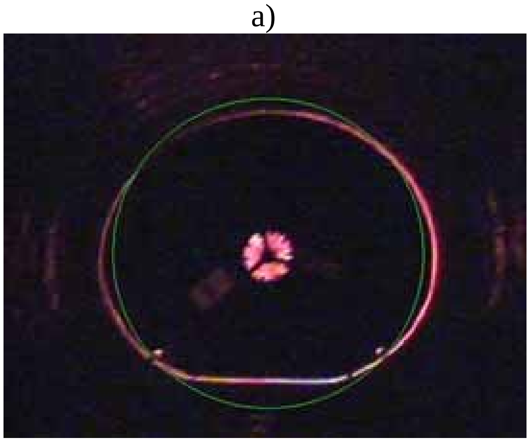
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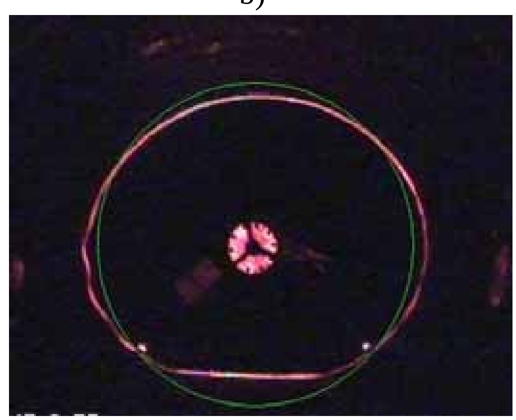
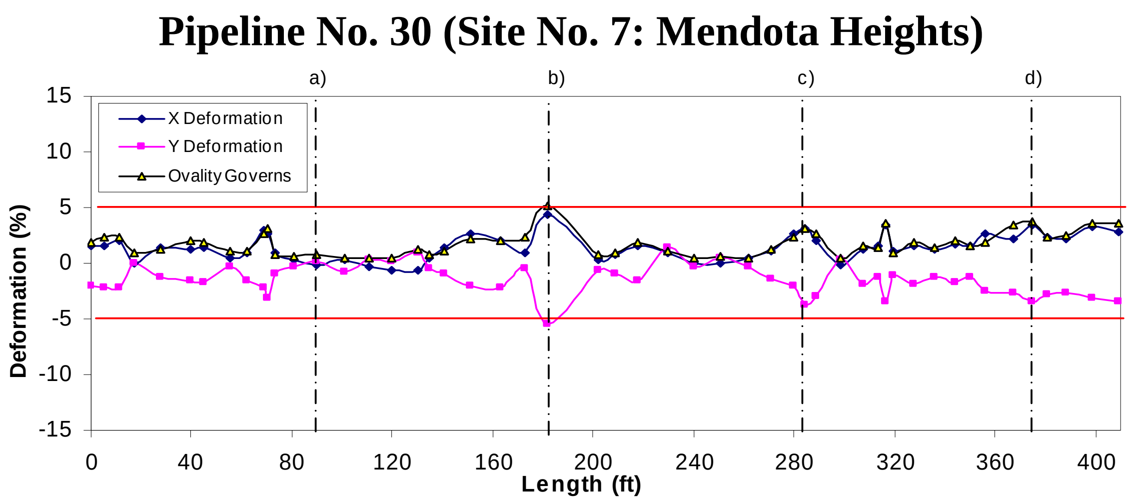
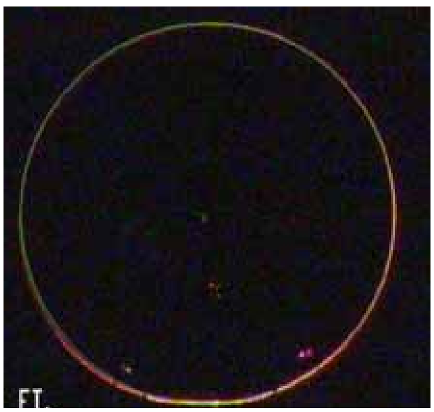

d)

Figure 195 Horizontal and vertical deformation of the pipeline No. 29 (Site No. 8: Fairmont)

Figure 196 View of corrugation growth and buckling failure for pipeline No. 29 (Site No. 8: Fairmont)

Figure 197 View of buckling failure for pipeline No. 29 (Site No. 8: Fairmont)





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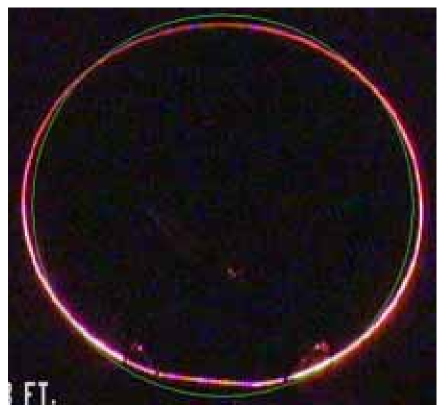

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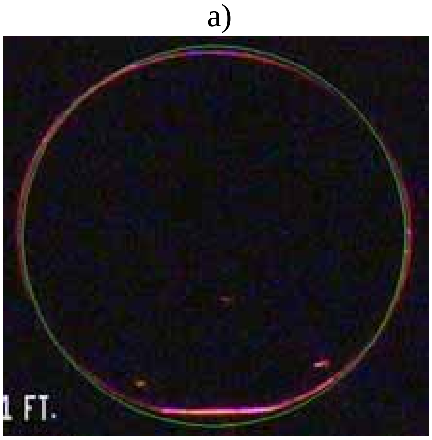

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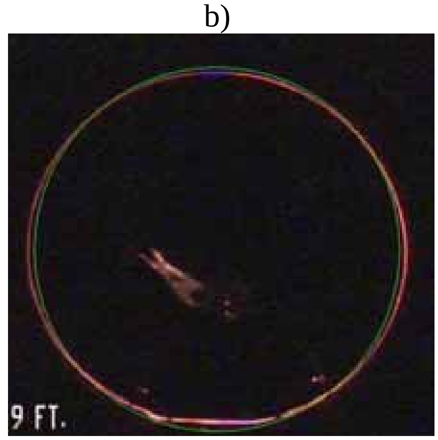
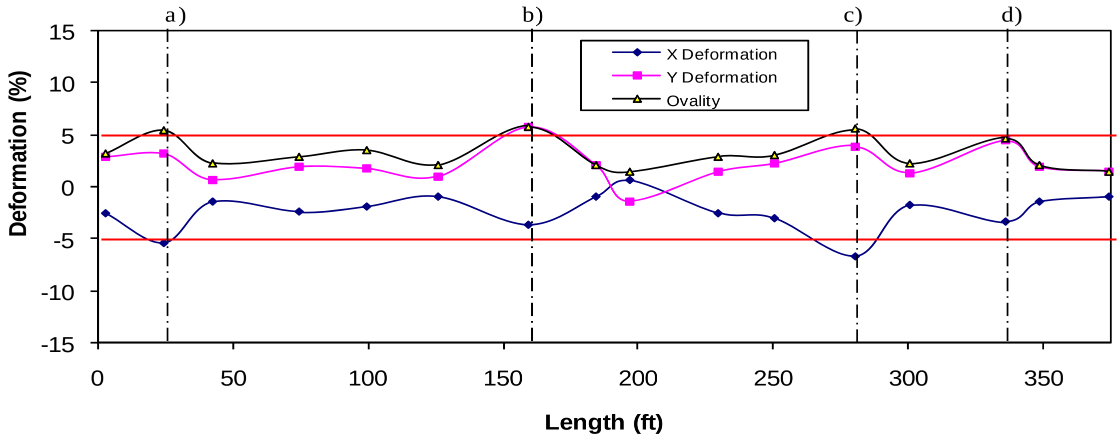


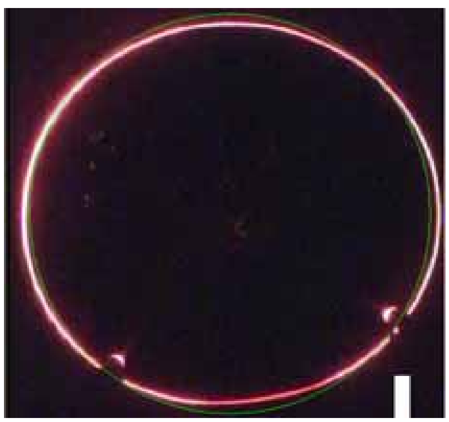
d)

Figure 198 Horizontal and vertical deformation of the pipeline No. 30 (Site No. 8: Fairmont)

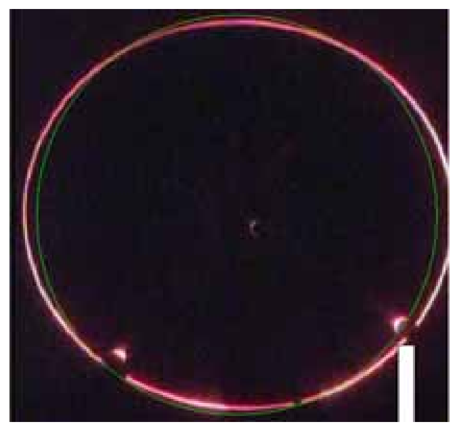
Figure 199 View of corrugation growth failure for pipeline No. 30 (Site No. 8: Fairmont)

Pipeline No. 31 (Site No. 9: Rochester)





a)



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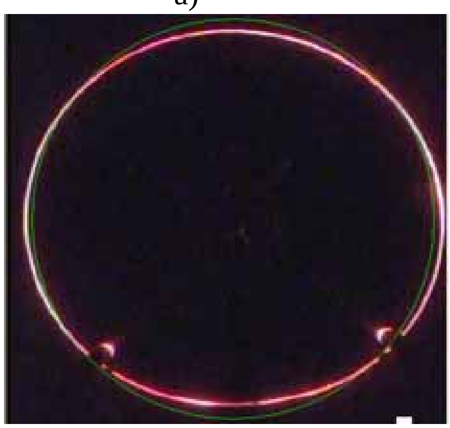

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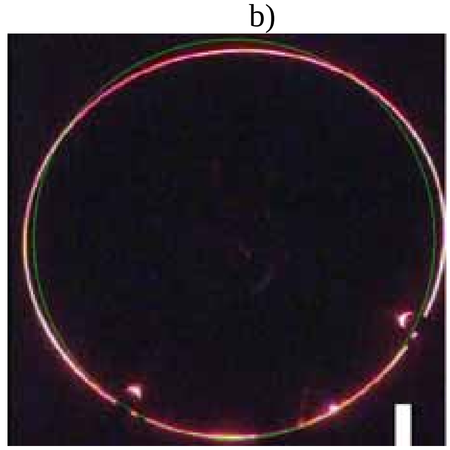


d)

Figure 200 Horizontal and vertical deformation of the pipeline No. 31 (Site No. 9: Rochester)

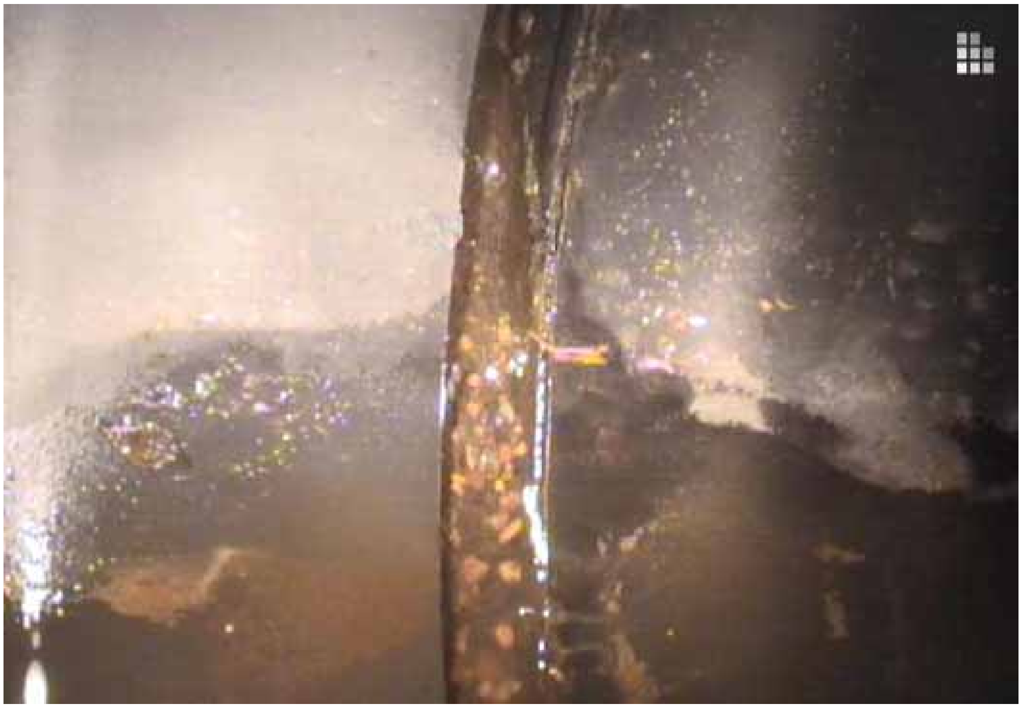


Figure 201 View of major joint displacement failure for pipeline No. 31 (Site No. 9: Rochester)

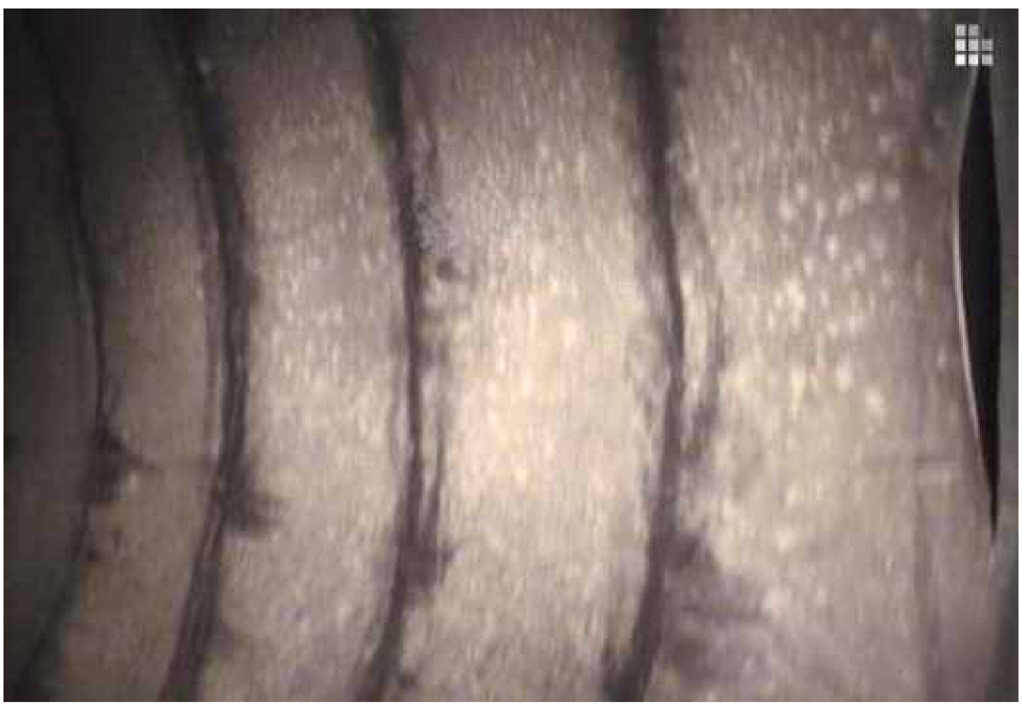


Figure 202 View of cracking/fracture failure for pipeline No. 31 (Site No. 9: Rochester)

Appendix 5 – State of Kansas

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Kansas. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

Figure 203 Layout of site locations

Table 16 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipeline Diameter (in.)	Inspection date	Length (ft)
1	Lenexa	1	42	7/26/2008	470
		2	48	7/26/2008	380
		3	42	7/26/2008	125
		4	36	7/26/2008	120
		5	36	7/26/2008	130
		6	48	7/26/2008	160
2	Wichita	7	30	5/14/2008	100
		8	36	5/14/2008	130
3	Galena	9	24	11/15/2008	90
		10	32	11/15/2008	80

Table 17 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corregation Growth	Buckling
1	Lenexa	1		✓			✓	
		2	✓	✓	✓		✓	
		3					✓	
		4		✓	✓		✓	✓
		5	✓	✓	✓		✓	✓
		6	✓	✓			✓	
2	Wichita	7		✓			✓	
		8		✓			✓	
3	Galena	9	✓				✓	
		10	✓				✓	
Percentage of pipelines experiencing failure mode			50%	70%	30%	0%	100%	20%

Table 18 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Lenexa	1	5.5	5.0	4.0	5.5
		2	5.2	5.9	6.8	6.8
		3	3.1	3.8	3.2	3.8
		4	9.5	10.4	9.5	10.4
		5	7.9	7.7	8.0	8.0
		6	2.8	3.6	5.3	5.3
2	Wichita	7	7.7	8.9	8.8	8.9
		8	9.4	10.4	9.7	10.4
3	Galena	9	3.9	3.6	3.9	3.9
		10	4.9	4.8	4.8	4.8
	Max		9.5	10.4	9.7	10.4
	Min		2.8	3.6	3.2	3.8
	Average		6.0	6.4	6.4	6.8

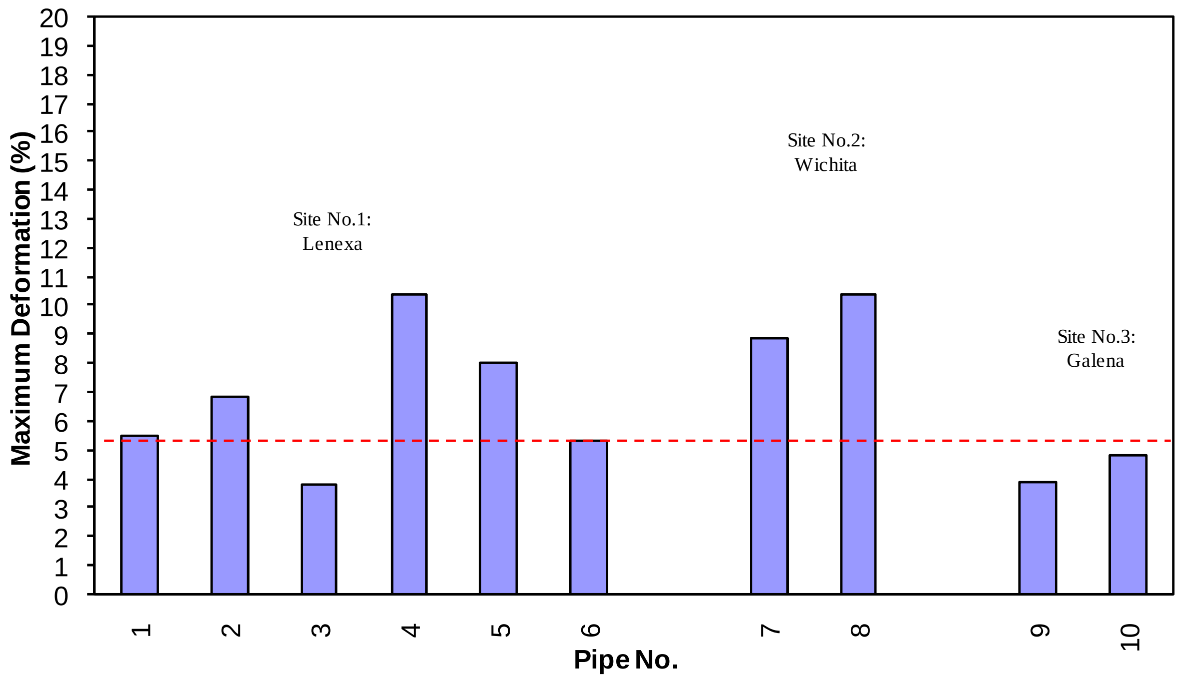
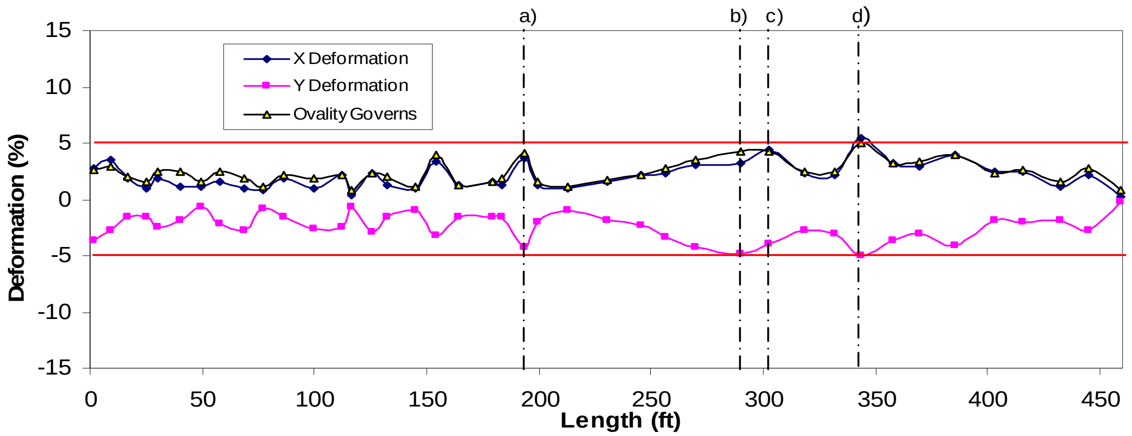
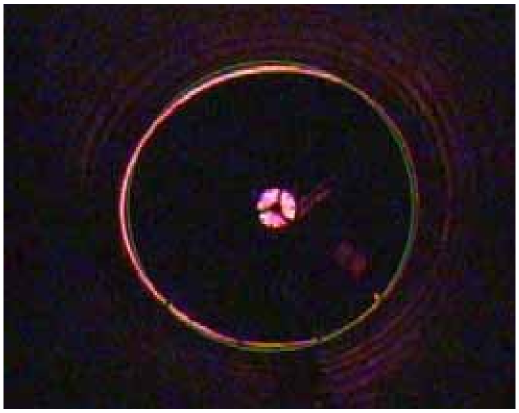


Figure 204 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Lenexa)

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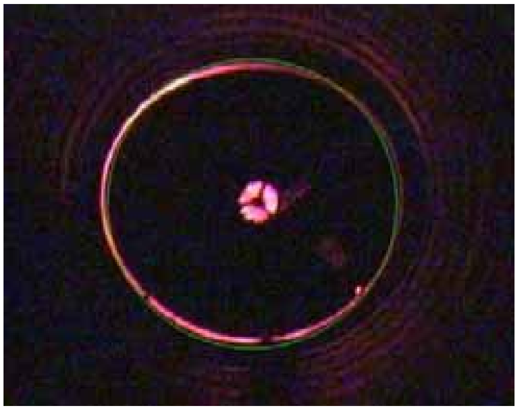
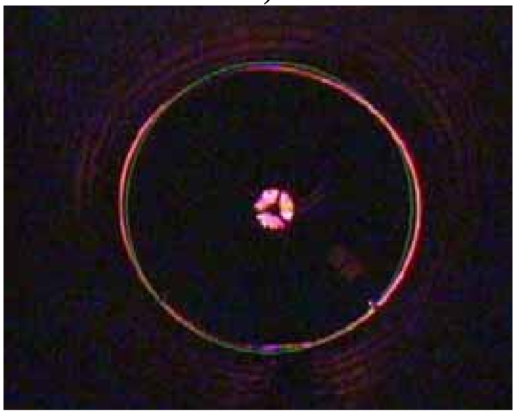

b)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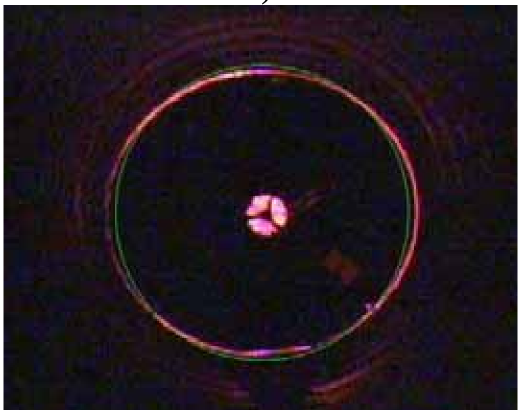
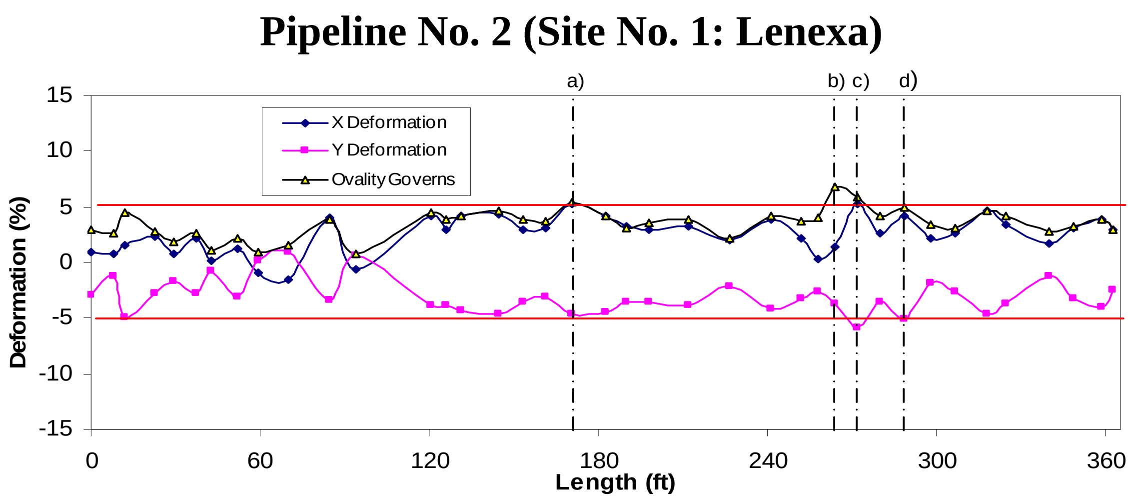
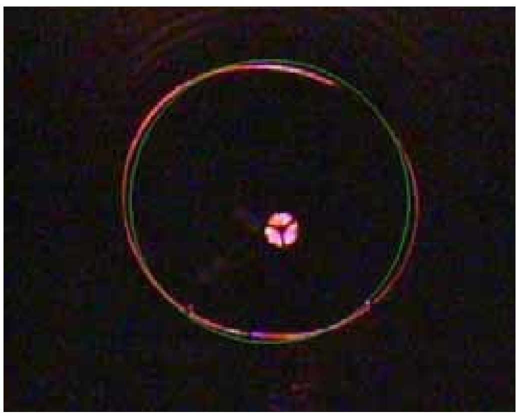

d)

Figure 205 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: Lenexa)

Figure 206 View of corrugation growth failure for pipeline No. 1 (Site No. 1: Lenexa)

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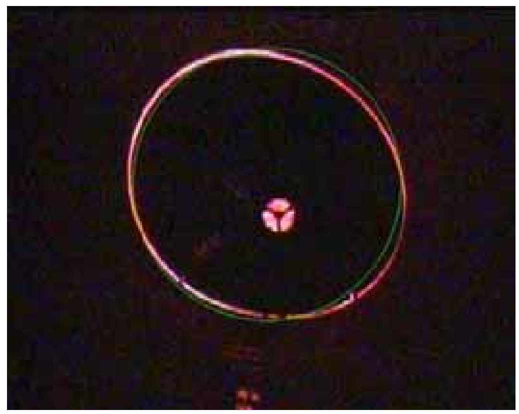
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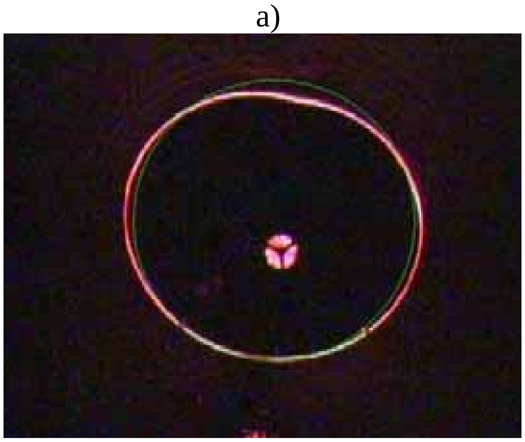
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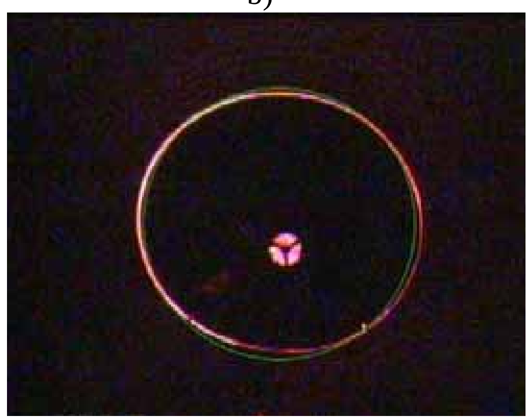

d)

Figure 207 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: Lenexa)

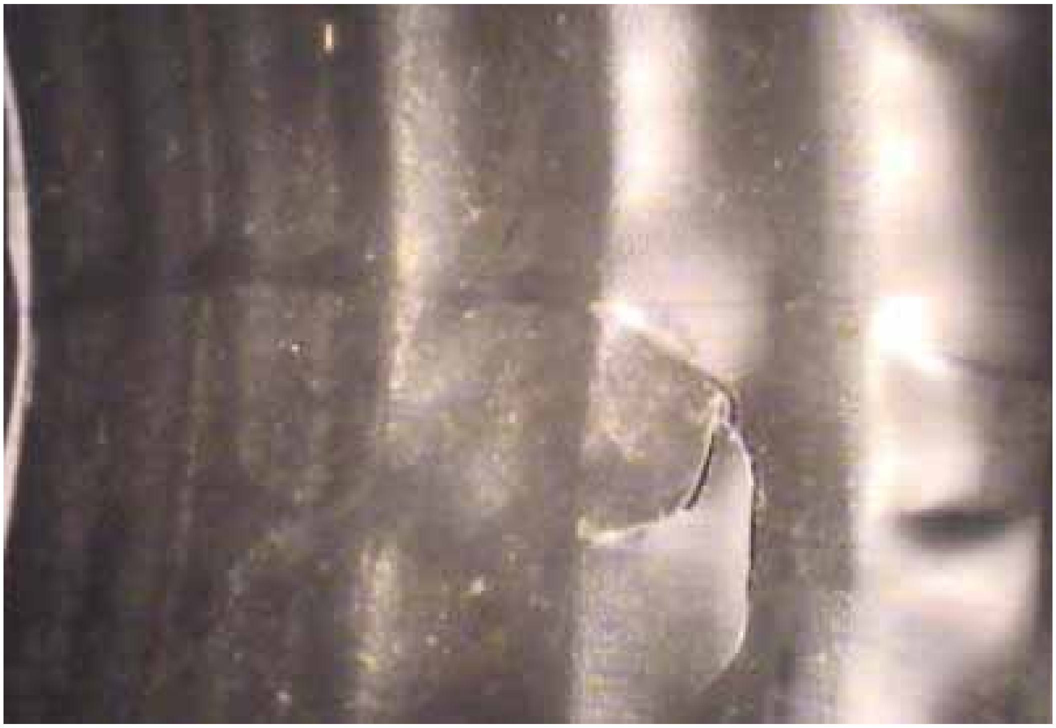


Figure 208 View of the cracking failure for pipeline No. 2 (Site No. 1: Lenexa)

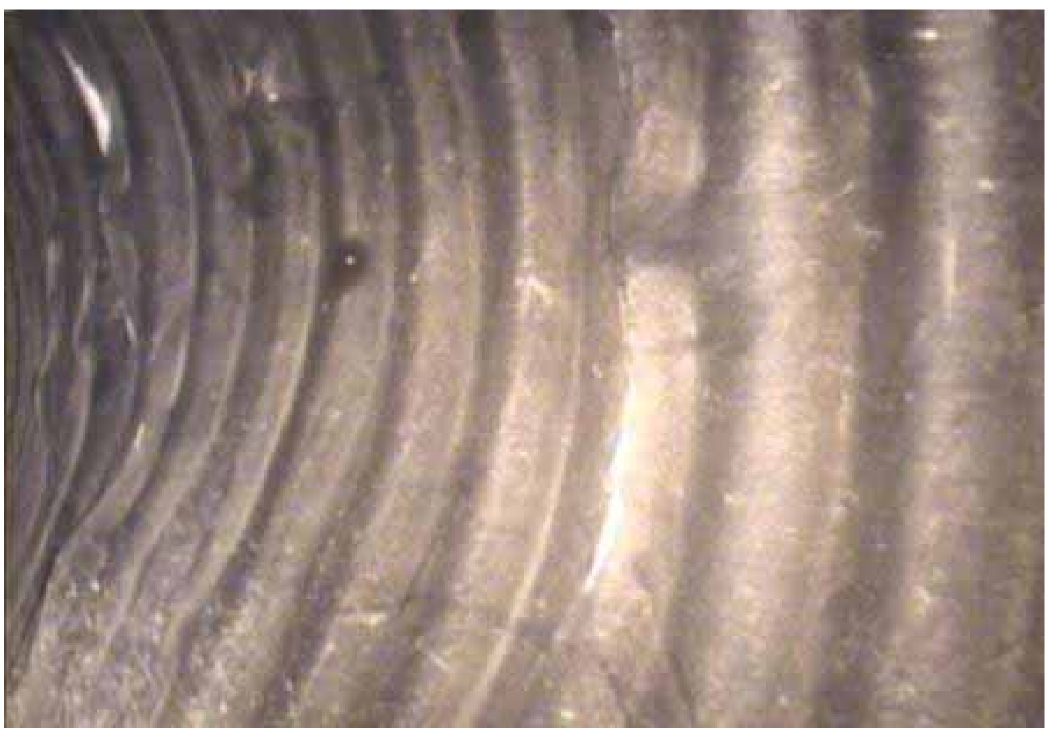
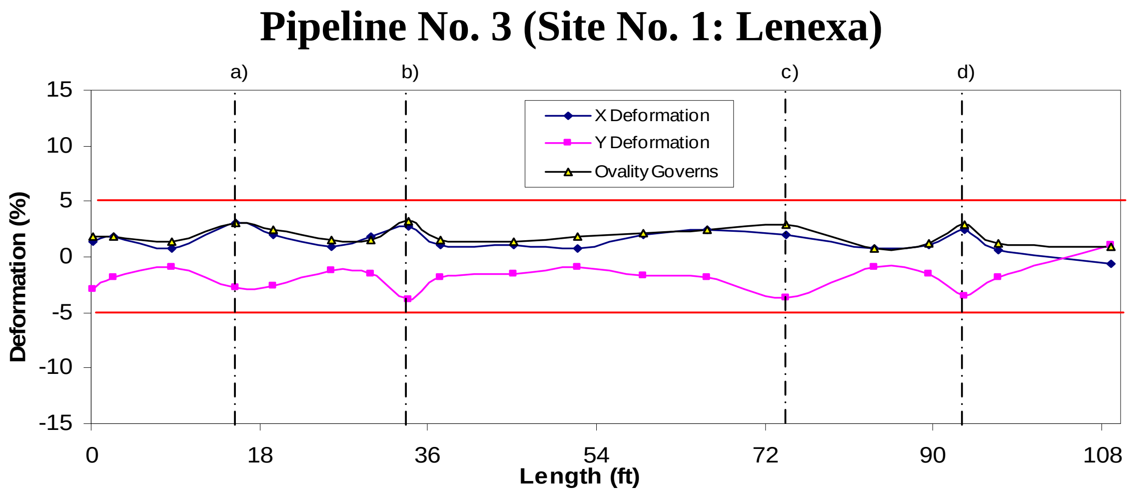


Figure 209 View of inverse curvature and corrugation growth failures for pipeline No. 2 (Site No. 1: Lenexa)



a)

b)

c)

d)

Figure 210 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: Lenexa)

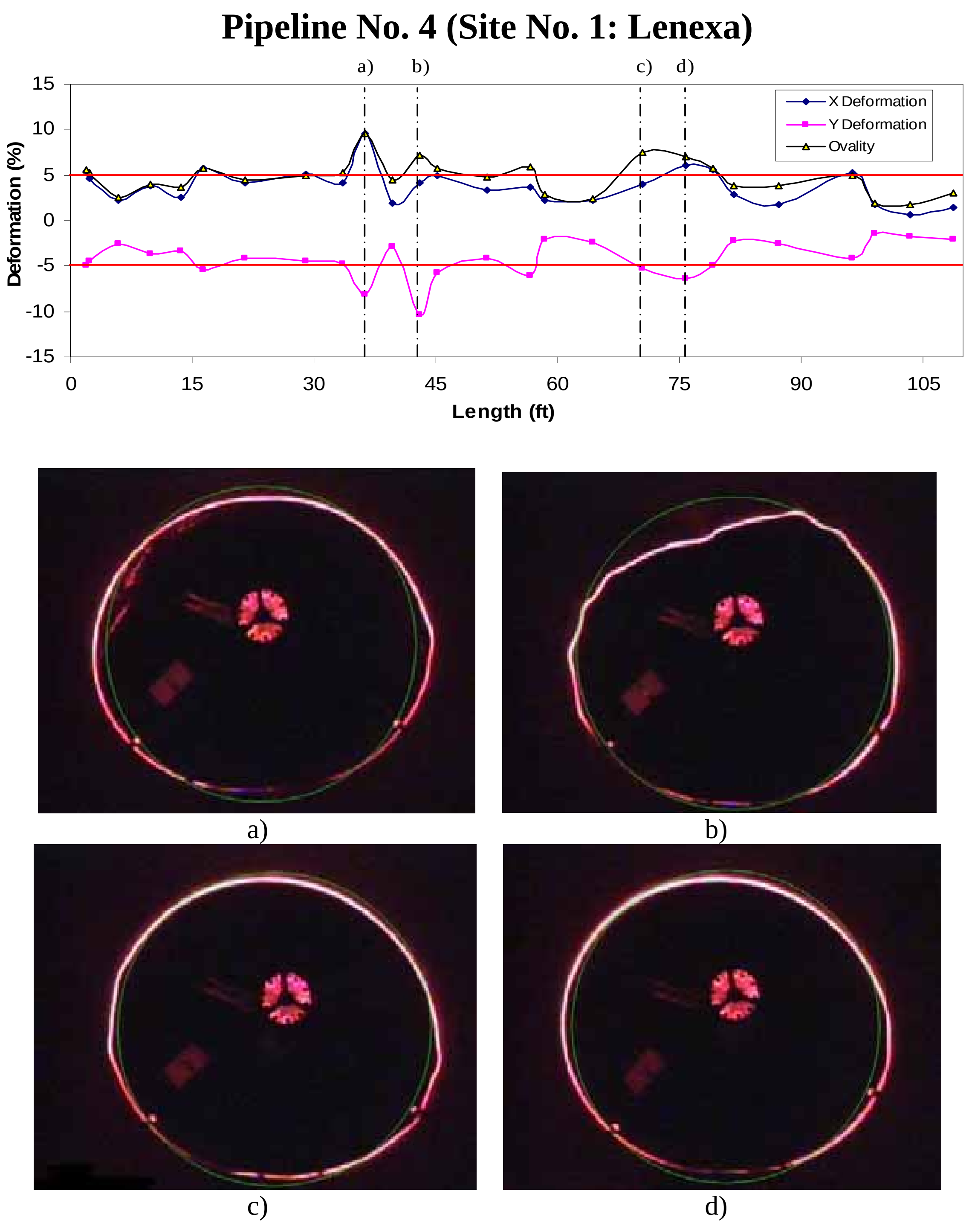


Figure 211 Horizontal and vertical deformation of the pipeline No. 4 (Site No. 1: Lenexa)

Figure 212 View of inverse curvature failure for pipeline No. 4 (Site No. 1: Lenexa)

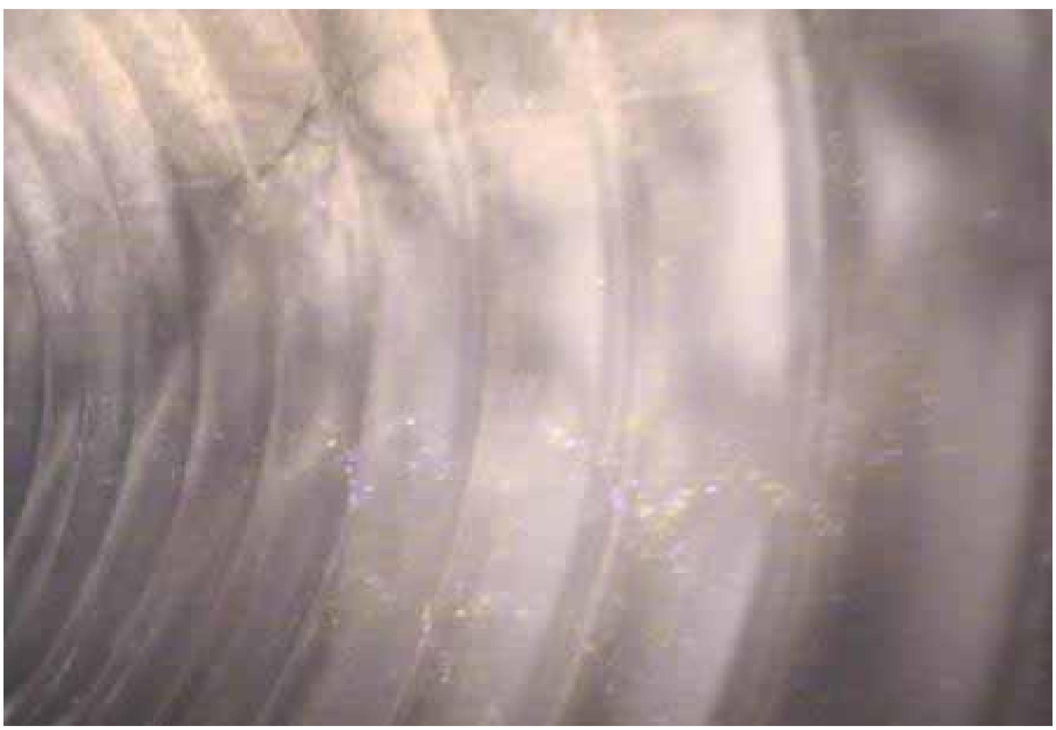
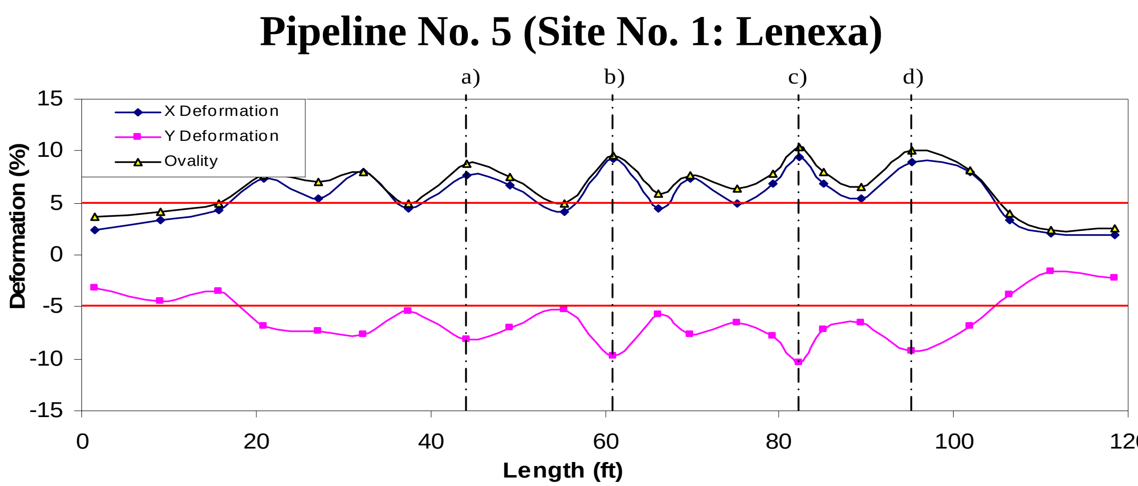


Figure 213 View of buckling failure for pipeline No. 4 (Site No. 1: Lenexa)



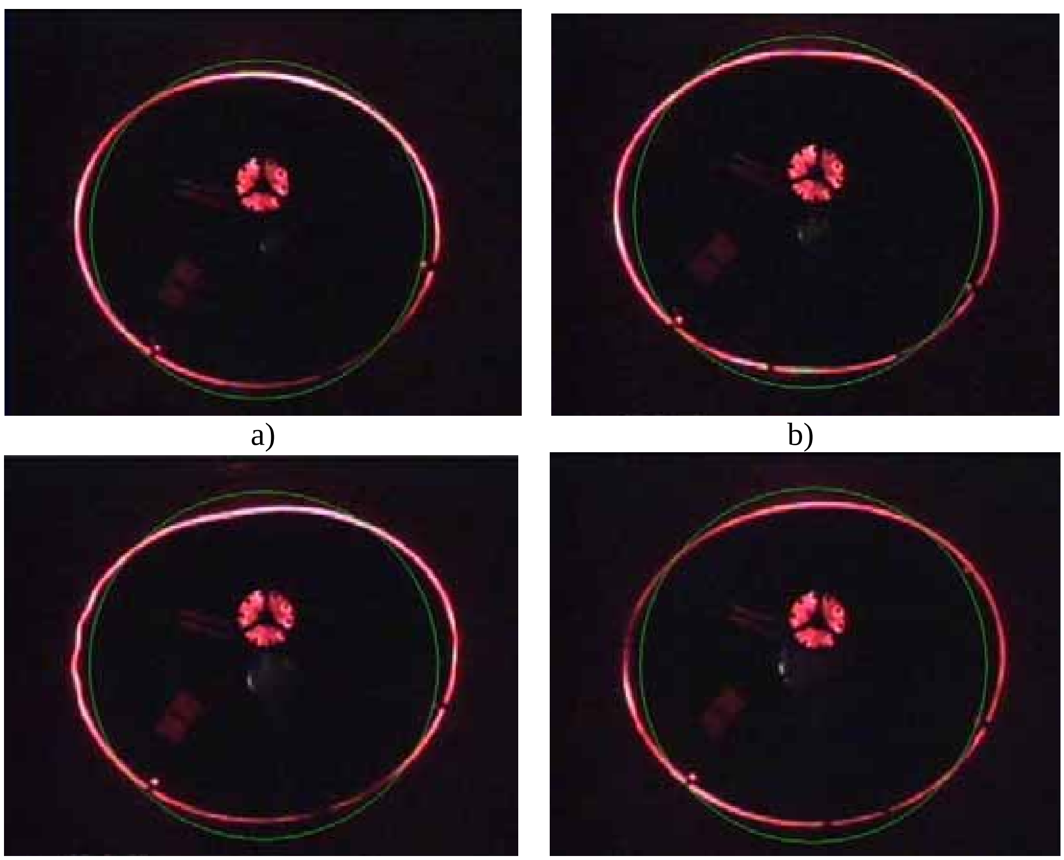


Figure 214 Horizontal and vertical deformation of the pipeline No. 5 (Site No. 1: Lenexa)

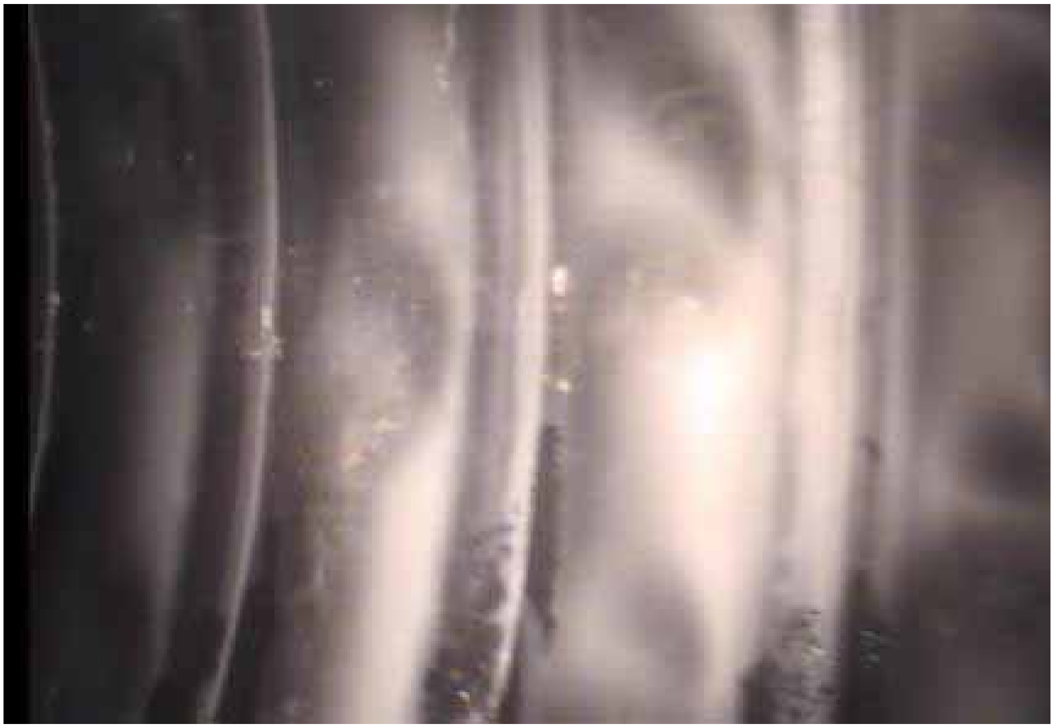
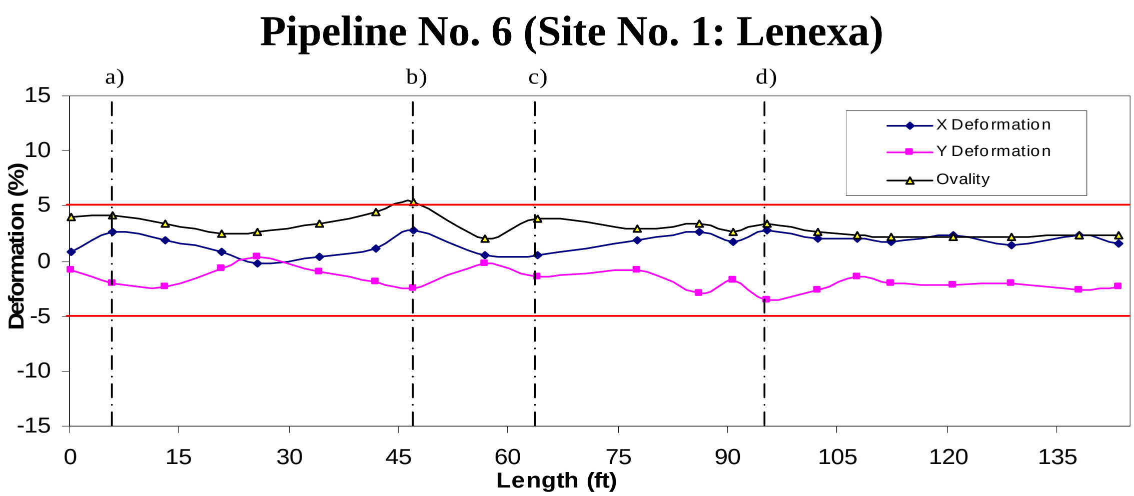
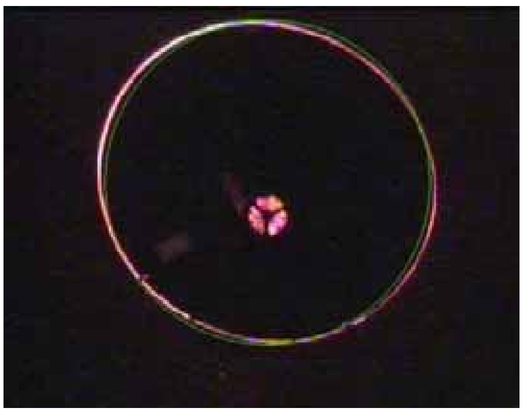


Figure 215 View of the buckling failure for pipeline No. 5 (Site No. 1: Lenexa)

Figure 216 View of cracking and corrugation failure for pipeline No. 5 (Site No. 1: Lenexa)

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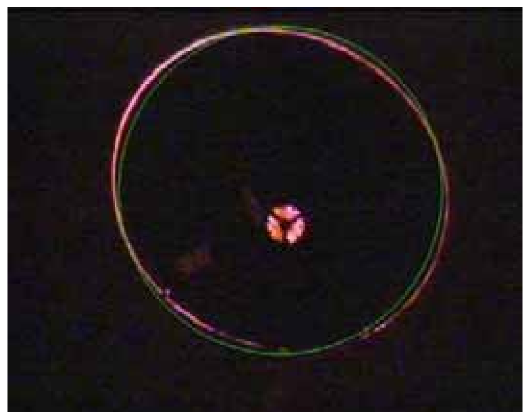
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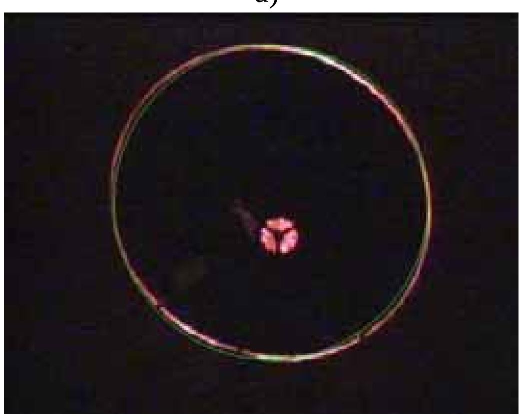
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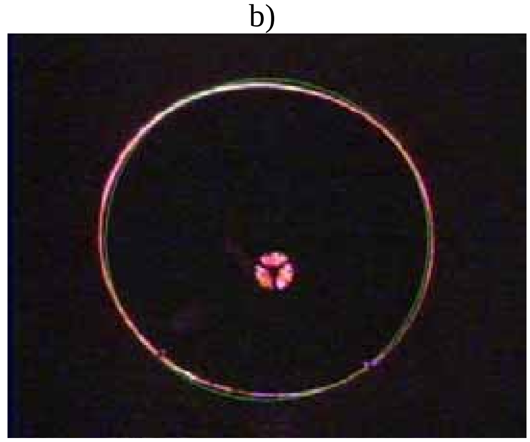
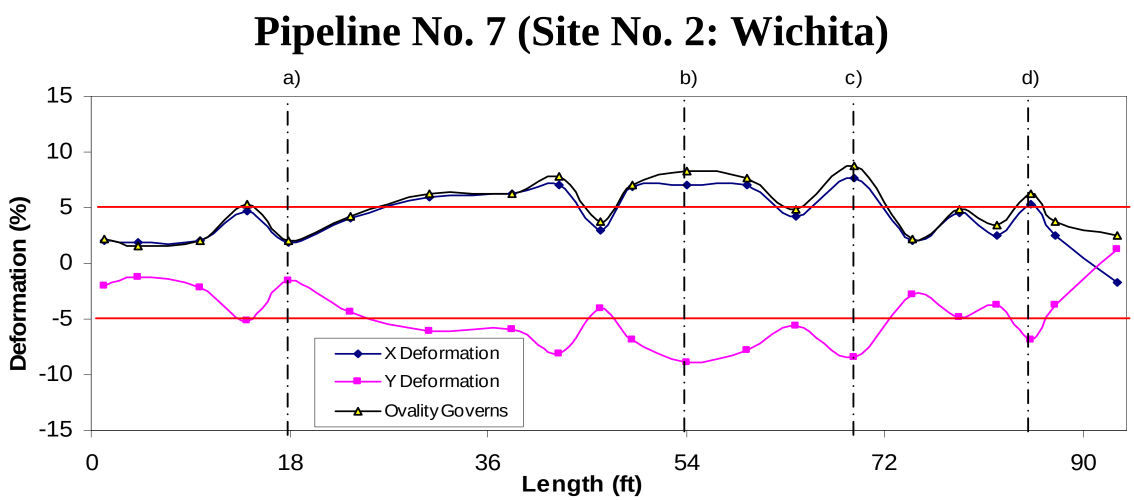
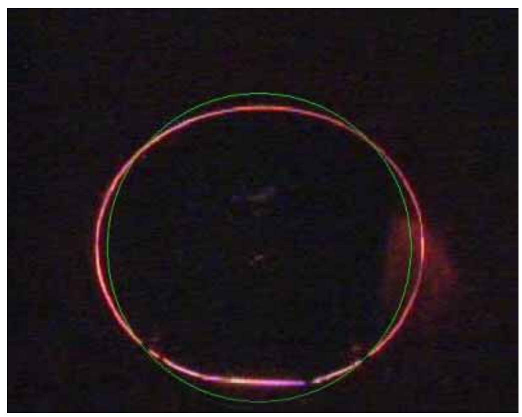

d)

Figure 217 Horizontal and vertical deformation of the pipeline No. 6 (Site No. 1: Lenexa)

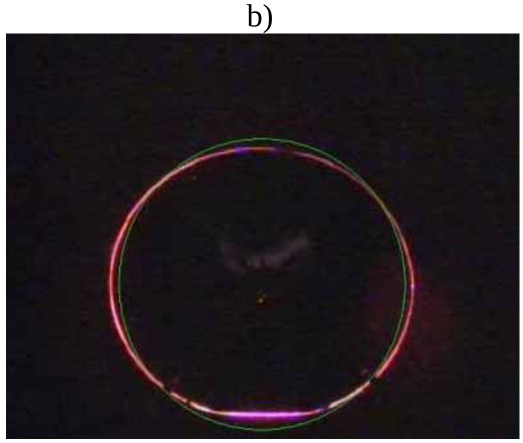
Figure 218 View of corrugation failure and pipe intrusion for pipeline No. 6 (Site No. 1: Lenexa)

Figure 219 View of pipe intrusion for pipeline No. 6 (Site No. 1: Lenexa)



a) b)

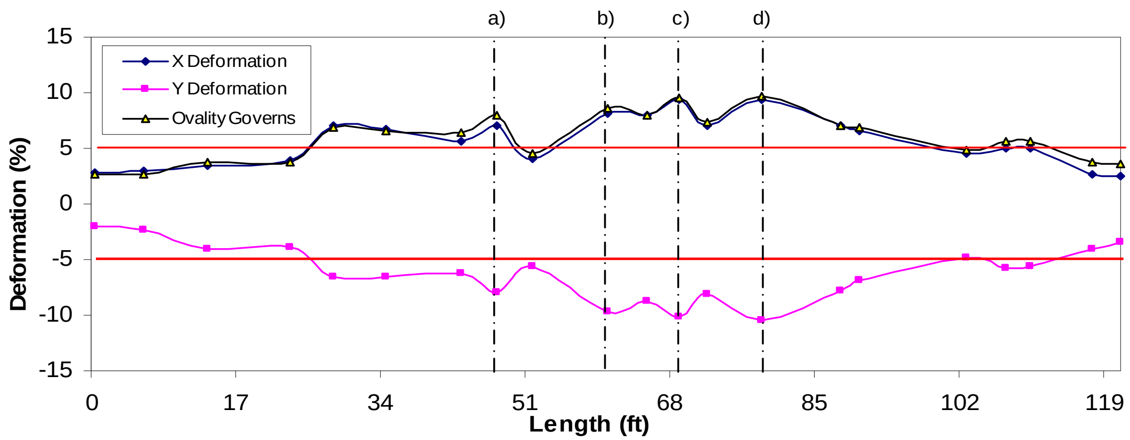



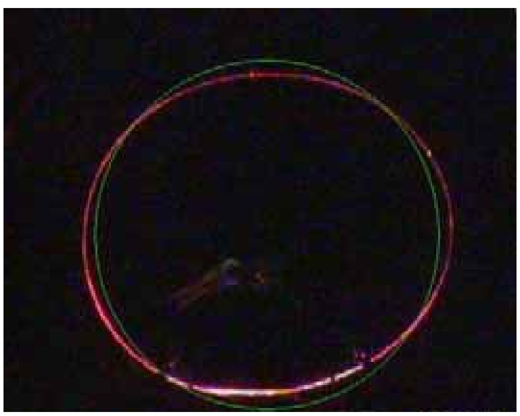
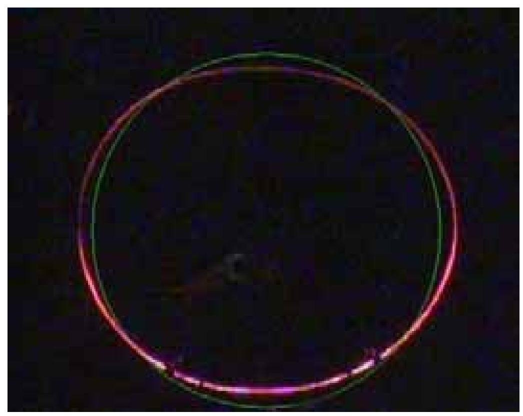
c) d)

Figure 220 Horizontal and vertical deformation of the pipeline No. 7 (Site No. 2: Wichita)

Figure 221 View of the corrugation growth failure for pipeline No. 7 (Site No. 2: Wichita)

Pipeline No. 8 (Site No. 2: Wichita)



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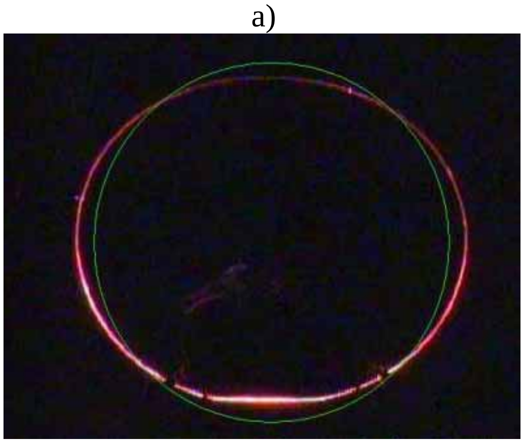
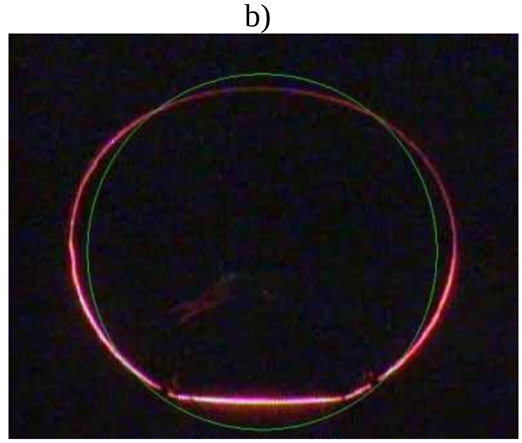
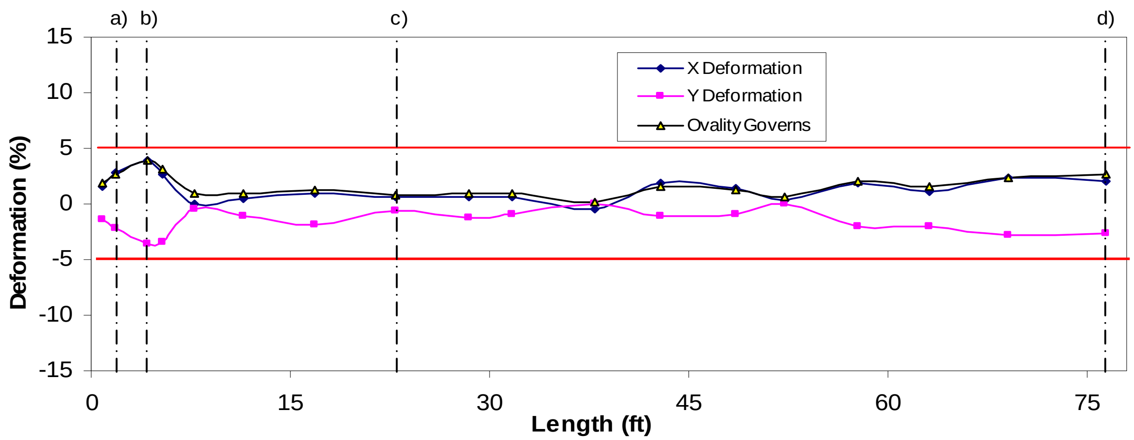



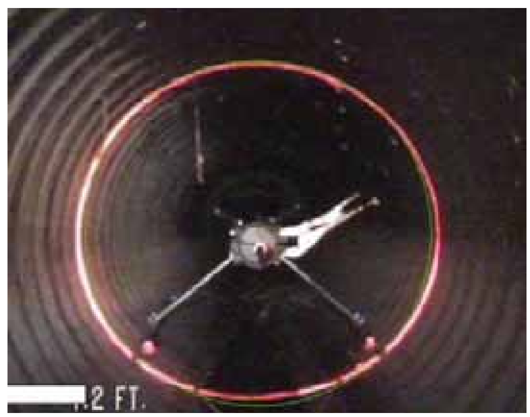
c) d)

Figure 222 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 2: Wichita)

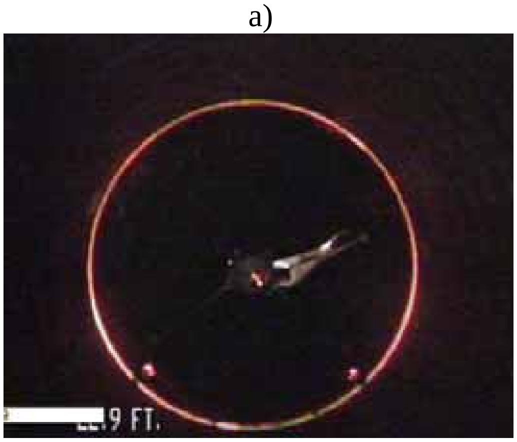
Pipeline No. 9 (Site No. 3: Galena)



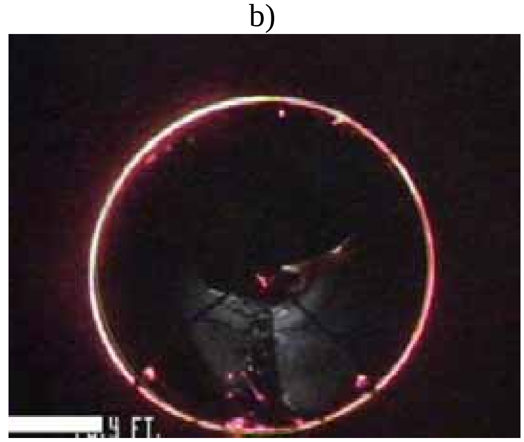
a)



b)



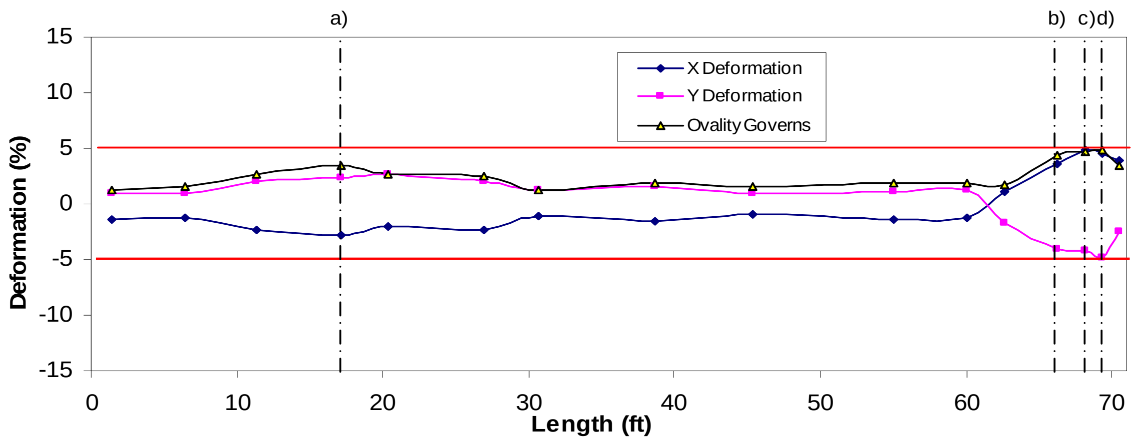
c)



d)

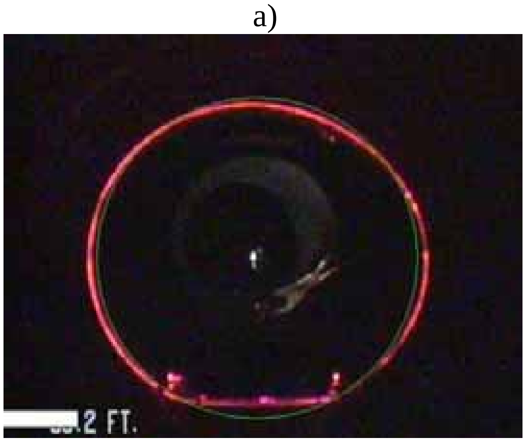
Figure 223 Horizontal and vertical deformation of the pipeline No. 9 (Site No. 3: Galena)

Pipeline No. 10 (Site No. 3: Galena)

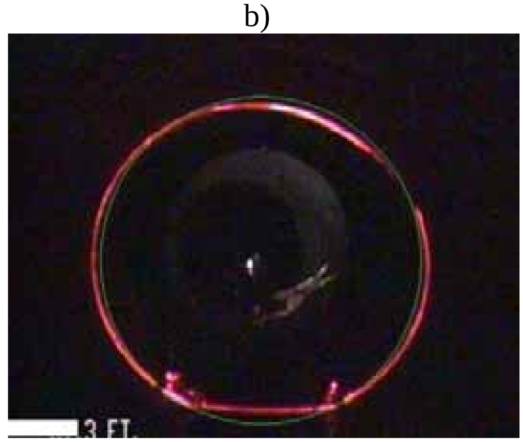


a)

b)



c)



d)

Figure 224 Horizontal and vertical deformation of the pipeline No. 10 (Site No. 3: Galena)

Appendix 6 – State of Missouri

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Missouri. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

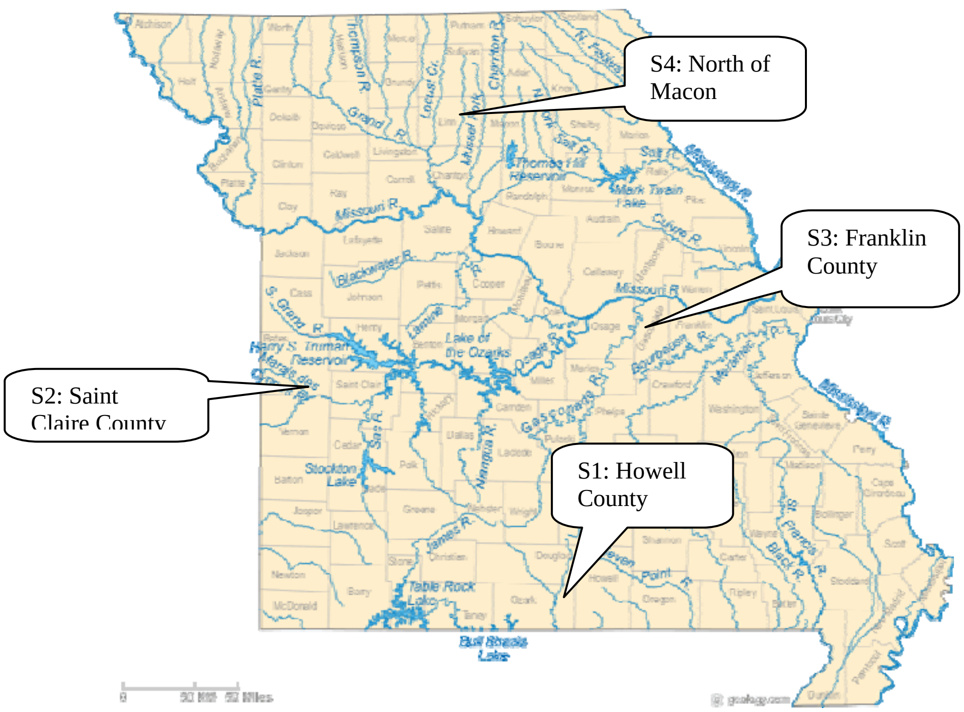


Figure 225 Layout of site numbers/locations

Table 19 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	Howell County – HW 63	1	48	8/11/2007	475
		2	48	8/11/2007	475
		3a	48	4/4/2008	300
		3b	60	4/4/2008	150
2	Saint Claire County – Route B	4	60	8/11/2007	50
3	Franklin County – Route FF	5	30	8/8/2007	35
		6	48	4/5/2008	35
		7	48	4/5/2008	20
		8	42	8/9/2007	30
		9	24	8/9/2007	30
		10*	12	8/9/2007	30
		11	18	8/9/2007	40
		12*	15	8/9/2007	10
		13	36	4/5/2008	110
4	North of Macon – HW 63	14	30	11/29/2006	85
		15	24	11/29/2006	70

* Laser video data was not collected

Table 20 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corrugation Growth	Buckling
1	Howell County - Hwy 63	1		✓			✓	
		2		✓			✓	
		3		✓			✓	
2	St. Clair County - Route B	4		✓			✓	
3	Franklin County - Route FF	5	✓	✓			✓	
		6		✓			✓	
		7		✓			✓	
		8					✓	
		9		✓			✓	
		10	✓	NA			✓	
		11	✓				✓	
		12		NA			✓	
		13		✓			✓	
4	North of Macon - Hwy 63	14					✓	
		15					✓	
Percentage of pipelines experiencing failure mode			13%	69%	0%	0%	100%	0%

NA: Laser video data was not collected

Table 21 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Howell County - Hwy 63	1	5.7	5.4	5.9	5.9
		2	3.1	6.3	5.5	6.3
		3	2.6	2.4	5.4	5.4
2	St. Clair County - Hwy 63	4	8.2	8.8	7.8	8.8
3	Franklin County - Route FF	5	6.7	5.3	5.7	6.7
		6	5.3	6.8	5.9	6.8
		7	5.7	4.7	5.3	5.3
		8	1.2	1.5	1.9	1.9
		9	6.3	6.3	6.3	6.3
		10	NA	NA	NA	NA
		11	1.2	1.2	1.1	1.2
		12	NA	NA	NA	NA
		13	4.7	4.1	5.1	5.1
4	North of Macon -	14	3.4	3.3	3.7	3.7
		15	3.6	3.9	3.7	3.9
	Max		8.2	8.8	7.8	8.8
	Min		1.2	1.2	1.1	1.2
	Average		4.4	4.6	4.9	5.2

* Laser video data was not collected

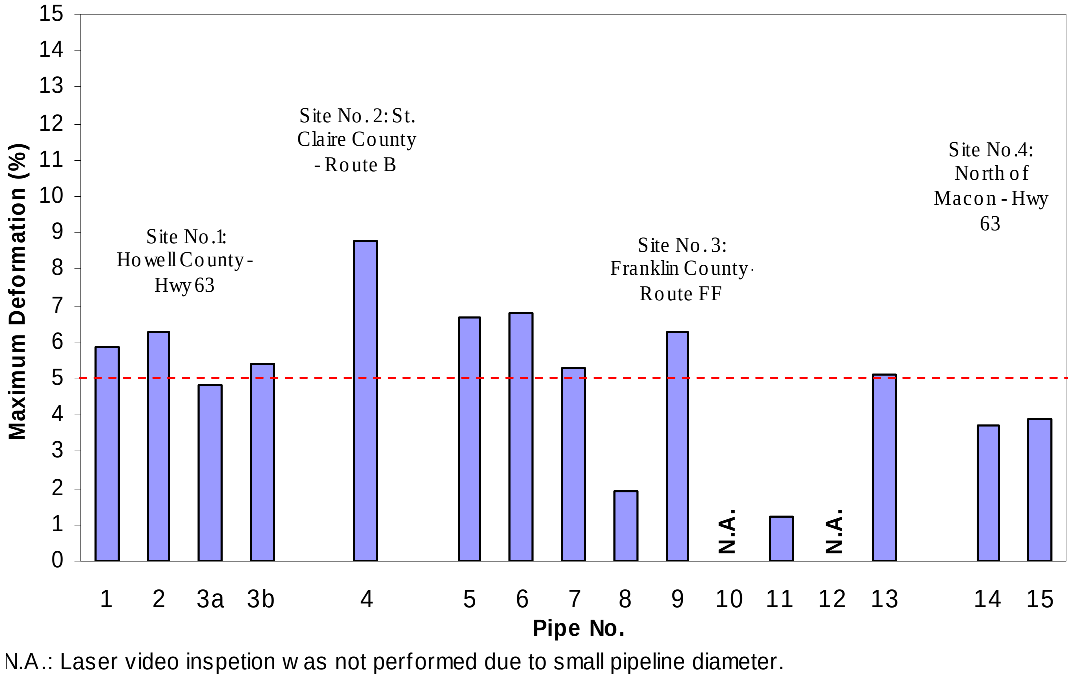
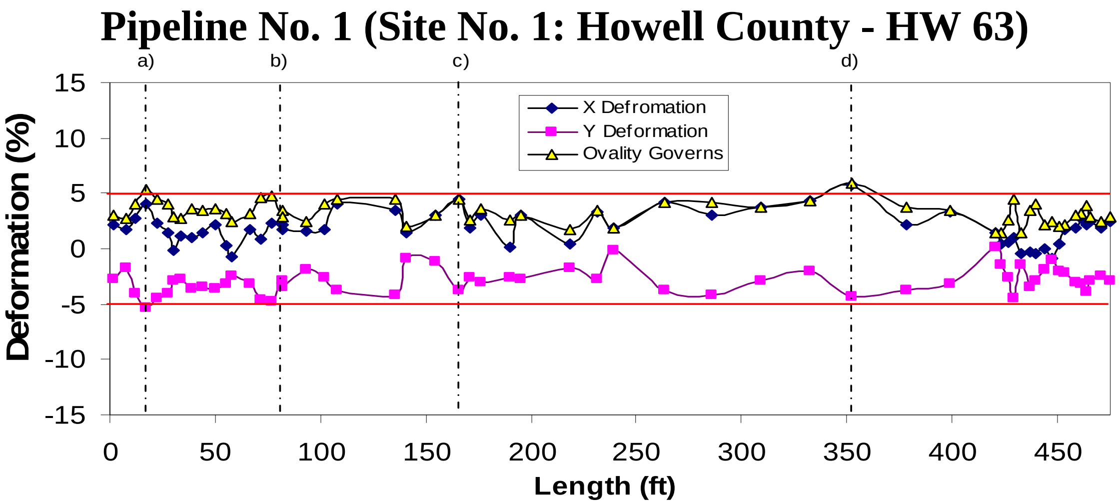
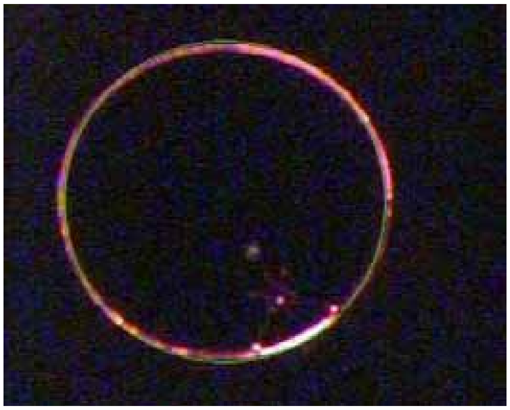


Figure 226 Comparison of Maximum deformations calculated for pipelines tested in different site locations




a)


b)


c)

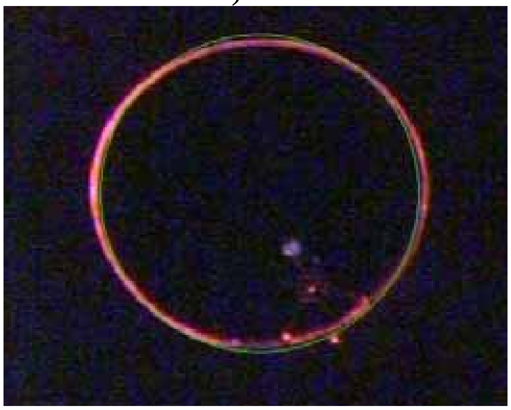
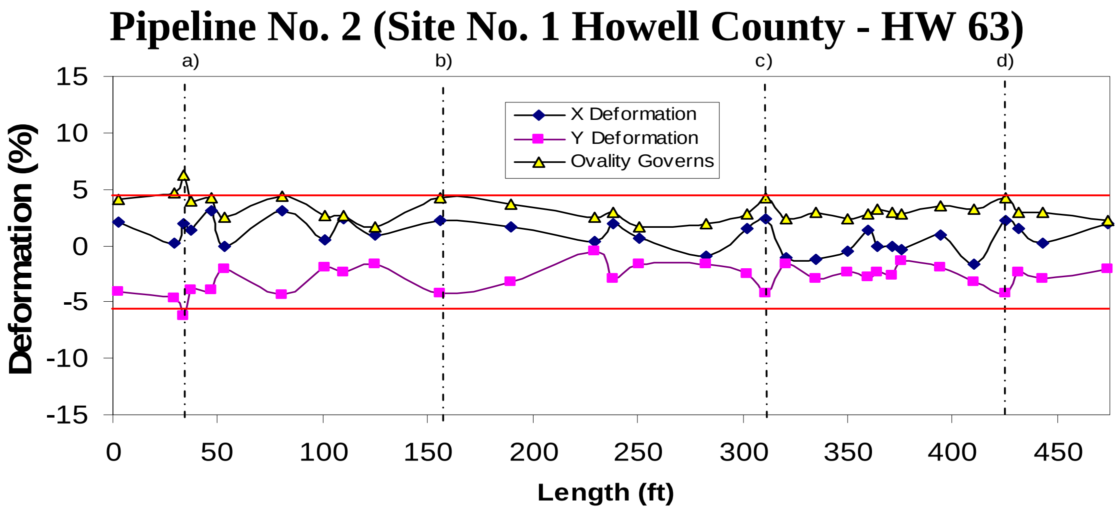
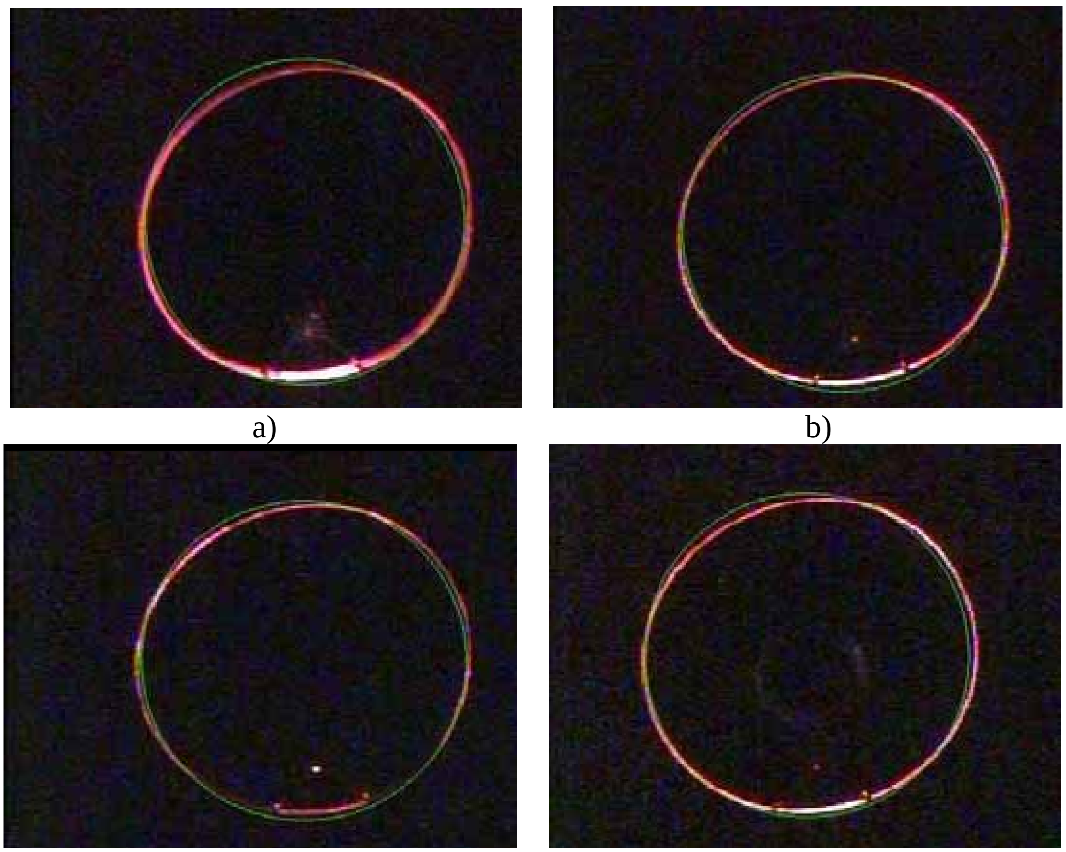

d)

Figure 227 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: Howell County - HW 63)





a) b)

c) d)

Figure 228 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1 Howell County - HW 63)

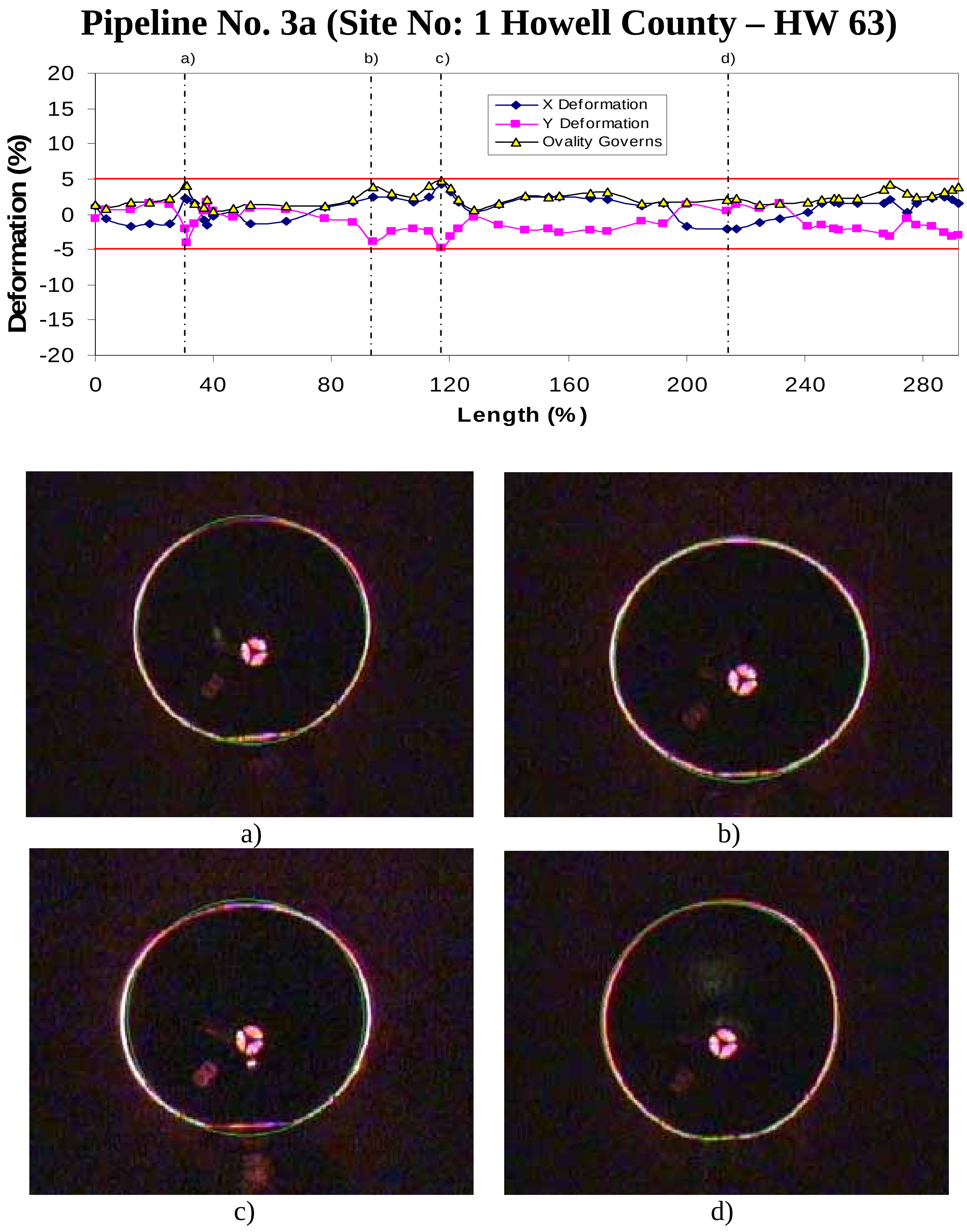
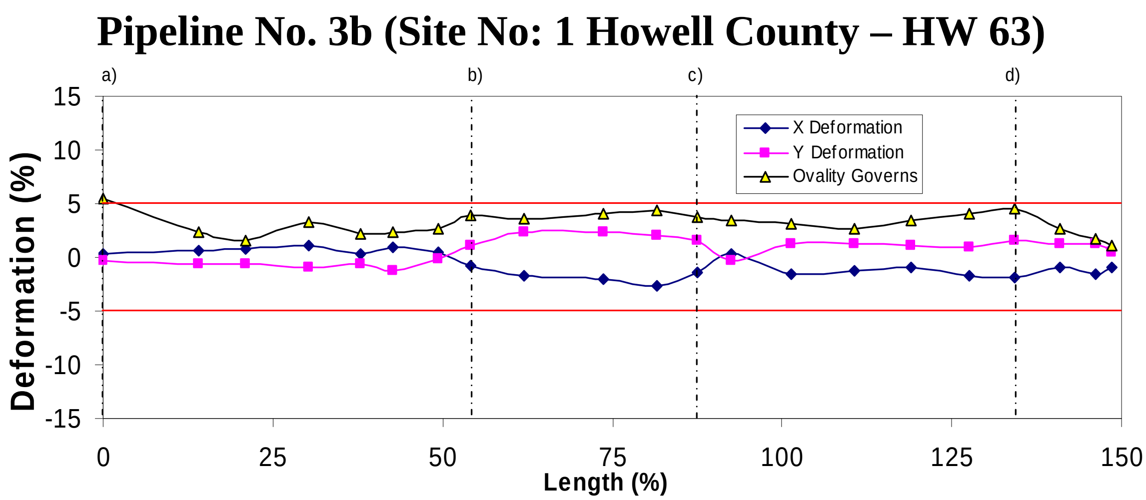
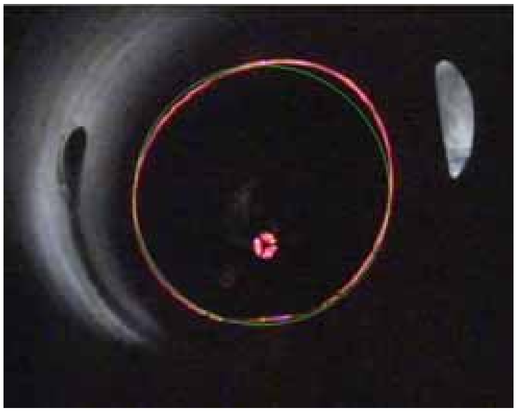
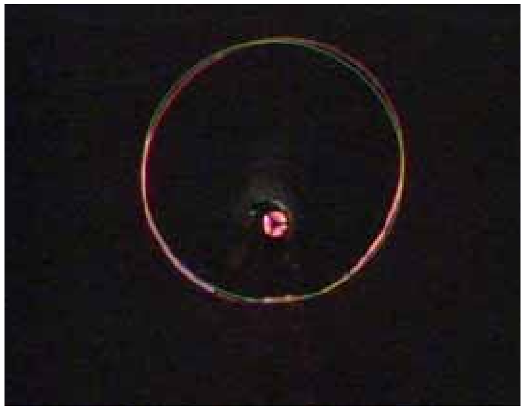


Figure 229 Horizontal and vertical deformation of the pipeline No. 3a (Site No. 1: Howell County – HW 63)




a)


b)


c)

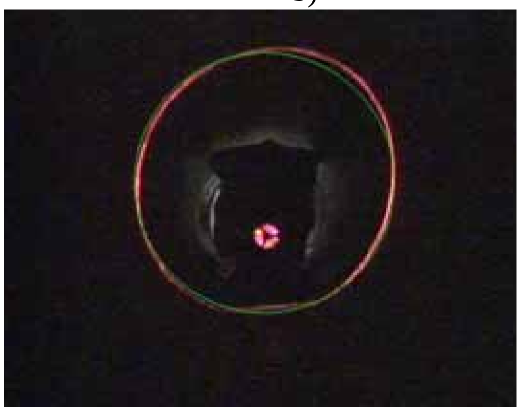
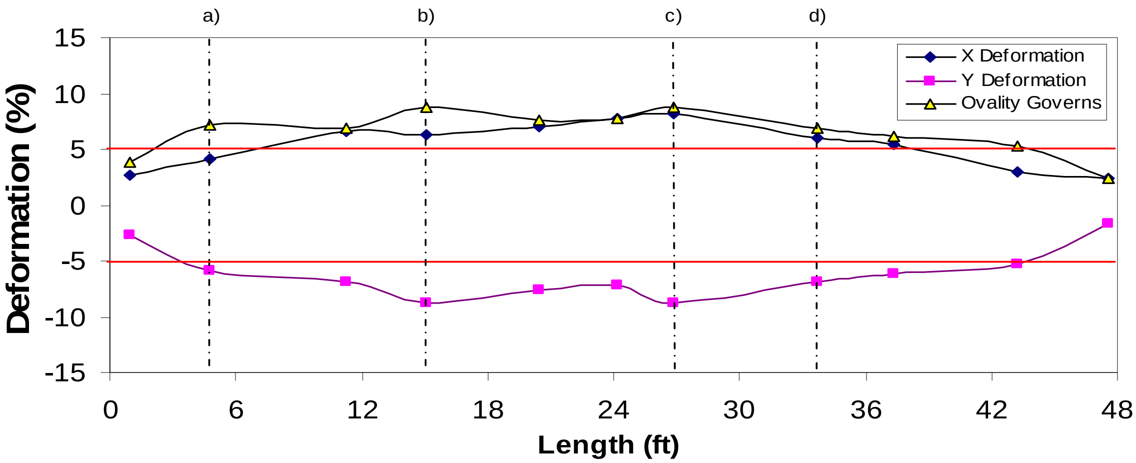
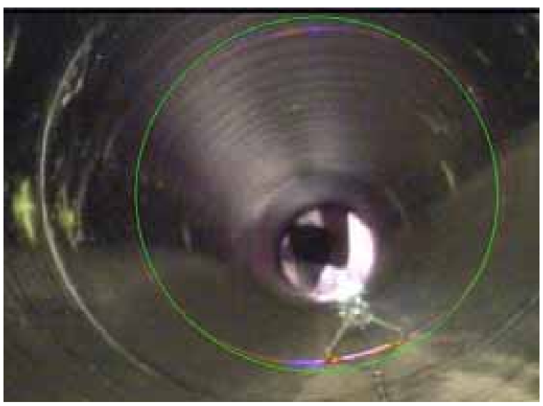

d)

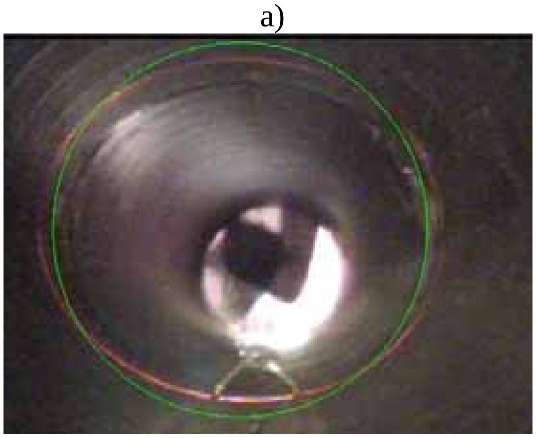
Figure 230 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: Howell County – HW 63)

Pipeline No. 4 (Site No. 2 St. Claire County – Route B)




a)


b)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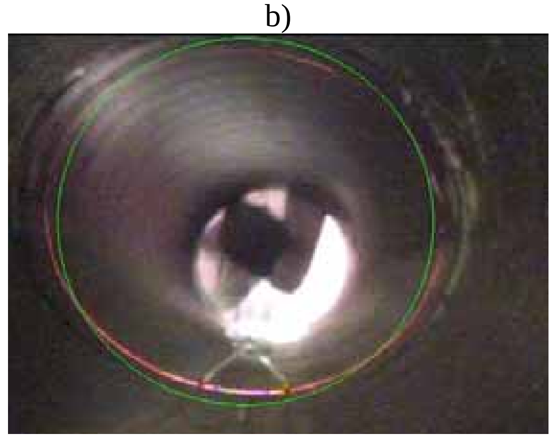
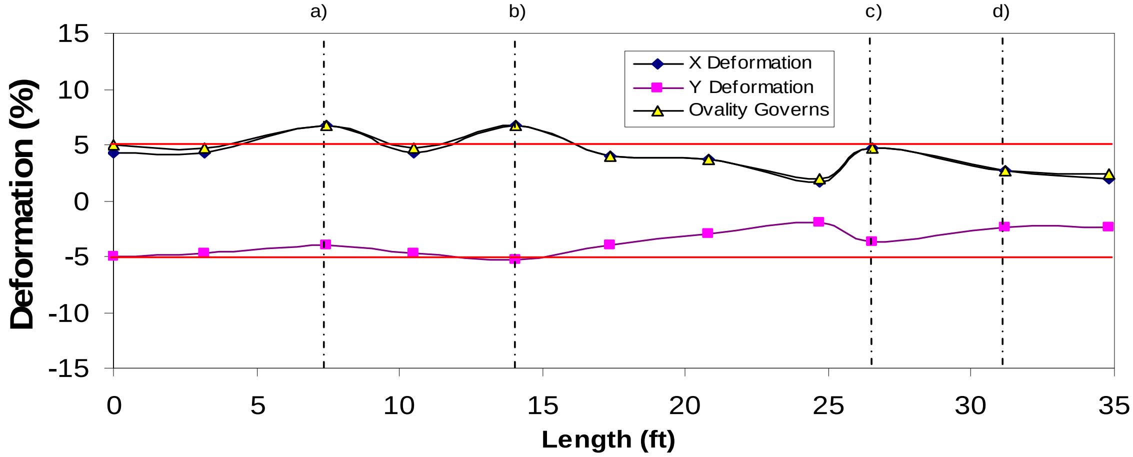

d)

Figure 231 Horizontal and vertical deformation of the pipeline No. 4 (Site No. 2: St Claire County – Route B)

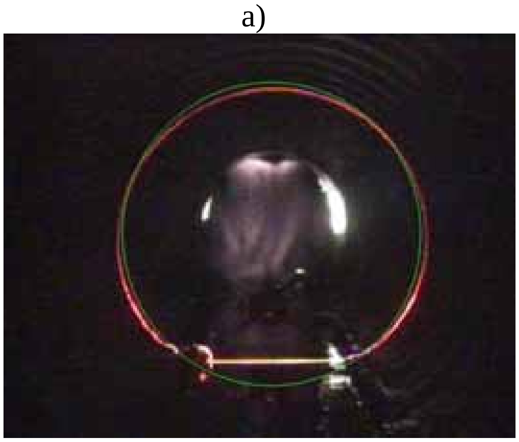
Figure 232 Corrugation growth for pipeline No. 4 (Site No. 2: St Claire County – Route B)

Pipeline No. 5 (Site No. 3: Franklin County – Route FF)




a)


b)


c)

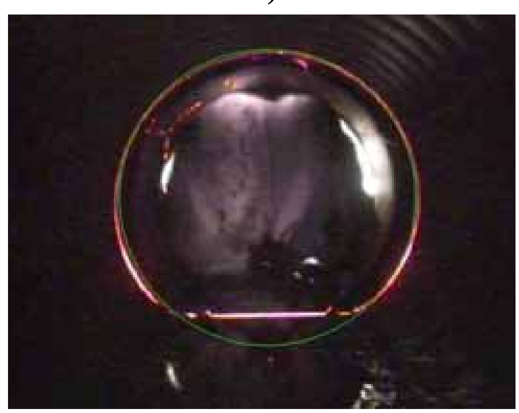

d)

Figure 233 Horizontal and vertical deformation of the pipeline No. 5 (Site No. 3: Franklin County – Route FF)

Figure 234 Corrugation growth for pipeline No. 5 (Site No. 3: Franklin County – Route FF)

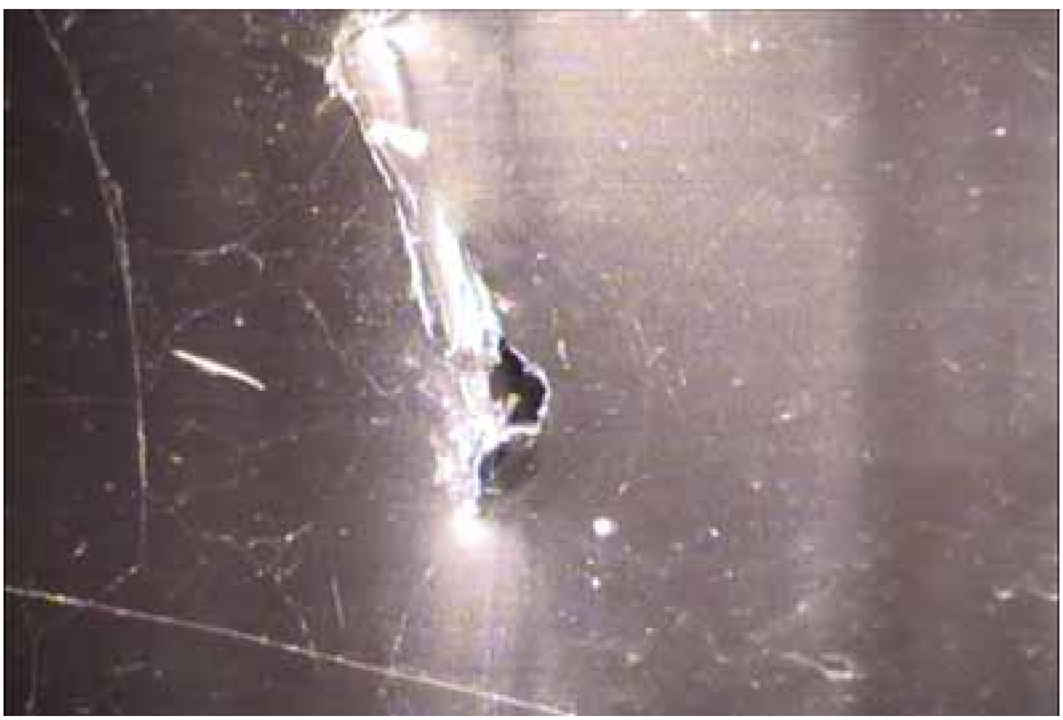
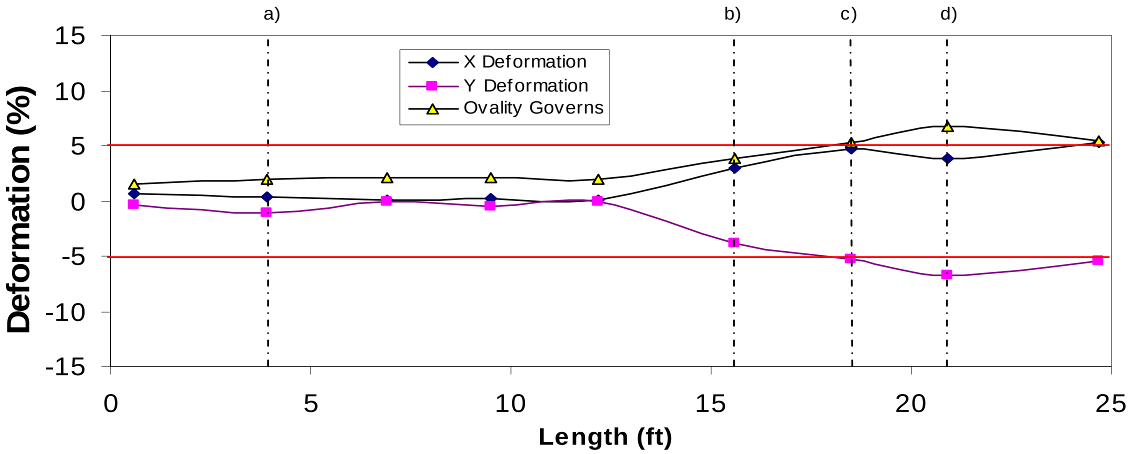


Figure 235 Cracking failure for pipeline No. 5 (Site No. 3: Franklin County – Route FF)

Pipeline No. 6 (Site No. 3: Franklin County – Route FF)



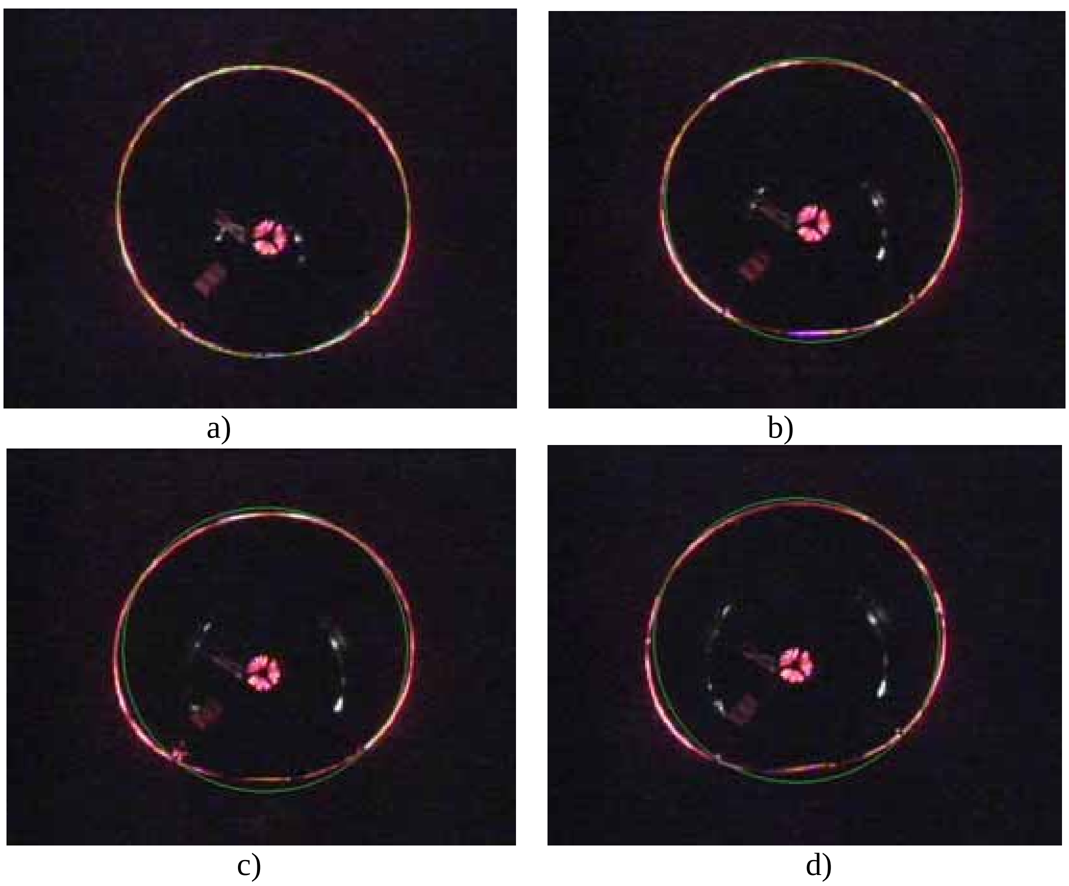
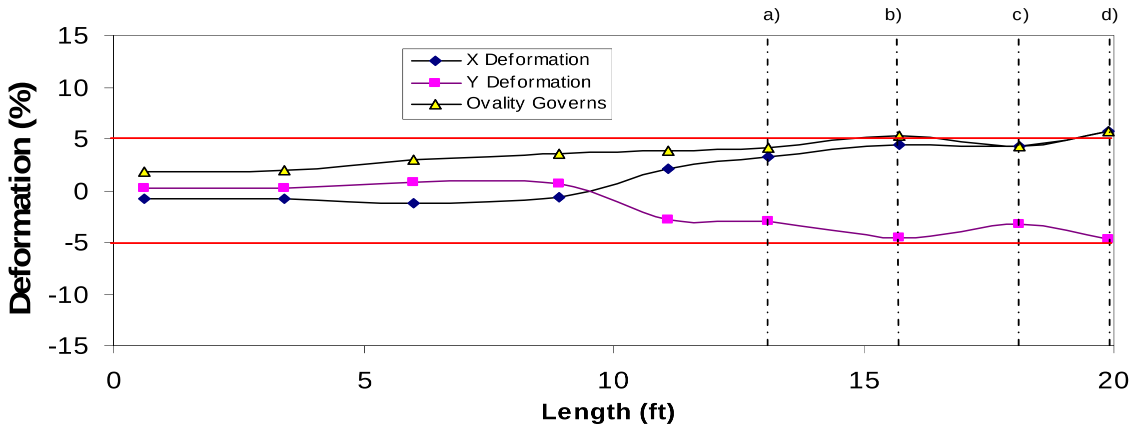
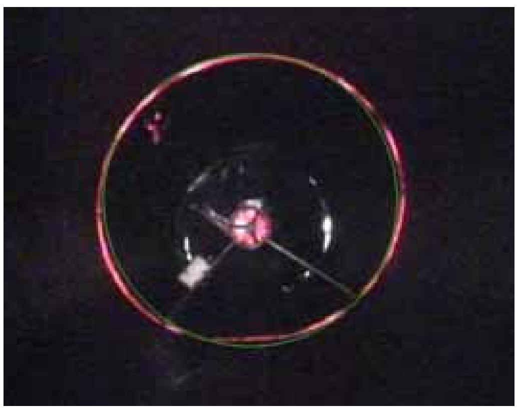
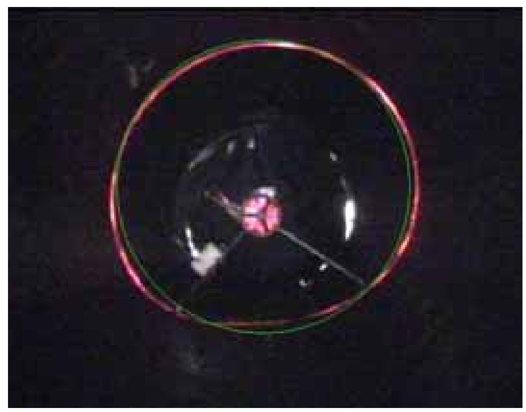


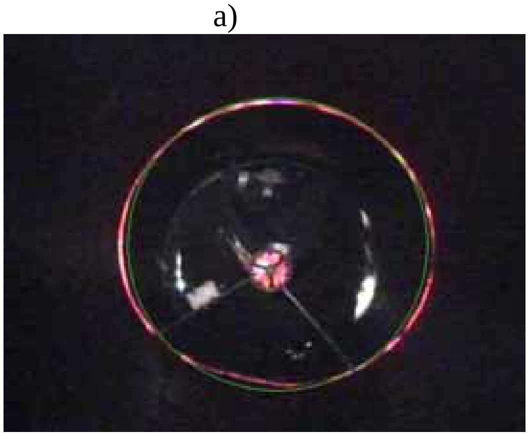
Figure 236 Horizontal and vertical deformation of the pipeline No. 6 (Site No. 3: Franklin County – Route FF)

Pipeline No. 7 (Site No. 3: Franklin County – Route FF)




a)


b)


c)

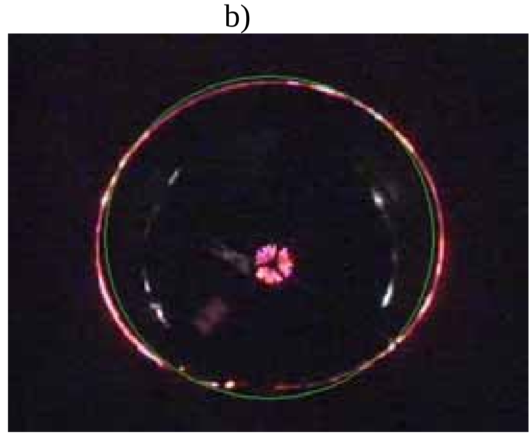
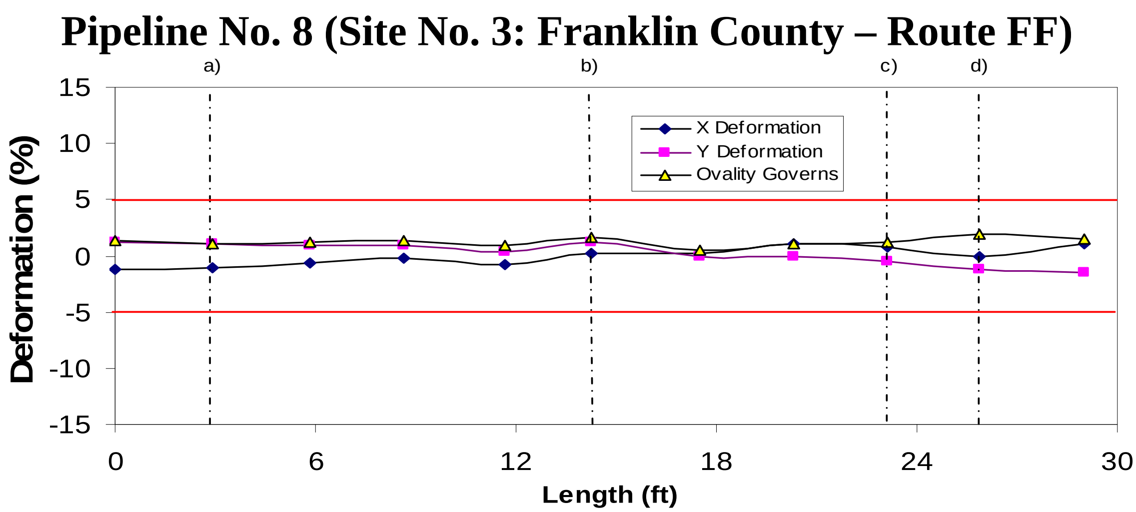
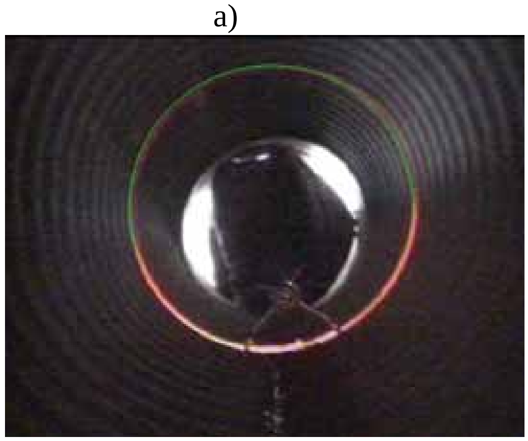

d)

Figure 237 Horizontal and vertical deformation of the pipeline No. 7 (Site No. 3: Franklin County – Route FF)



a)

b)



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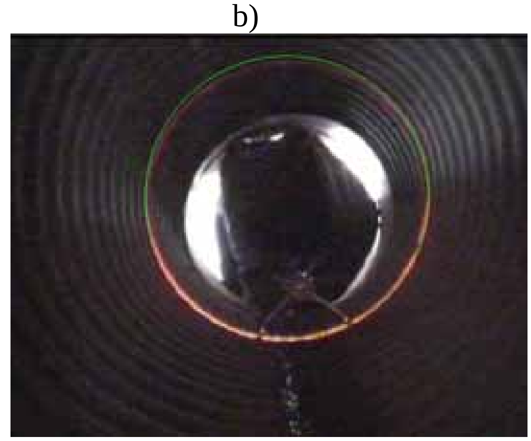
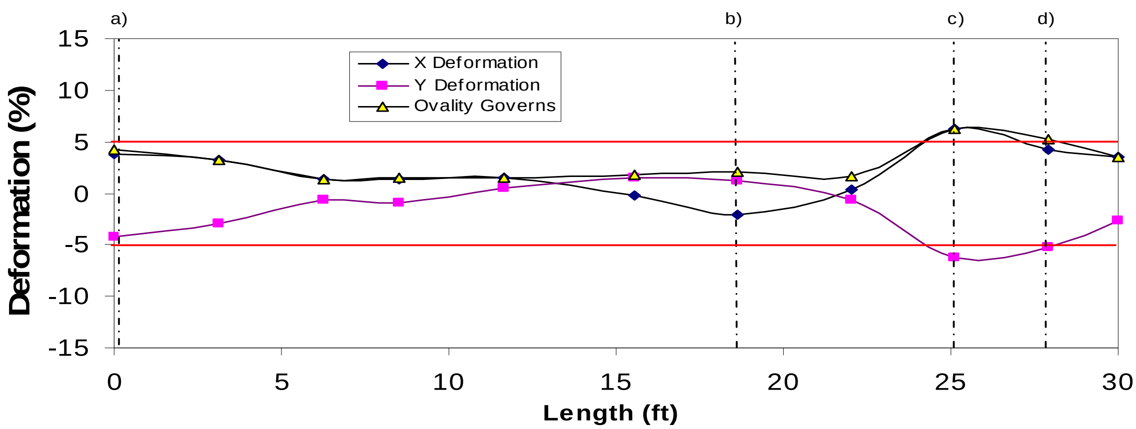


d)

Figure 238 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 3: Franklin County – Route FF)

Pipeline No. 9 (Site No. 3: Franklin County – Route FF)



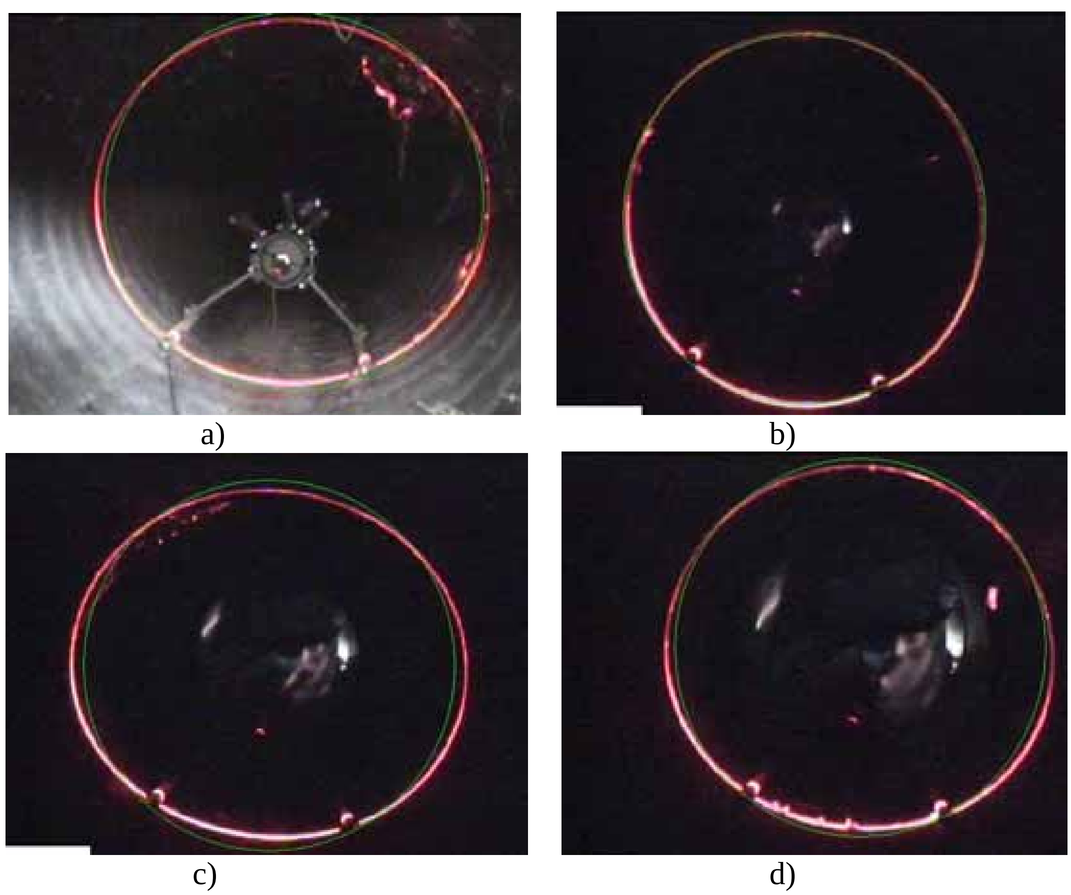


Figure 239 Horizontal and vertical deformation of the pipeline No. 9 (Site No. 3: Franklin County – Route FF)

Figure 240 Corrugation growth for pipeline No. 9 (Site No. 3: Franklin County – Route FF)

Pipeline No. 10 (Site No. 3: Franklin County – Route FF)

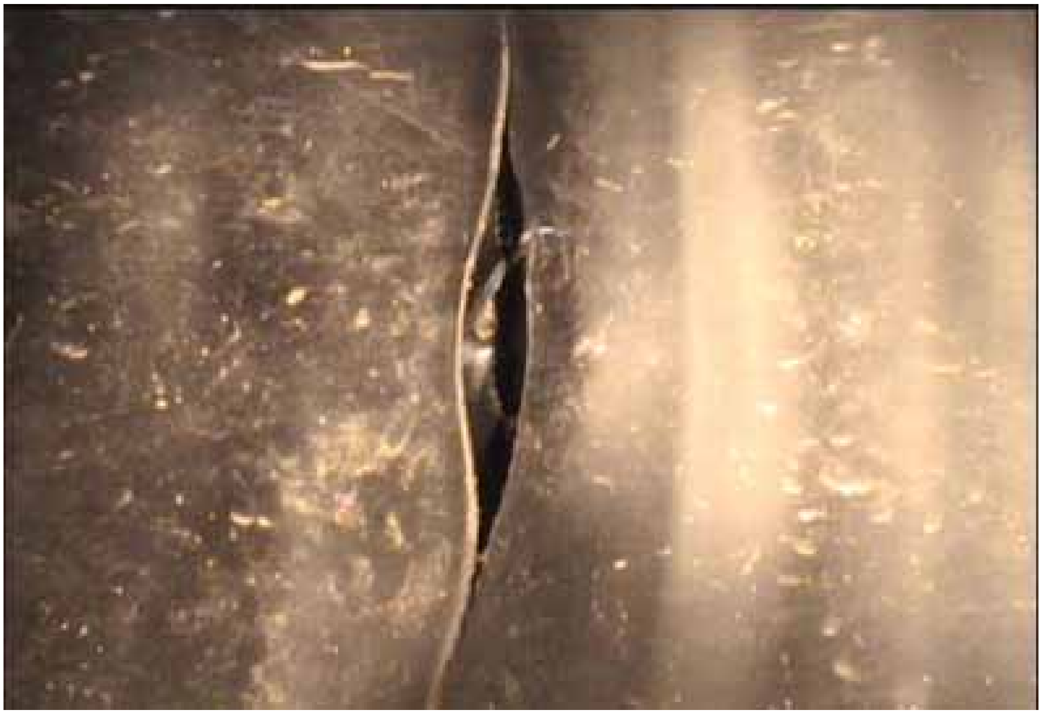
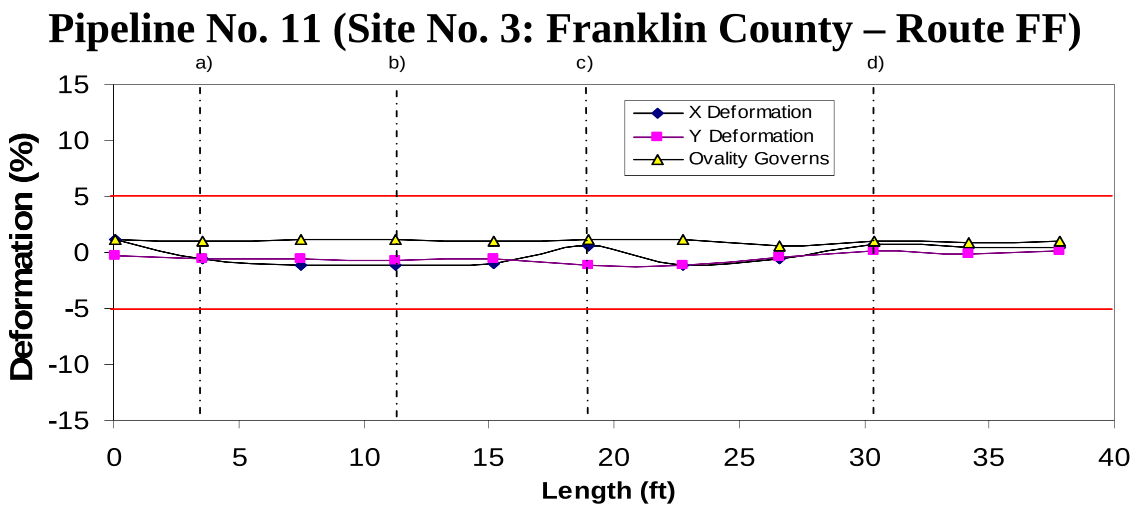
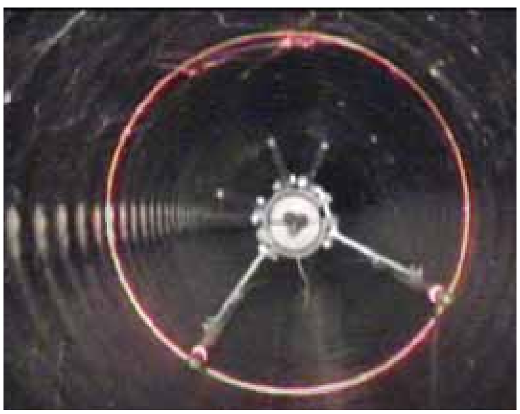
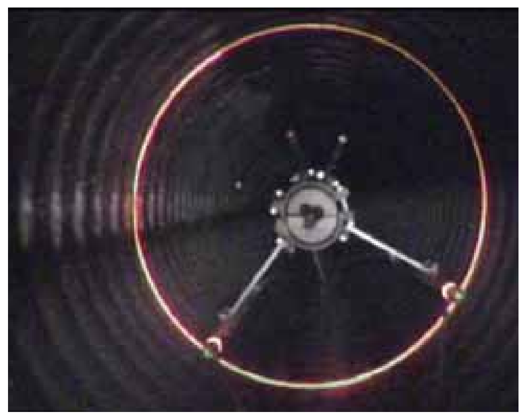


Figure 241 Cracking failure for pipeline No. 10 (Site No. 3: Franklin County – Route FF)

Figure 242 Corrugation growth for pipeline No. 10 (Site No. 3: Franklin County – Route FF)




a)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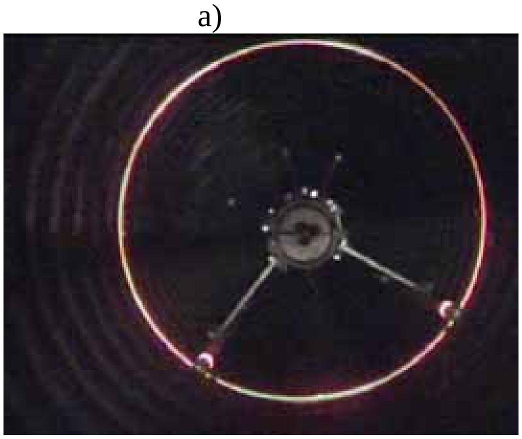

c)

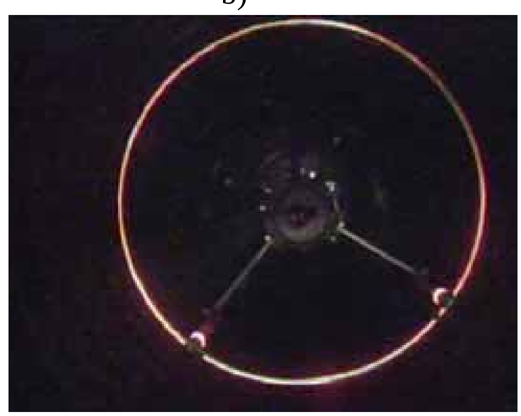
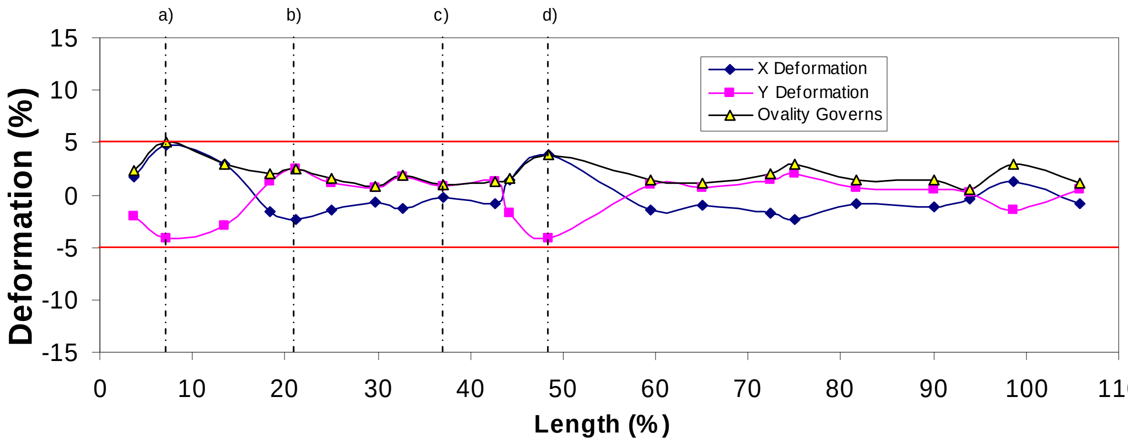

d)

Figure 243 Horizontal and vertical deformation of the pipeline No. 11 (Site No. 3: Franklin County – Route FF)

Figure 244 Cracking failure for pipeline No. 11 (Site No. 3: Franklin County – Route FF)

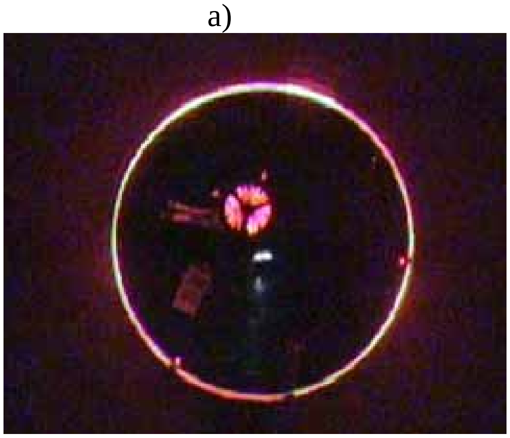
Figure 245 Corrugation growth failure for pipeline No. 11 (Site No. 3: Franklin County – Route FF)

Pipeline No. 13 (Site No: 3 Franklin County – Route FF)

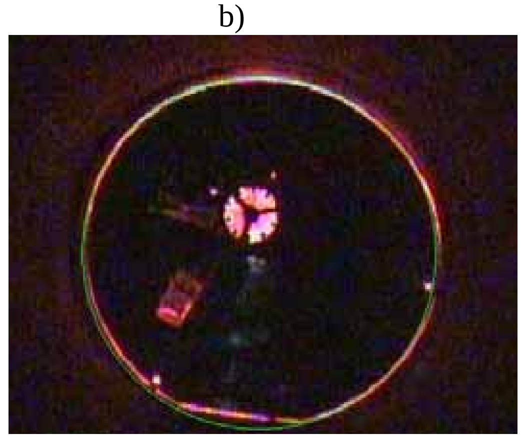


a)

b)



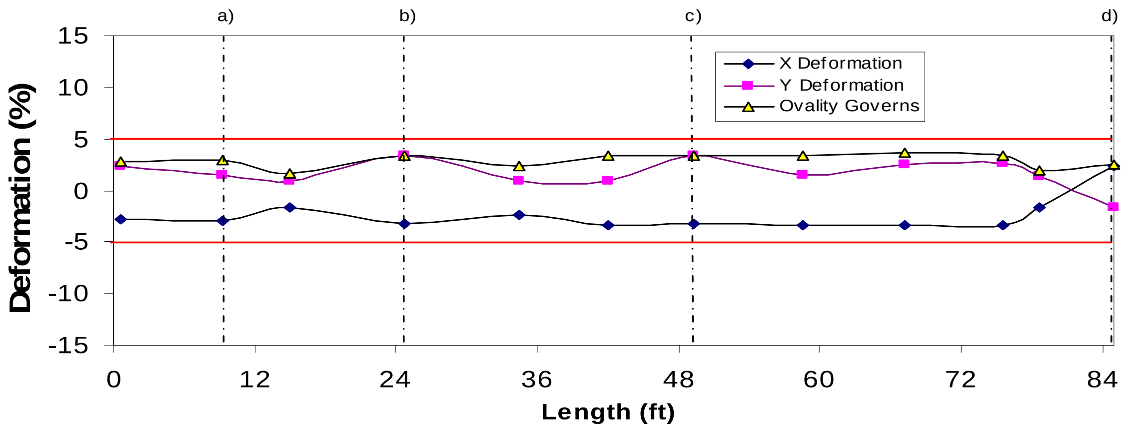
c)

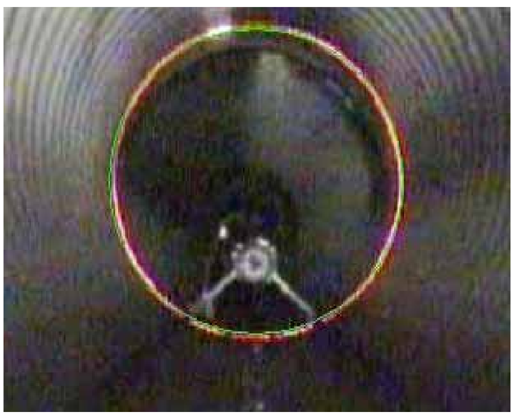


d)

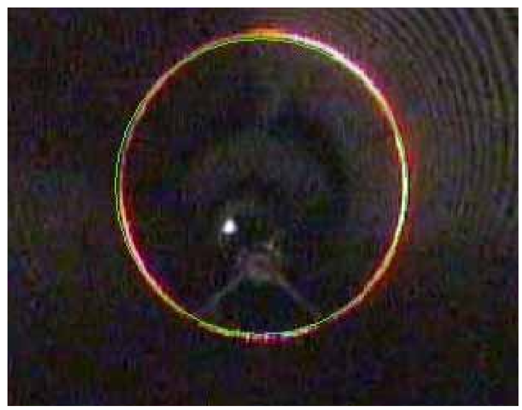
Figure 246 Horizontal and vertical deformation of the pipeline No. 13 (Site No. 1: Howell County – HW 63)

Pipeline No. 14 (Site No: 4 North of Macon – HW 63)





a)



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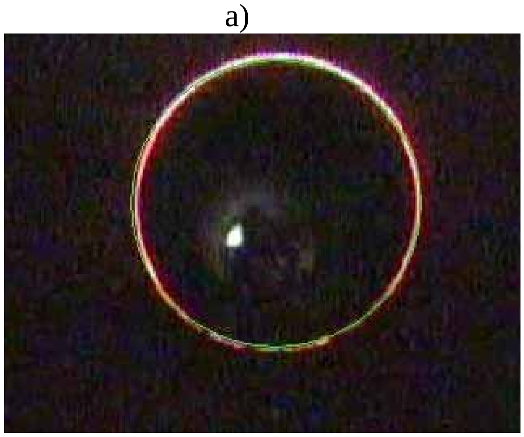
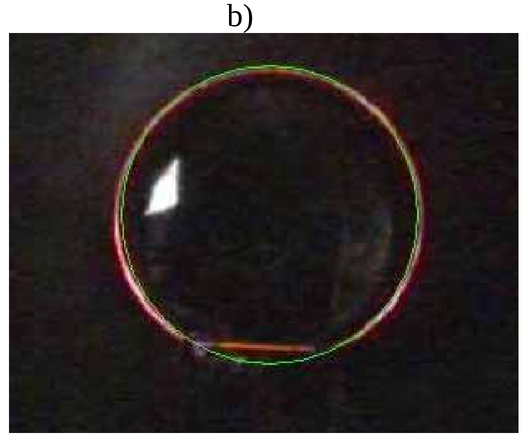


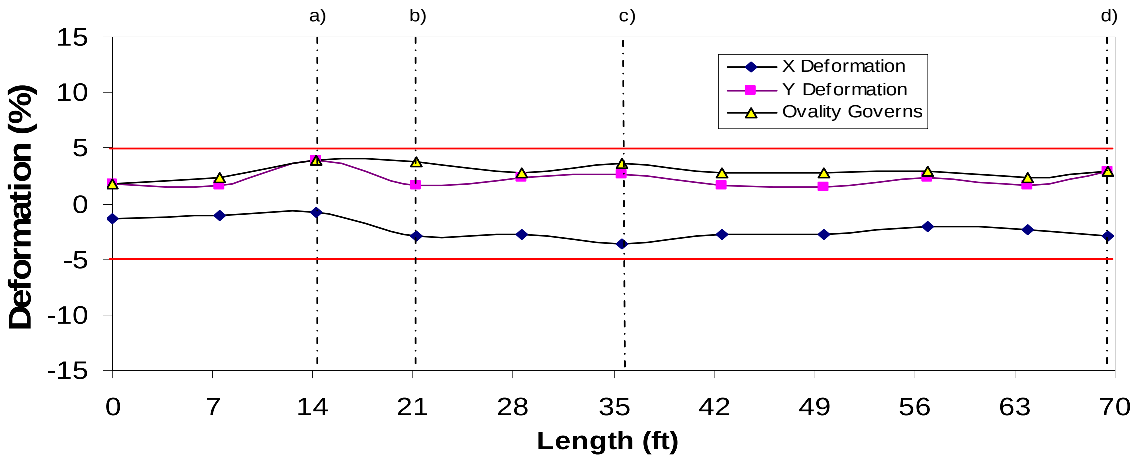
c)

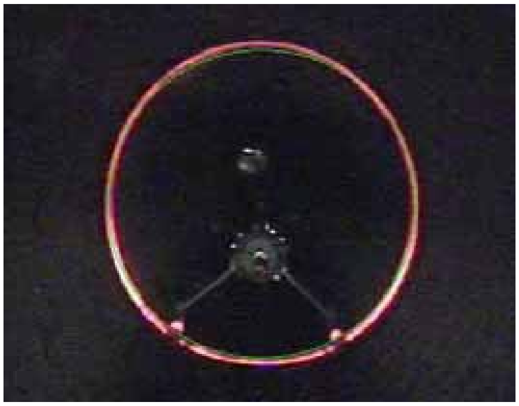


d)

Figure 247 Horizontal and vertical deformation of the pipeline No. 14 (Site No. 4: North of Macon – Hwy 63)

Pipeline No. 15 (Site No: 4 North of Macon – HW 63)

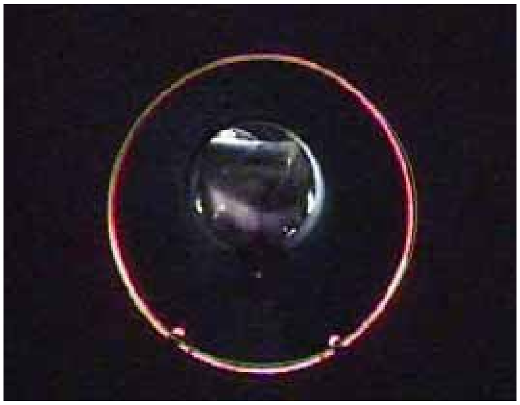




a)

b)

c)



d)

Figure 248 Horizontal and vertical deformation of the pipeline No. 15 (Site No. 4: North of Macon – HW 63)

Appendix 7 – State of California

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of California. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

Figure 249 Layout of site numbers/locations

Table 22 Specification of Project Sites

Site Number	Site Location	Pipeline Number	CalTran Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	Route 101	1*	4.82*	24	1/10/2009	130
		2	5.08	24	1/10/2009	140
		3	5.43	24	1/10/2009	135
		4	5.49	24	1/10/2009	130
		5	5.53	24	1/10/2009	130
		6*	5.56*	24	1/10/2009	90
		7	5.6	24	1/10/2009	155
		8	5.63	24	1/10/2009	130
		9	5.66	24	1/11/2009	120
		10	5.72	24	1/11/2009	115
		11	5.78	24	1/11/2009	170
		12	6.42	24	1/11/2009	140
		13	6.44	24	1/11/2009	100
		14	7.69	24	1/11/2009	130
		15	7.91	24	1/11/2009	125
2	Route 36	16	30	24	1/9/2009	40
		17	86	24	1/9/2009	40
		18*	14.96*	24	1/9/2009	45
		19	15.25	36	1/9/2009	50
		20*	19.19*	24	1/9/2009	35
		21	23.48	24	1/9/2009	55
		22	30.13	24	1/8/2008	45
		23	31.27	24	1/8/2008	70
		24	33.25	24	1/8/2008	40
		25	33.29	24	1/8/2008	40
		26	39.62	24	1/8/2008	30
		27	40.66	24	1/8/2008	35
		28	41.42	24	1/8/2008	40
		29	41.96	24	1/8/2008	40

* Laser video data was not collected.

Table 23 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	CalTran Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corregation Growth	Buckling
		1	4.82	✓	**NA**			✓	
		2	5.08	✓		✓	✓	✓	✓
		3	5.43	✓	✓			✓	
		4	5.49	✓				✓	
		5	5.53	✓				✓	
		6	5.56	✓	**NA**			✓	
		7	5.6	✓		✓		✓	
1	Route 101	8	5.63	✓	✓	✓		✓	
		9	5.66	✓	✓	✓		✓	
		10	5.72	✓	✓			✓	
		11	5.78		✓			✓	
		12	6.42	✓	✓	✓		✓	
		13	6.44					✓	
		14	7.69		✓			✓	
		15	7.91		✓			✓	
		16	30	✓				✓	
		17	86	✓				✓	
		18	14.96		**NA**			✓	
		19	15.25	✓	✓			✓	
		20	19.19	✓	**NA**	✓		✓	
		21	23.48	✓	✓			✓	
2	Route 36	22	30.13	✓	✓			✓	
		23	31.27	✓	✓		✓	✓	
		24	33.25	✓				✓	
		25	33.29		✓			✓	
		26	39.62					✓	
		27	40.66	✓				✓	
		28	41.42					✓	
		29	41.96					✓	
Percentage of pipelines experiencing failure mode				69%	52%	21%	7%	100%	3%

N.A. Laser video was not performed due to limited access

Table 24 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Route 101	1*	4.82*	NA	NA	NA	NA
		2	5.07	2.6	4	4.7	4.7
		3	5.43	5.6	2.9	4.7	5.6
		4	5.49	2.5	2.7	2.6	2.7
		5	5.53	2.7	3.8	2.9	3.8
		6*	5.56*	NA	NA	NA	NA
		7	5.6	2.5	3.3	3.4	3.4
		8	5.63	4.0	12.2	8.6	12.2
		9	5.66	6.3	8.0	7.1	8
		10	5.72	6.2	9.3	8.5	9.3
		11	5.78	5.9	6.3	6.9	6.9
		12	6.42	7.1	7.3	7.2	7.3
		13	6.44	1.8	1.9	2.3	2.3
		14	7.69	2.9	5.3	4.2	5.3
		15	7.91	11.5	14.1	13.5	14.1
2	Route 36	16	0.3	2.1	2.2	2.6	2.6
		17	0.86	3.9	2.6	4.5	4.5
		18*	14.96*	NA	NA	NA	NA
		19	15.25	7.4	7.8	8.6	8.6
		20*	19.19*	NA	NA	NA	NA
		21	24.38	4.9	5.5	5.2	5.5
		22	30.13	6.9	7.5	7.5	7.5
		23	31.27	12.3	14.6	15.3	15.3
		24	33.25	1.9	1.2	1.8	1.9
		25	33.29	5.1	5.4	5.4	5.4
		26	39.62	3.6	2.9	3.4	3.6
		27	40.66	2.6	2.1	2.6	2.6
		28	41.42	1.1	1.2	1.4	1.4
		29	41.96	1.8	1.9	2.6	2.6
Max				12.3	14.6	15.3	15.3
Min				1.1	1.2	1.4	1.4
Average				4.6	5.4	5.5	5.9

*Laser video data was not collected

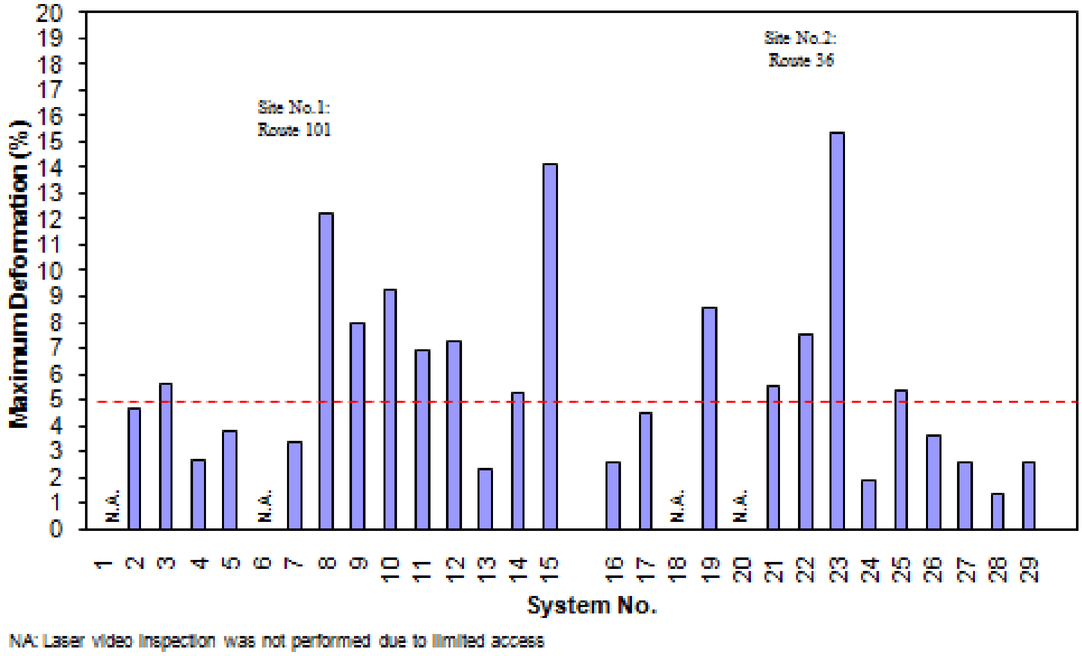


Figure 250 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Route 101)

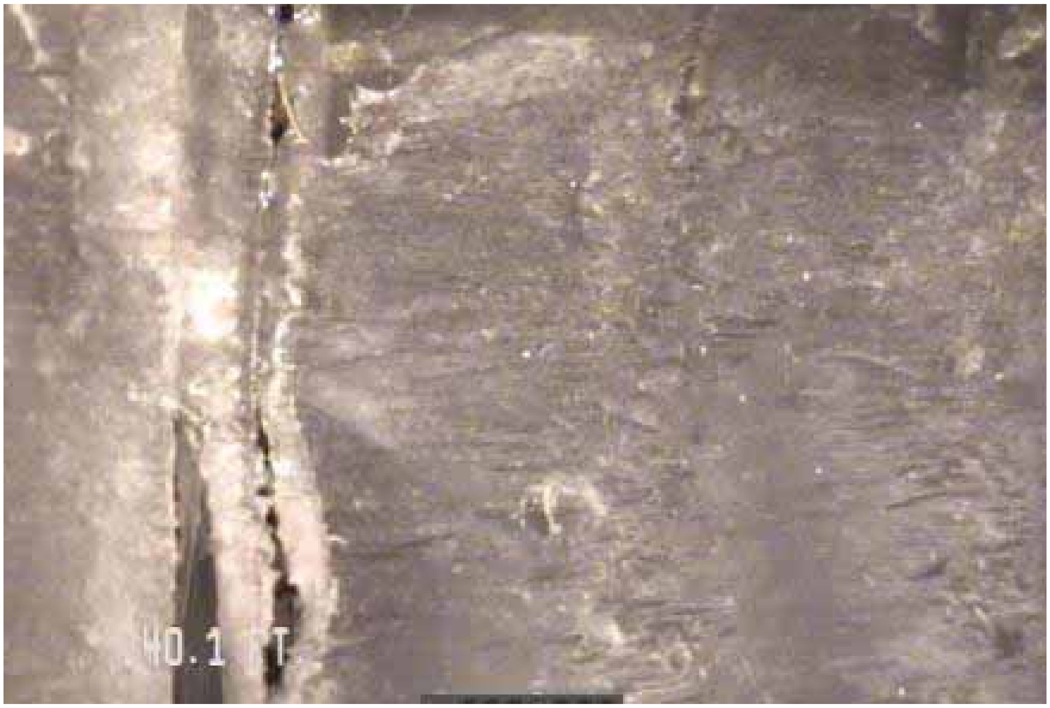


Figure 251 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

Figure 252 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

Figure 253 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

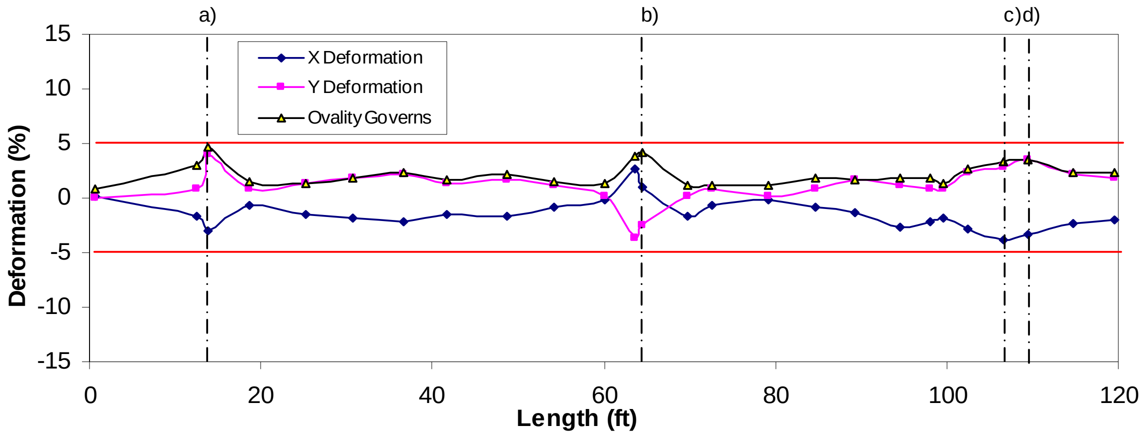
Figure 254 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

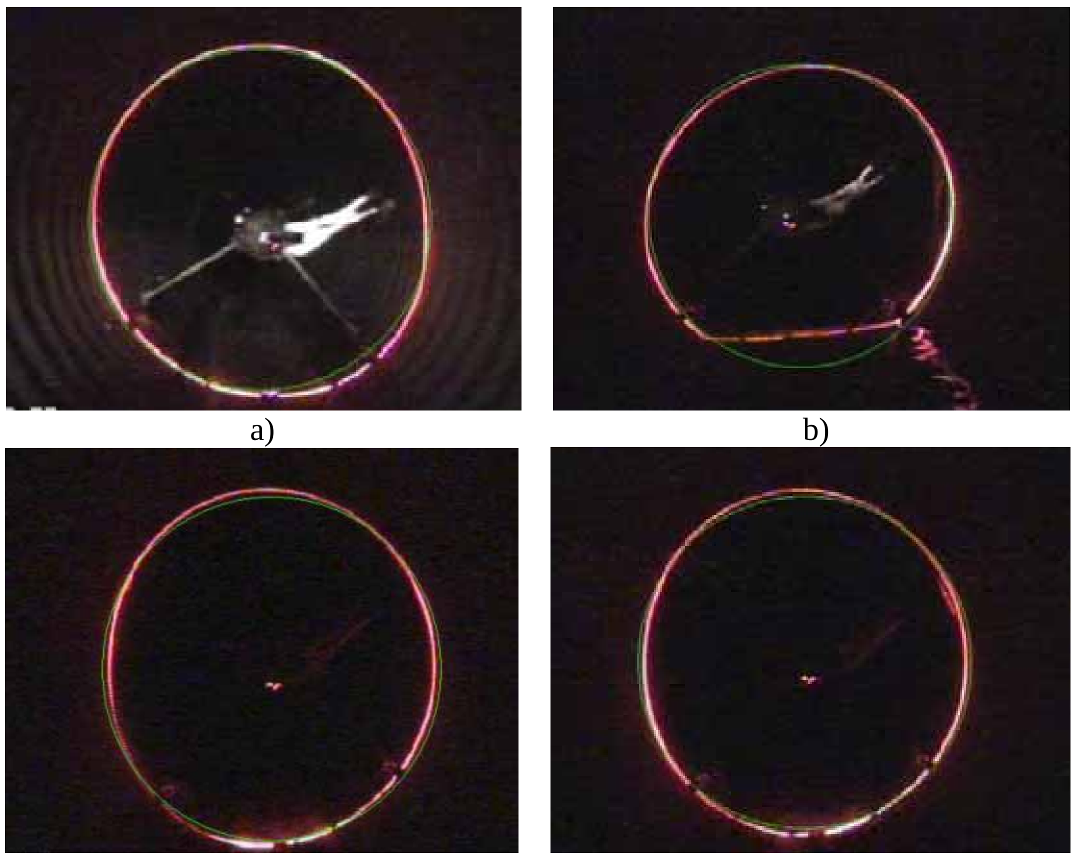
Figure 255 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

Figure 256 Cracking/fracture failure for Pipeline No. 1 (Site No. 1: Route 101)

Figure 257 Corrugation growth failure for Pipeline No. 1 (Site No. 1: Route 101)

Pipeline No. 2 (Site No. 1: Route 101)





a) b) c) d)

Figure 258 Horizontal and vertical deformation of Pipeline No. 2 (Site No. 1: Route 101)

Figure 259 Cracking/fracture failure for Pipeline No. 2 (Site No. 1: Route 101)

Figure 260 Cracking/fracture failure for Pipeline No. 2 (Site No. 1: Route 101)

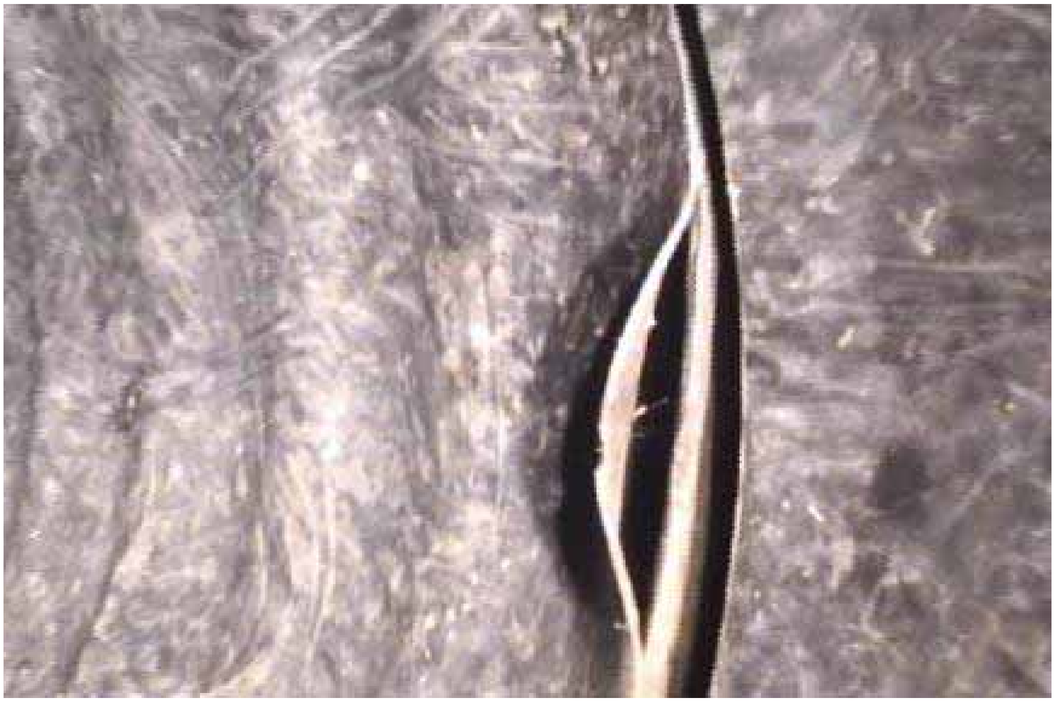


Figure 261 Cracking/fracture failure for Pipeline No. 2 (Site No. 1: Route 101)

Figure 262 Cracking/fracture, inverse curvature, and excessive deformation failures for Pipeline No. 2 (Site No. 1: Route 101)

Figure 263 Cracking/fracture failure for Pipeline No. 2 (Site No. 1: Route 101)

Figure 264 Cracking/fracture failures for Pipeline No. 2 (Site No. 1: Route 101)

Figure 265 Corrugation growth and excessive deformation failures for Pipeline No. 2 (Site No. 1: Route 101)

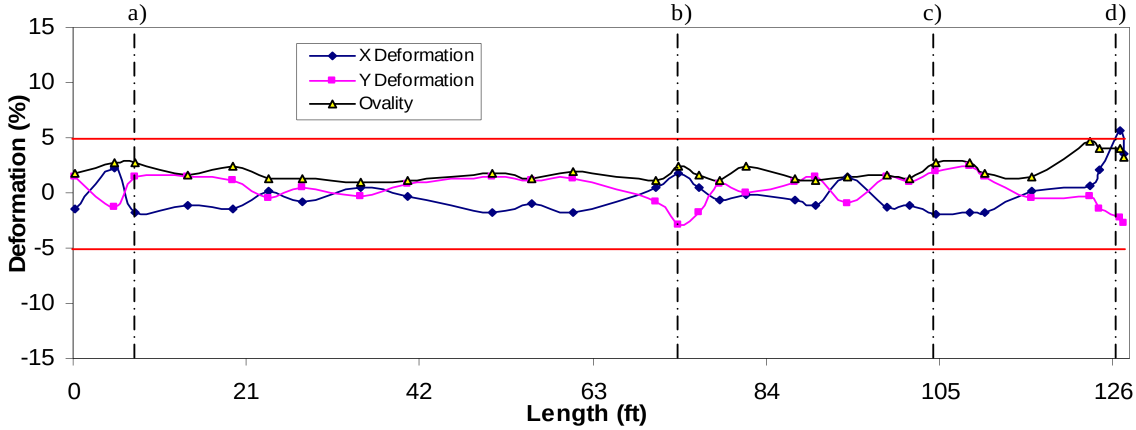
Figure 266 Corrugation growth, excessive deformation, cracking/fracture, and inverse curvature failures for Pipeline No. 2 (Site No. 1: Route 101)

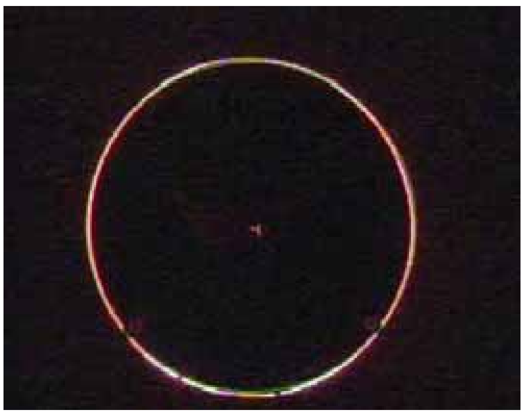
Figure 267 Corrugation growth and cracking/fracture failures for Pipeline No. 2 (Site No. 1: Route 101)

Figure 268 Corrugation growth and cracking/fracture failures for Pipeline No. 2 (Site No. 1: Route 101)

Figure 269 Inverse curvature, cracking/fracture, excessive deformation, and corrugation growth failures for Pipeline No. 2 (Site No. 1: Route 101)

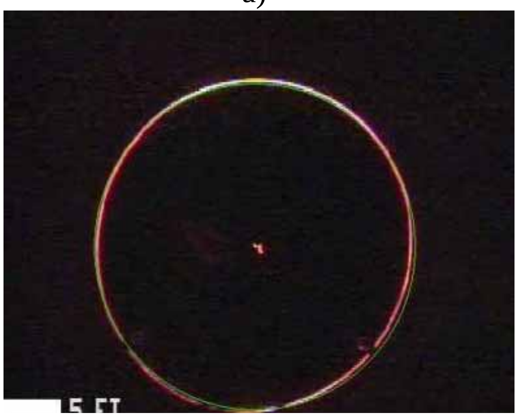
Pipeline No. 3 (Site No. 1: Route 101)



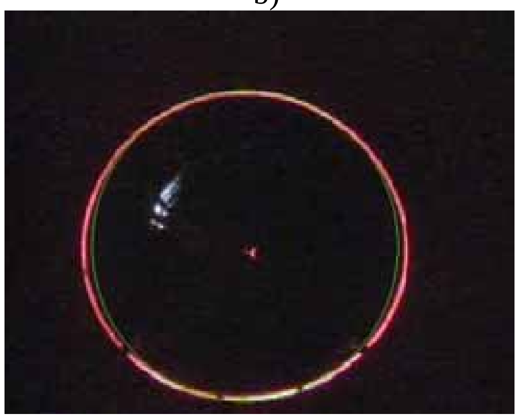


a)

b)



c)



d)

Figure 270 Horizontal and vertical deformation of Pipeline No. 3 (Site No. 1: Route 101)

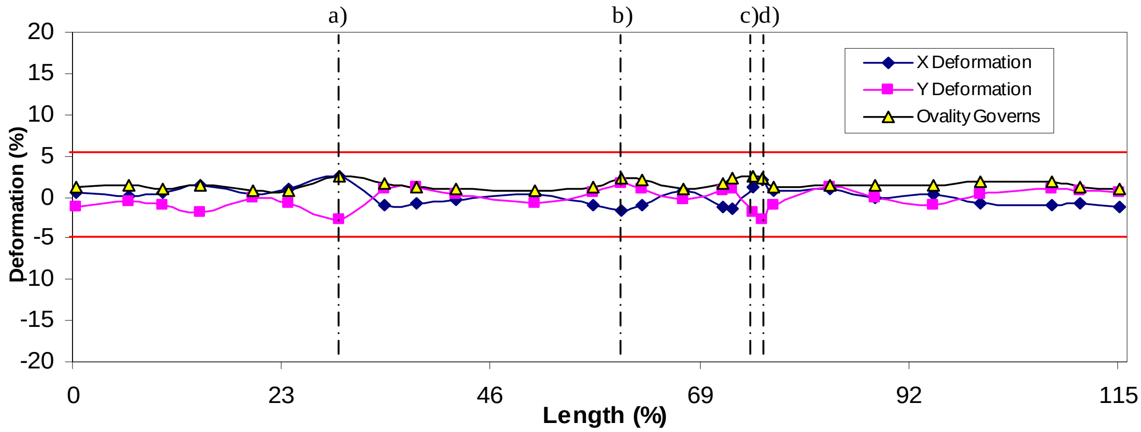
Figure 271 Cracking/fracture failure for Pipeline No. 3 (Site No. 1: Route 101)

Figure 272 Cracking/fracture failure for Pipeline No. 3 (Site No. 1: Route 101)

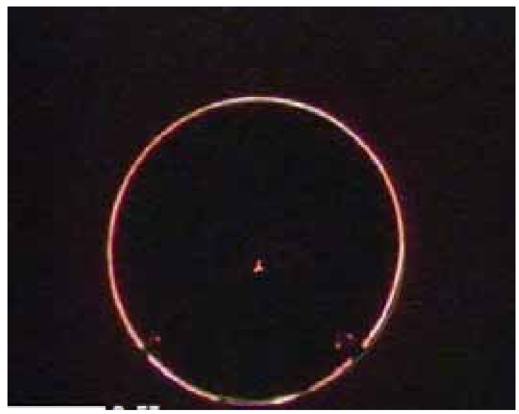
Figure 273 Cracking/fracture failure for Pipeline No. 3 (Site No. 1: Route 101)

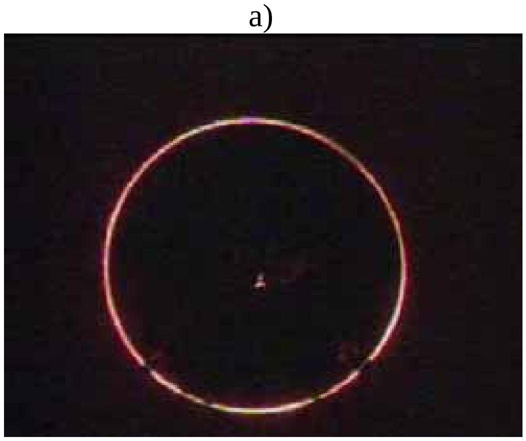
Figure 274 Cracking/fracture failure for Pipeline No. 3 (Site No. 1: Route 101)

Pipeline No. 4 (Site No. 1: Route 101)




a)


b)


c)

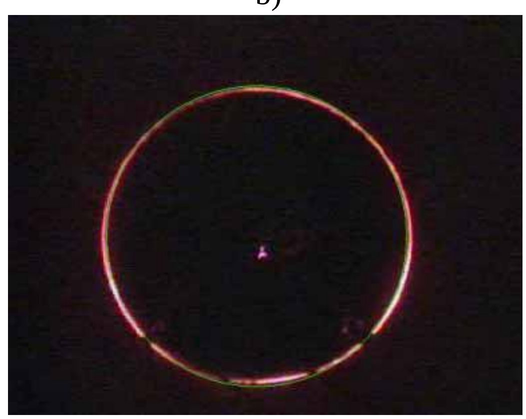

d)

Figure 275 Horizontal and vertical deformation of Pipeline No. 4 (Site No. 1: Route 101)

Figure 276 Cracking/fracture failure for Pipeline No. 4 (Site No. 1: Route 101)

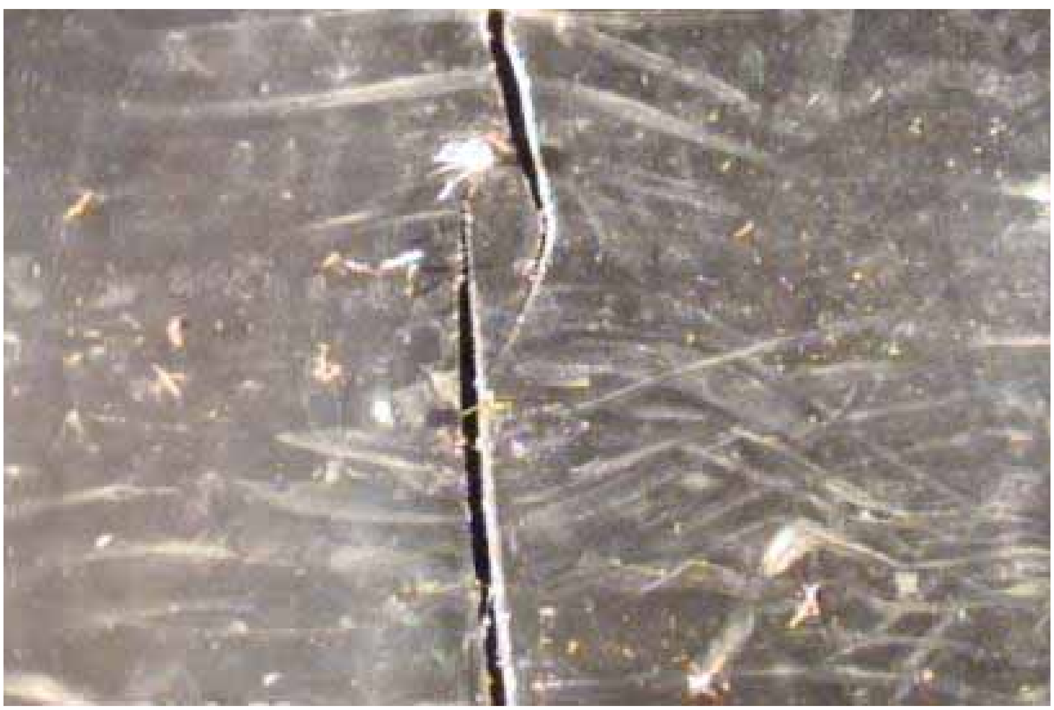
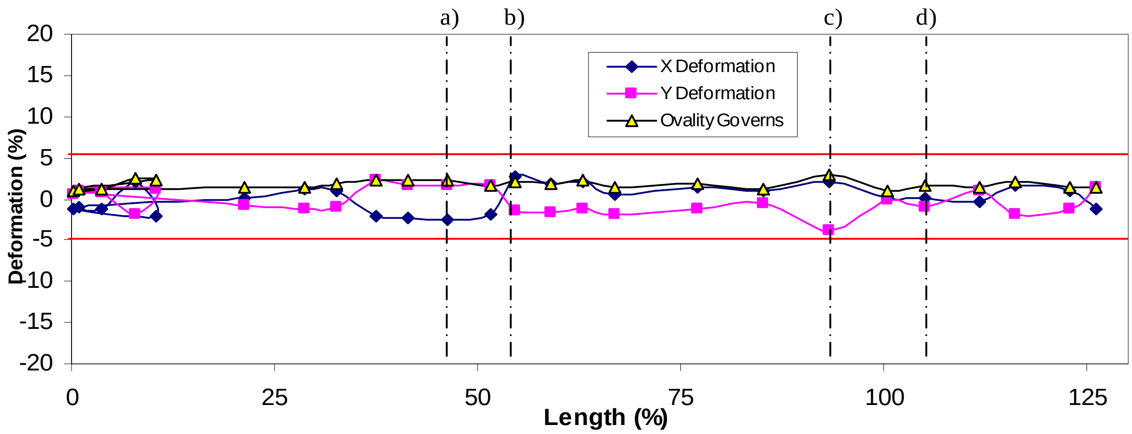
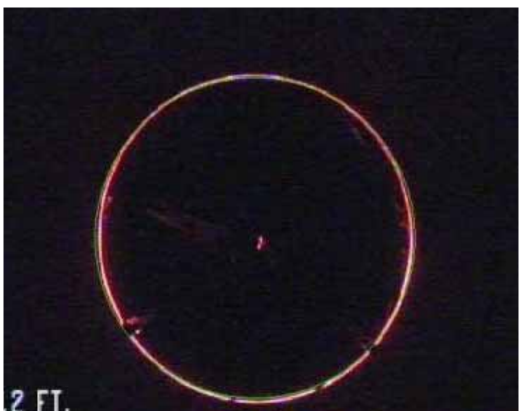


Figure 277 Cracking/fracture failure for Pipeline No. 4 (Site No. 1: Route 101)

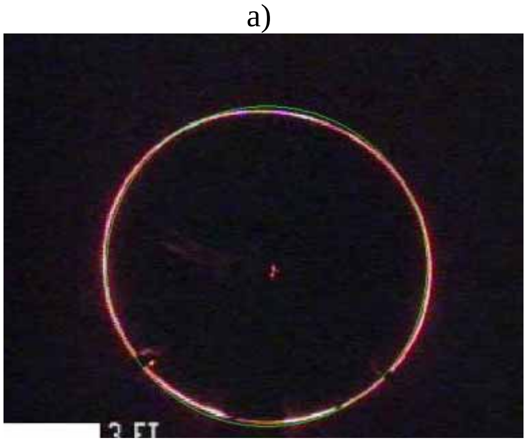
Pipeline No. 5 (Site No. 1: Route 101)



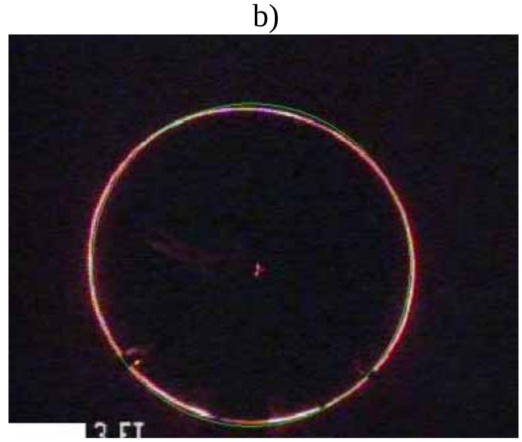


a)

b)



c)



d)

Figure 278 Horizontal and vertical deformation of Pipeline No. 5 (Site No. 1: Route 101

Figure 279 Cracking/fracture failure for Pipeline No. 5 (Site No. 1: Route 101)

Figure 280 Cracking/fracture failure for Pipeline No. 5 (Site No. 1: Route 101)

Figure 281 Cracking/fracture failure for Pipeline No. 5 (Site No. 1: Route 101)

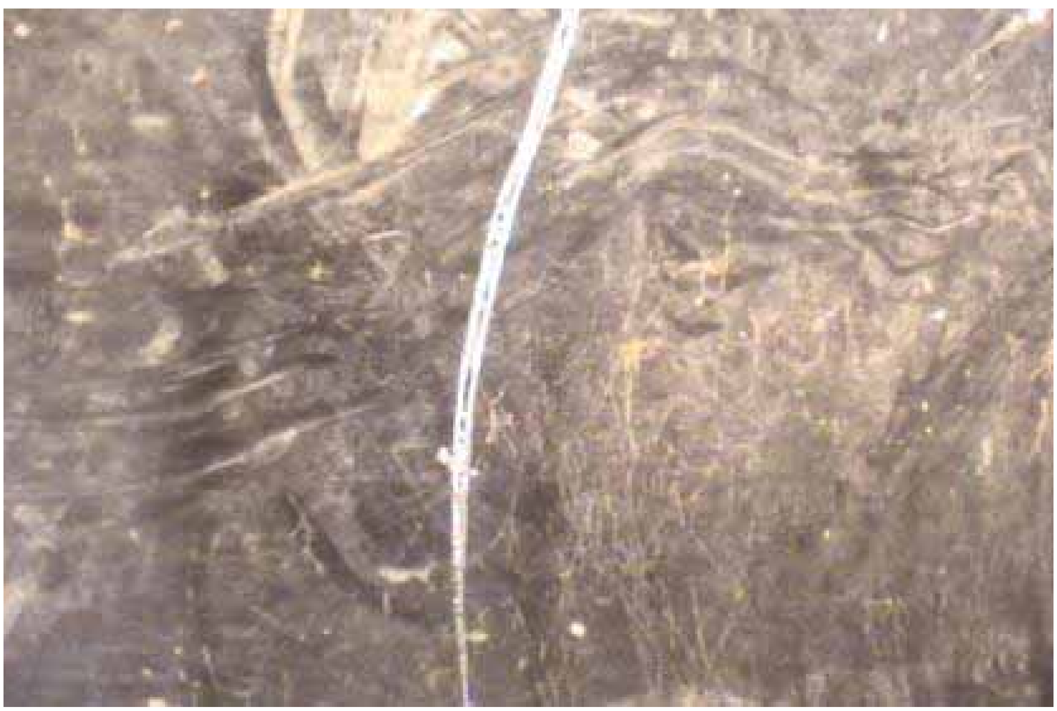


Figure 282 Cracking/fracture failure for Pipeline No. 5 (Site No. 1: Route 101)

Figure 283 Cracking/fracture and corrugation growth failure for Pipeline No. 5 (Site No. 1: Route 101)

Pipeline No. 6 (Site No. 1: Route 101)

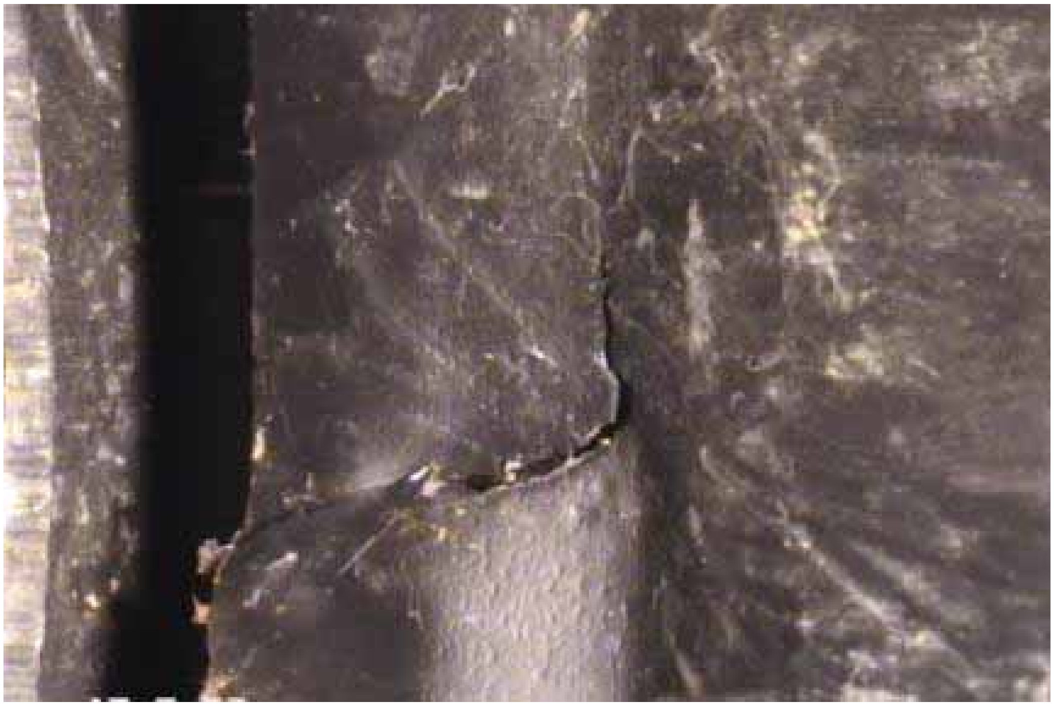


Figure 284 Cracking/fracture failure for Pipeline No. 6 (Site No. 1: Route 101)

Figure 285 Cracking/fracture failure for Pipeline No. 6 (Site No. 1: Route 101)

Figure 286 Cracking/fracture failure for Pipeline No. 6 (Site No. 1: Route 101)

Figure 287 Debris blockage for Pipeline No. 6 (Site No. 1: Route 101)

Pipeline No. 7 (Site No. 1: Route 101)

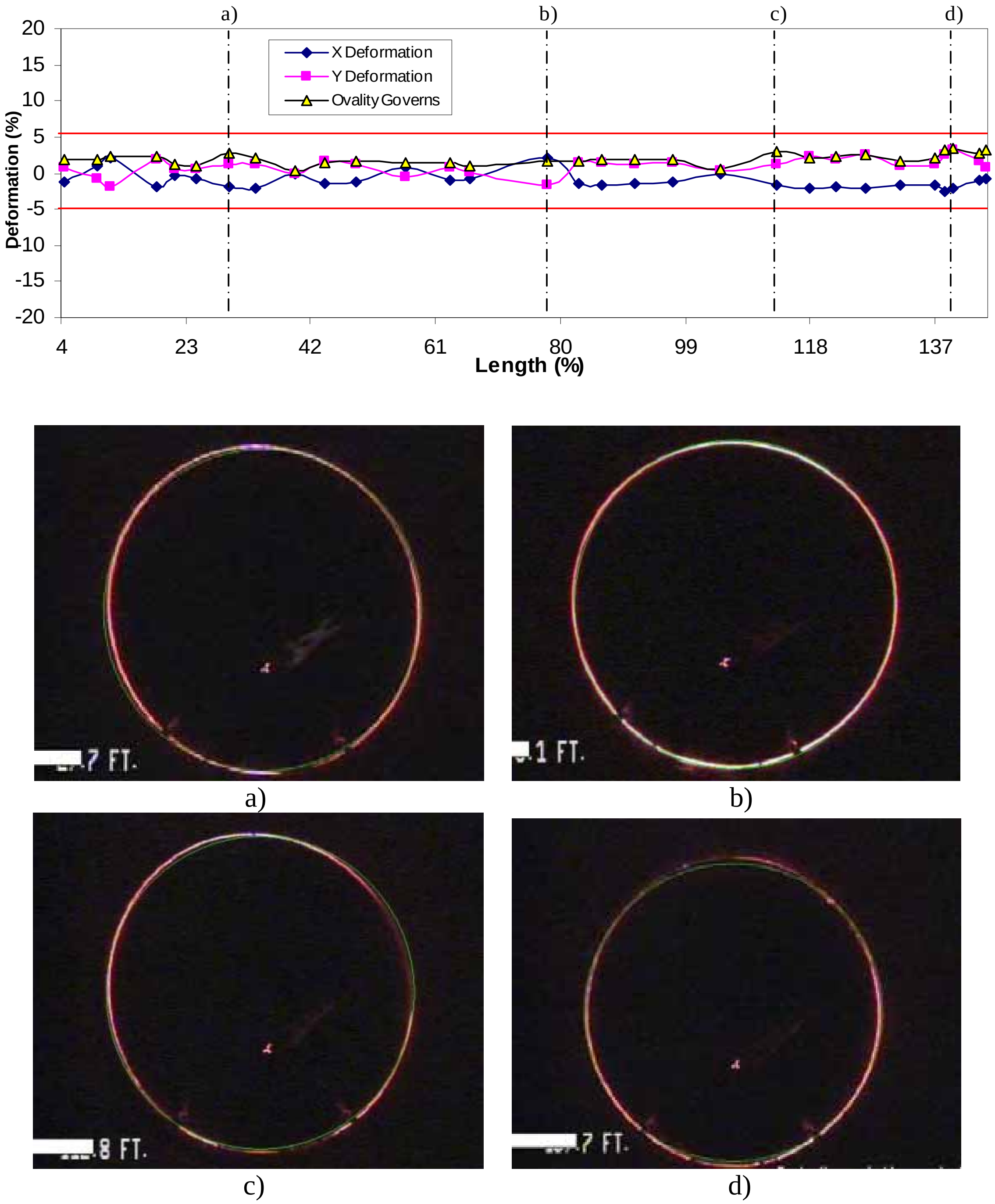


Figure 288 Horizontal and vertical deformation of Pipeline No. 7 (Site No. 1: Route 101)

Figure 289 Cracking/fracture and corrugation growth failures for Pipeline No. 7 (Site No. 1: Route 101)

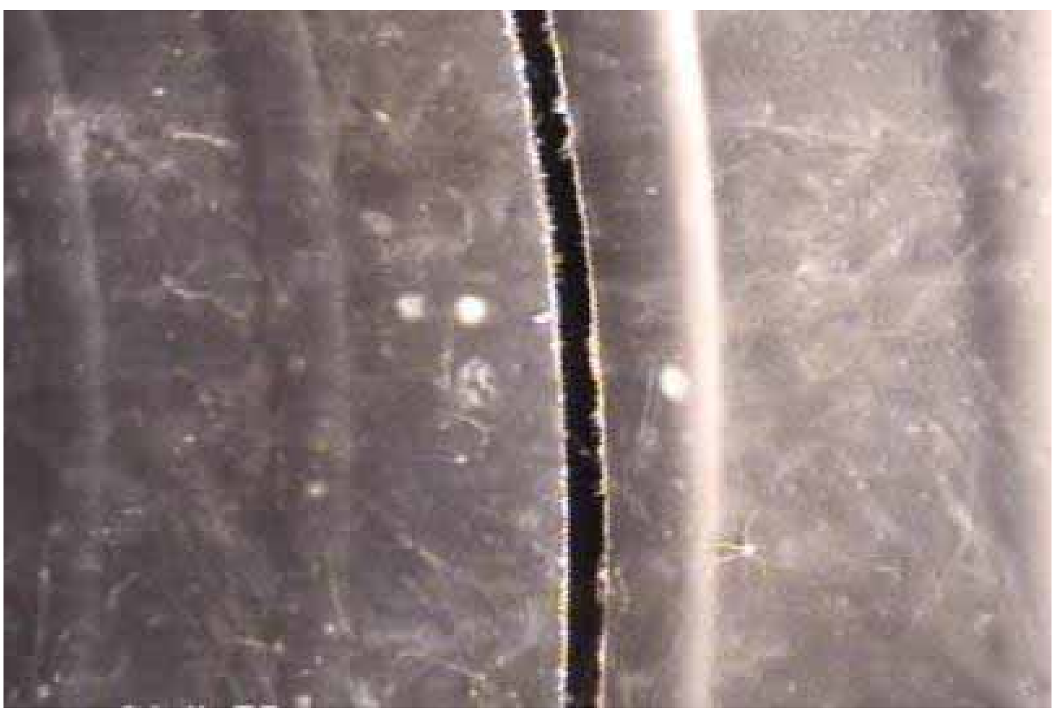


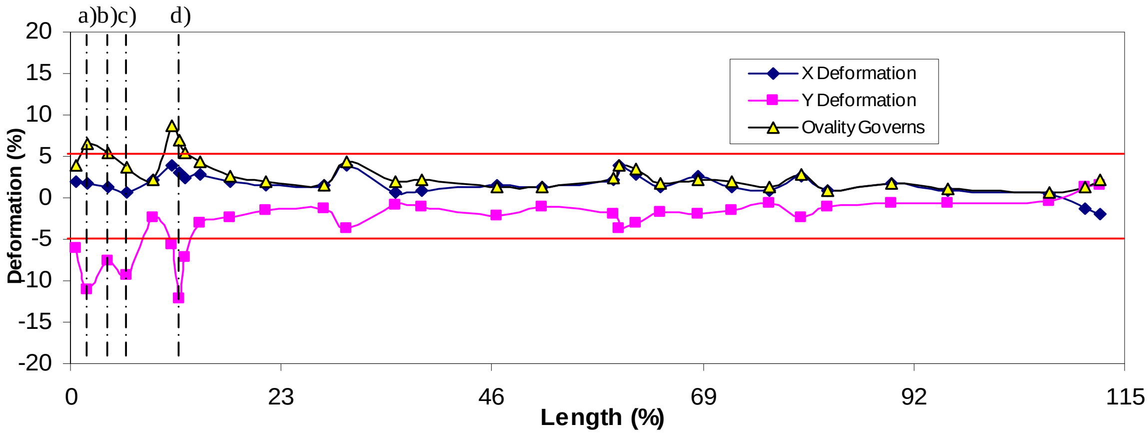
Figure 290 Cracking/fracture failure for Pipeline No. 7 (Site No. 1: Route 101)

Figure 291 Cracking/fracture failure for Pipeline No. 7 (Site No. 1: Route 101)

Figure 292 Cracking/fracture failure for Pipeline No. 7 (Site No. 1: Route 101)

Figure 293 Cracking/fracture for Pipeline No. 7 (Site No. 1: Route 101)

Pipeline No. 8 (Site No. 1: Route 101)



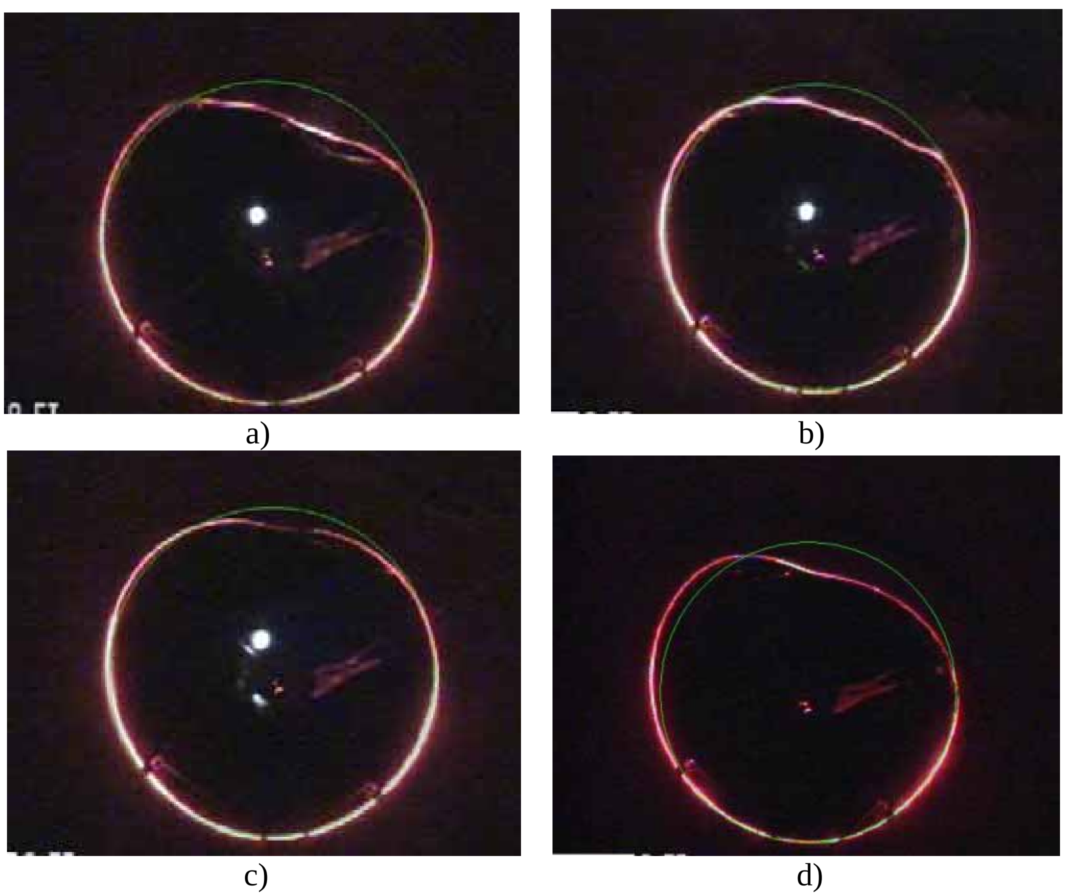


Figure 294 Horizontal and vertical deformation of Pipeline No. 8 (Site No. 1: Route 101)

Figure 295 Corrugation growth failure for Pipeline No. 8 (Site No. 1: Route 101)

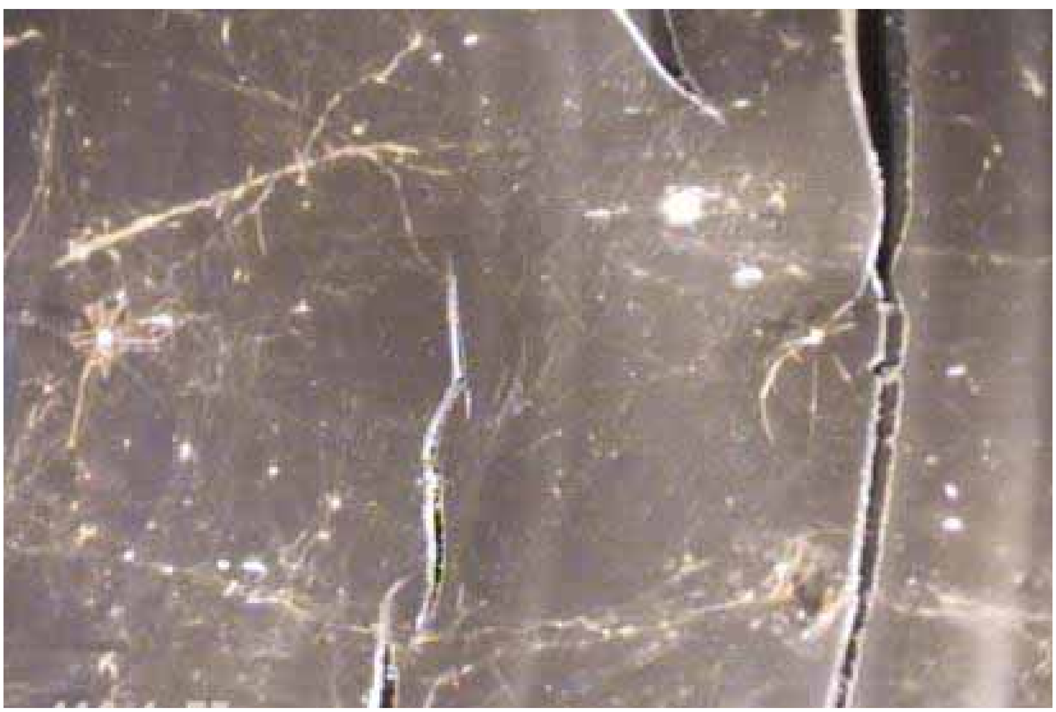


Figure 296 Cracking/fracture failure for Pipeline No. 8 (Site No. 1: Route 101)

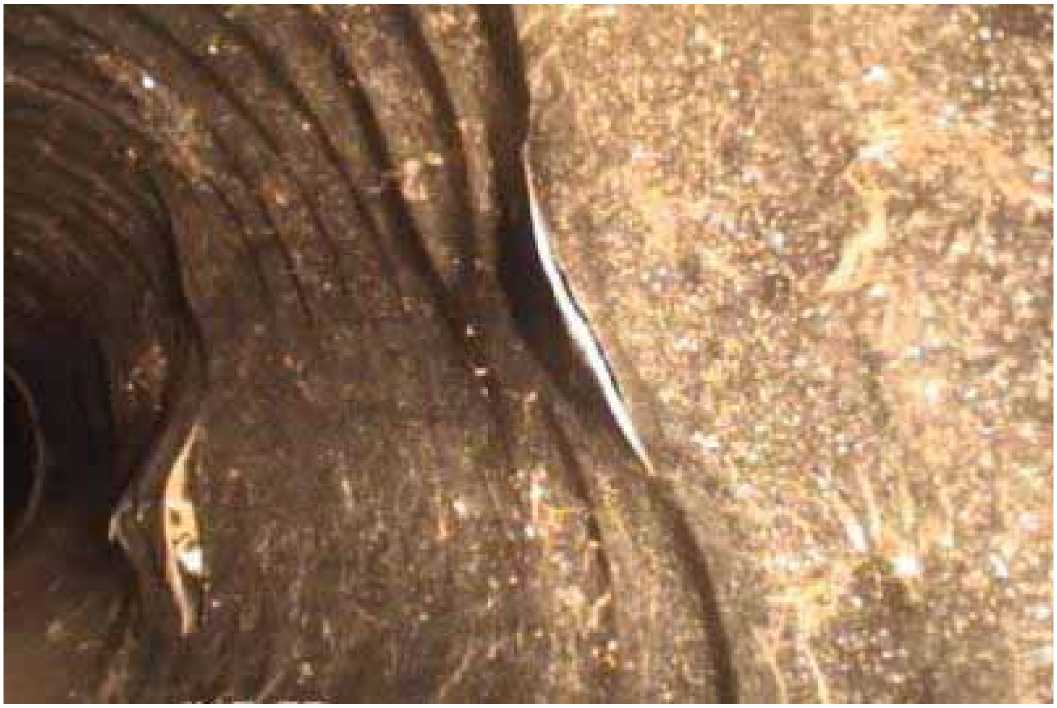


Figure 297 Cracking/fracture and corrugation growth failure for Pipeline No. 8 (Site No. 1: Route 101)

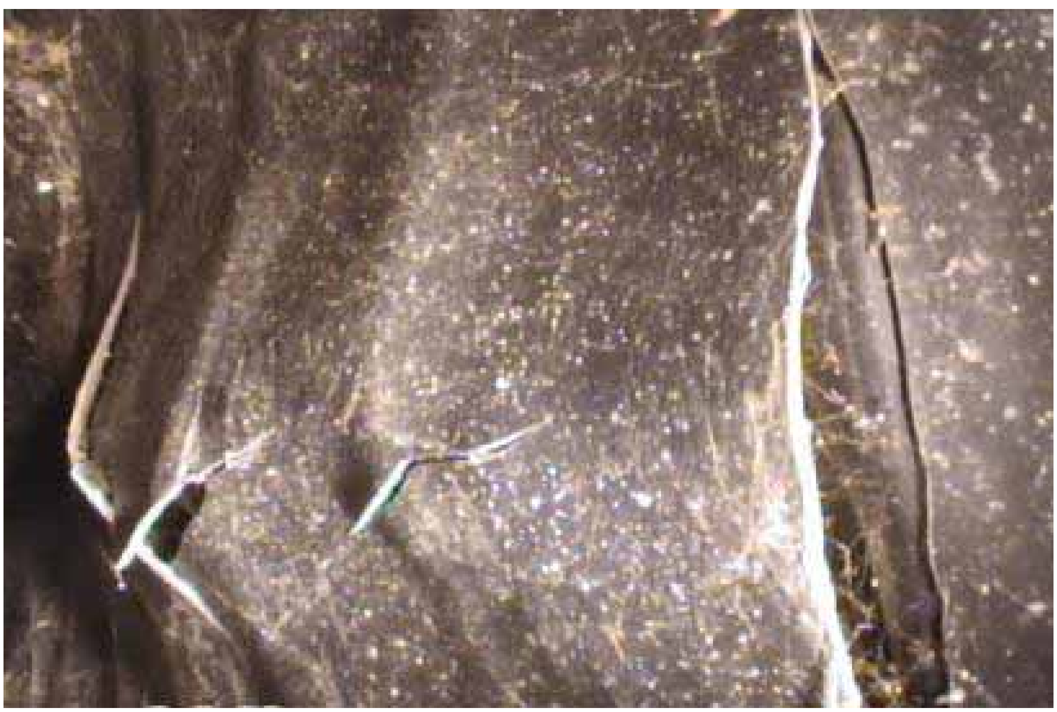


Figure 298 Cracking/fracture and inverse curvature failure for Pipeline No. 8 (Site No. 1: Route 101)

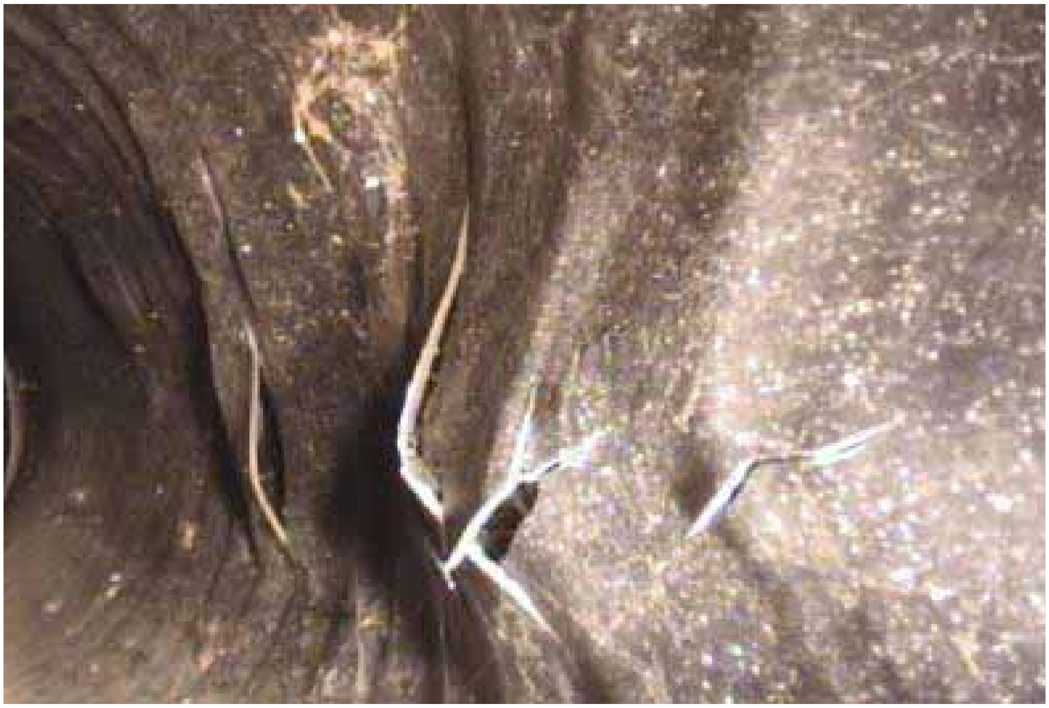


Figure 299 Cracking/fracture, inverse curvature, and corrugation growth failure for Pipeline No. 8 (Site No. 1: Route 101)

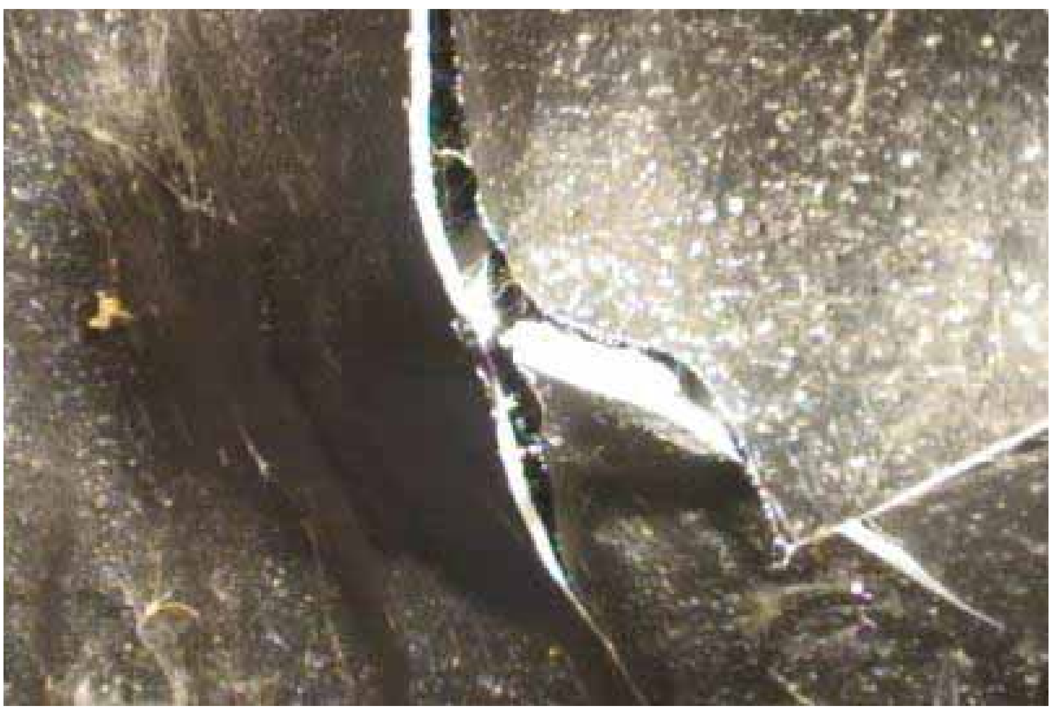
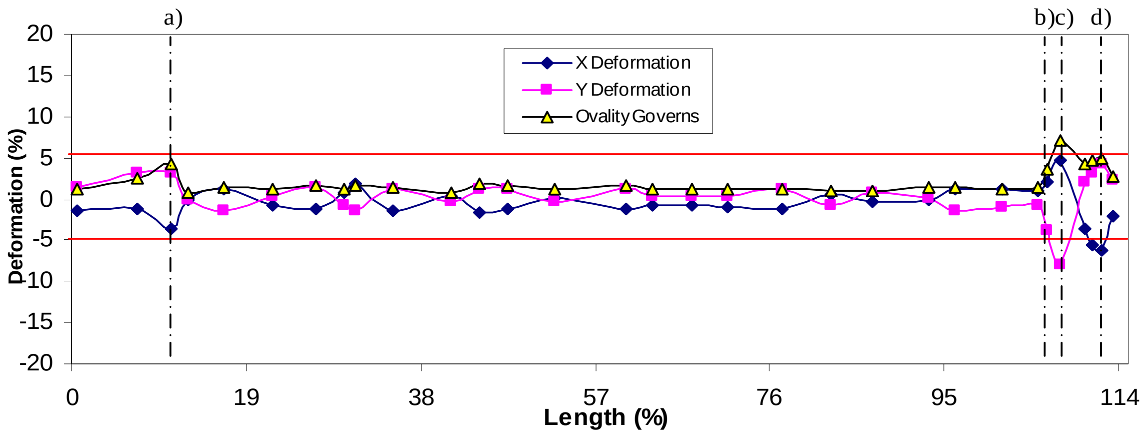
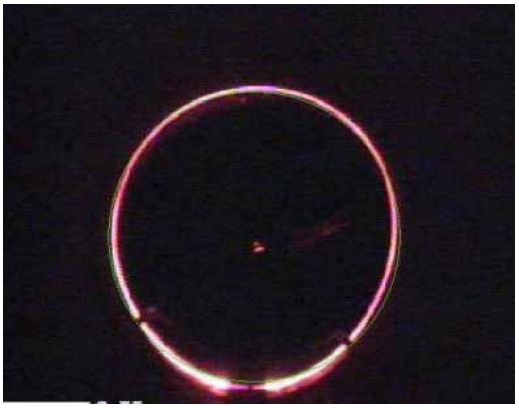


Figure 300 Cracking/fracture and inverse curvature failure for Pipeline No. 8 (Site No. 1: Route 101)

Pipeline No. 9 (Site No. 1: Route 101)

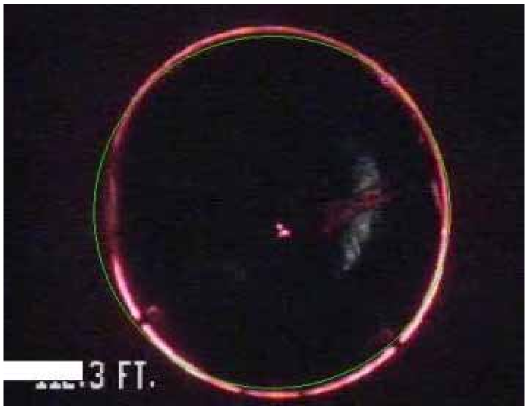




a)

b)

c)



d)

Figure 301 Horizontal and vertical deformation of Pipeline No. 9 (Site No. 1: Route 101)

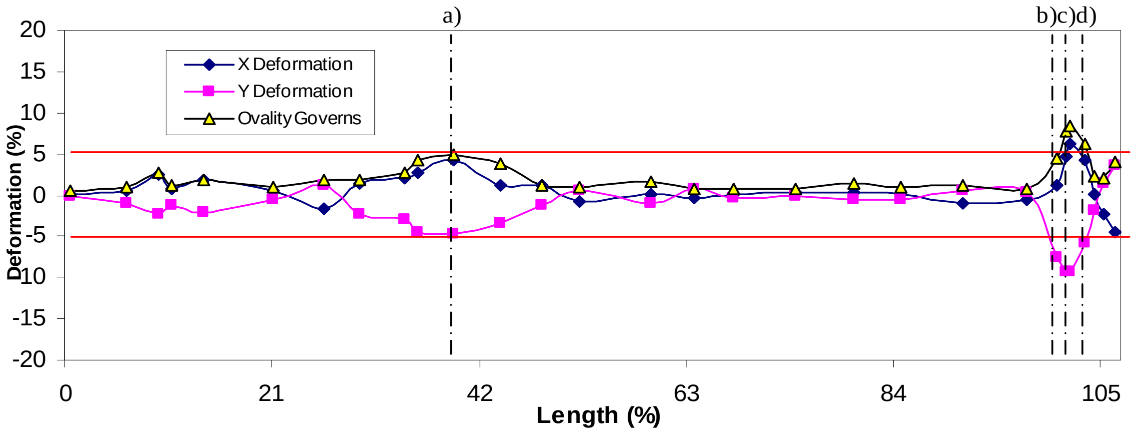
Figure 302 Cracking/fracture failure for Pipeline No. 9 (Site No. 1: Route 101)

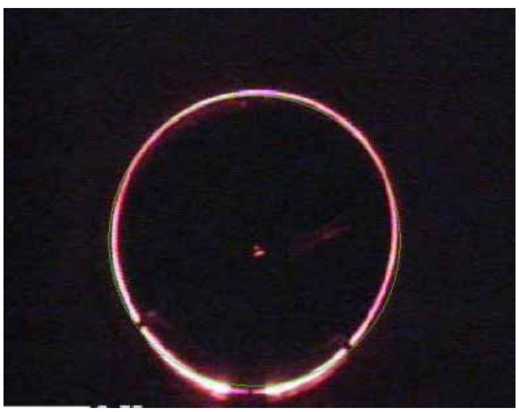
Figure 303 Cracking/fracture failure for Pipeline No. 9 (Site No. 1: Route 101)

Figure 304 Cracking/fracture, inverse curvature, and corrugation growth failure for Pipeline No. 9 (Site No. 1: Route 101)

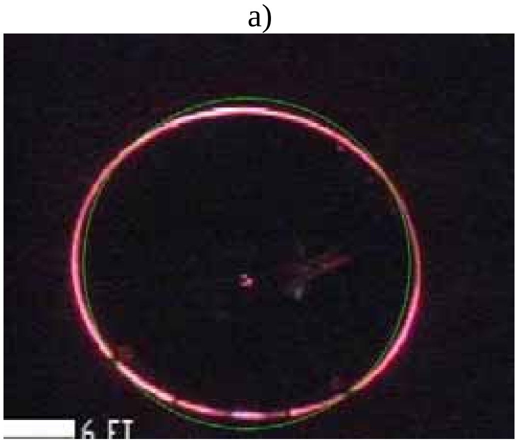
Figure 305 Cracking/fracture and inverse curvature failure for Pipeline No. 9 (Site No. 1: Route 101)

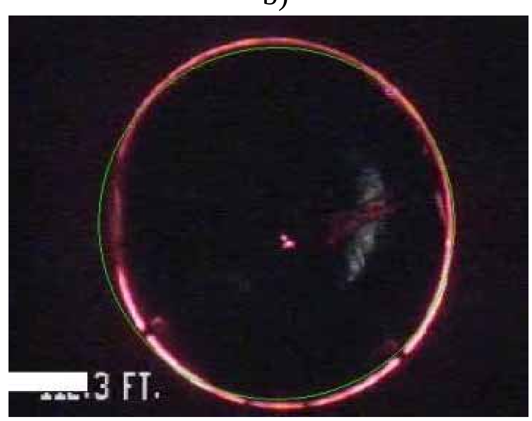
Pipeline No. 10 (Site No. 1: Route 101)




a)


b)


c)



d)

Figure 306 Horizontal and vertical deformation of Pipeline No. 10 (Site No. 1: Route 101)

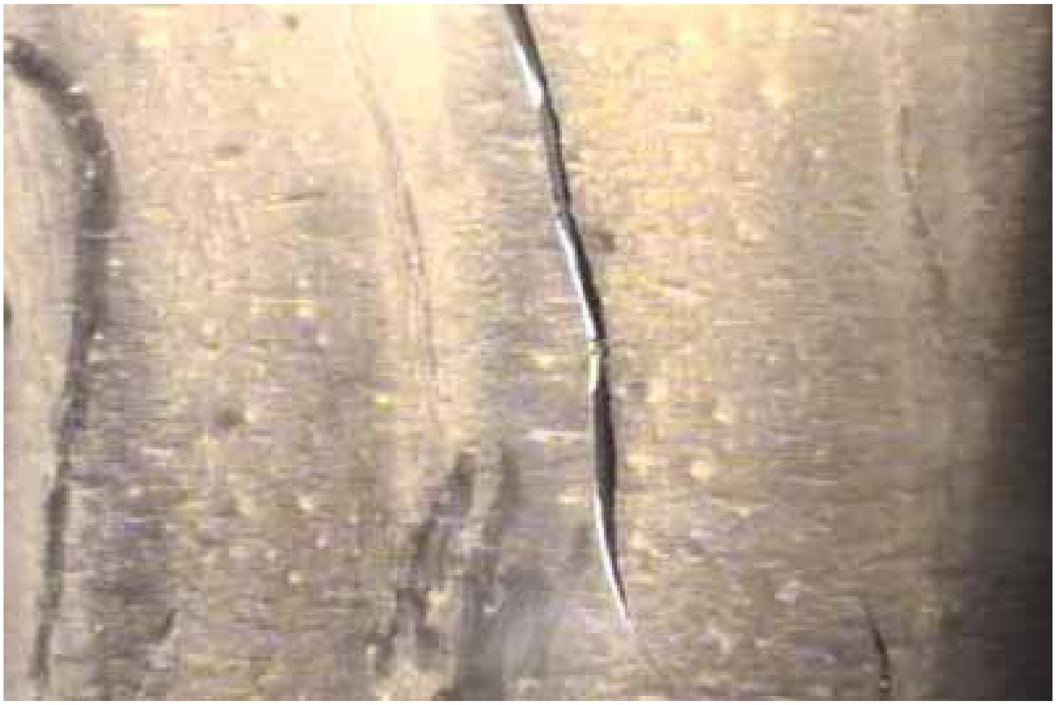


Figure 307 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

Figure 308 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

Figure 309 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

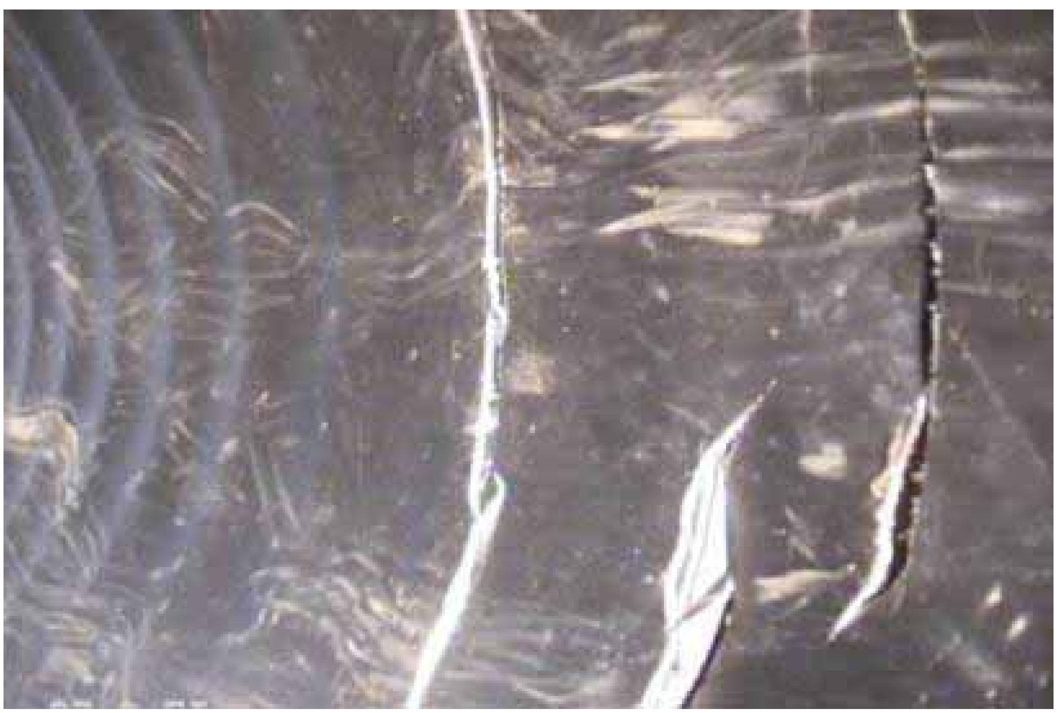


Figure 310 Cracking/fracture and corrugation growth failure for Pipeline No. 10 (Site No. 1: Route 101)

Figure 311 Cracking/fracture and corrugation growth failure for Pipeline No. 10 (Site No. 1: Route 101)

Figure 312 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

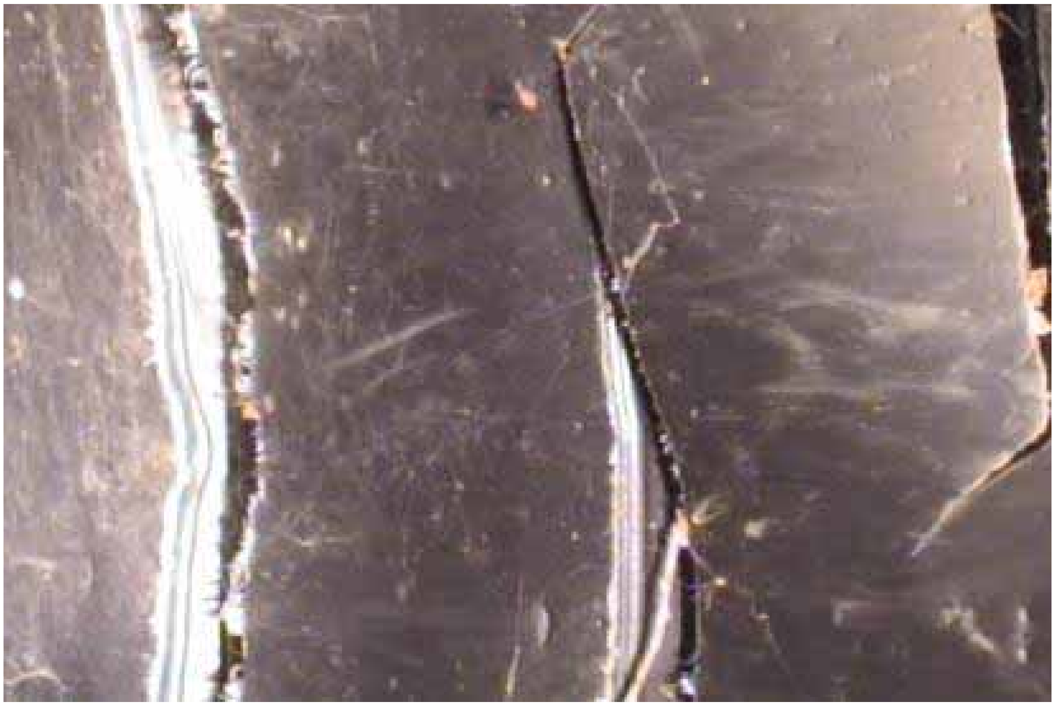
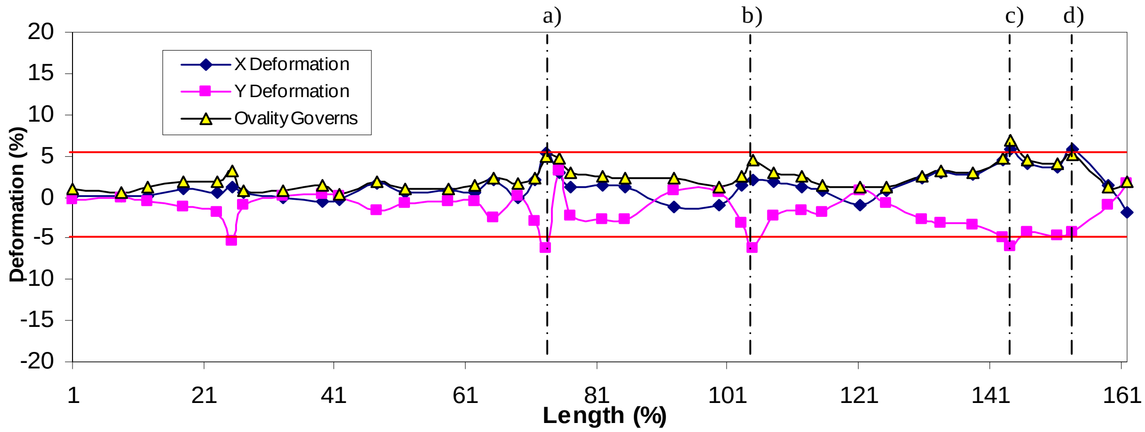


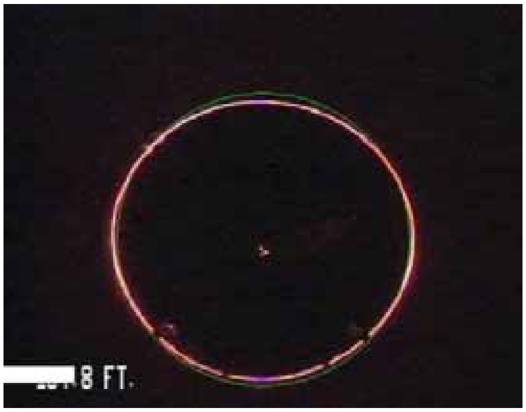
Figure 313 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

Figure 314 Cracking/fracture failure for Pipeline No. 10 (Site No. 1: Route 101)

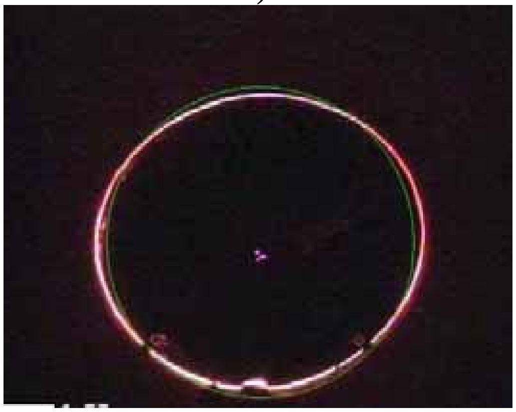
Pipeline No. 11 (Site No. 1: Route 101)



a)



b)

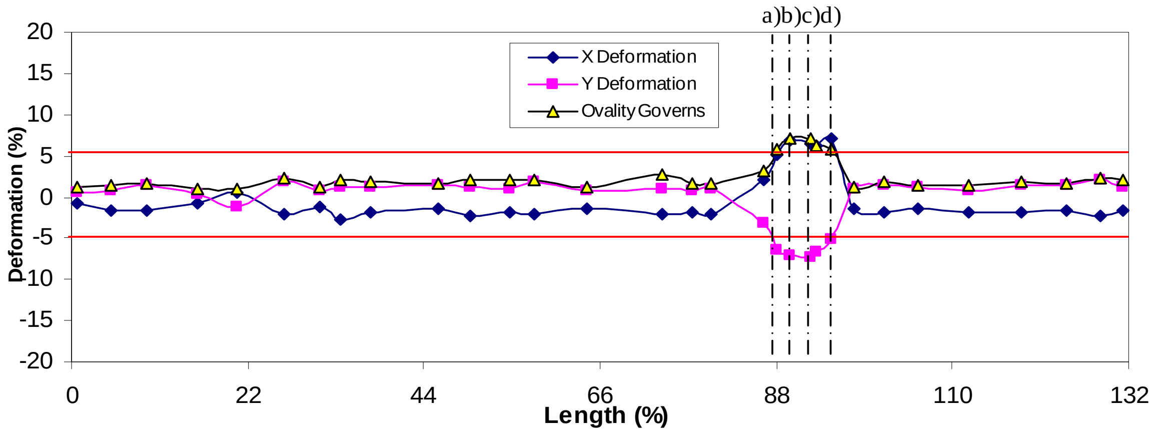


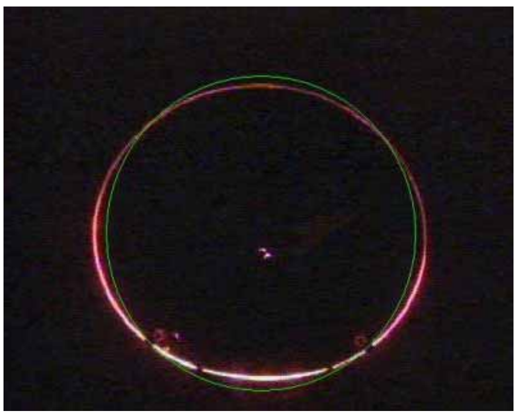
c)

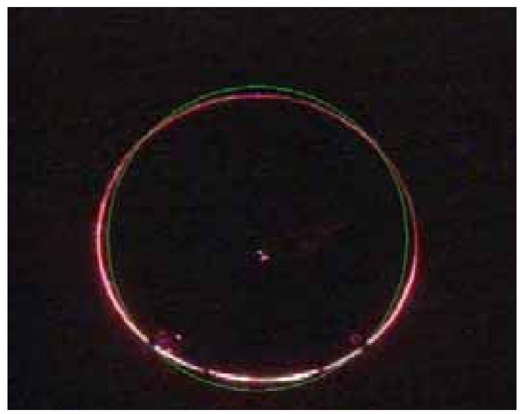
d)

Figure 315 Horizontal and vertical deformation of Pipeline No. 11 (Site No. 1: Route 101)

Pipeline No. 12 (Site No. 1: Route 101)




a)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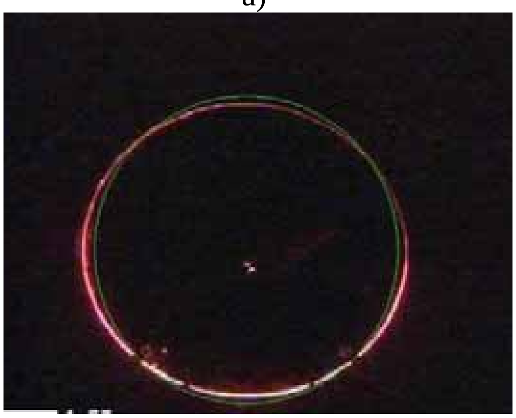
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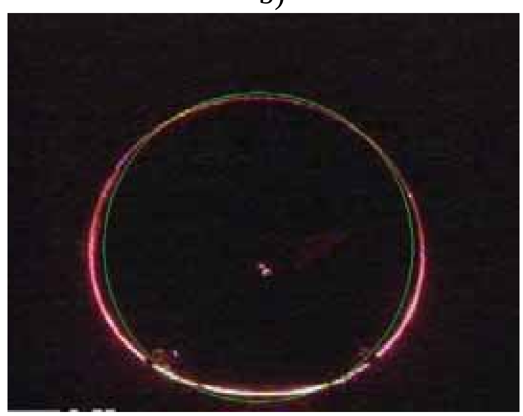
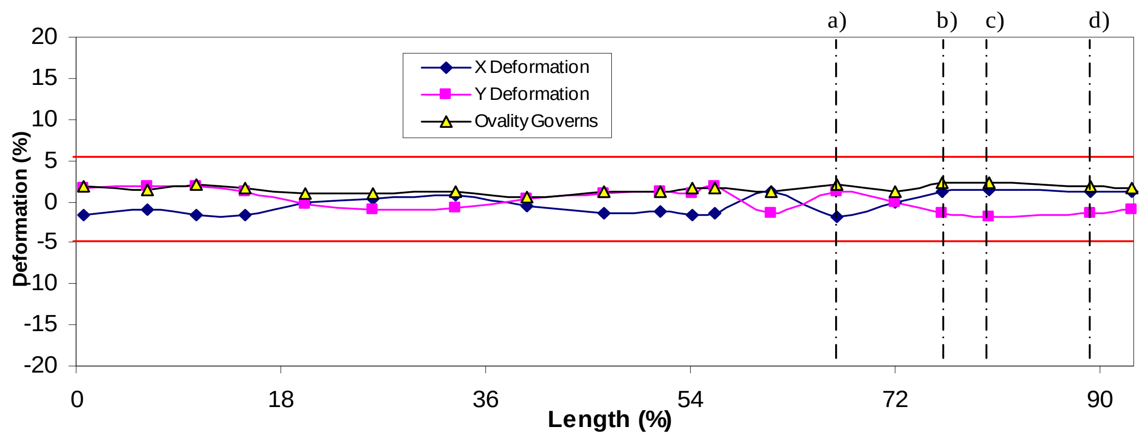
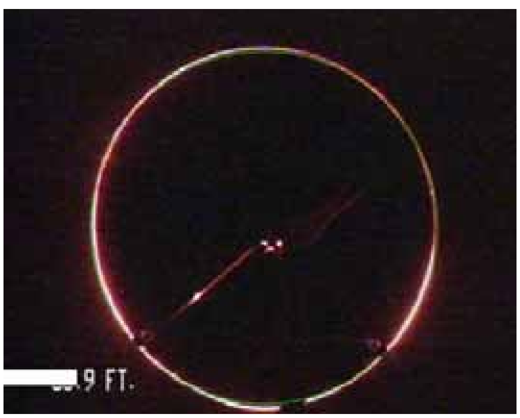

d)

Figure 316 Horizontal and vertical deformation of Pipeline No. 12 (Site No. 1: Route 101)

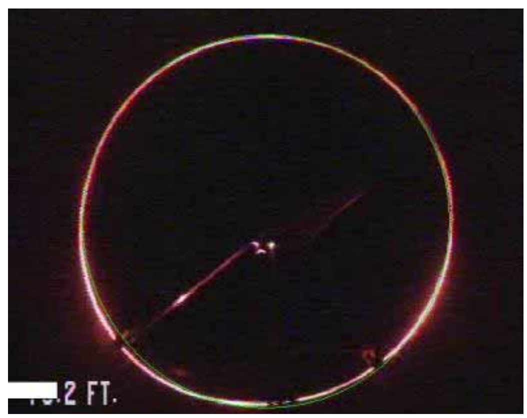
Figure 317 Cracking/fracture failure for Pipeline No. 12 (Site No. 1: Route 101)

Pipeline No. 13 (Site No. 1: Route 101)

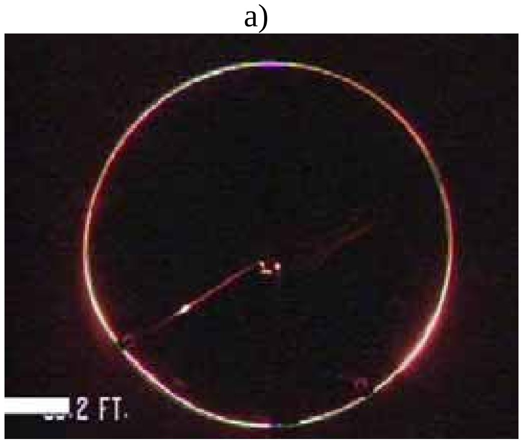




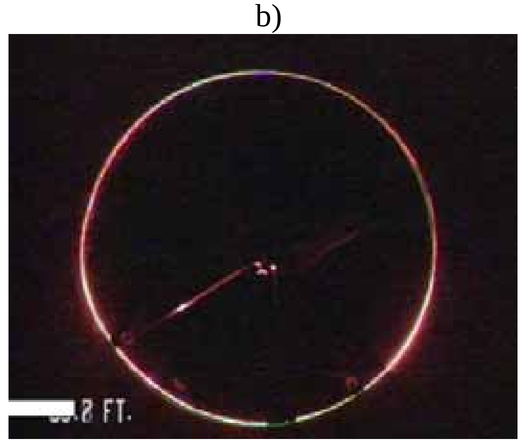
a)



b)



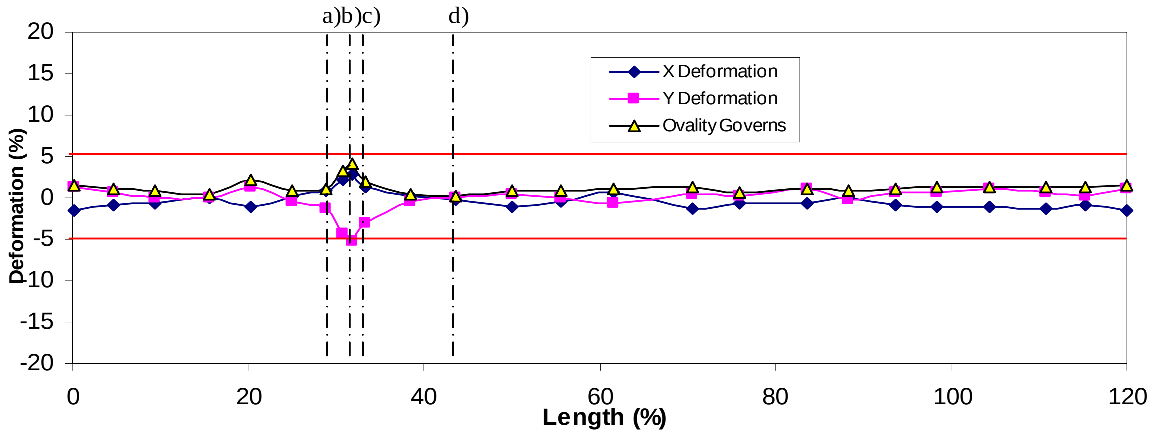
c)



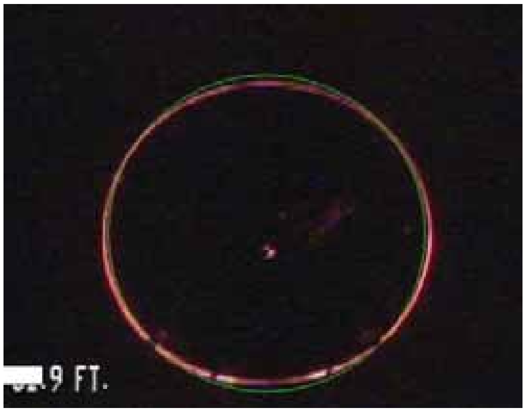
d)

Figure 318 Horizontal and vertical deformation of Pipeline No. 13 (Site No. 1: Route 101)

Pipeline No. 14 (Site No. 1: Route 101)




a)


b)


c)

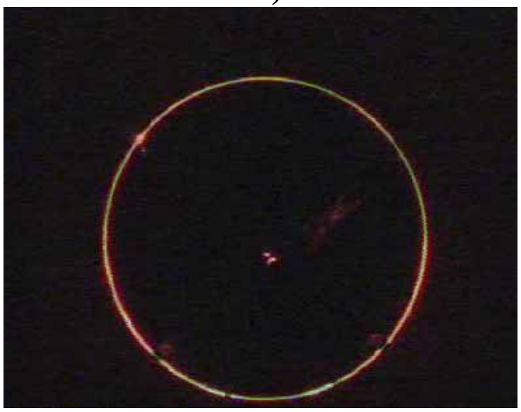
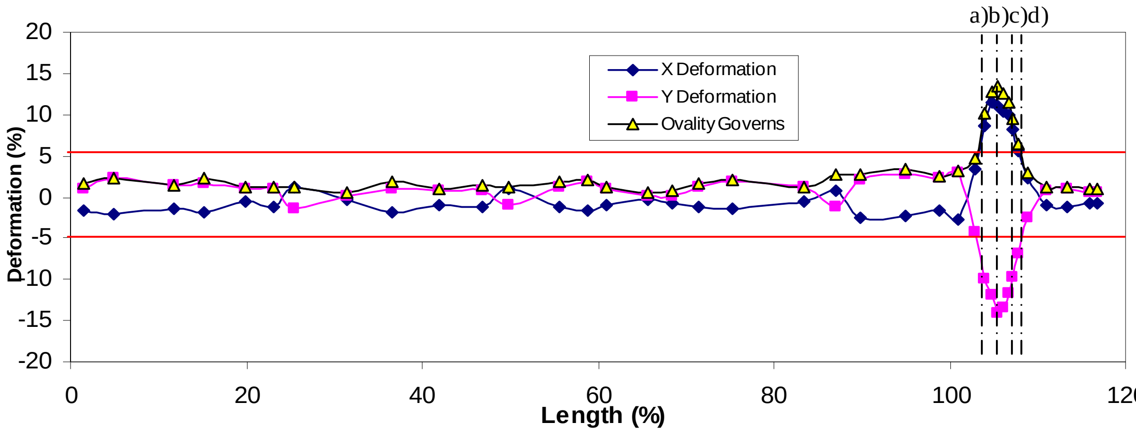
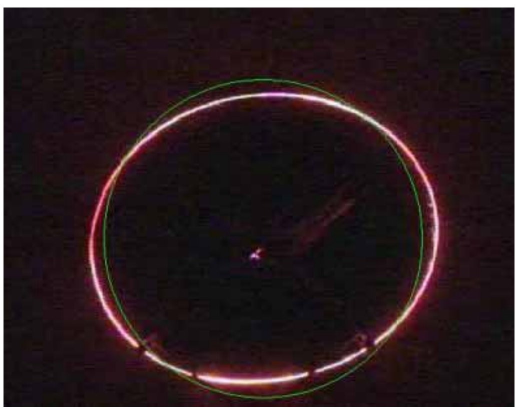
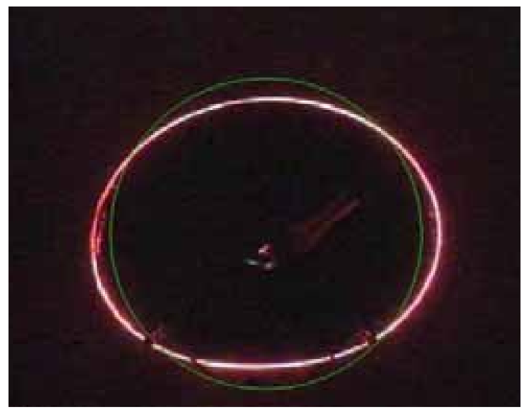

d)

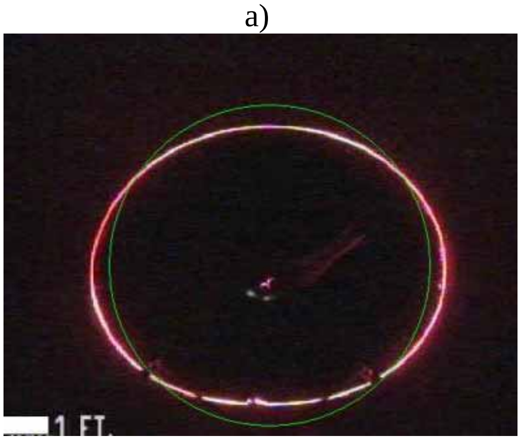
Figure 319 Horizontal and vertical deformation of Pipeline No. 14 (Site No. 1: Route 101)

Pipeline No. 15 (Site No. 1: Route 101)




a)


b)


c)

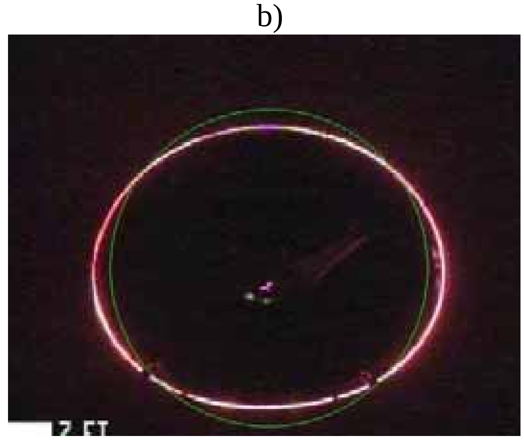
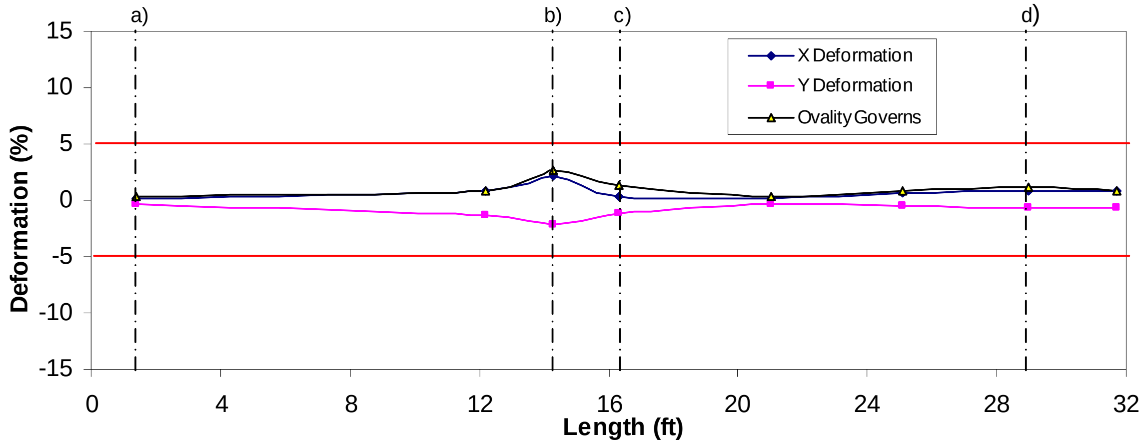
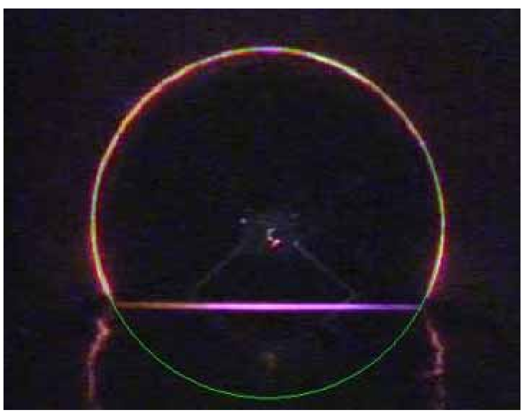

d)

Figure 320 Horizontal and vertical deformation of Pipeline No. 15 (Site No. 1: Route 101)

Pipeline No. 16 (Site No. 2: Route 36)

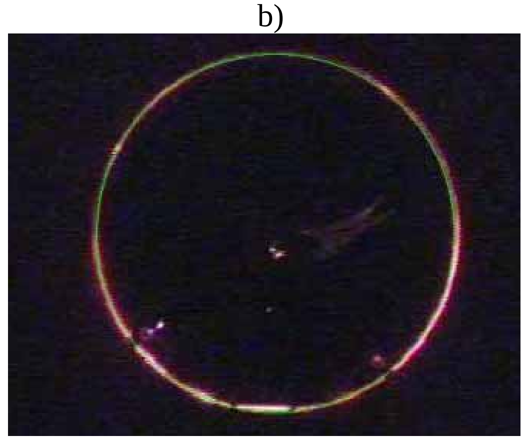




a)

b)

c)

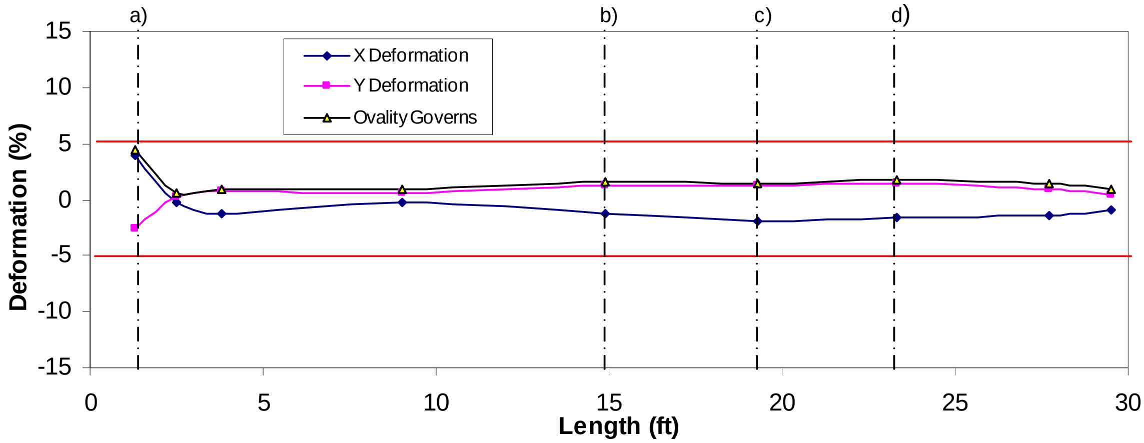


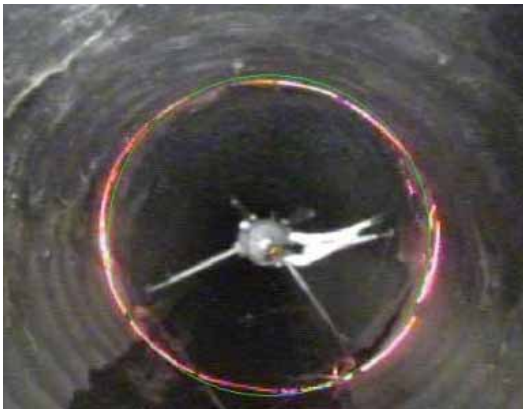
d)

Figure 321 Horizontal and vertical deformation of Pipeline No. 16 (Site No. 2: Route 36)

Figure 322 Cracking/fracture failure for Pipeline No. 16 (Site No. 2: Route 36)

Pipeline No. 17 (Site No. 2: Route 36)





a)

b)

c)

d)

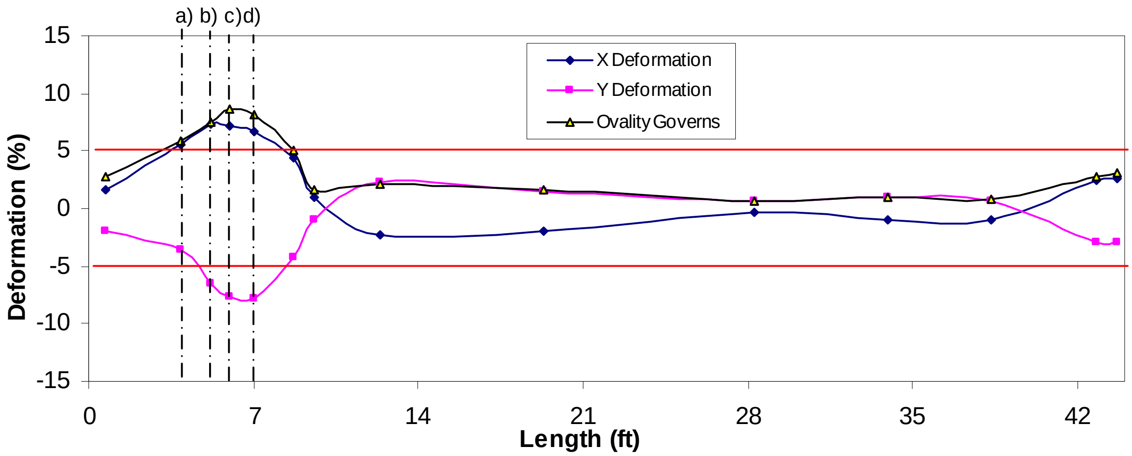
Figure 323 Horizontal and vertical deformation of Pipeline No. 17 (Site No. 2: Route 36)

Figure 324 Cracking/fracture failure for Pipeline No. 17 (Site No. 2: Route 36)

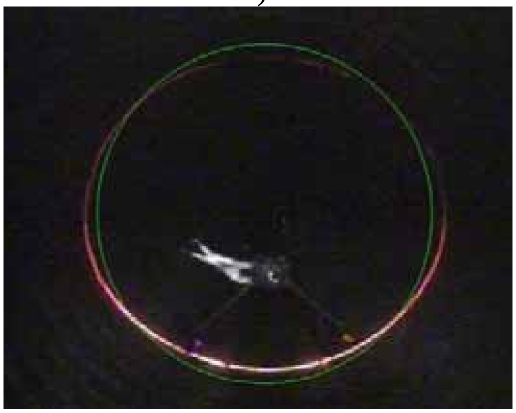
Pipeline No. 18 (Site No. 2: Route 36)

Figure 325 Corrugation growth failure for Pipeline No. 18 (Site No. 2: Route 36)

Pipeline No. 19 (Site No. 2: Route 36)



a) b)



c) d)

Figure 326 Horizontal and vertical deformation of Pipeline No. 19 (Site No. 2: Route 36)

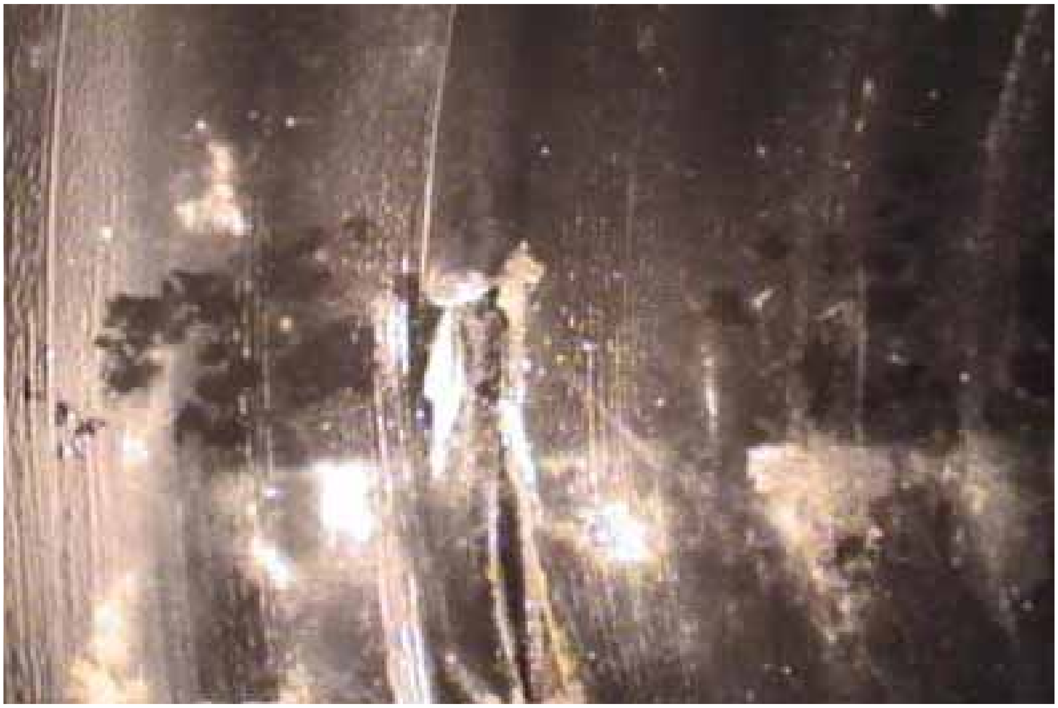


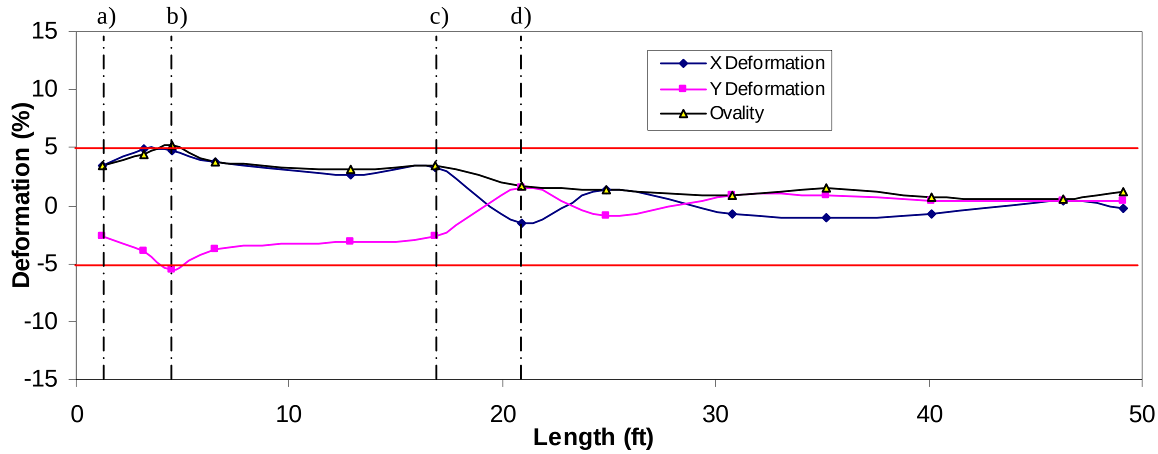
Figure 327 Cracking/fracture and corrugation growth failure for Pipeline No. 19 (Site No. 2: Route 36)

Pipeline No. 20 (Site No. 2: Route 36)

Figure 328 Cracking/fracture and corrugation growth failure for Pipeline No. 20 (Site No. 2: Route 36)

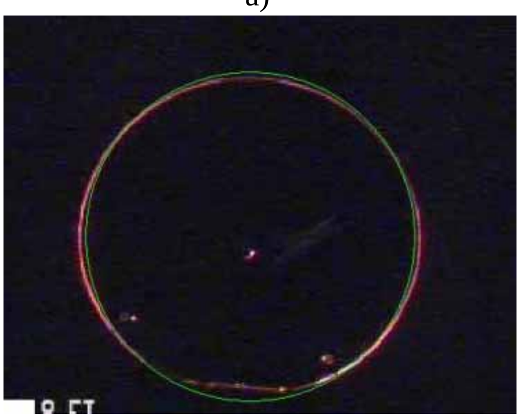
Figure 329 Cracking/fracture failure for Pipeline No. 20 (Site No. 2: Route 36)

Pipeline No. 21 (Site No. 2: Route 36)

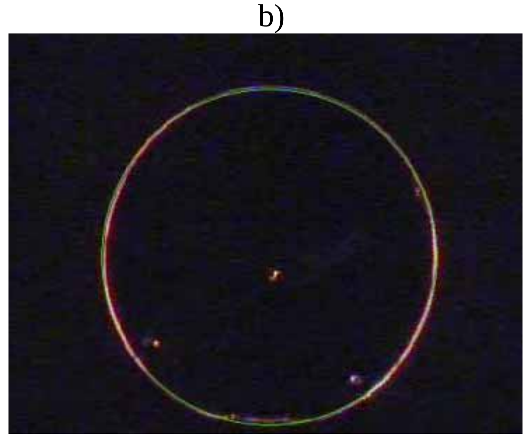


a)

b)



c)



d)

Figure 330 Horizontal and vertical deformation of Pipeline No. 21 (Site No. 2: Route 36)

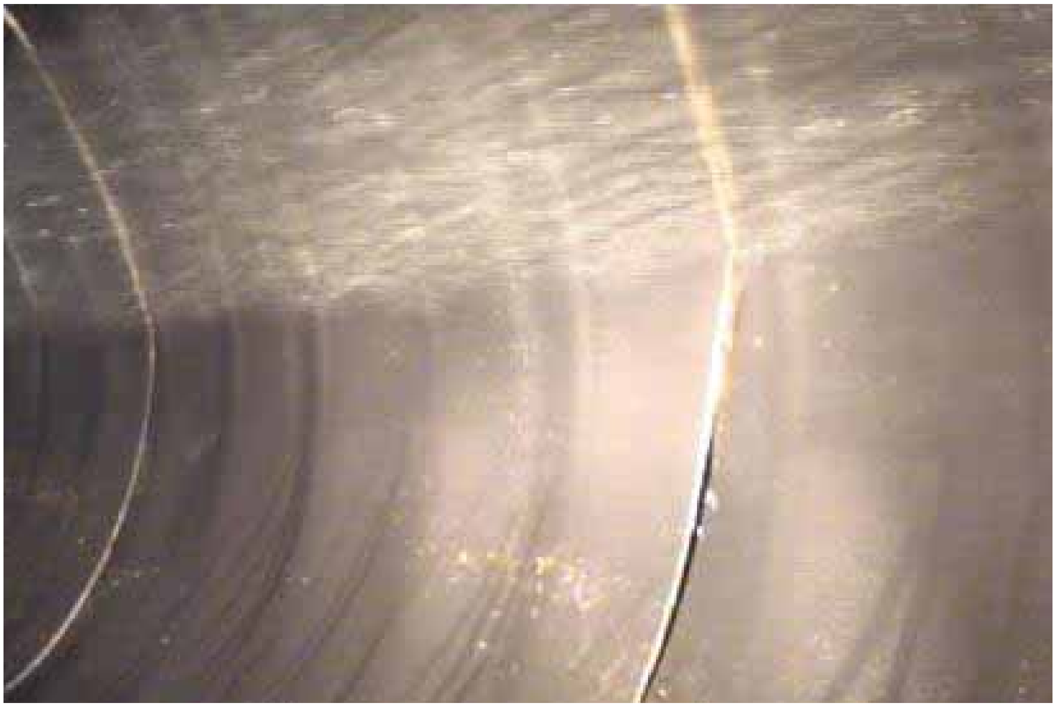


Figure 331 Cracking/fracture failure for Pipeline No. 21 (Site No. 2: Route 36)

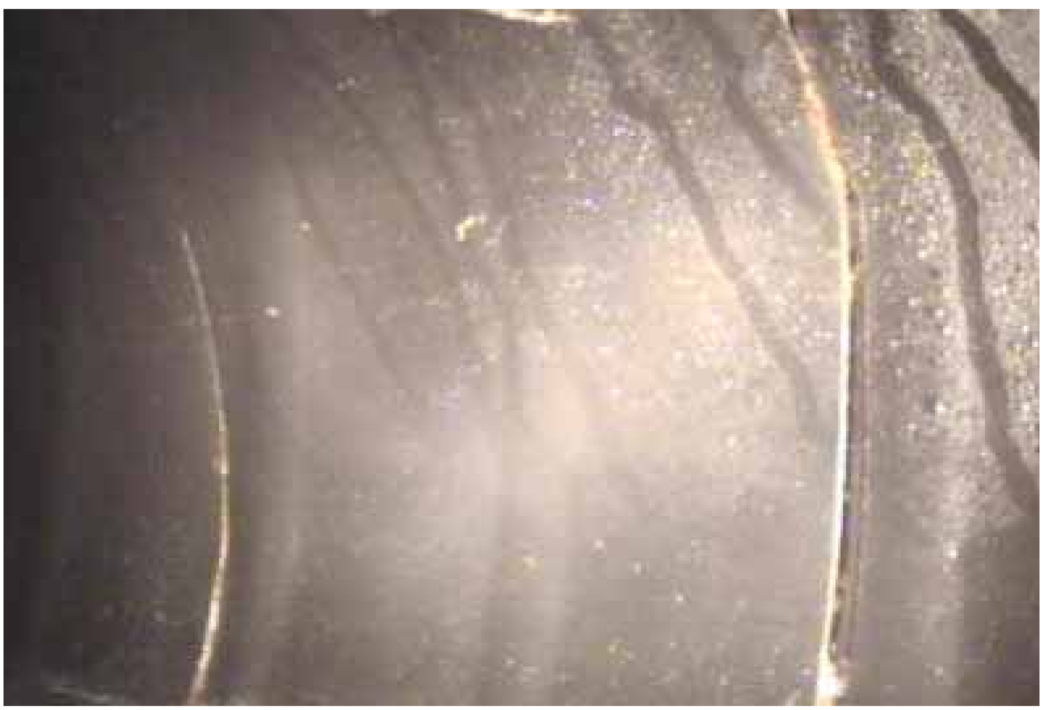
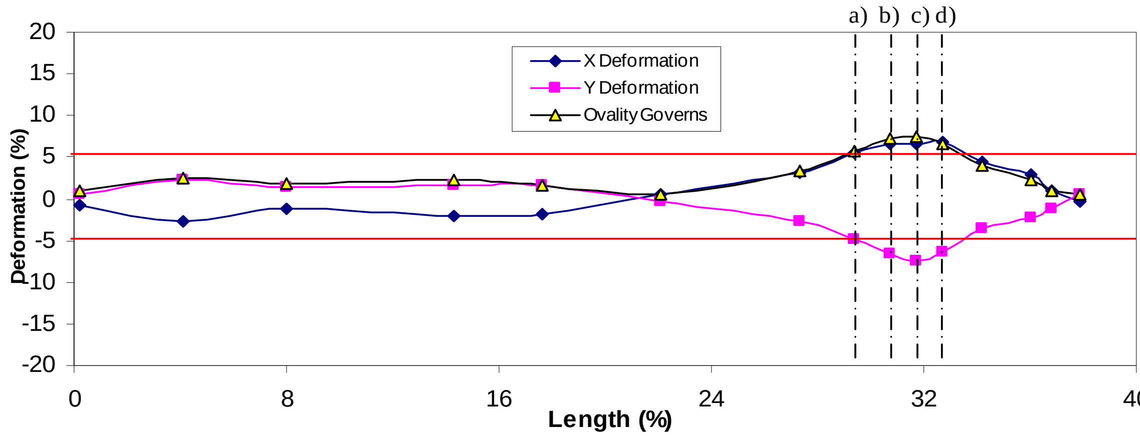


Figure 332 Cracking/fracture failure for Pipeline No. 21 (Site No. 2: Route 36)

Pipeline No. 22 (Site No. 2: Route 36)




a)


b)


c)

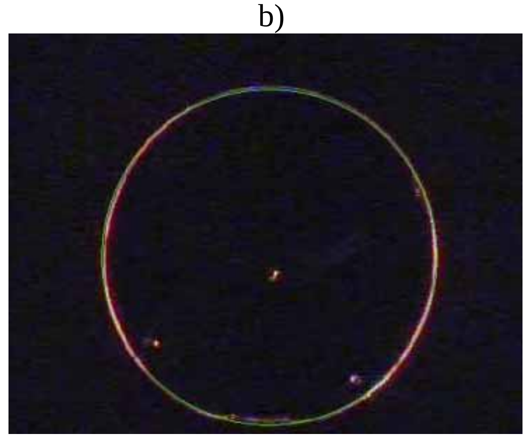

d)

Figure 333 Horizontal and vertical deformation of Pipeline No. 22 (Site No. 2: Route 36)

Figure 334 Cracking/fracture and corrugation growth failure for Pipeline No. 22 (Site No. 2: Route 36)

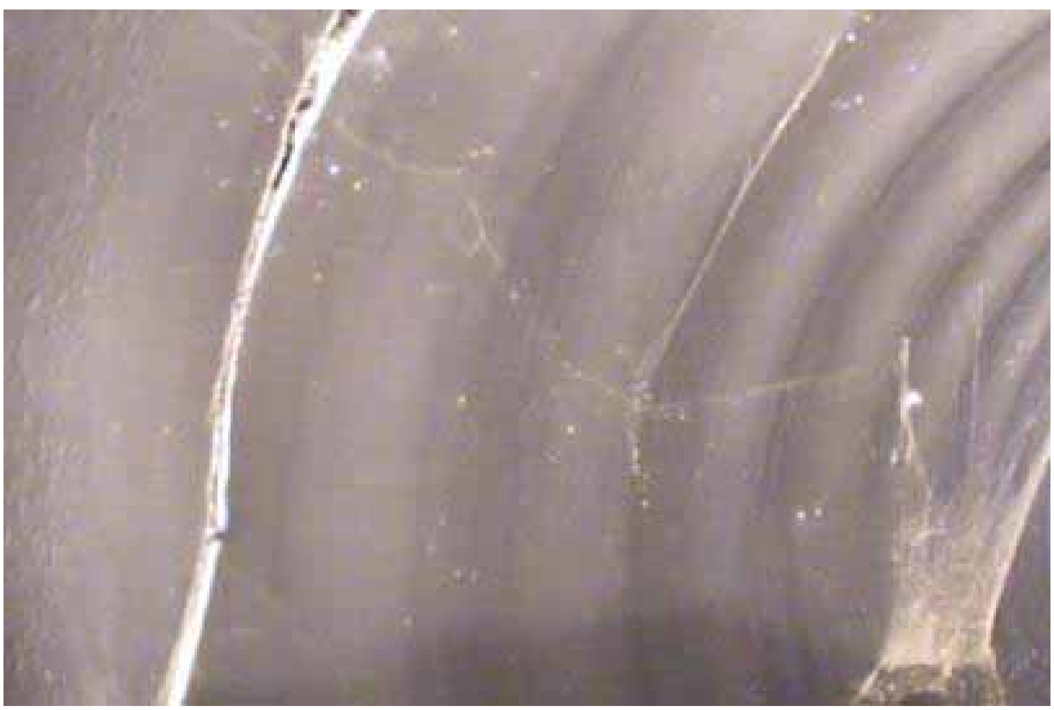


Figure 335 Cracking/fracture and corrugation growth failure for Pipeline No. 22 (Site No. 2: Route 36)

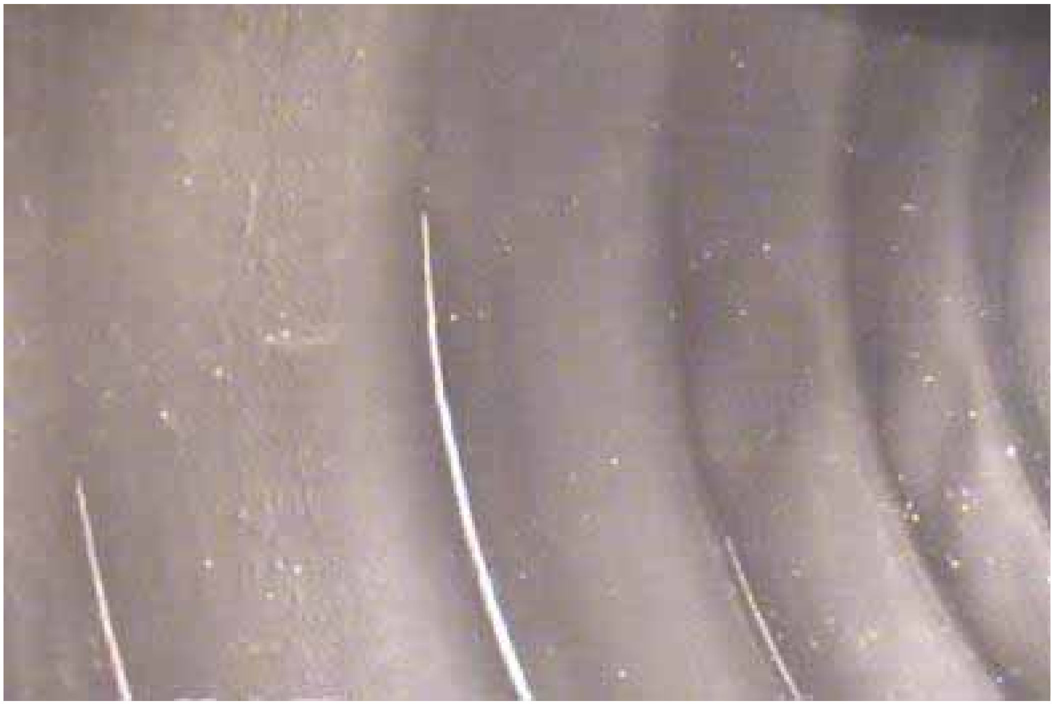
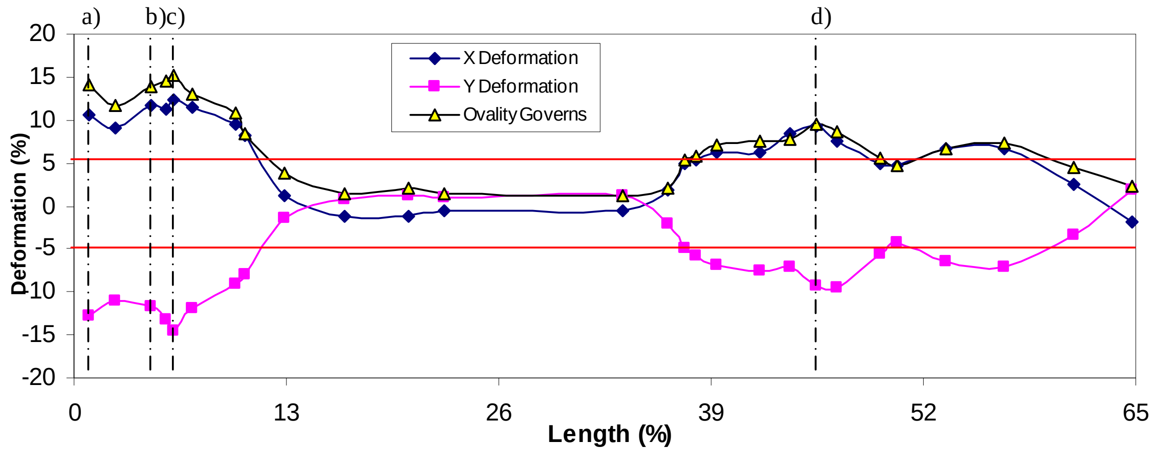
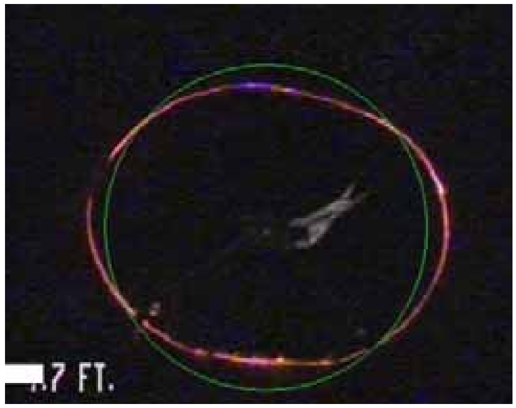


Figure 336 Cracking/fracture and corrugation growth failure for Pipeline No. 22 (Site No. 2: Route 36)

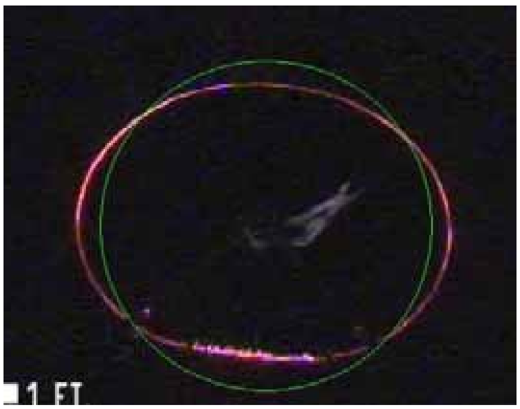
Pipeline No. 23 (Site No. 2: Route 36)



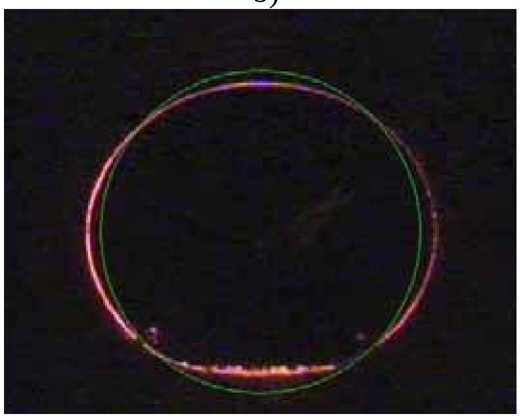
a)



b)



c)



d)

Figure 337 Horizontal and vertical deformation of Pipeline No. 23 (Site No. 2: Route 36)

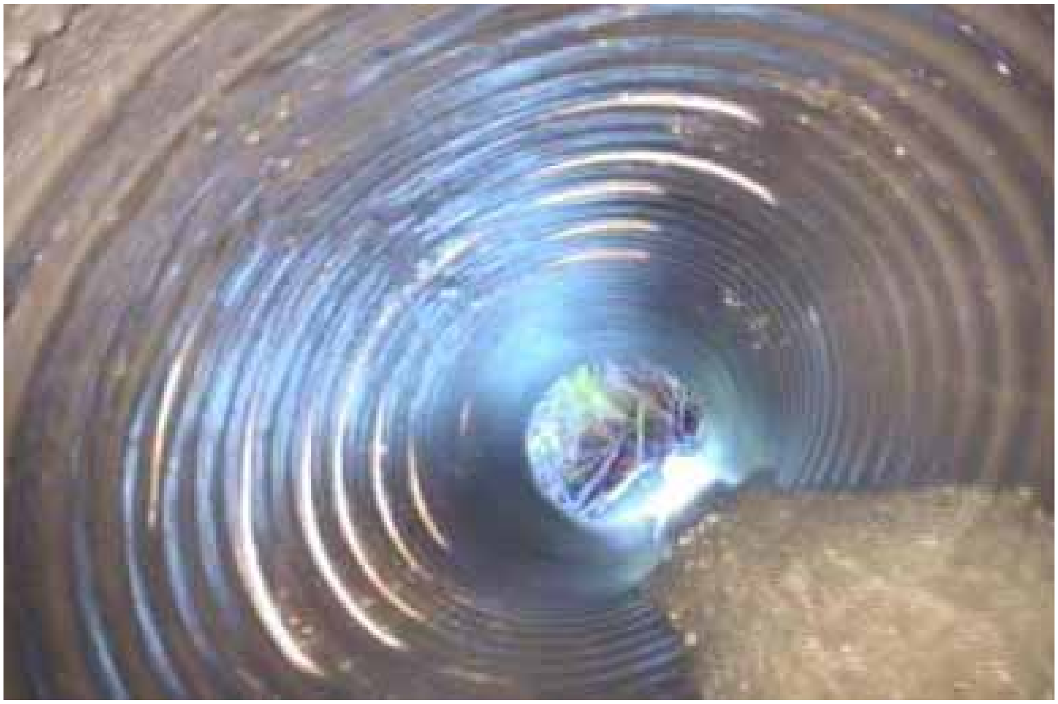


Figure 338 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

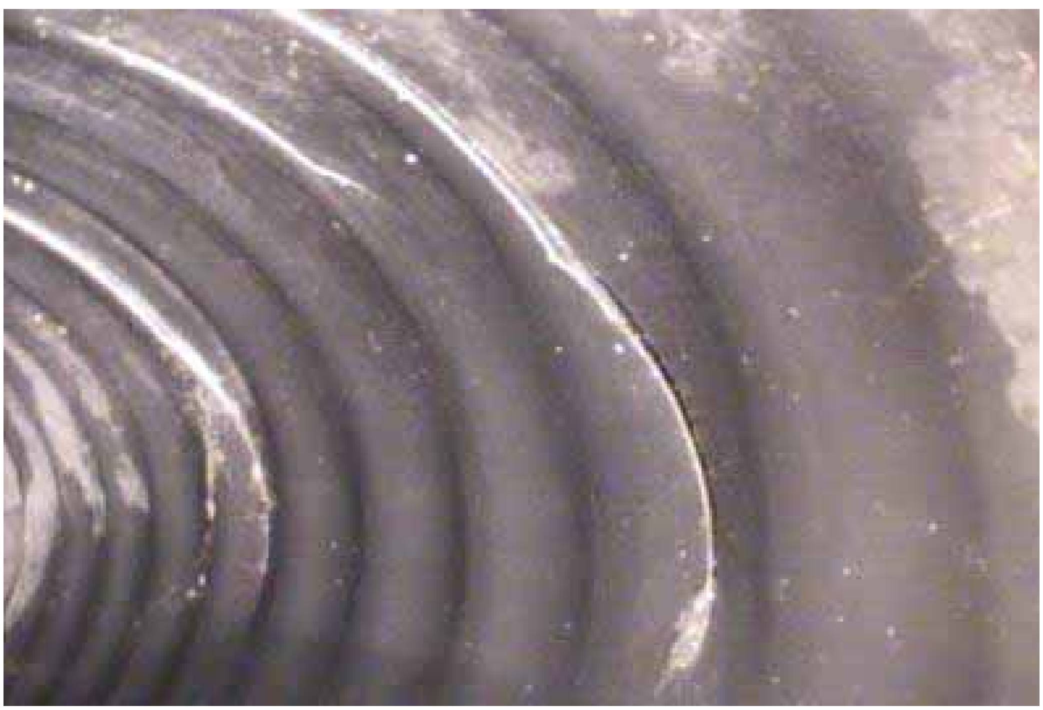


Figure 339 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

Figure 340 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

Figure 341 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

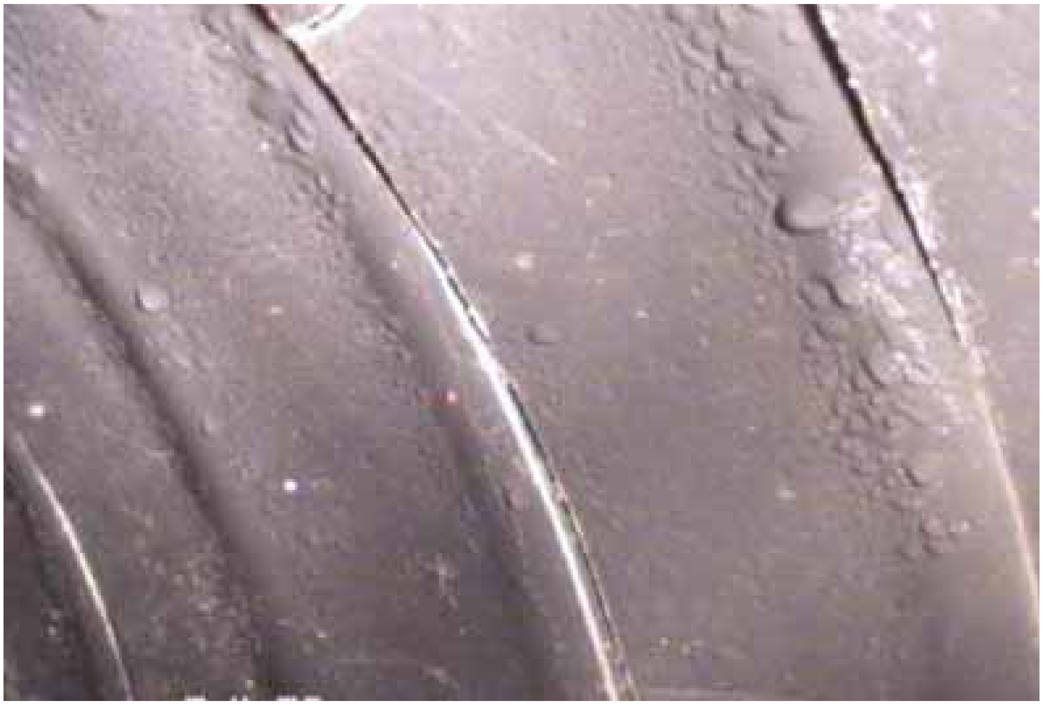


Figure 342 Cracking/fracture failure for Pipeline No. 23 (Site No. 2: Route 36)

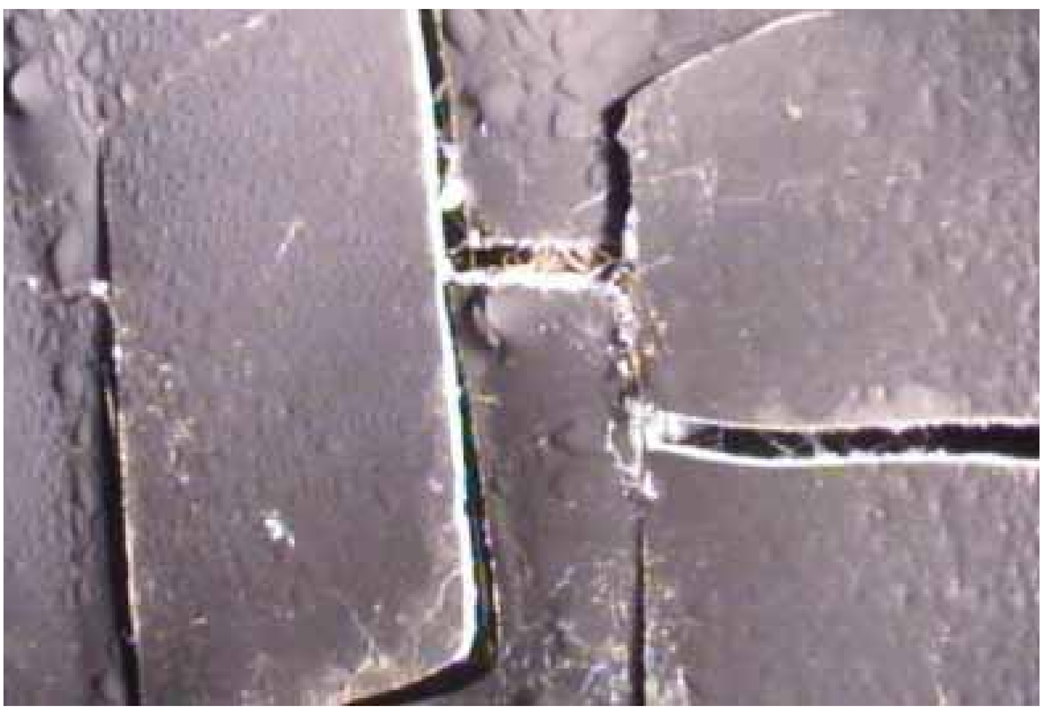


Figure 343 Cracking/fracture failure for Pipeline No. 23 (Site No. 2: Route 36)

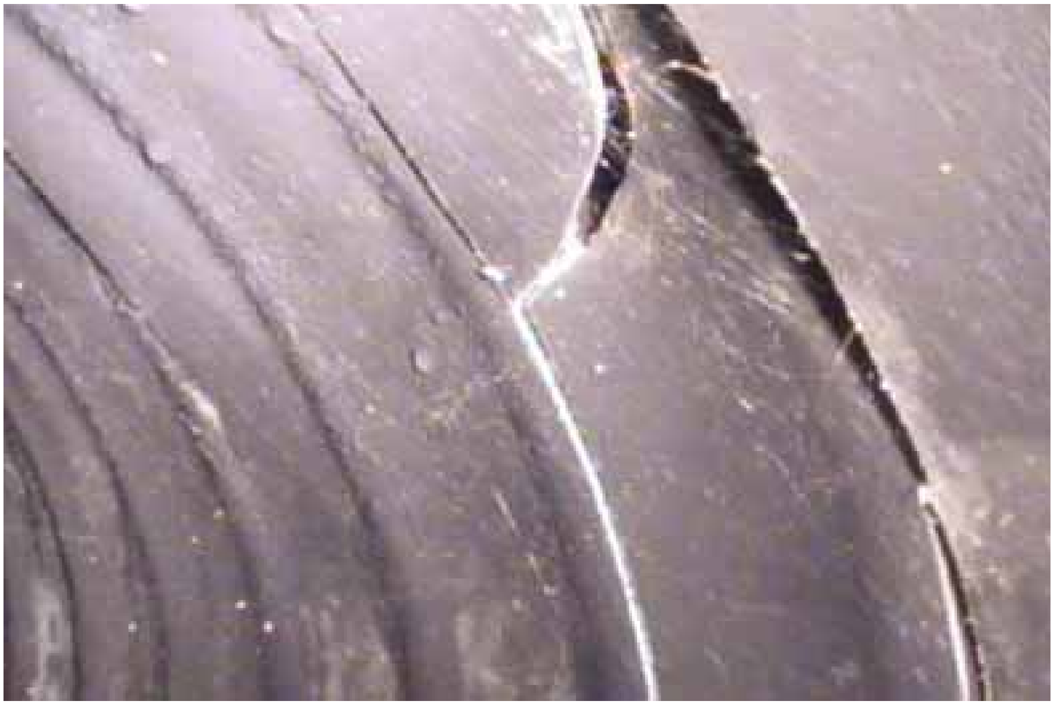


Figure 344 Cracking/fracture failure for Pipeline No. 23 (Site No. 2: Route 36)

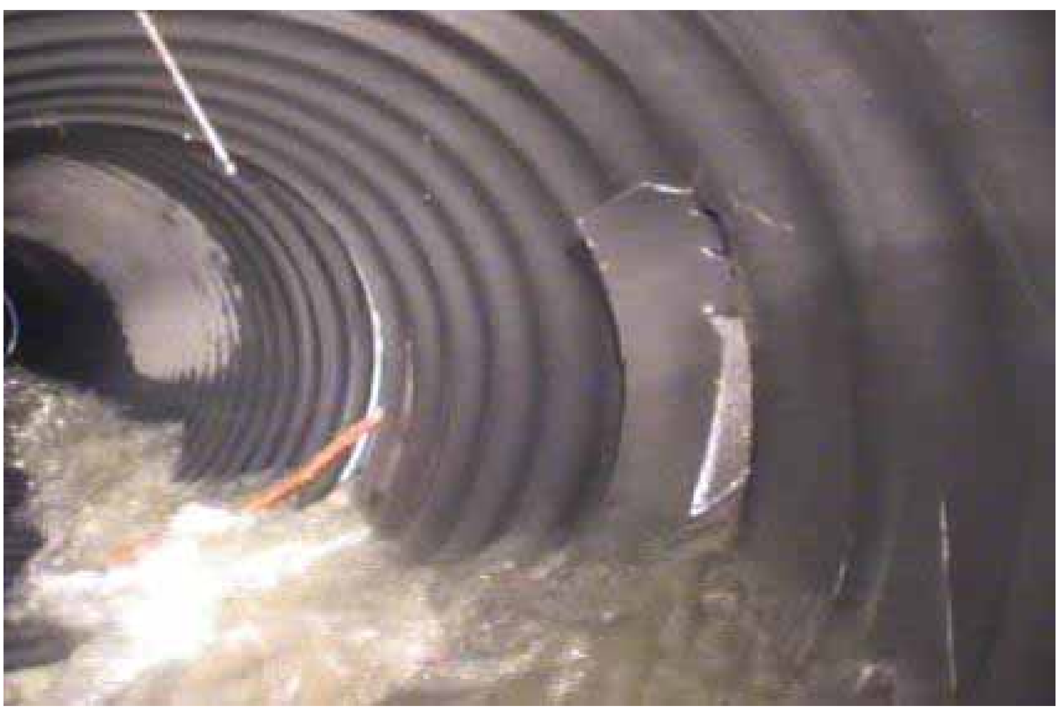


Figure 345 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

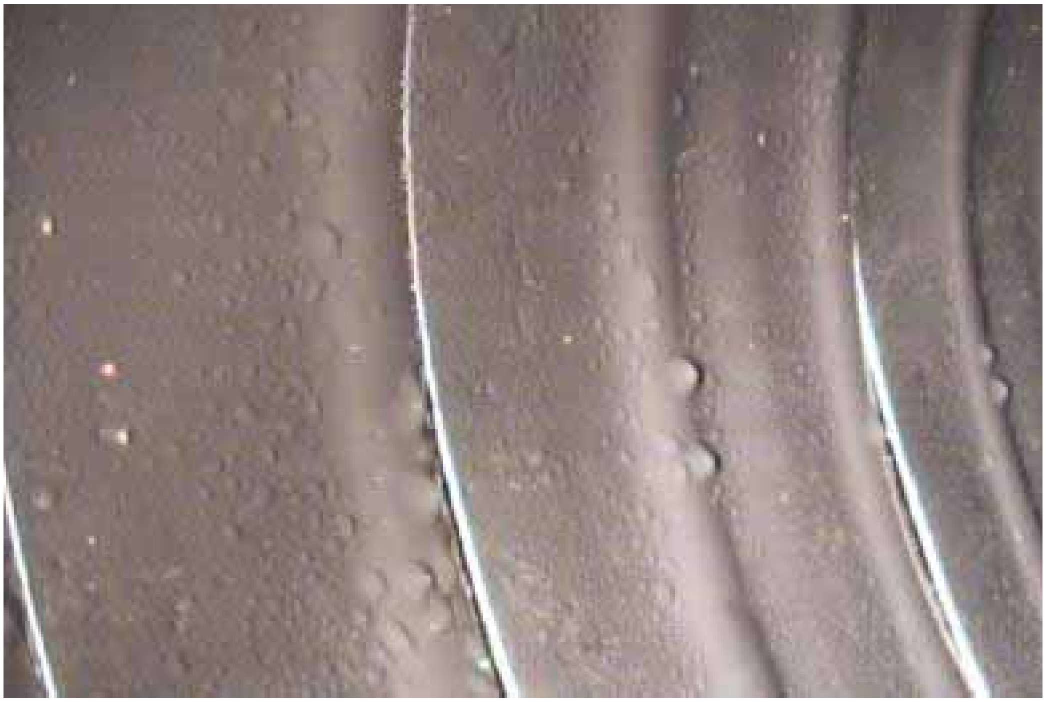


Figure 346 Cracking/fracture failure for Pipeline No. 23 (Site No. 2: Route 36)

Figure 347 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

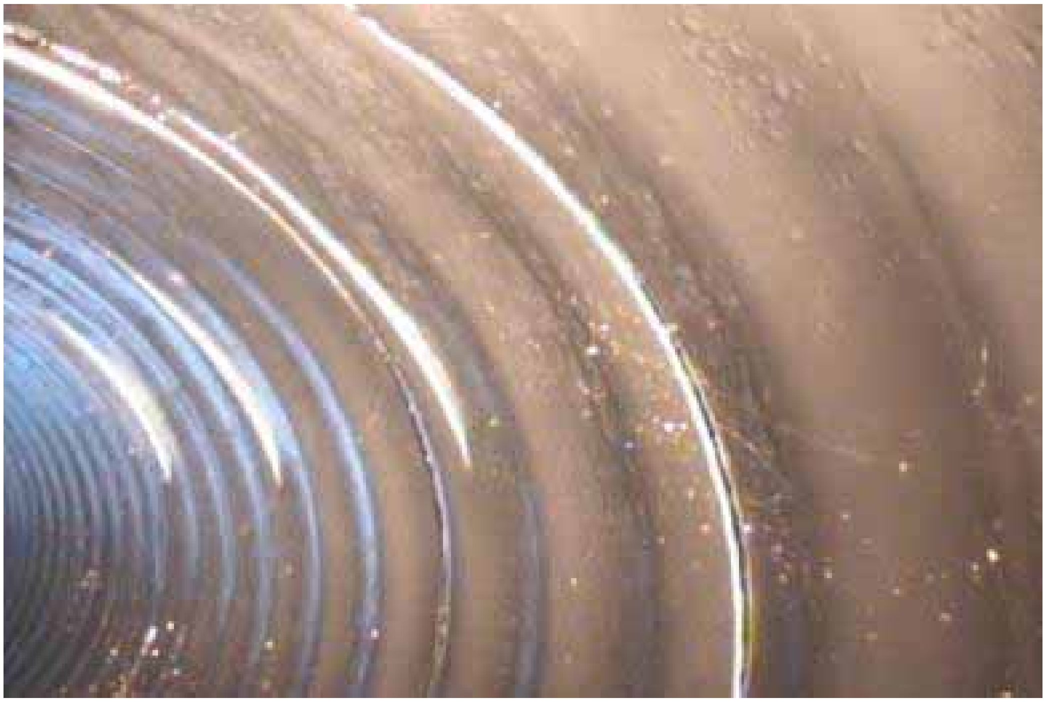
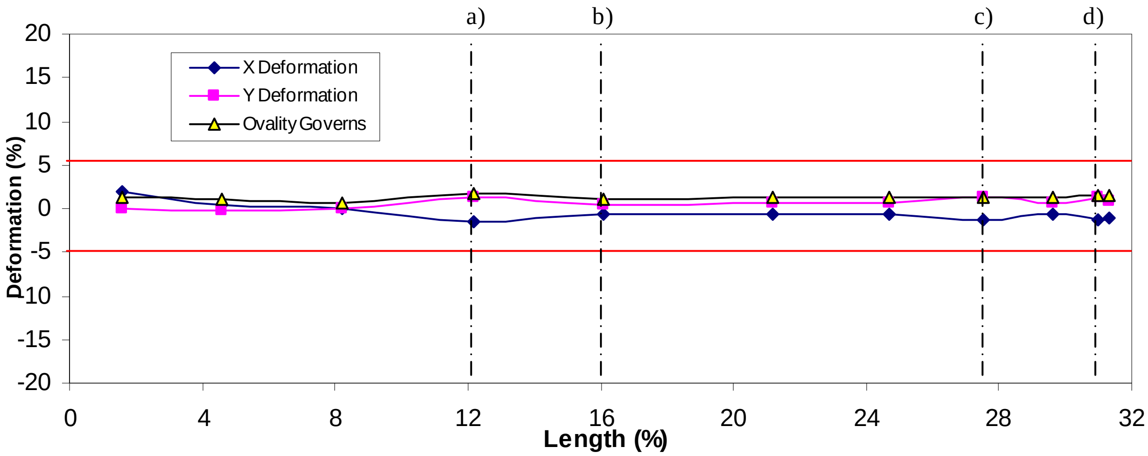
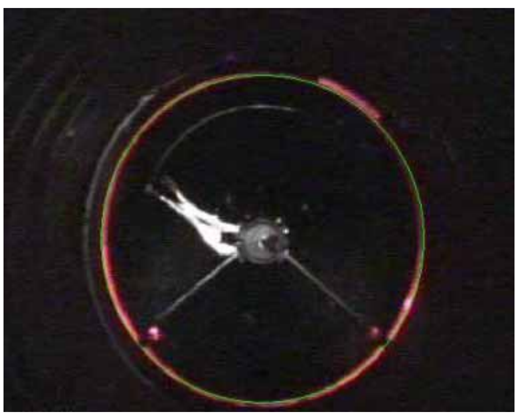


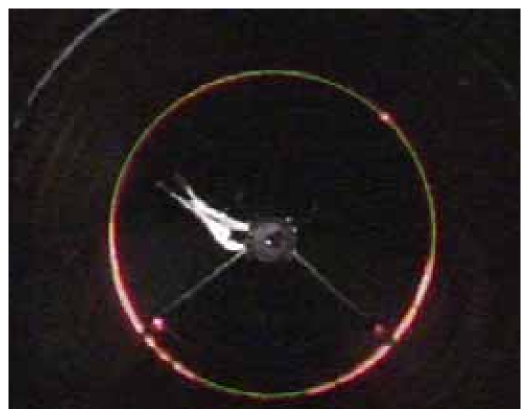
Figure 348 Cracking/fracture and corrugation growth failure for Pipeline No. 23 (Site No. 2: Route 36)

Pipeline No. 24 (Site No. 2: Route 36)

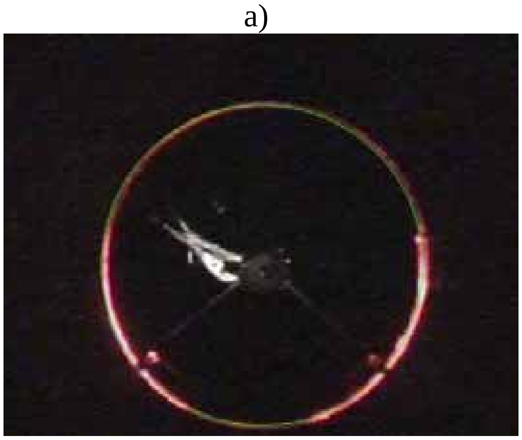




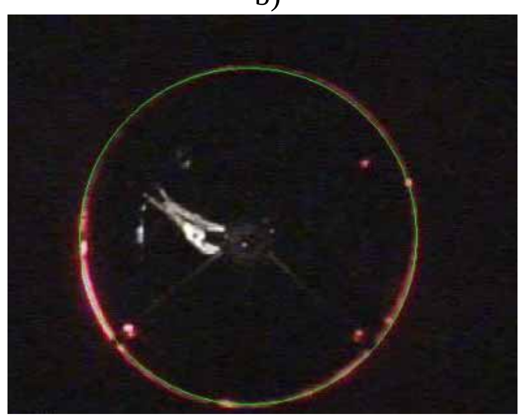
a)



b)



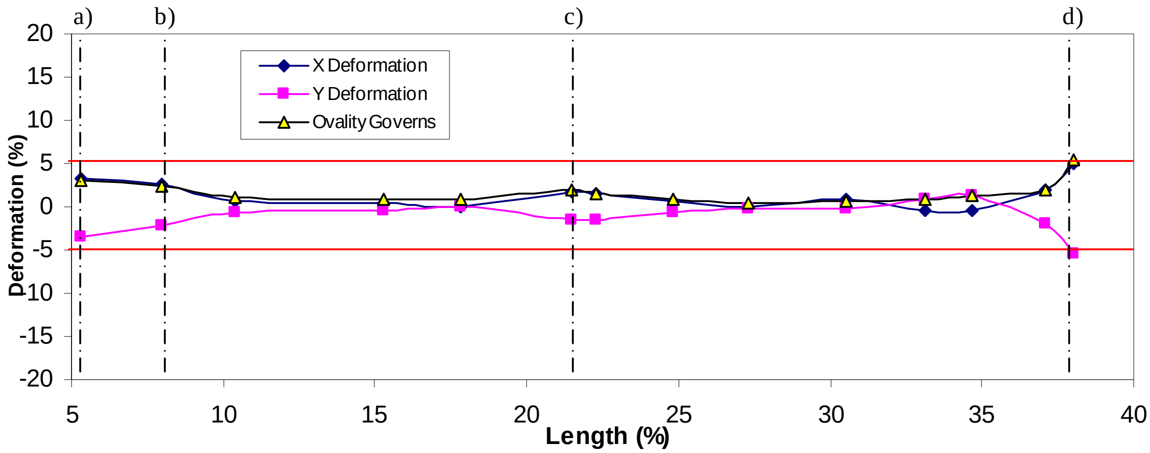
c)

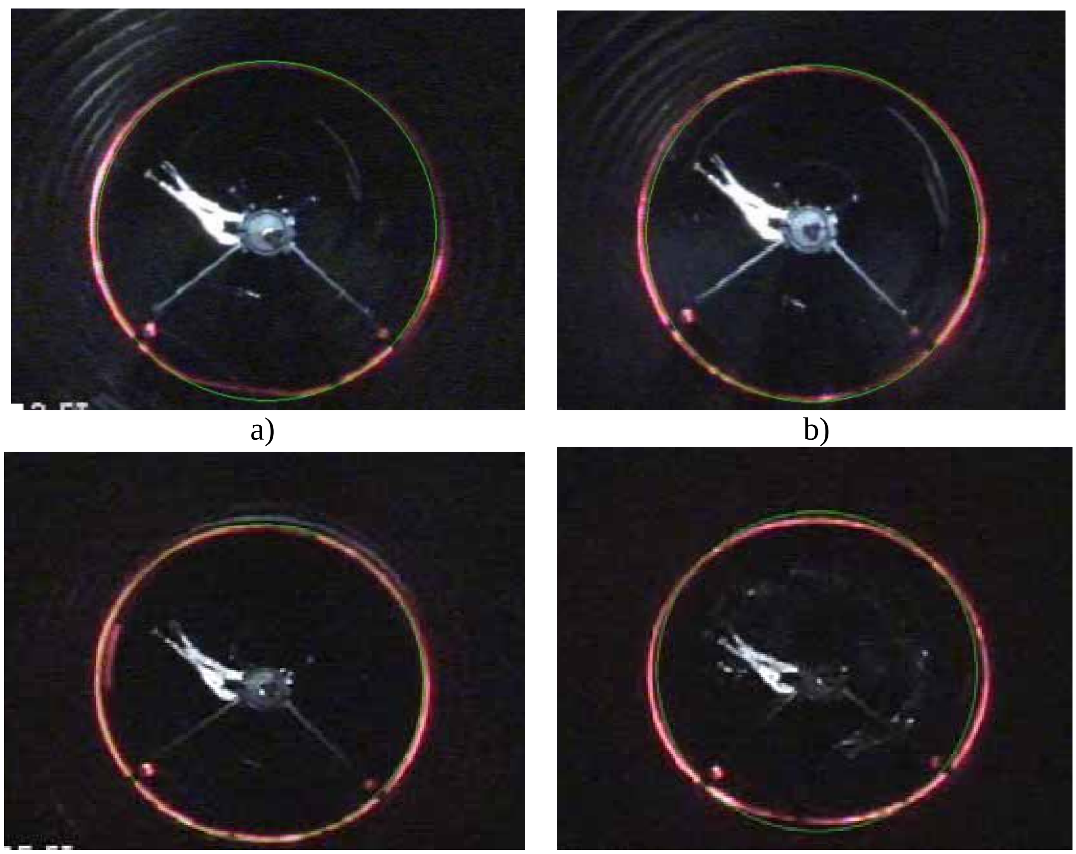


d)

Figure 349 Horizontal and vertical deformation of Pipeline No. 24 (Site No. 2: Route 36)

Pipeline No. 25 (Site No. 2: Route 36)

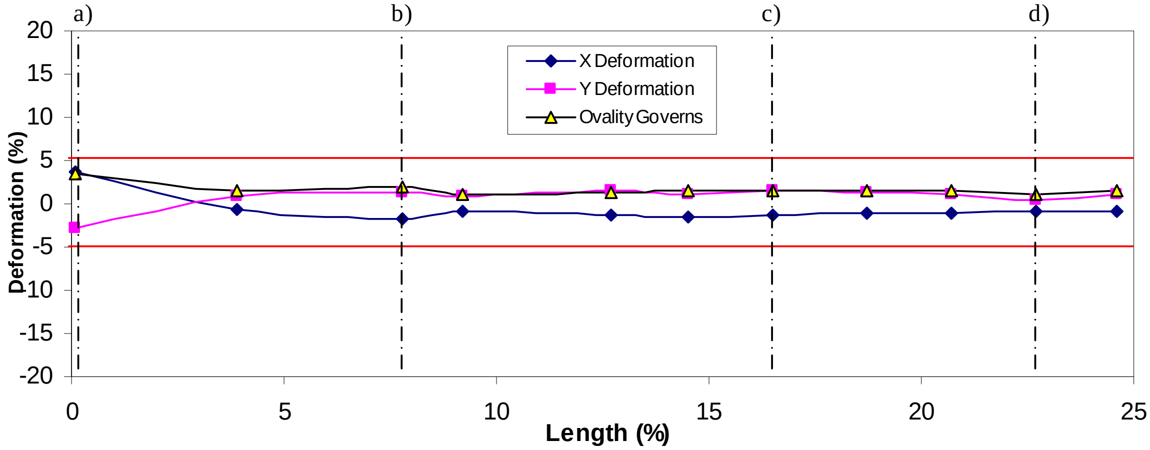


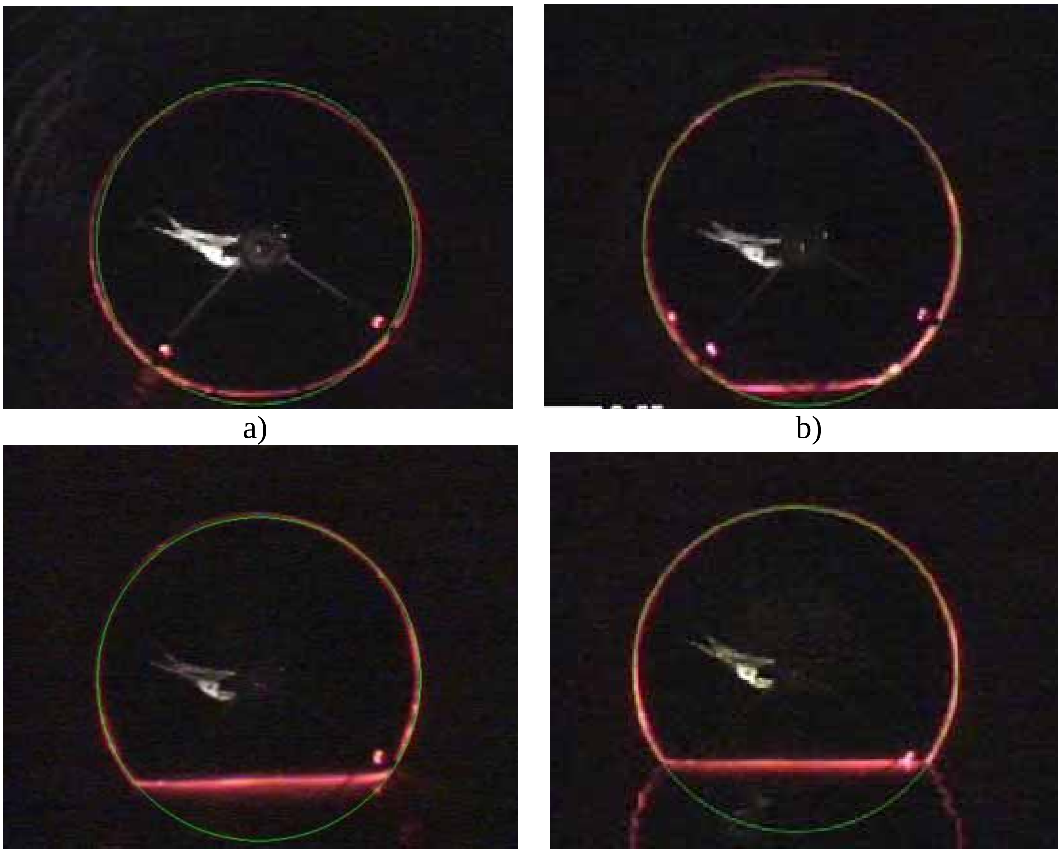


a) b) c) d)

Figure 350 Horizontal and vertical deformation of Pipeline No. 25 (Site No. 2: Route 36)

Pipeline No. 26 (Site No. 2: Route 36)

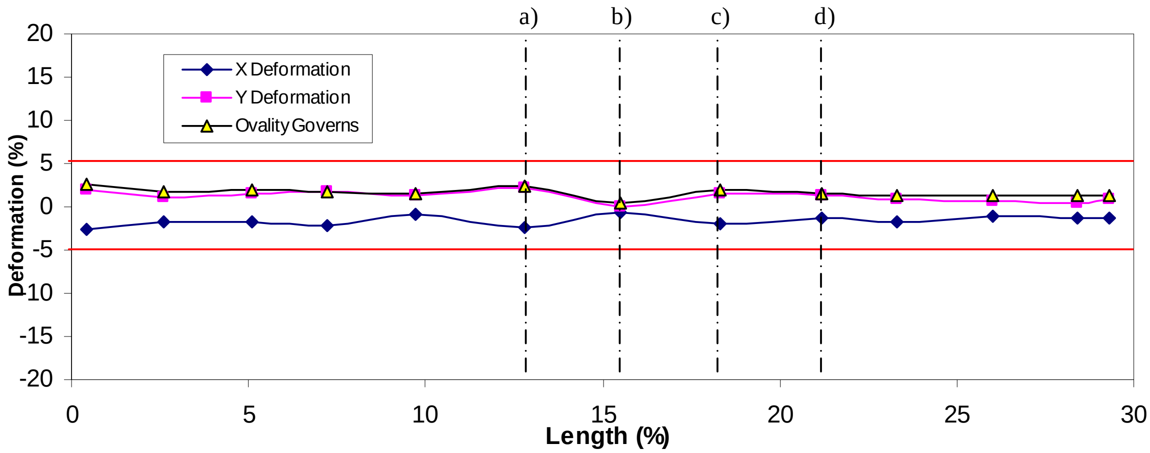




a) b) c) d)

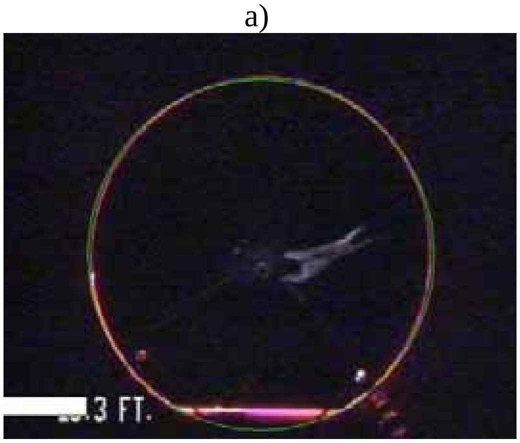
Figure 351 Horizontal and vertical deformation of Pipeline No. 26 (Site No. 2: Route 36)

Pipeline No. 27 (Site No. 2: Route 36)

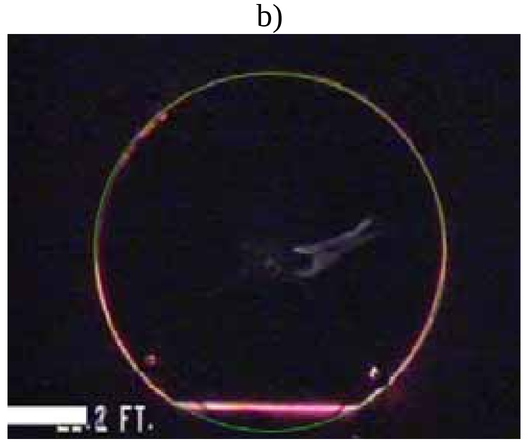


a)

b)



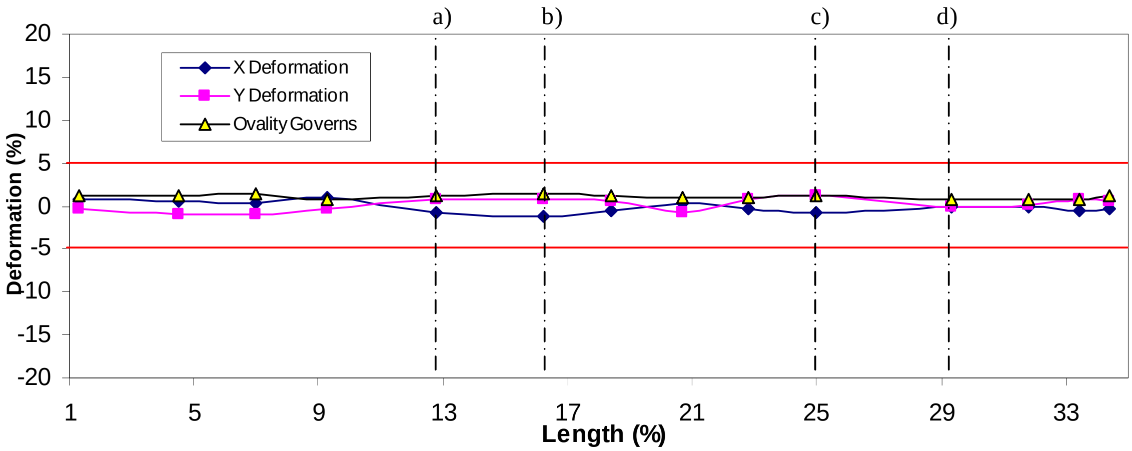
c)



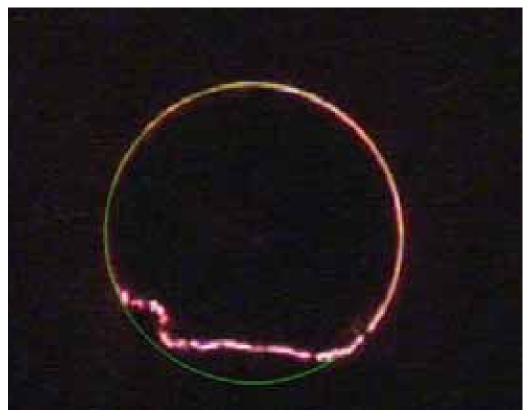
d)

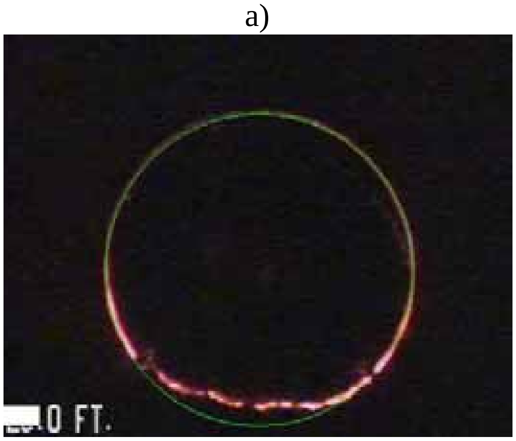
Figure 352 Horizontal and vertical deformation of Pipeline No. 27 (Site No. 2: Route 36)

Pipeline No. 28 (Site No. 2: Route 36)




a)


b)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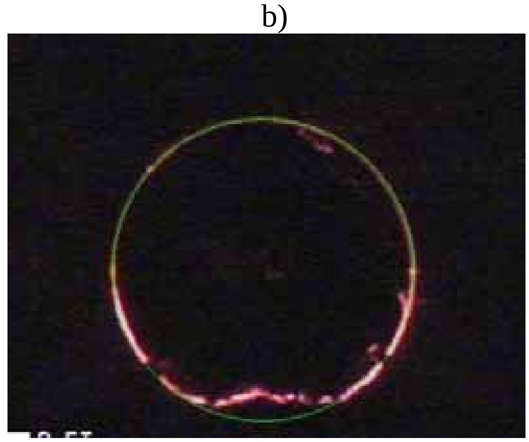
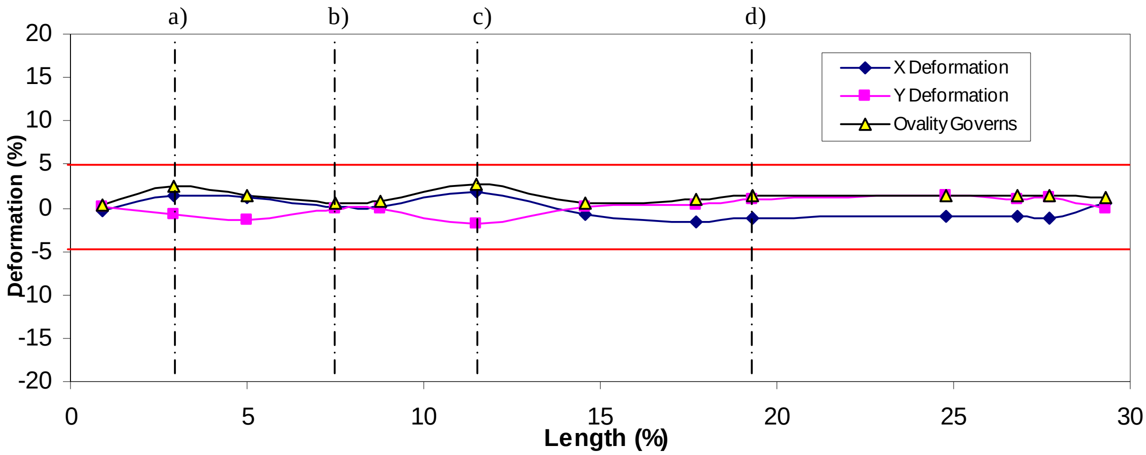

d)

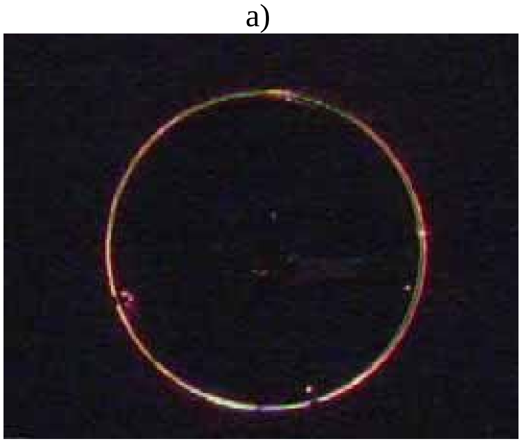
Figure 353 Horizontal and vertical deformation of Pipeline No. 28 (Site No. 2: Route 36)

Pipeline No. 29 (Site No. 2: Route 36)



a)

b)



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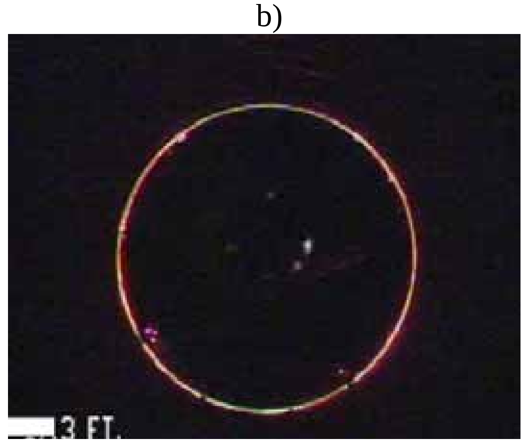


d)

Figure 354 Horizontal and vertical deformation of Pipeline No. 29 (Site No. 2: Route 36)

Appendix 8 – State of Utah

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Utah. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

Figure 355 Layout of site numbers/locations

Table 25 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	Legacy Parkway	1	24	5/29/2009	190
		2	24	5/30/2009	180
		3	24	5/30/2009	190
		4	24	5/30/2009	70
		5	24	5/30/2009	80
		6*	42	5/30/2009	110
		7	42	5/30/2009	90
		8	36	5/30/2009	170
2	Silver Creek Parkway	9	30	5/29/2009	235
		10	30	5/29/2009	210

* Laser video data was not collected.

Table 26 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corrugation Growth	Buckling
1	Legacy Parkway	1		✓			✓	
		2	✓	✓	✓		✓	
		3		✓			✓	
		4		✓			✓	
		5		✓			✓	
		6	✓	**NA**	✓		✓	
		7		✓			✓	
		8		✓			✓	
2	Silver Creek Parkway	9	✓	✓	✓	✓	✓	✓
		10	✓	✓	✓	✓	✓	✓
Percentage of pipelines experiencing failure mode			40%	100%	40%	20%	100%	20%

N.A. Laser Video was not performed due to limited access

Table 27 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Legacy Parkway	1	4.8	5.6	6.2	6.2
		2	5.6	5.7	5.6	5.7
		3	5.5	5.4	6.1	6.1
		4	7.7	8.8	9.6	9.6
		5	7.9	8.1	9.6	9.6
		6*	NA	NA	NA	NA
		7	4.8	5.3	6.7	6.7
		8	4.6	7.6	6.9	7.6
2	Silver Creek Parkway	9	8.4	34.0	11.9	34
		10	7.7	7.7	8.5	8.5
	Max		8.4	34.0	11.9	34.0
	Min		4.6	5.3	5.6	5.7
	Average		6.3	9.8	7.9	10.4

*Laser video data was not collected

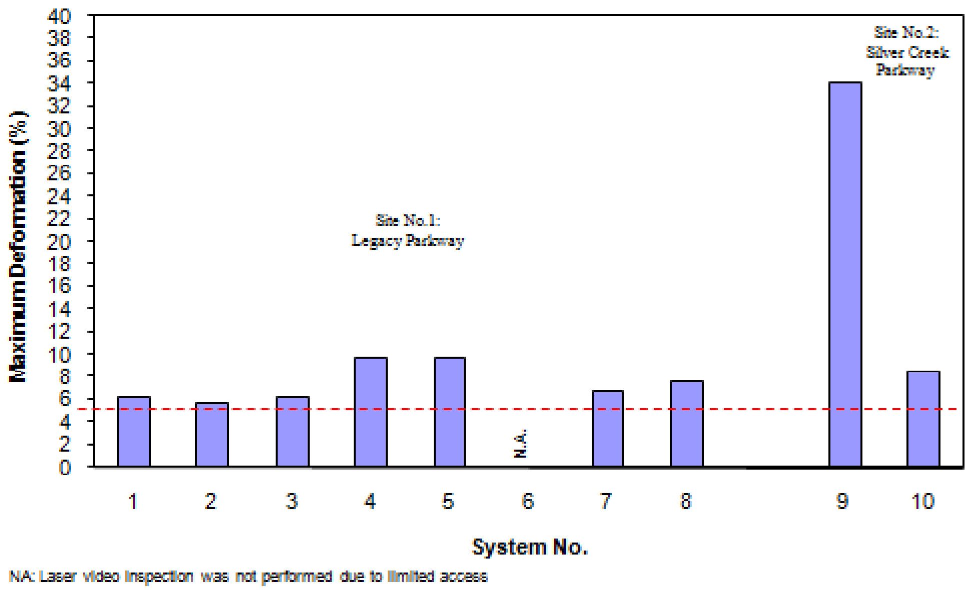
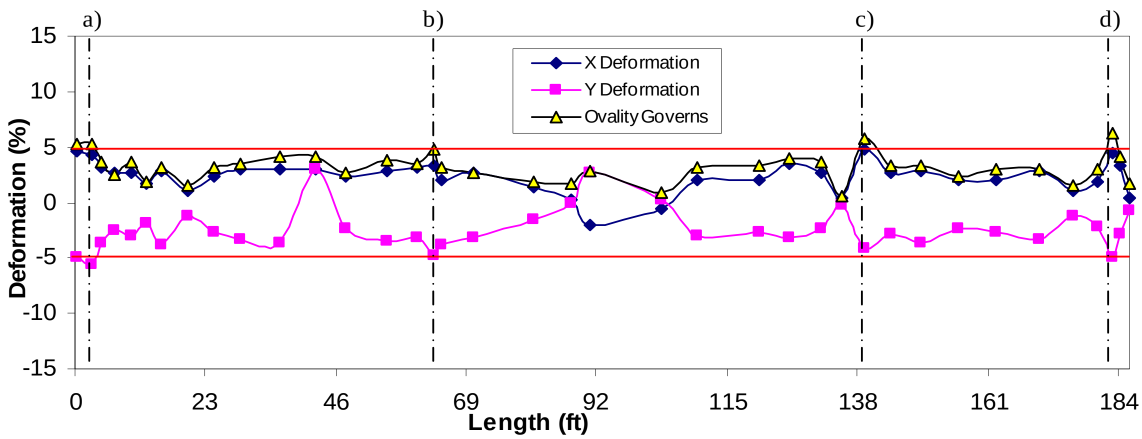
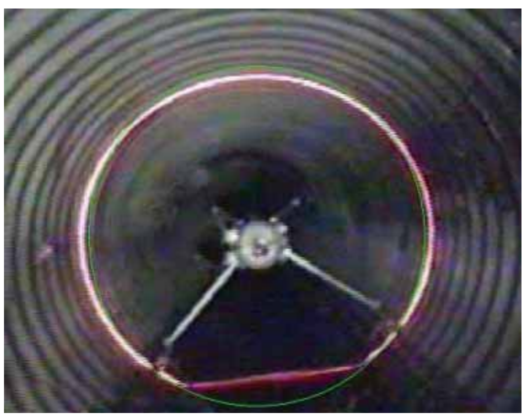


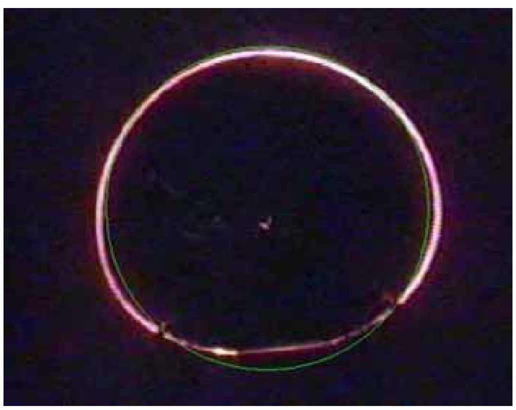
Figure 356 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Legacy Parkway)




a)


b)


c)

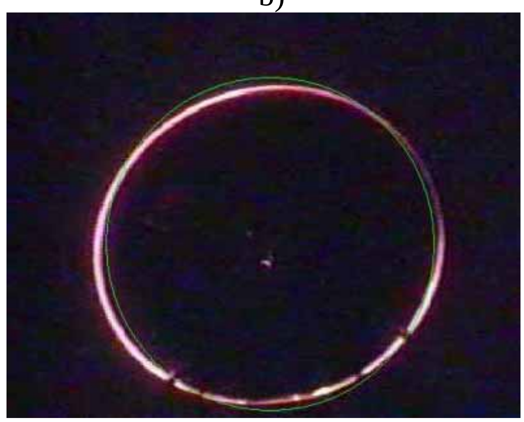
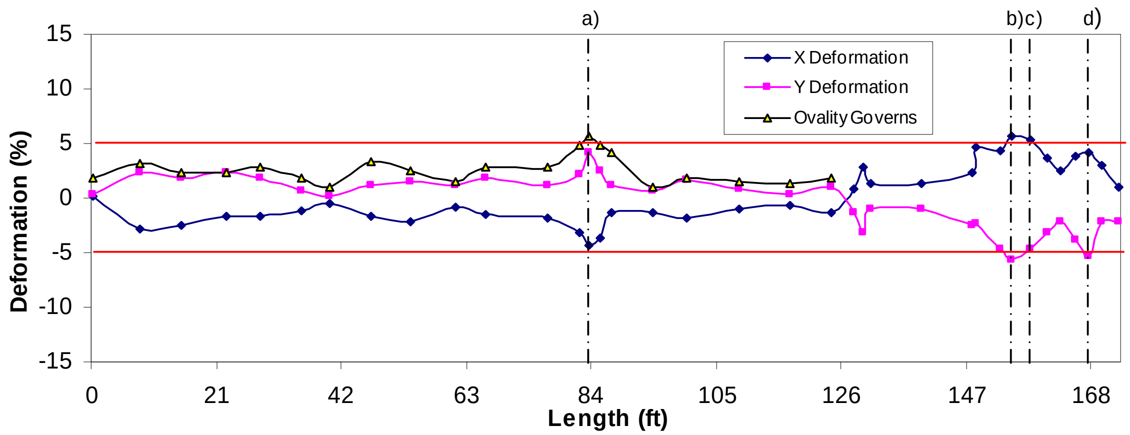
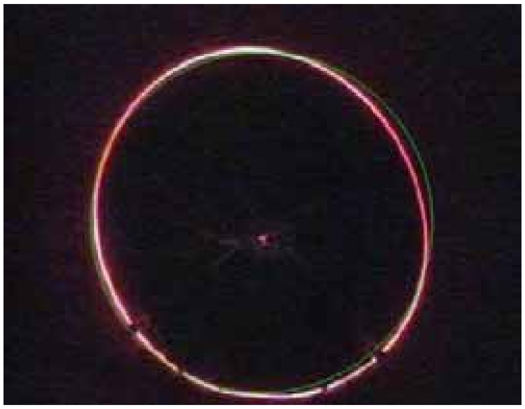

d)

Figure 357 Horizontal and vertical deformation of Pipeline No. 1 (Site No. 1: Legacy Parkway)

Figure 358 Corrugation growth and excessive deformation (refer to Figure 357-d) failure for Pipeline No. 1 (Site No. 1: Legacy Parkway)

Pipeline No. 2 (Site No. 1: Legacy Parkway)

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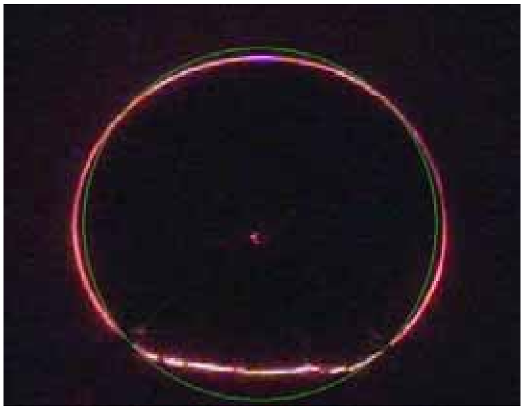
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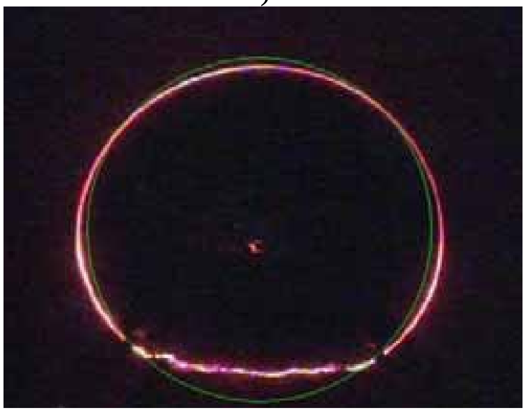
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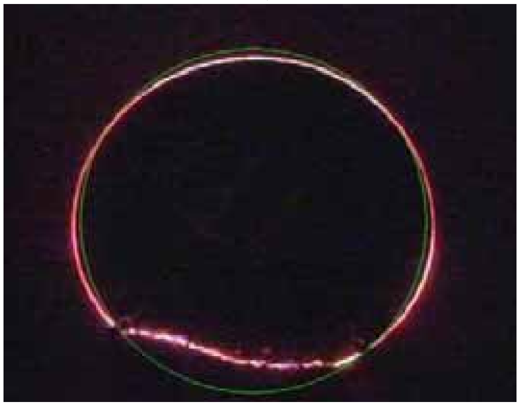

d)

Figure 359 Horizontal and vertical deformation of Pipeline No. 2 (Site No. 1: Legacy Parkway)

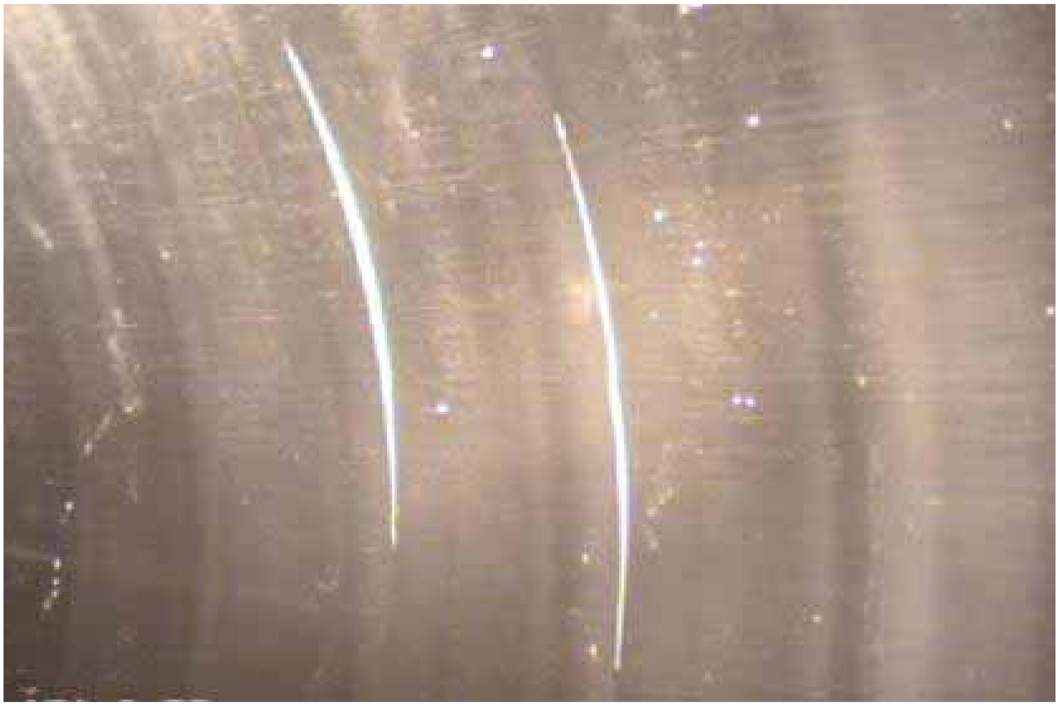


Figure 360 Cracking/fracture failure for Pipeline No. 2 (Site No. 1: Legacy Parkway)

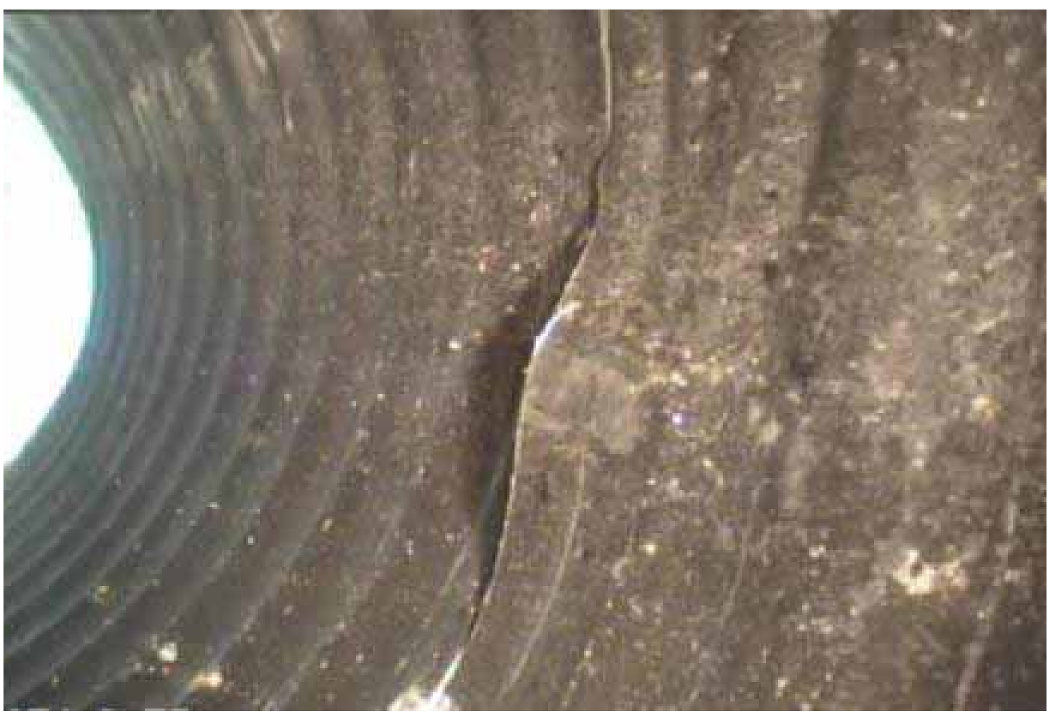
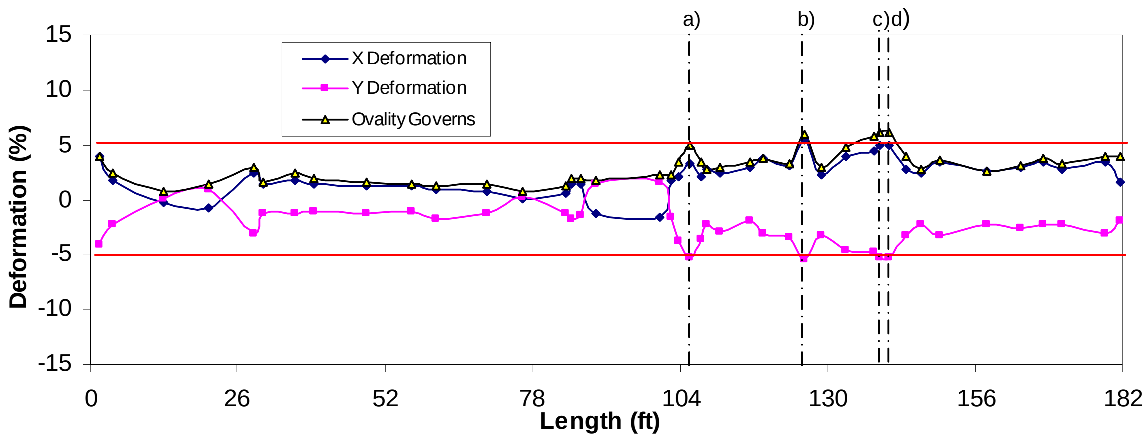
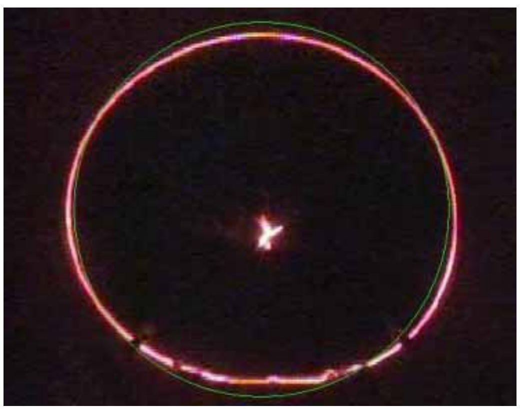


Figure 361 Cracking/fracture and inverse curvature failure for Pipeline No. 2 (Site No. 1: Legacy Parkway)

Pipeline No. 3 (Site No. 1: Legacy Parkway)





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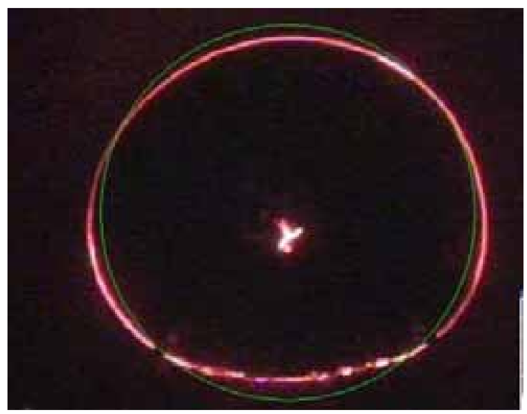

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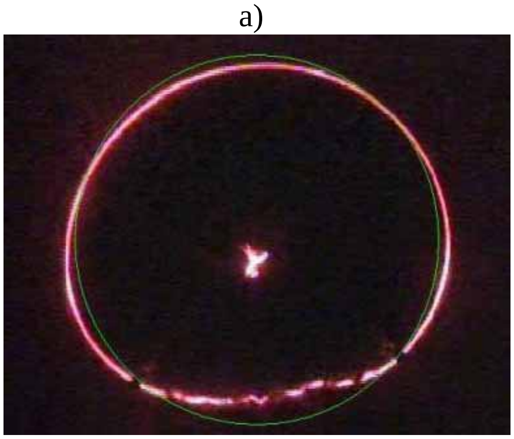

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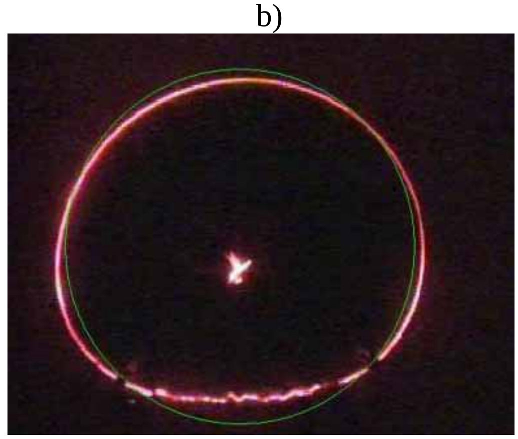
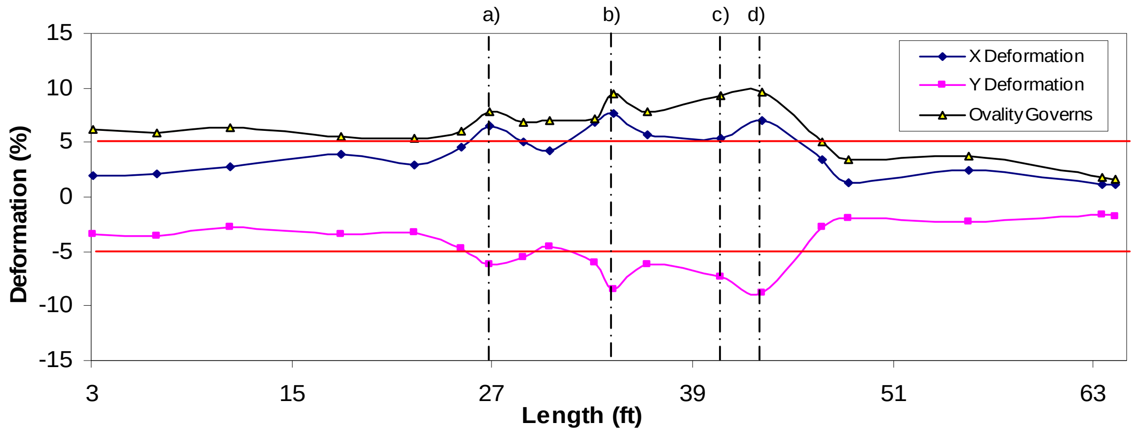


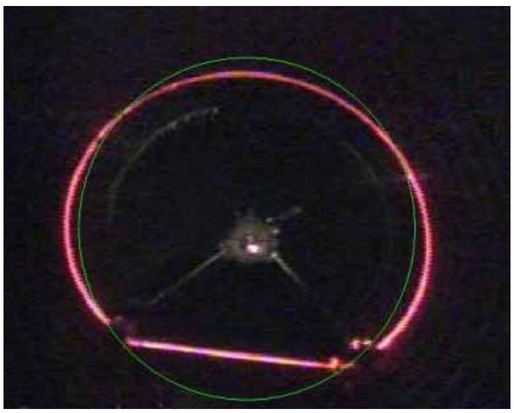
d)

Figure 362 Horizontal and vertical deformation of Pipeline No. 3 (Site No. 1: Legacy Parkway)

Figure 363 Excessive deformation failure (refer to Figure 362-d) for Pipeline No. 3 (Site No. 1: Legacy Parkway)

Pipeline No. 4 (Site No. 1: Legacy Parkway)

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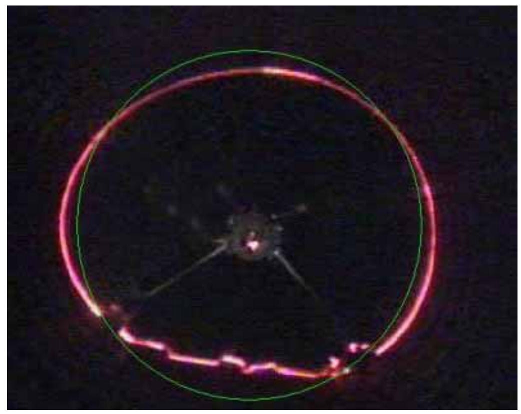
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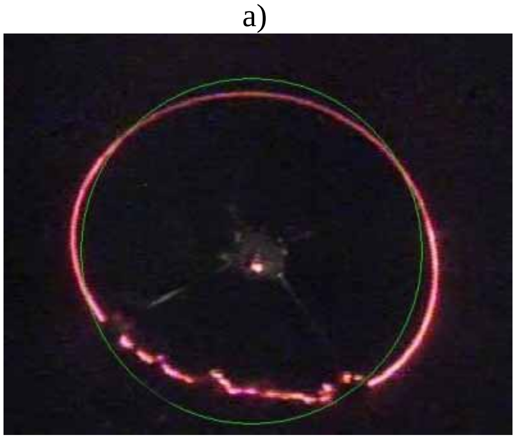
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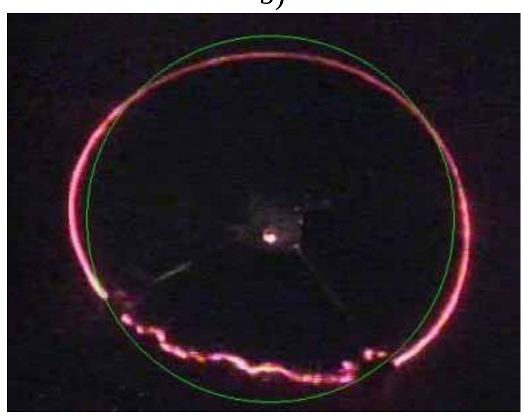

d)

Figure 364 Horizontal and vertical deformation of Pipeline No. 4 (Site No. 1: Legacy Parkway)

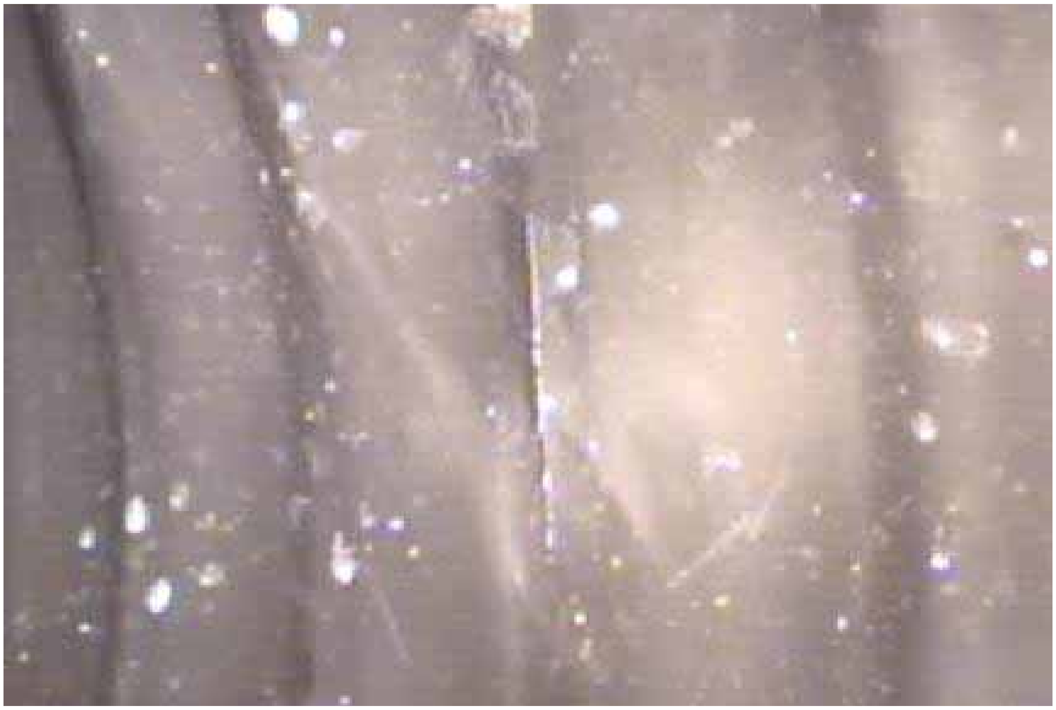


Figure 365 Cracking/fracture failure for Pipeline No. 4 (Site No. 1: Legacy Parkway)

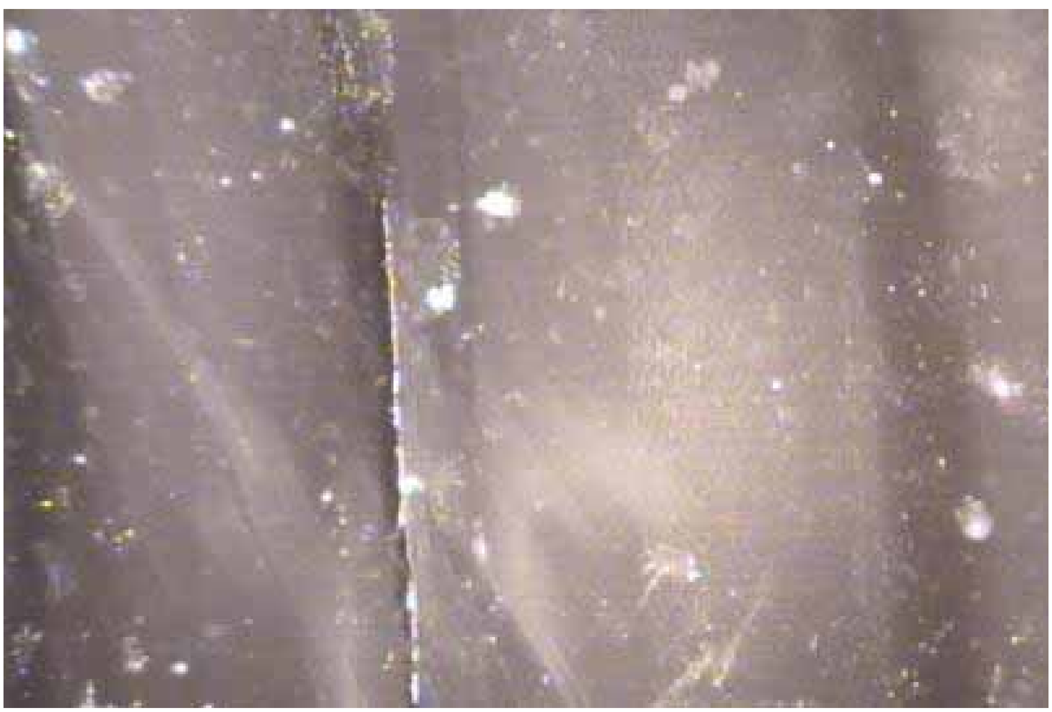
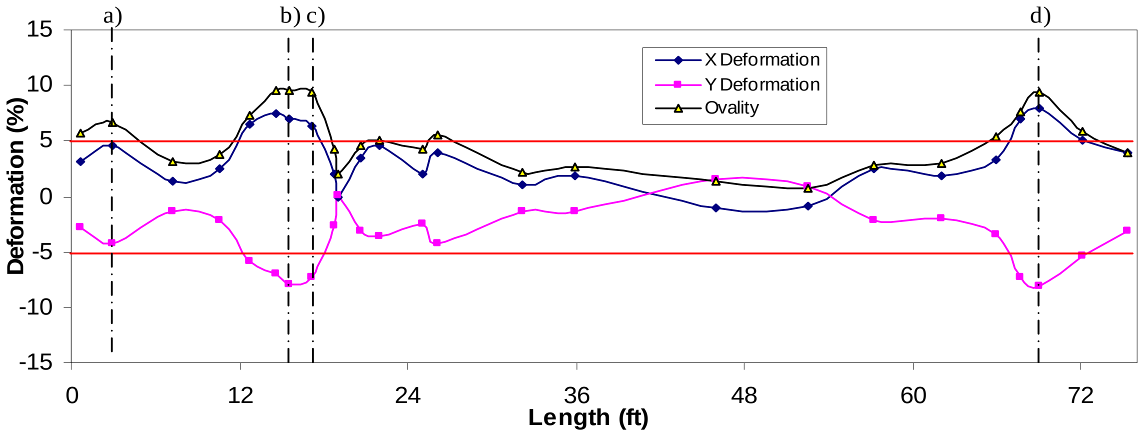


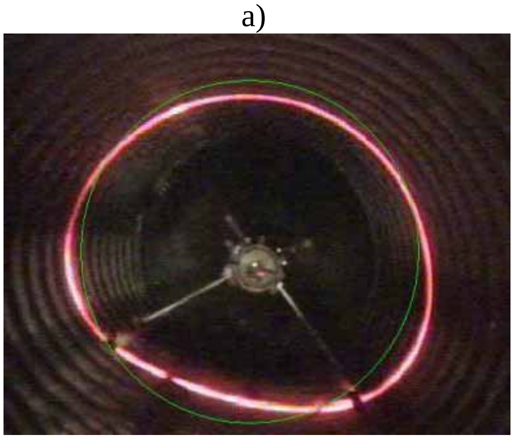
Figure 366 Cracking/fracture failure for Pipeline No. 4 (Site No. 1: Legacy Parkway)

Pipeline No. 5 (Site No. 1: Legacy Parkway)




a)


b)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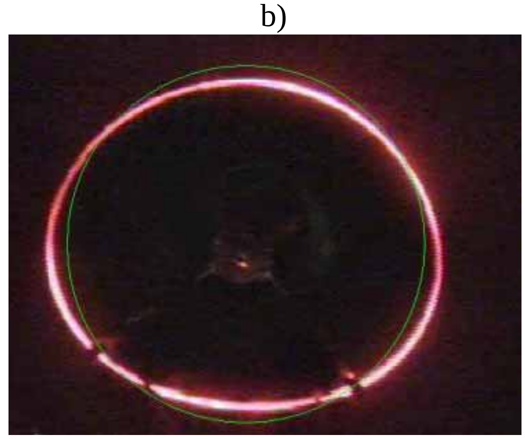

d)

Figure 367 Horizontal and vertical deformation of Pipeline No. 5 (Site No. 1: Legacy Parkway)

Pipeline No. 6 (Site No. 1: Legacy Parkway)

Figure 368 Corrugation growth, cracking/fracture, and inverse curvature failure and debris for Pipeline No. 6 (Site No. 1: Legacy Parkway)

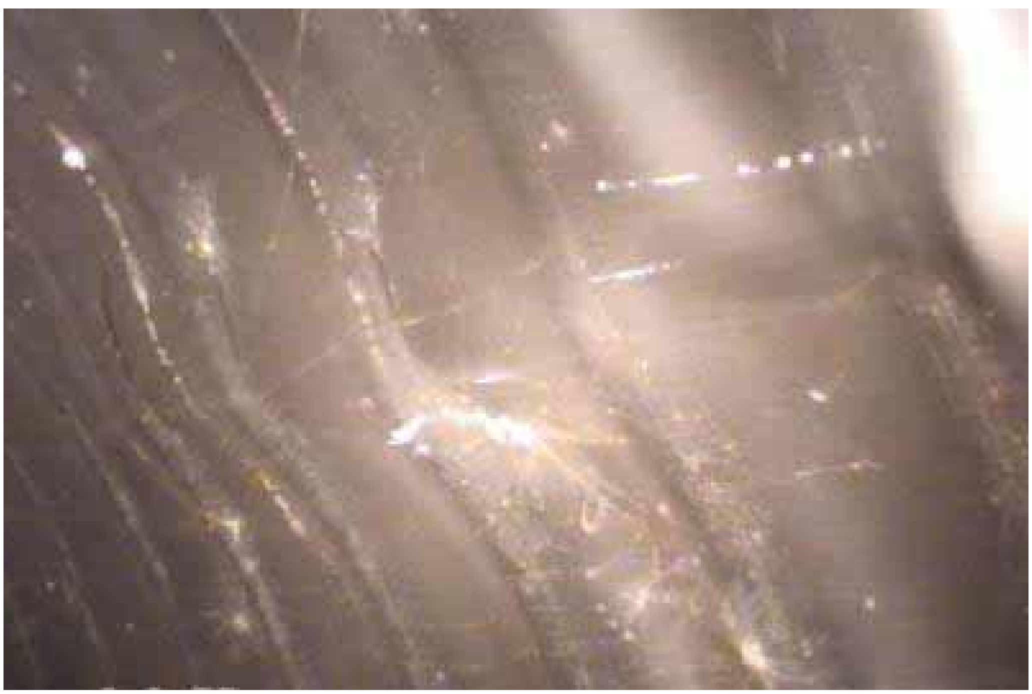


Figure 369 Cracking/fracture, buckling, and inverse curvature failure for Pipeline No. 6 (Site No. 1: Legacy Parkway)

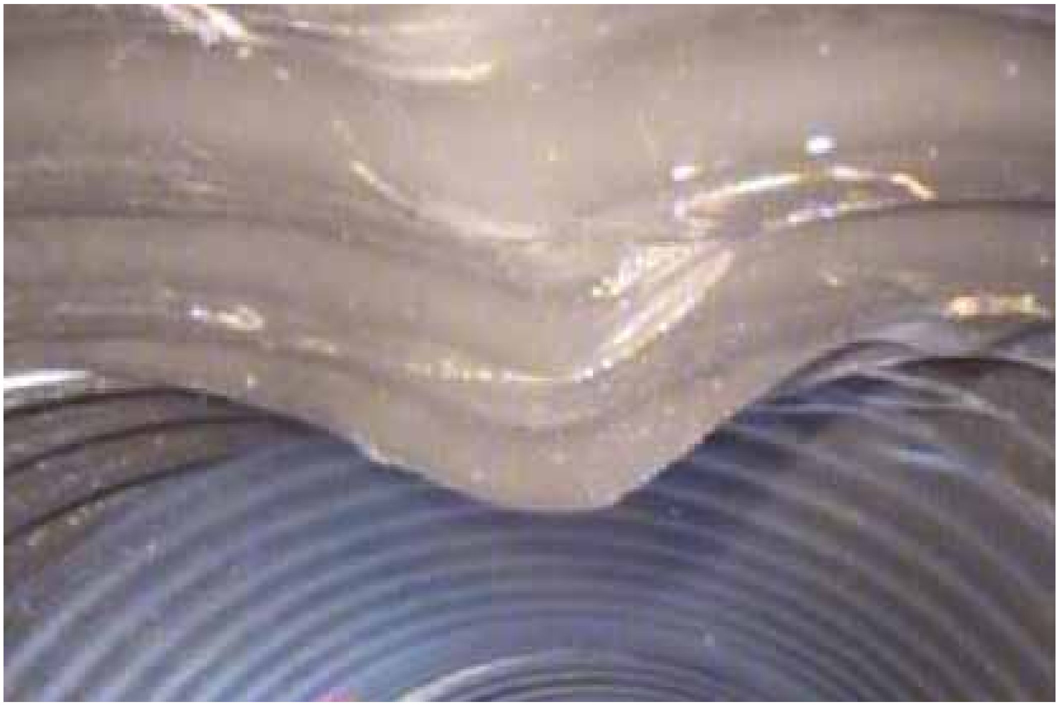


Figure 370 Cracking/fracture, corrugation growth, and inverse curvature failure for Pipeline No. 6 (Site No. 1: Legacy Parkway)

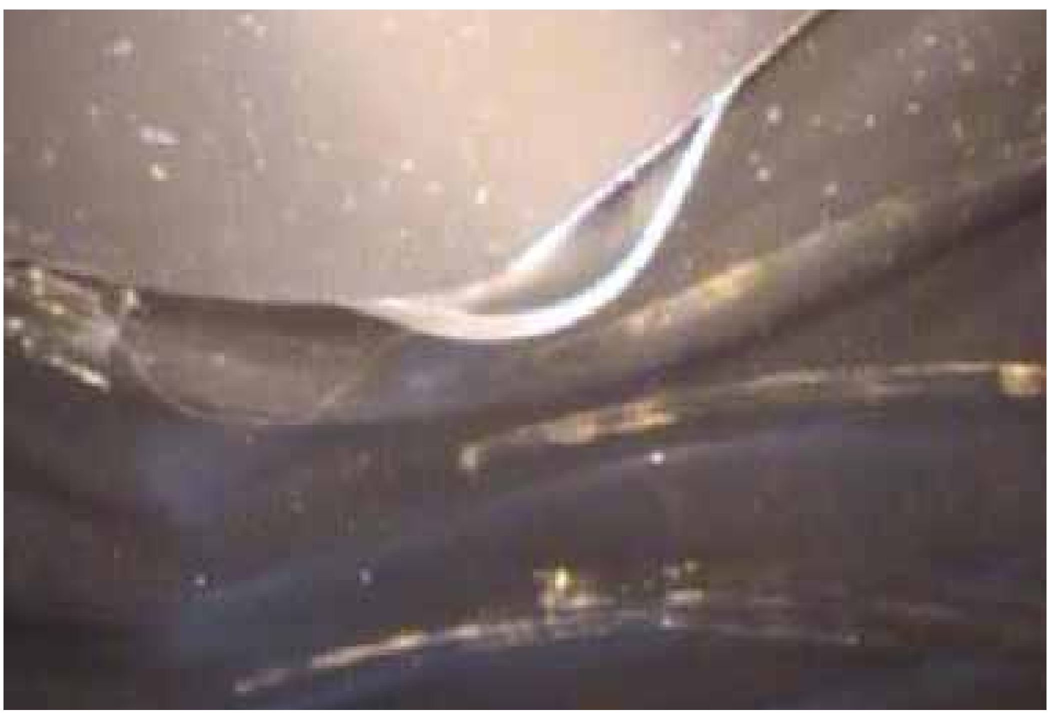
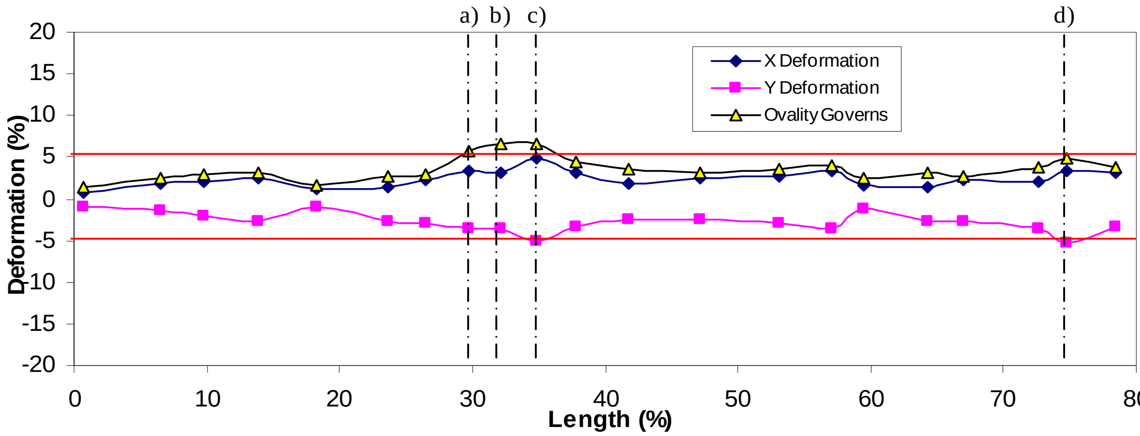
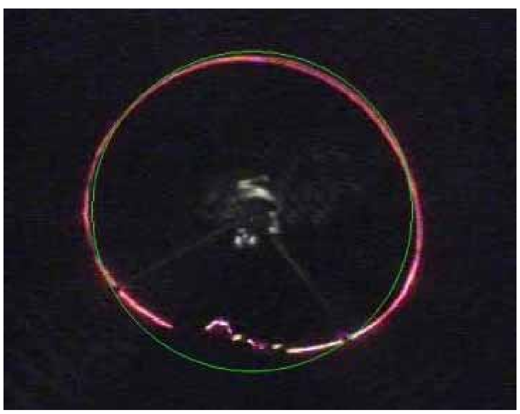


Figure 371 Cracking/fracture and inverse curvature failure for Pipeline No. 6 (Site No. 1: Legacy Parkway)

Figure 372 Cracking/fracture, corrugation growth, and inverse curvature failure for Pipeline No. 6 (Site No. 1: Legacy Parkway)

Pipeline No. 7 (Site No. 1: Legacy Parkway)

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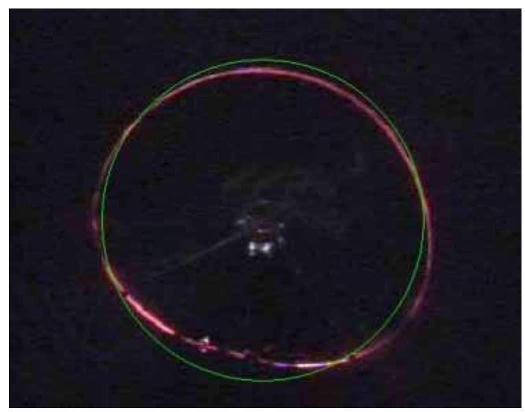
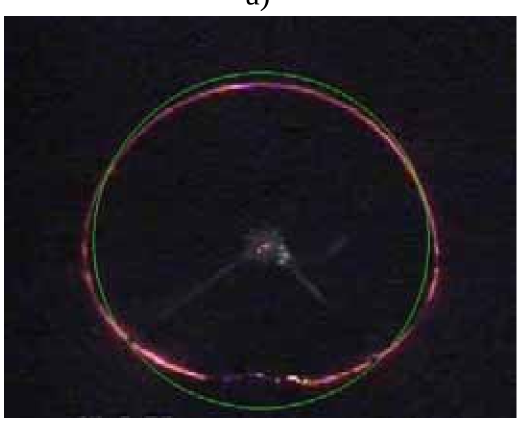

b)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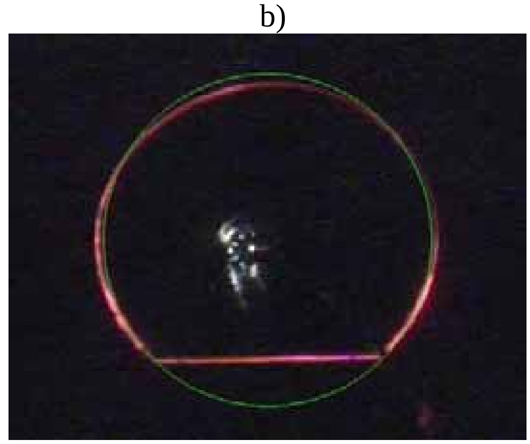

d)

Figure 373 Horizontal and vertical deformation of Pipeline No. 7 (Site No. 1: Legacy Parkway)

Pipeline No. 8 (Site No. 1: Legacy Parkway)

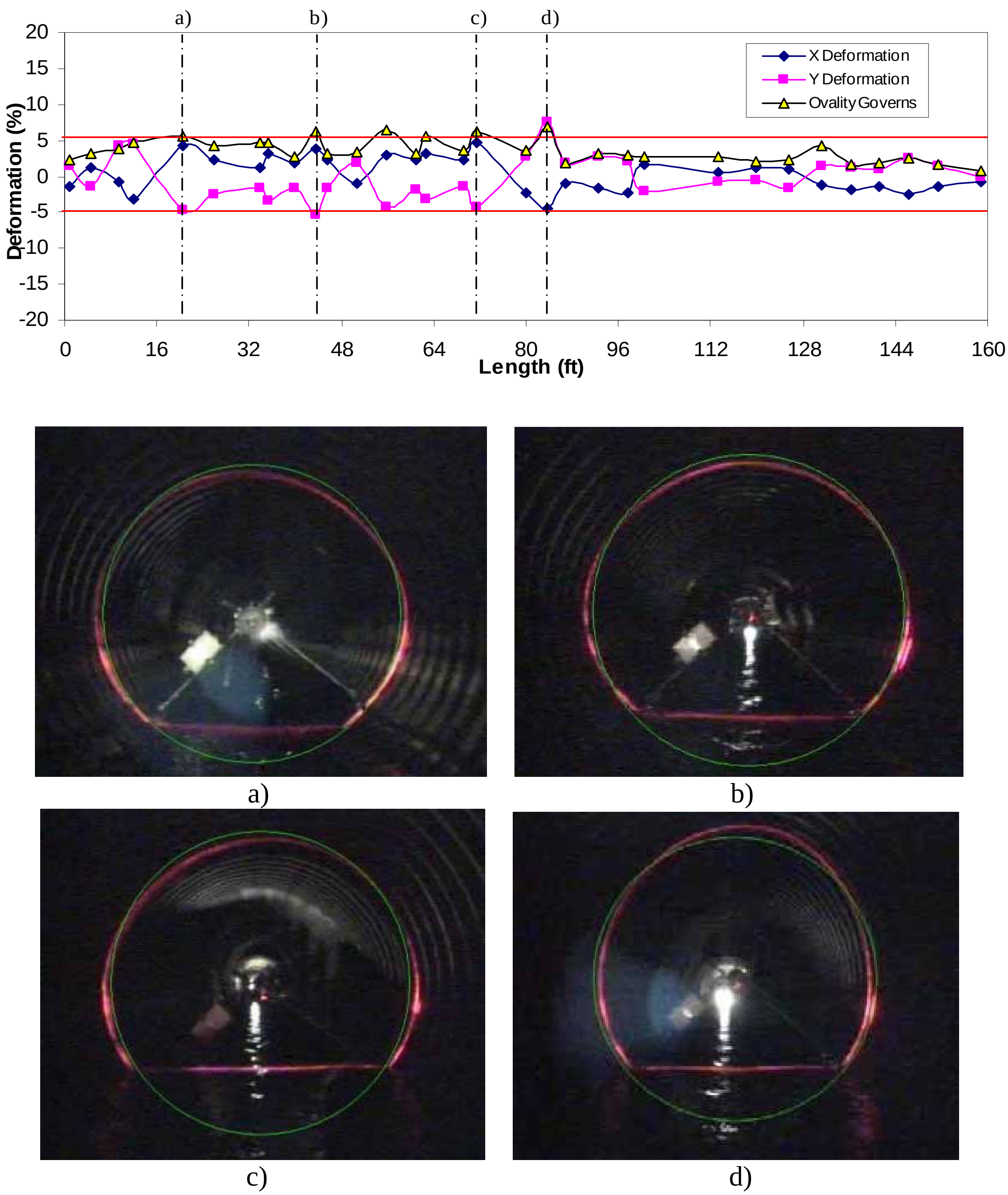
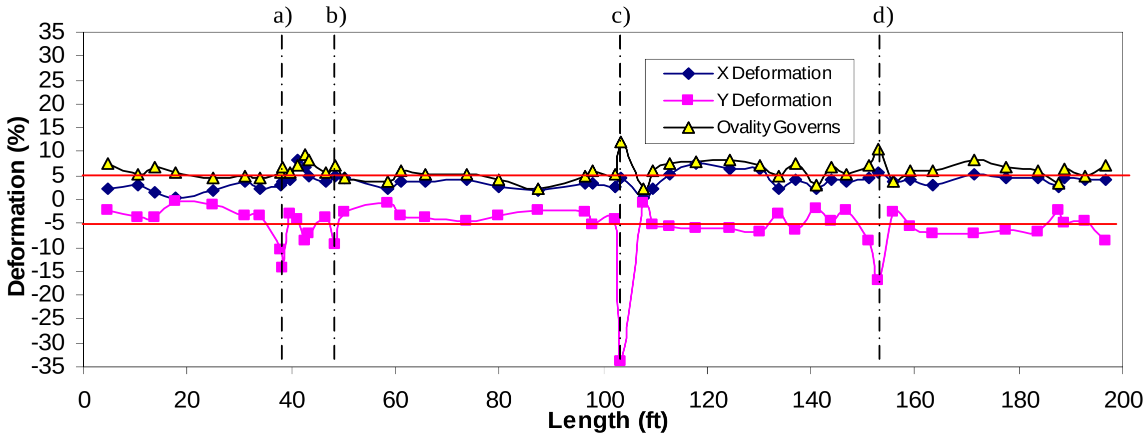
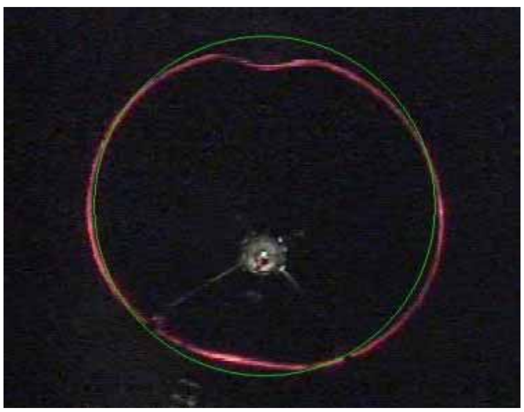


Figure 374 Horizontal and vertical deformation of Pipeline No. 8 (Site No. 1: Legacy Parkway)

Figure 375 Excessive deformation failure (refer to Figure 374-d) for Pipeline No. 8 (Site No. 1: Legacy Parkway)

Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

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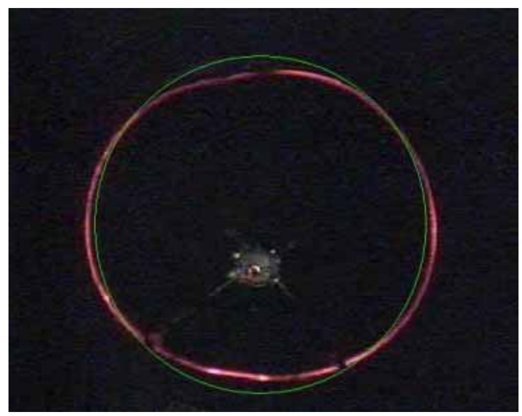
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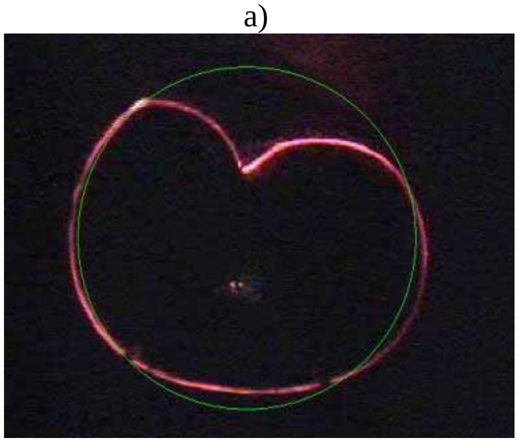
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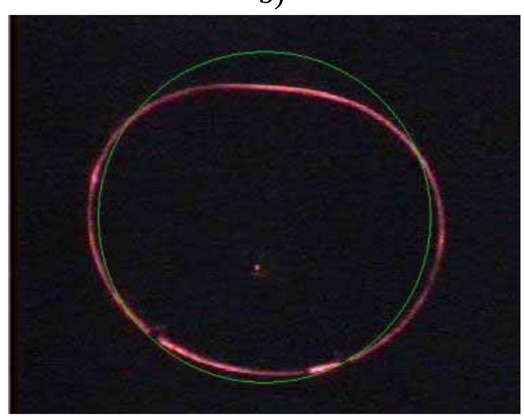

d)

Figure 376 Horizontal and vertical deformation of Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 377 Cracking/fracture failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 378 Cracking/fracture failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 379 Cracking/fracture and buckling failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 380 Cracking/fracture failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

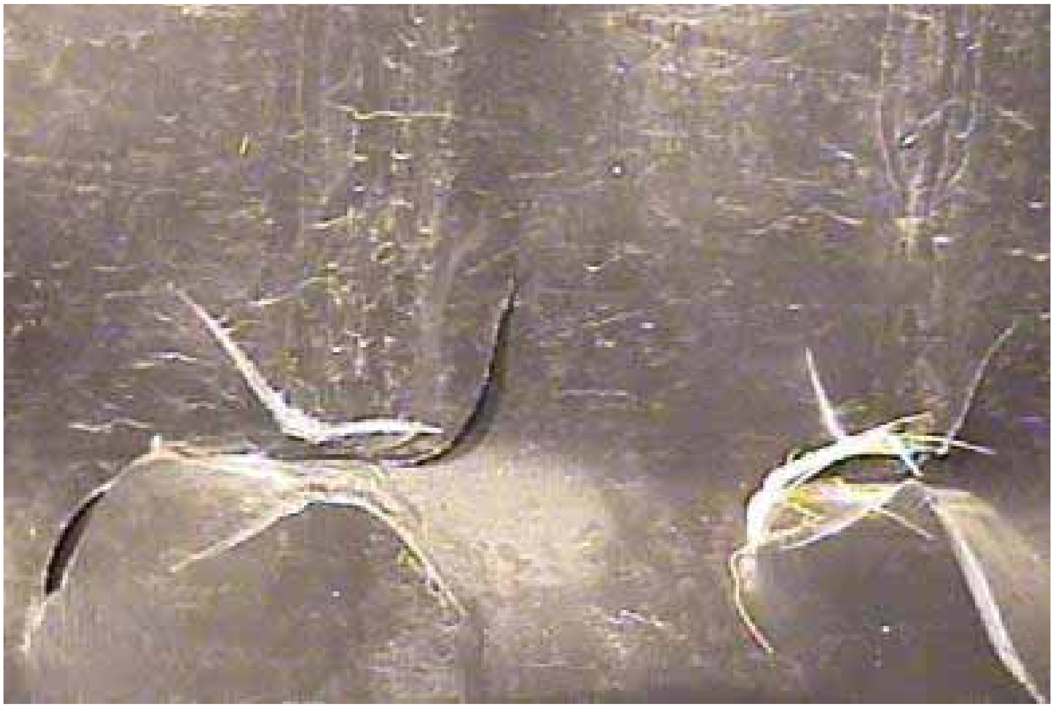


Figure 381 Cracking/fracture and buckling failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 382 Cracking/fracture failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Figure 383 Cracking/fracture, inverse curvature, buckling, and excessive deformation (refer to Figure 376-c), and corrugation growth failure for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

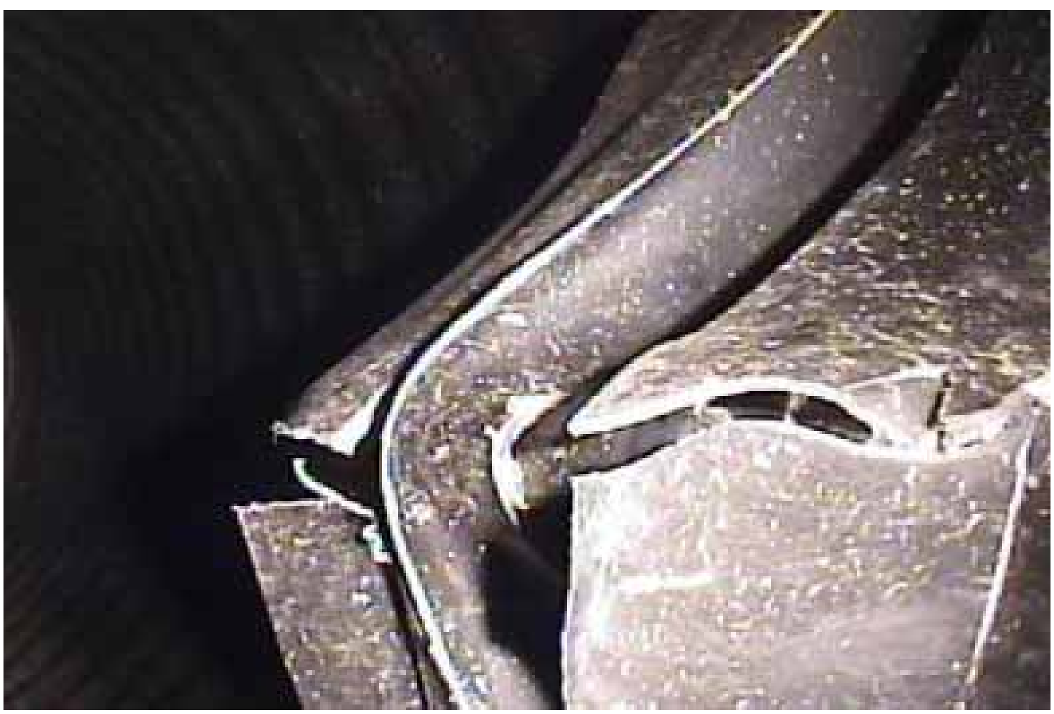
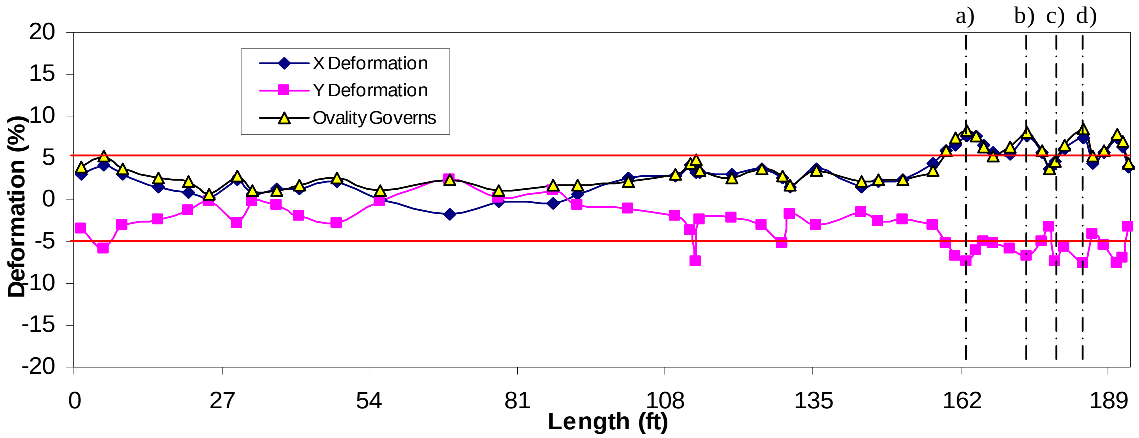


Figure 384 Cracking/fracture and inverse curvature failure from Figure 383 above for Pipeline No. 9 (Site No. 2: Silver Creek Parkway)

Pipeline No. 10 (Site No. 2: Silver Creek Parkway)



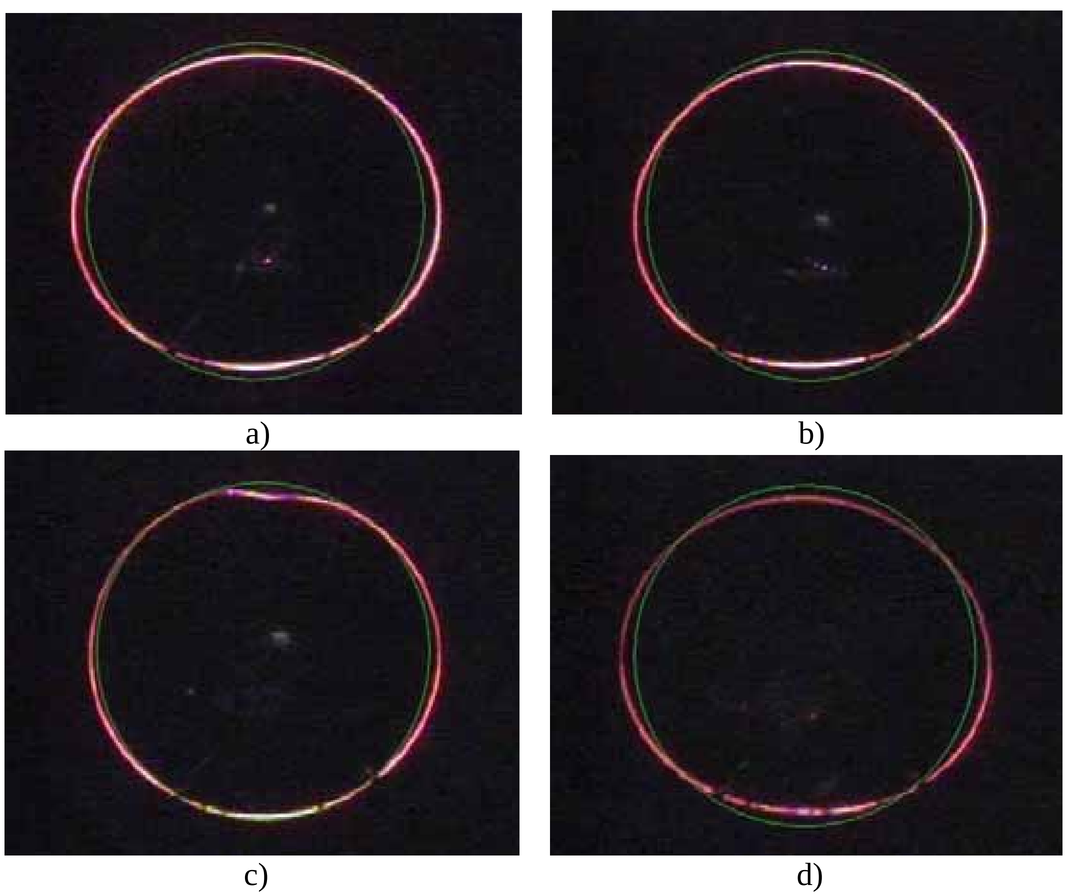


Figure 385 Horizontal and vertical deformation of Pipeline No. 10 (Site No. 2: Silver Creek Parkway)

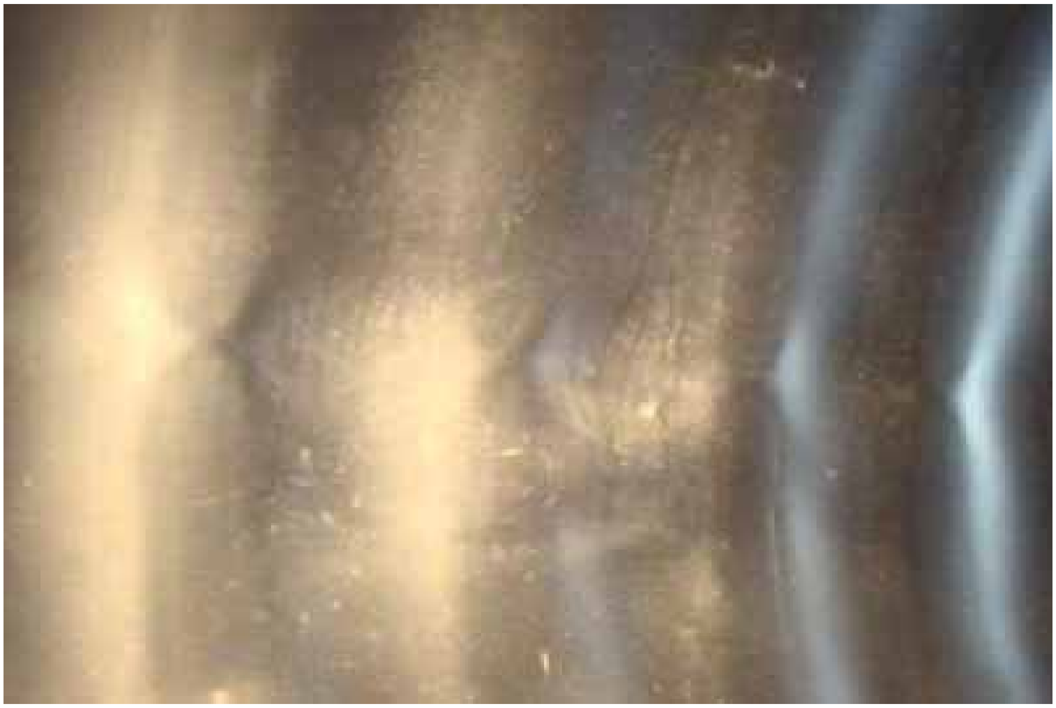


Figure 386 Buckling and corrugation growth failure for Pipeline No. 10 (Site No. 2: Silver Creek Parkway)

Figure 387 Cracking/fracture and buckling failure for Pipeline No. 10 (Site No. 2: Silver Creek Parkway)

Figure 388 Cracking/fracture and joint displacement failure for Pipeline No. 10 (Site No. 2: Silver Creek Parkway)

Figure 389 Cracking/fracture, corrugation growth, and inverse curvature failure for Pipeline No. 10 (Site No. 2: Silver Creek Parkway

Appendix 9 – State of Michigan

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Michigan. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

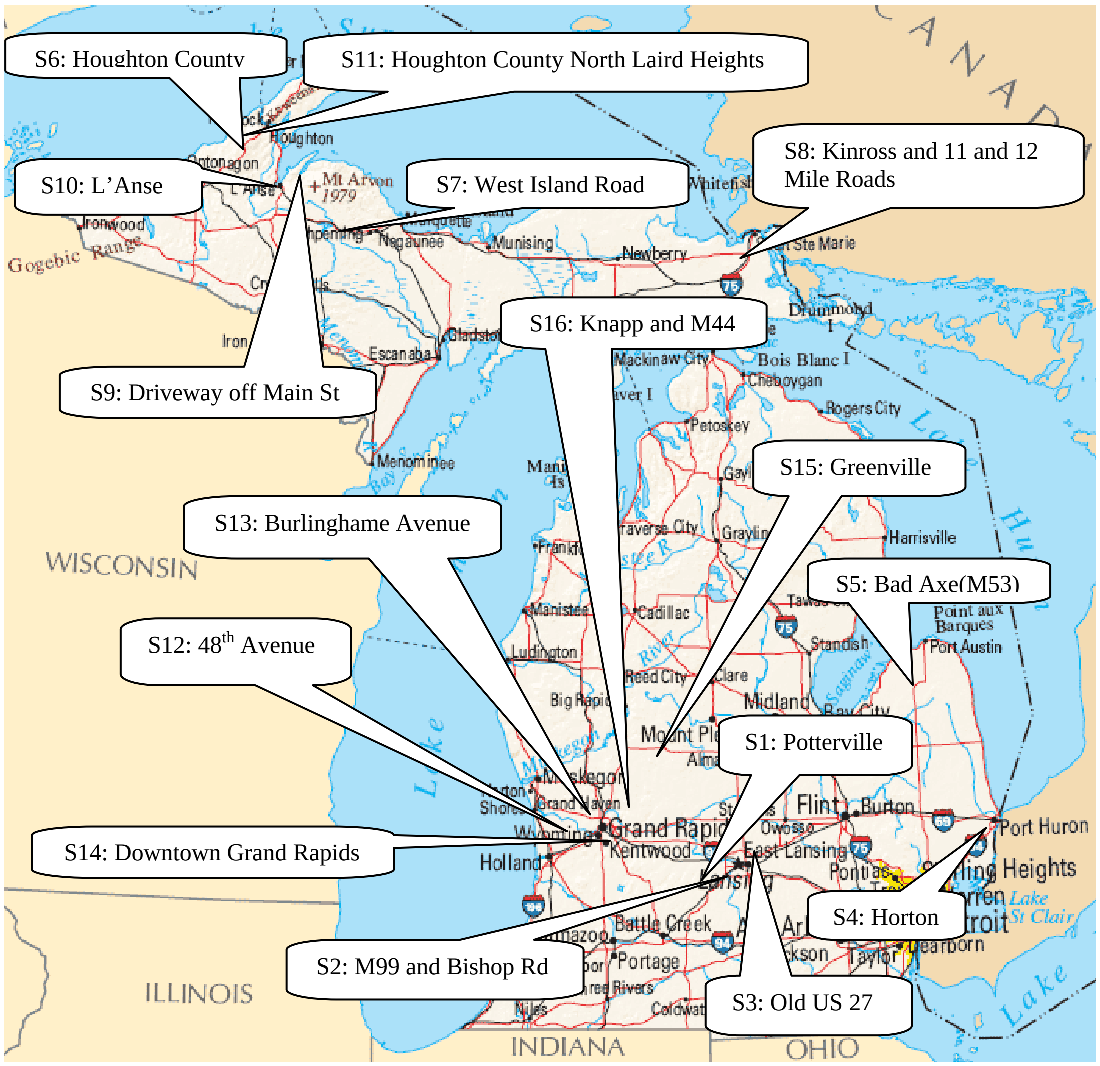


Figure 390 Layout of site numbers/locations

Table 28 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipe Sizes (in.)	Inspection date	Length (ft)
1	Potterville	1	30	8/18/2009	9
2	M99 & Bishop Rd	2	30	8/18/2009	370
3	Old US 27	3	60	8/18/2009	110
4	Horton	4	42	8/18/2009	420
5	Bad Axe (M53)	5	36	8/16/2009	385
6	Houghton County (M92)	6a*	42	8/14/2009	275
		6b	42	8/14/2009	350
7	W. Island Road	7*	30	8/16/2009	240
		8	36	8/17/2009	225
8	Kinross Road	9	36	8/16/2009	50
		10	36	8/16/2009	45
		11	36	8/16/2009	55
		12	36	8/16/2009	50
		13	48	8/15/2009	70
		14	18	8/15/2009	50
		15	18	8/15/2006	50
9	Driveway off Main Street L'Anse	16*	24	8/14/2009	30
10	L'Anse	17	24	8/14/2009	55
		18	24	8/14/2009	55
11	Houghton County-North Laird Heights	19	18	8/13/2009	35
		20	18	8/13/2009	35
		21	36	8/13/2009	50
		22	18	8/13/2009	35
12	48th Avenue	23	36	8/21/2009	90
13	Burlinghame Ave	24a	36	8/21/2009	160
		24b	36	8/21/2009	430
14	Downtown Grand Rapids	25	24	8/19/2009	290
15	Greenville	26	60	8/19/2009	325
		27	60	8/19/2009	385
16	Knapp and M44	28	24	8/19/2009	310
		29	24	8/19/2009	110

* Laser video data was not collected.

Table 29 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corrugation Growth	Buckling
1	Potterville	1		✓			✓	
2	M99 & Bishop Rd	2		✓			✓	
3	Old US 27	3					✓	
4	Horton	4	✓	✓			✓	✓
5	Bad Axe (M53)	5	✓	✓		✓	✓	
6	Houghton County (M92)	6a	✓	N.A.	✓	✓	✓	✓
		6b	✓	✓	✓		✓	✓
7	W. Island Road	7	✓	N.A.		✓	✓	
		8	✓	✓		✓	✓	✓
8	Kinross Road	9	✓	✓			✓	
		10		✓			✓	
		11		✓			✓	
		12		✓			✓	
		13	✓	✓			✓	✓
		14		✓			✓	
		15		✓			✓	
9	Driveway off Main Street L'Anse	16		N.A.			✓	
10	L'Anse	17					✓	
		18					✓	
11	Houghton County-North Laird Heights	19		✓			✓	
		20		✓			✓	
		21		✓			✓	✓
		22		✓			✓	
12	48th Avenue	23	✓	✓	✓	✓	✓	✓
13	Burlinghame Ave	24a		✓			✓	
		24b	✓	✓		✓	✓	
14	Downtown Grand Rapids	25					✓	
15	Greenville	26		✓			✓	
		27		✓			✓	
16	Knapp and M44	28					✓	
		29		✓			✓	
Percentage of pipelines experiencing failure mode			33%	82%	10%	19%	100%	23%

N.A. Laser Video was not performed due to limited access and/or inapplicable.

Table 30 Comparison and summary of deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Potterville	1	7.1	5.8	7.3	7.3
2	M99 & Bishop Rd	2	8	12.1	7.1	12.1
3	Old US 27	3	3.1	4.5	3.5	4.5
4	Horton	4	9.6	11.5	10.5	11.5
5	Bad Axe (M53)	5	6.1	7.9	6.8	7.9
6	Houghton County (M92)	6a*	NA	NA	NA	NA
		6b	9.8	15.5	14.1	15.5
7	W. Island Road	7*	NA	NA	NA	NA
		8	9.6	16.3	14.2	16.3
8	Kinross Road	9	7.0	8.9	8.3	8.9
		10	7.1	7.3	7.7	7.7
		11	11.6	11.2	13.6	13.6
		12	10.4	14.2	14.1	14.2
		13	13.1	19.8	16.8	19.8
		14	10.6	10.7	11.7	11.7
		15	7.1	8.8	8.5	8.8
9	Driveway off Main Street L'Anse	16*	NA	NA	NA	NA
10	L'Anse	17	4.3	3.3	4.4	4.4
		18	2.9	4.2	3.9	4.2
11	Houghton County-North Laird Heights	19	4.6	5.7	6.1	6.1
		20	5.6	5.4	5.9	5.9
		21	19.1	14.3	21.8	21.8
		22	8.7	7.8	10.1	10.1
12	48th Avenue	23	13.3	23.1	22.8	23.1
13	Burlinghame Ave	24a	5.6	6.1	7.3	7.3
		24b	9.6	19.8	12.5	19.8
14	Downtown Grand Rapids	25	3.4	4.1	4.1	4.1
15	Greenville	26	7.7	10.3	10.7	10.7
		27	4.3	5.6	6.1	6.1
16	Knapp and M44	28	3.5	3.7	3.8	3.8
		29	6.3	5.2	5.6	6.3
	Max		19.1	23.1	22.8	23.1
	Min		2.9	3.3	3.5	3.8
	Average		7.8	9.8	9.6	10.5

*Laser video data was not collected

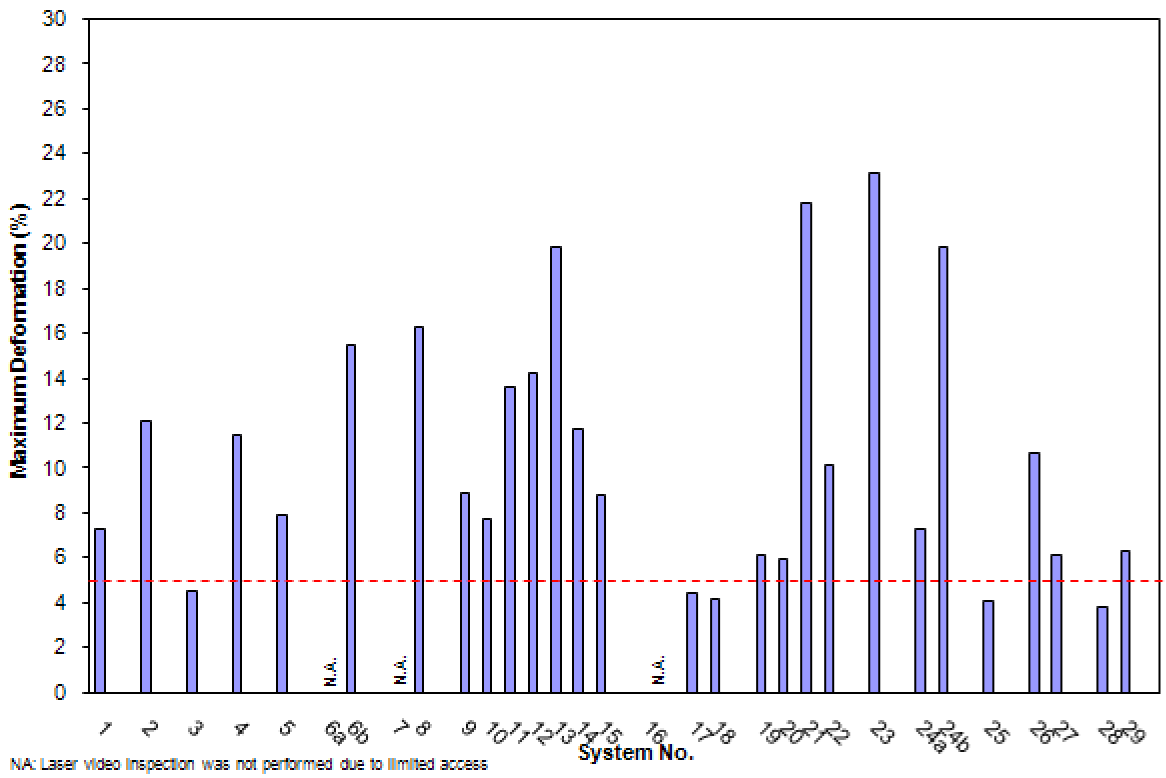
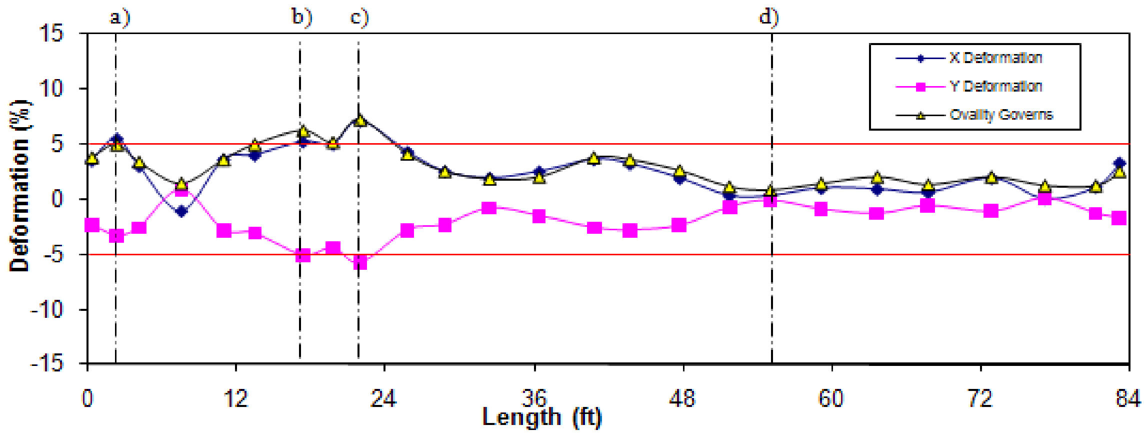
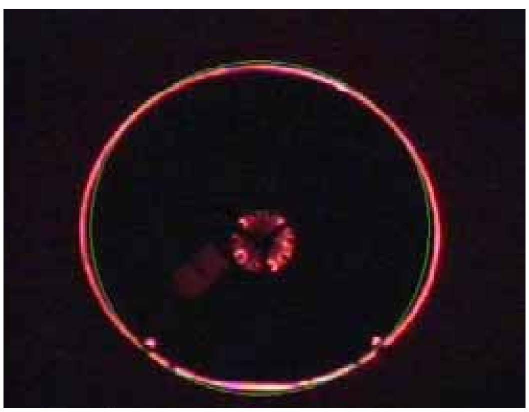
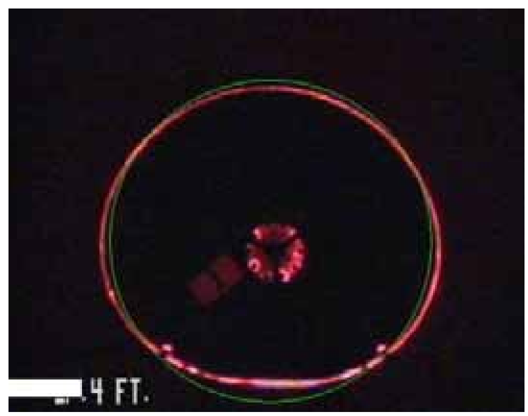


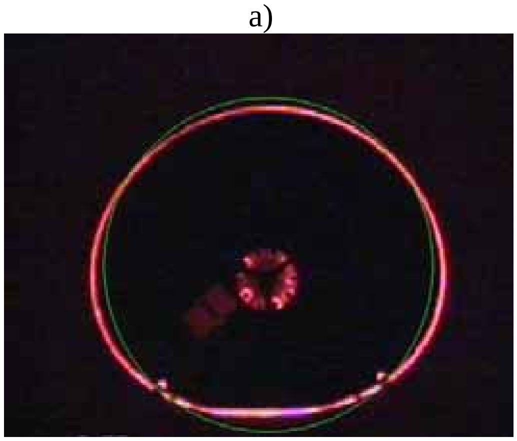
Figure 391 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Potterville)




a)

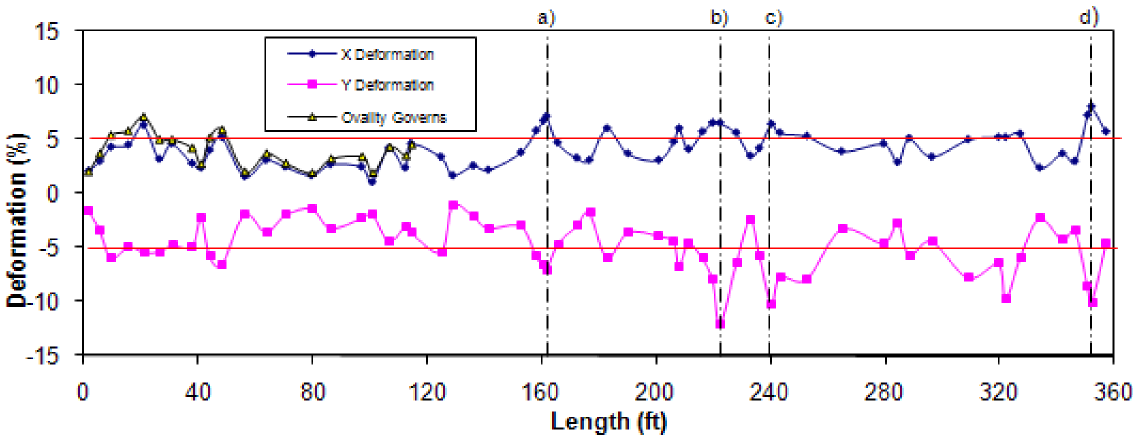

b)

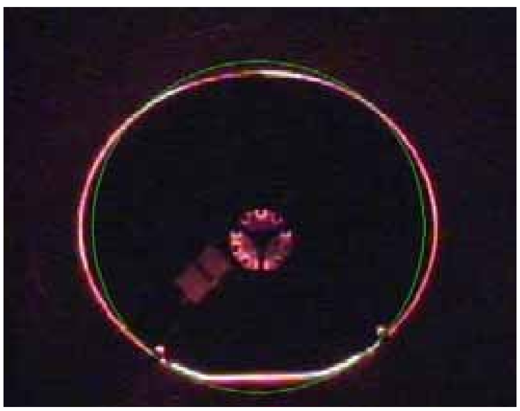

c)


d)

Figure 392 Horizontal and vertical deformation of Pipeline No. 1 (Site No. 1: Potterville)

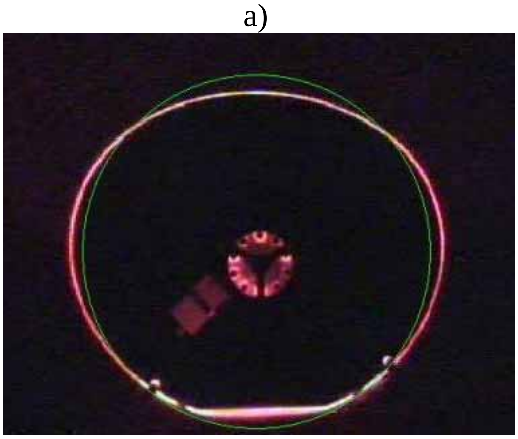
Pipeline No. 2 (Site No. 2: M99 & Bishop Rd.)





a)

b)



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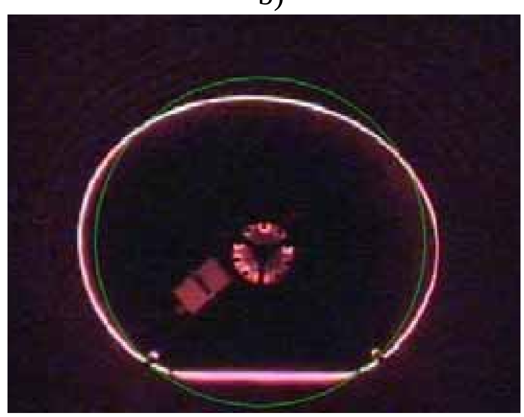
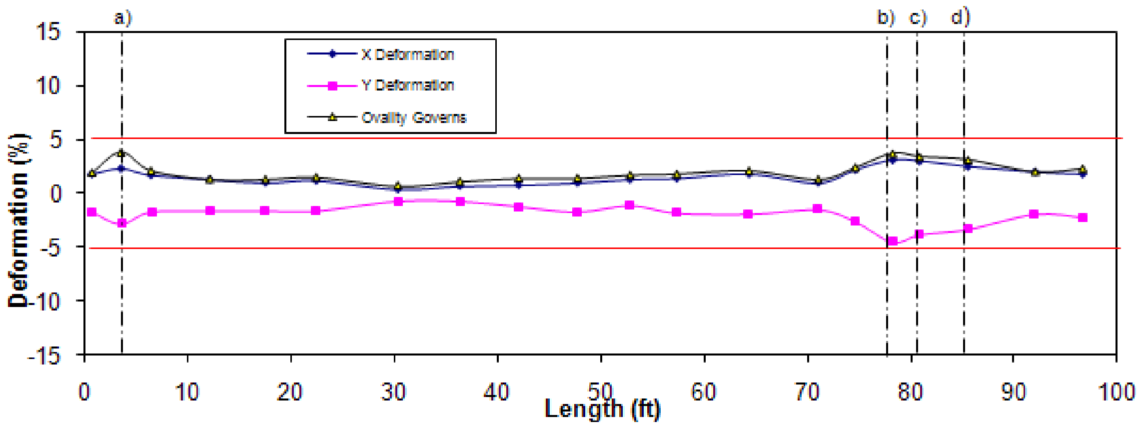


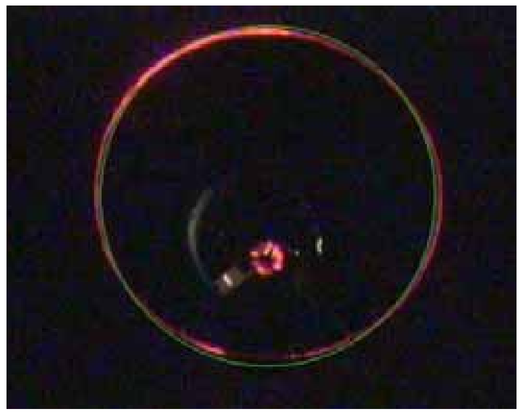
d)

Figure 393 Horizontal and vertical deformation of Pipeline No. 2 (Site No. 2: M99 & Bishop Rd.)

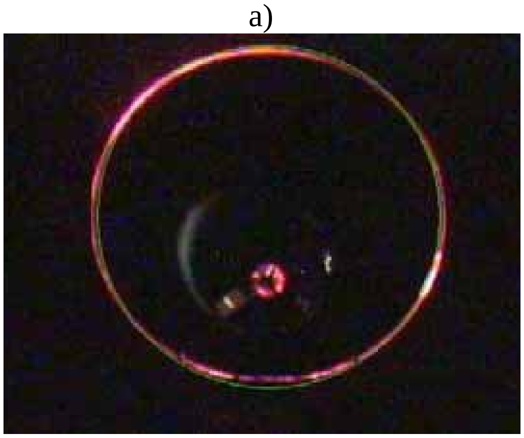
Pipeline No. 3 (Site No. 3 Old US 27)



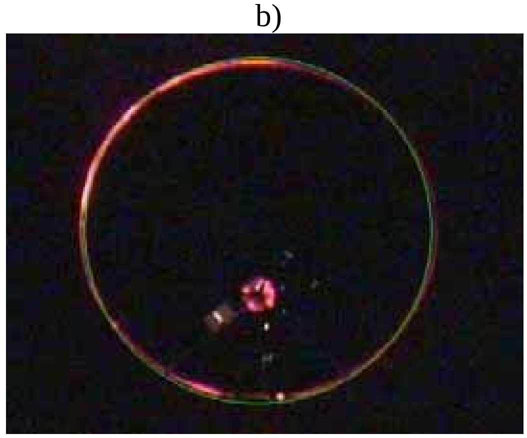
a)



b)



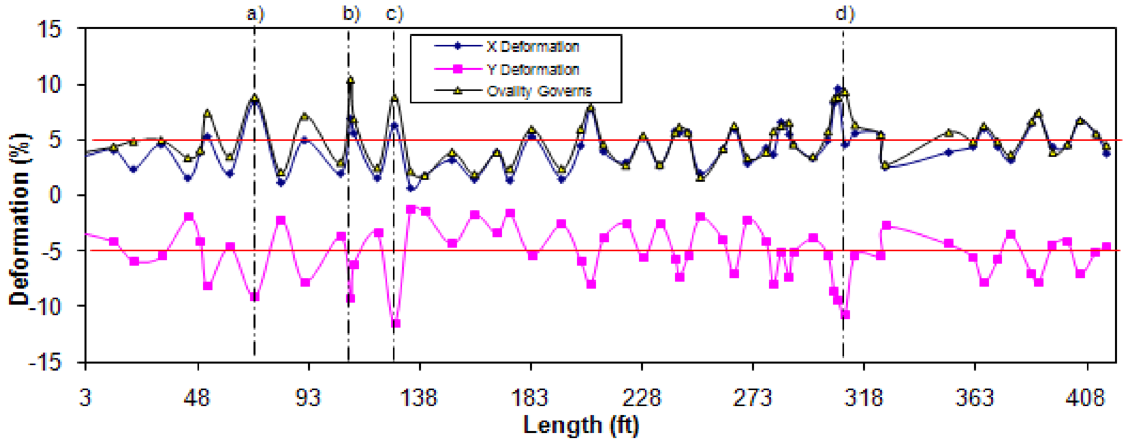
c)



d)

Figure 394 Horizontal and vertical deformation of Pipeline No. 3 (Site No. 3: Old US 27)

Pipeline No. 4 (Site No. 4 Horton)



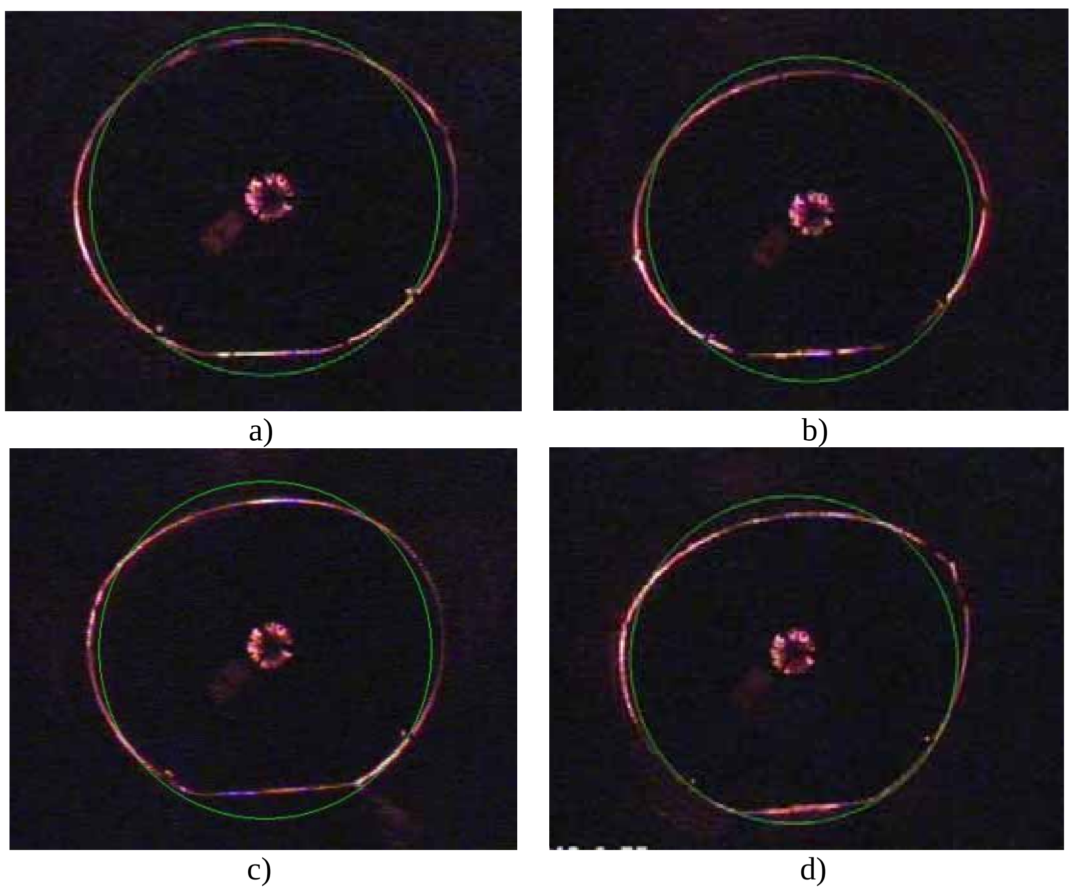


Figure 395 Horizontal and vertical deformation of Pipeline No. 4 (Site No. 4: Horton)

Figure 396 Cracking/fracture, corrugation growth, and buckling failure for Pipeline No. 4 (Site No. 4: Horton)

Figure 397 Corrugation growth and buckling failure for Pipeline No. 4 (Site No. 4: Horton Parkway

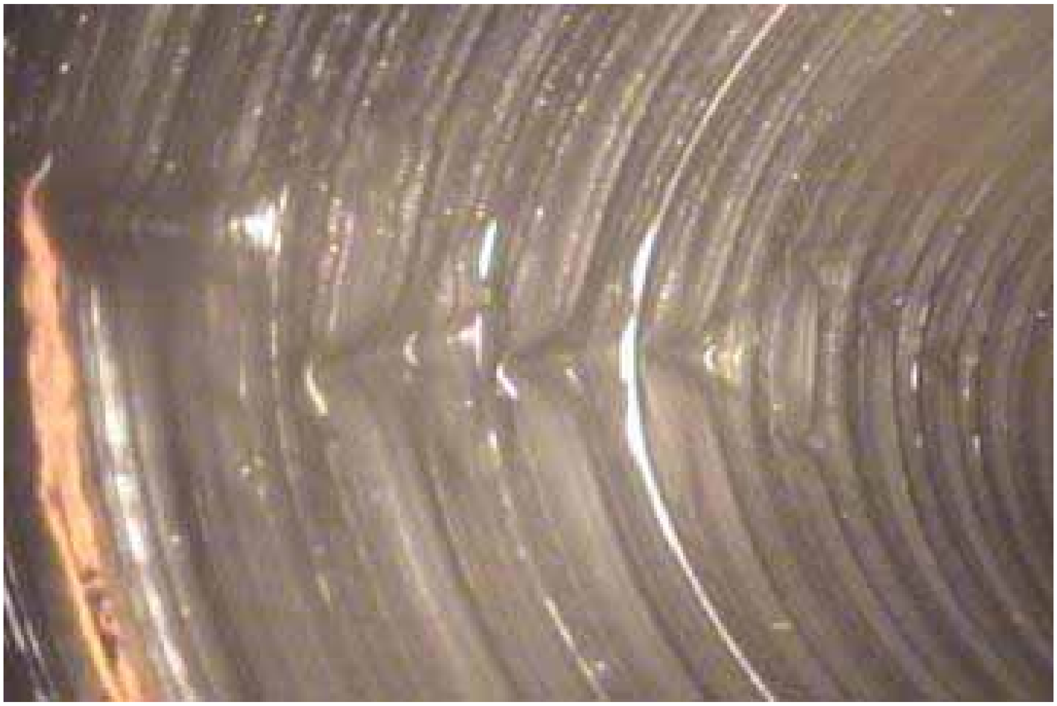


Figure 398 Cracking/fracture, corrugation growth, and buckling failure for Pipeline No. 4 (Site No. 4: Horton)

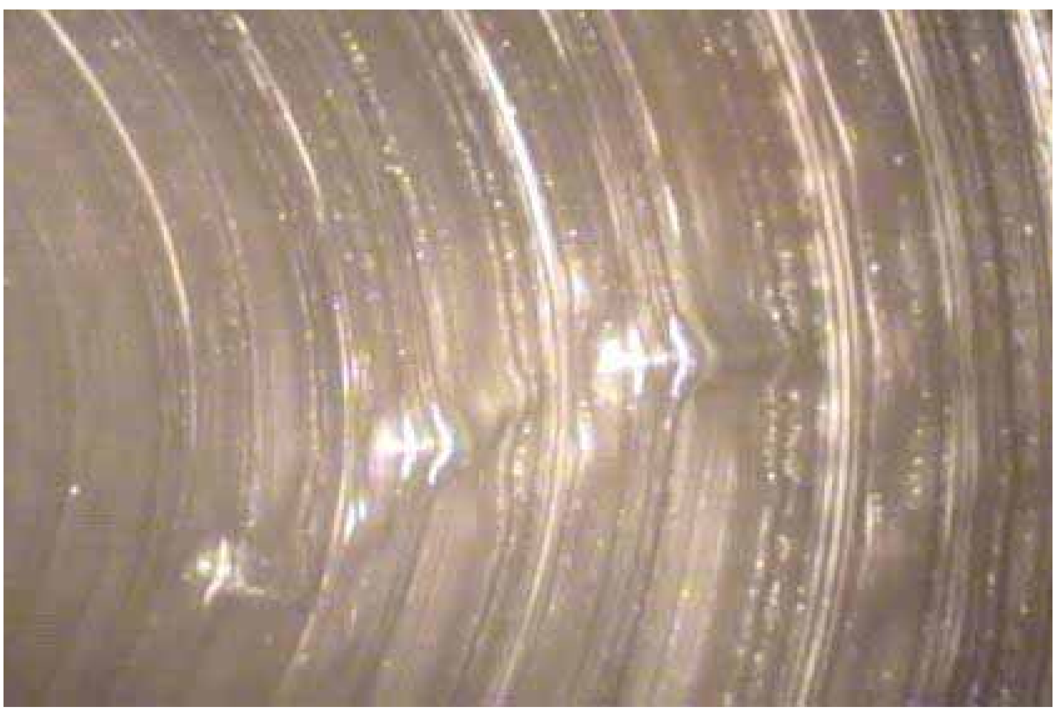
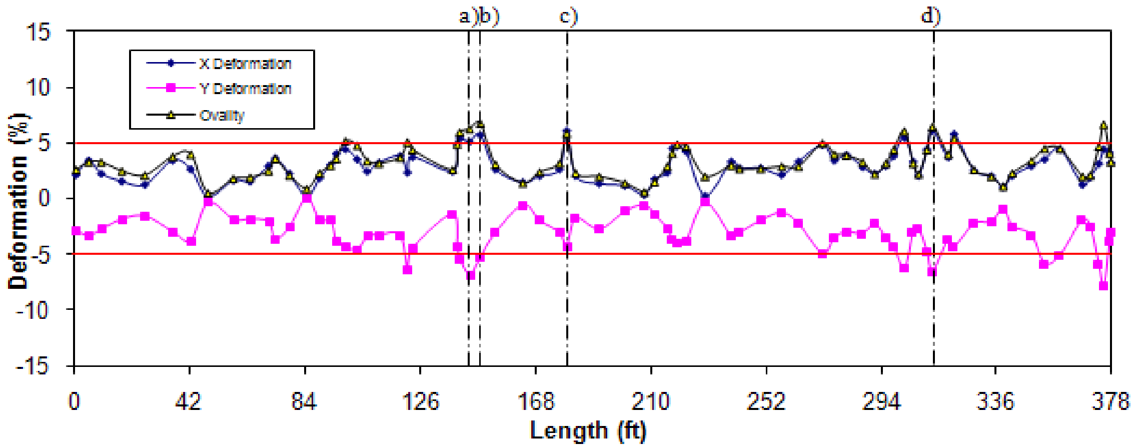
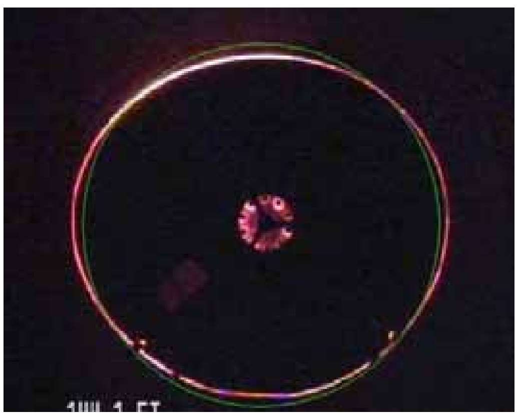


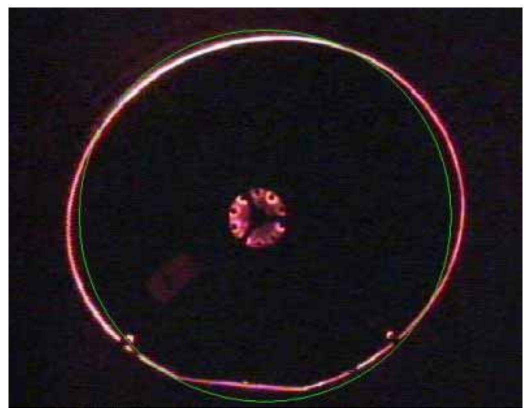
Figure 399 Cracking/fracture, corrugation growth, and buckling failure for Pipeline No. 4 (Site No. 4: Horton Parkway

Pipeline No. 5 (Site No. 5 Bad Axe M53)

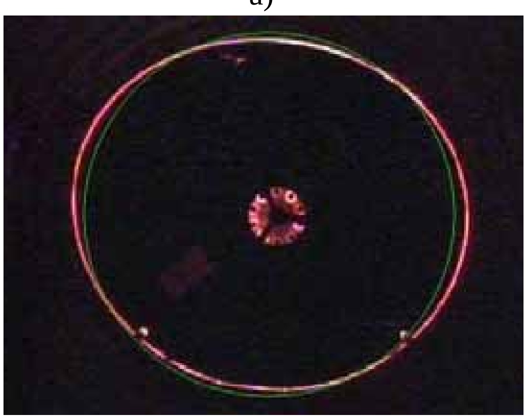




a)



b)



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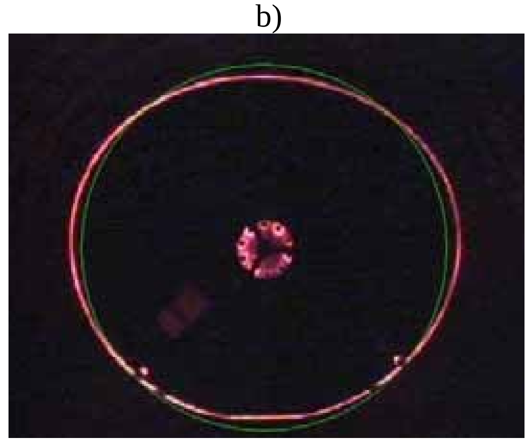


d)

Figure 400 Horizontal and vertical deformation of Pipeline No. 5 (Site No. 5: Bad Axe)

Figure 401 Cracking/fracture and major joint failure for Pipeline No. 5 (Site No. 5: Bad Axe)

Figure 402 Cracking/fracture and major joint failure for Pipeline No. 5 (Site No. 5: Bad Axe)

Figure 403 Cracking/fracture and major joint failure for Pipeline No. 5 (Site No. 5: Bad Axe)

Figure 404 Corrugation growth and major joint displacement failure for Pipeline No. 5 (Site No. 5: Bad Axe)

Pipeline No. 6a (Site No. 6 Houghton County M92)

Figure 405 Corrugation growth failure and debris for Pipeline No. 6a (Site No. 6: Houghton County M92)

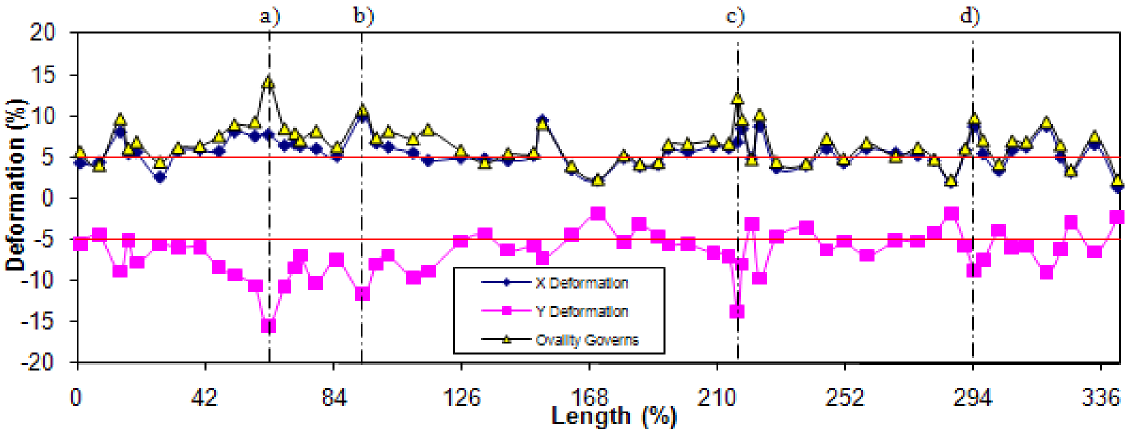
Figure 406 Corrugation growth failure with inlet added after installation for Pipeline No. 6a (Site No. 6: Houghton County M92)

Figure 407 Cracking/fracture failure for Pipeline No. 6a (Site No. 6: Houghton County M92)

Figure 408 Corrugation growth and cracking/fracture failure for Pipeline No. 6a (Site No. 6: Houghton County M92)

Figure 409 Cracking/fracture failure for Pipeline No. 6a (Site No. 6: Houghton County M92)

Pipeline No. 6b (Site No. 6 Houghton County M92)



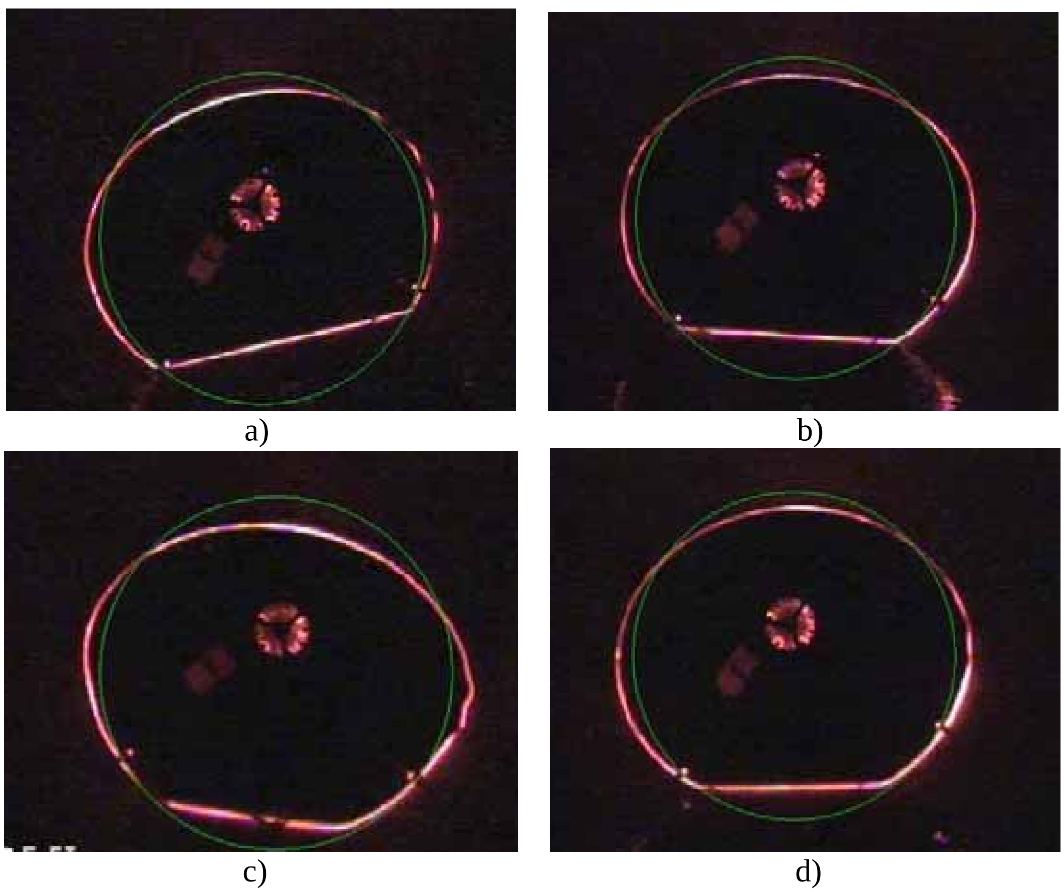


Figure 410 Horizontal and vertical deformation of Pipeline No. 6b (Site No. 6: Houghton County M92)

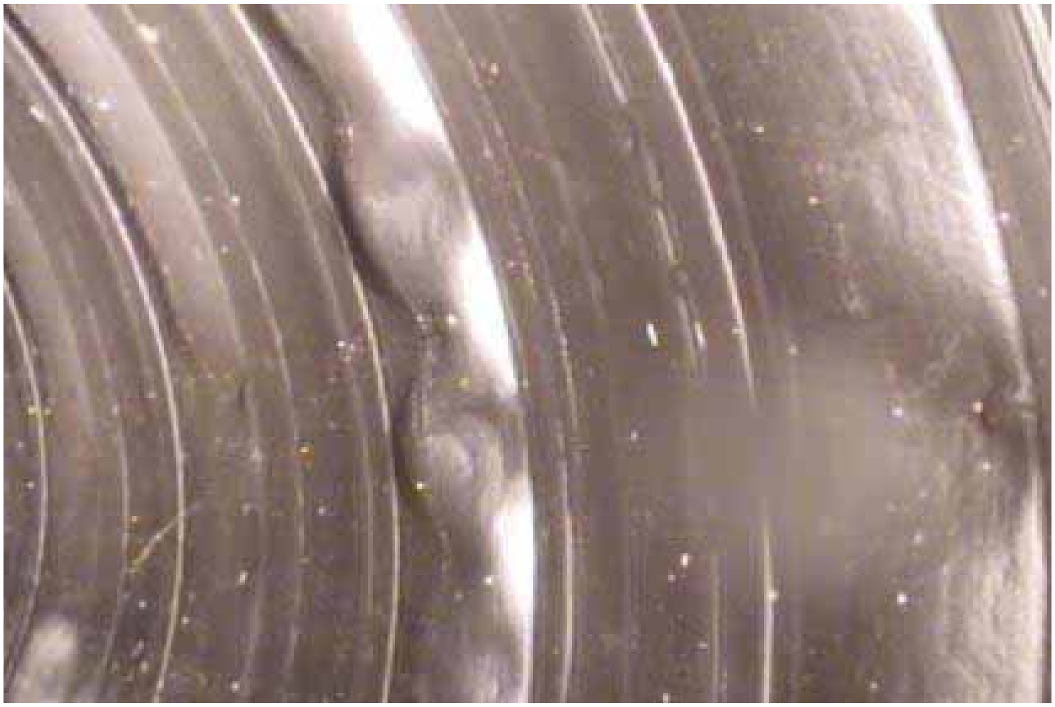


Figure 411 Buckling failure for Pipeline No. 6b (Site No. 6: Houghton County M92)

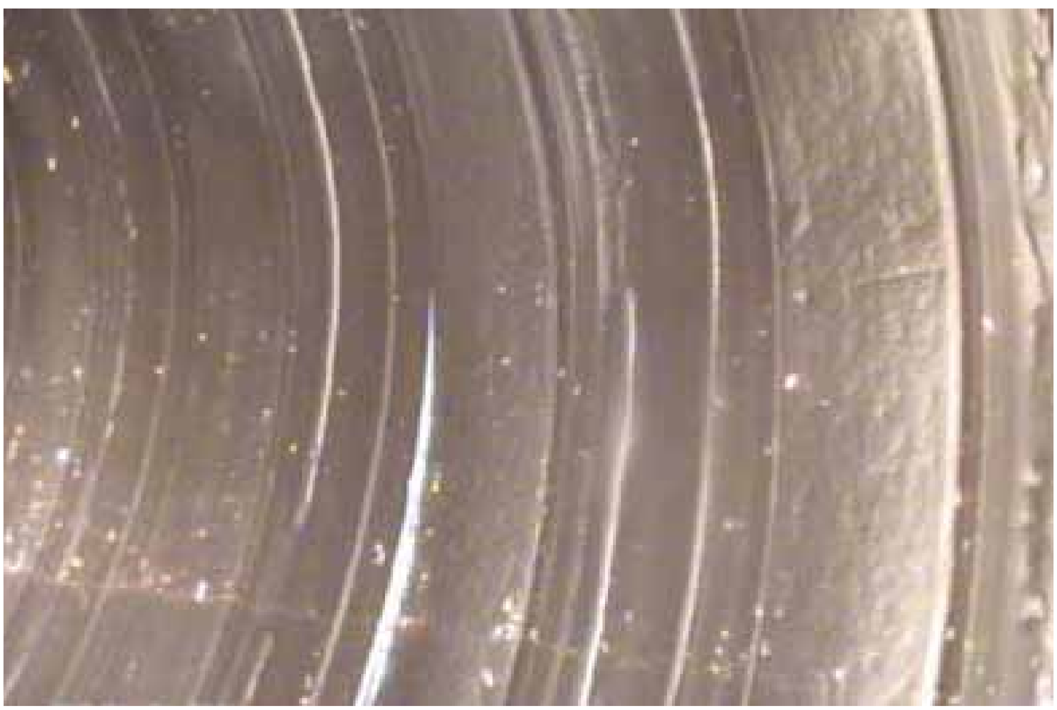


Figure 412 Cracking/fracture failure for Pipeline No. 6b (Site No. 6: Houghton County M92)

Figure 413 Cracking/fracture failure for Pipeline No. 6b (Site No. 6: Houghton County M92)

Figure 414 Cracking/fracture and inverse curvature failure for Pipeline No. 6b (Site No. 6: Houghton County M92)

Pipeline No. 7 (Site No. 7 West Island Road)

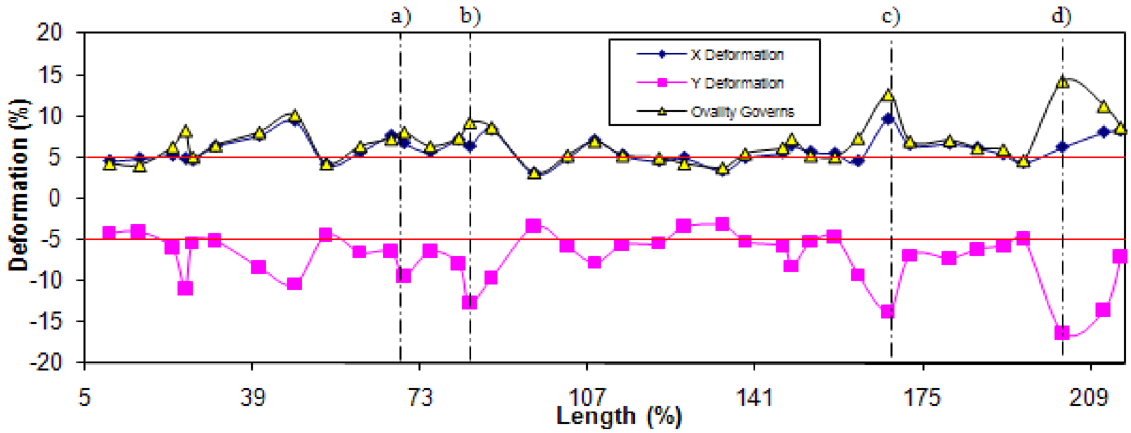
Figure 415 Cracking/fracture and major joint displacement failure for Pipeline No. 7 (Site No. 7: West Island Road)

Figure 416 Cracking/fracture, major joint displacement, and corrugation growth failure for Pipeline No. 7 (Site No. 7: West Island Road)

Figure 417 Cracking/fracture failure for Pipeline No. 7 (Site No. 7: West Island Road)

Figure 418 Cracking/fracture and corrugation growth failure for Pipeline No. 7 (Site No. 7: West Island Road)

Pipeline No. 8 (Site No. 7 West Island Road)



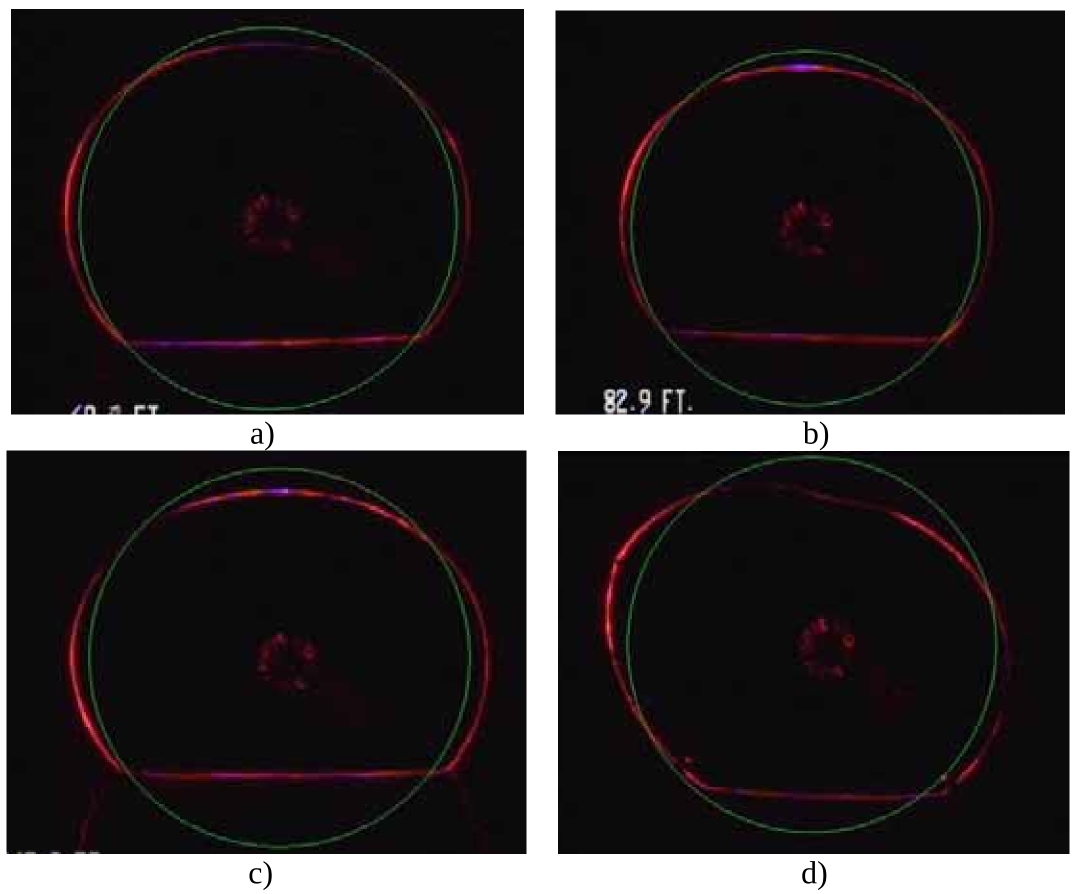


Figure 419 Horizontal and vertical deformation of Pipeline No. 8 (Site No. 7: West Island Road)

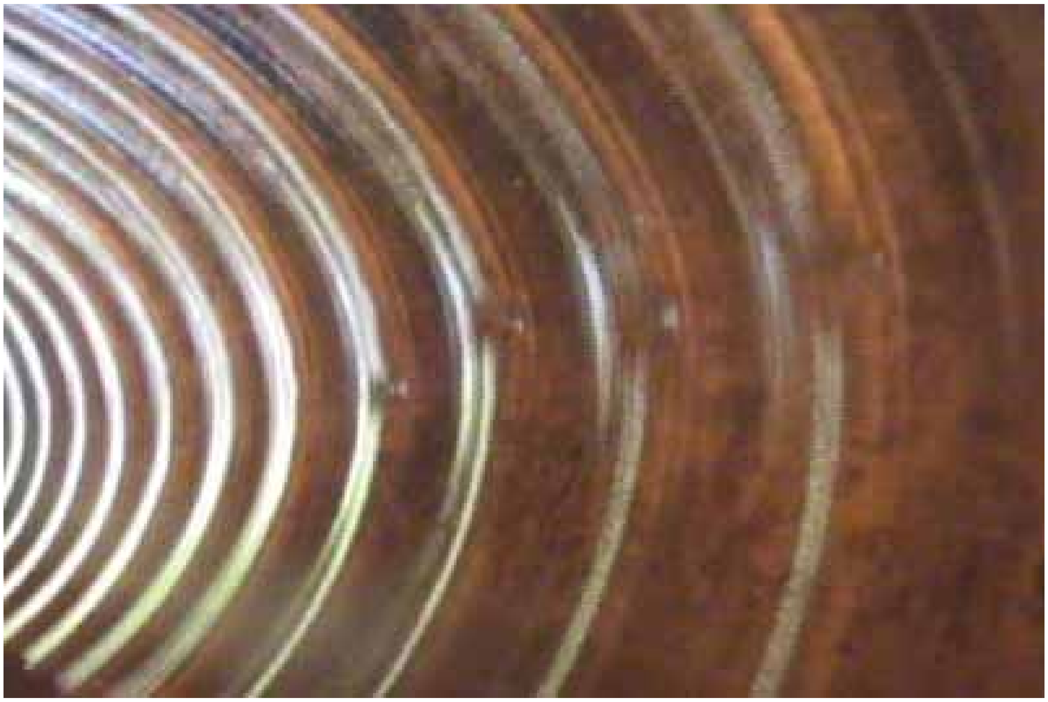


Figure 420 Corrugation growth and buckling failure for Pipeline No. 8 (Site No. 7: West Island Road)

Figure 421 Corrugation growth, excessive deformation, and buckling failure for Pipeline No. 8 (Site No. 7: West Island Road)

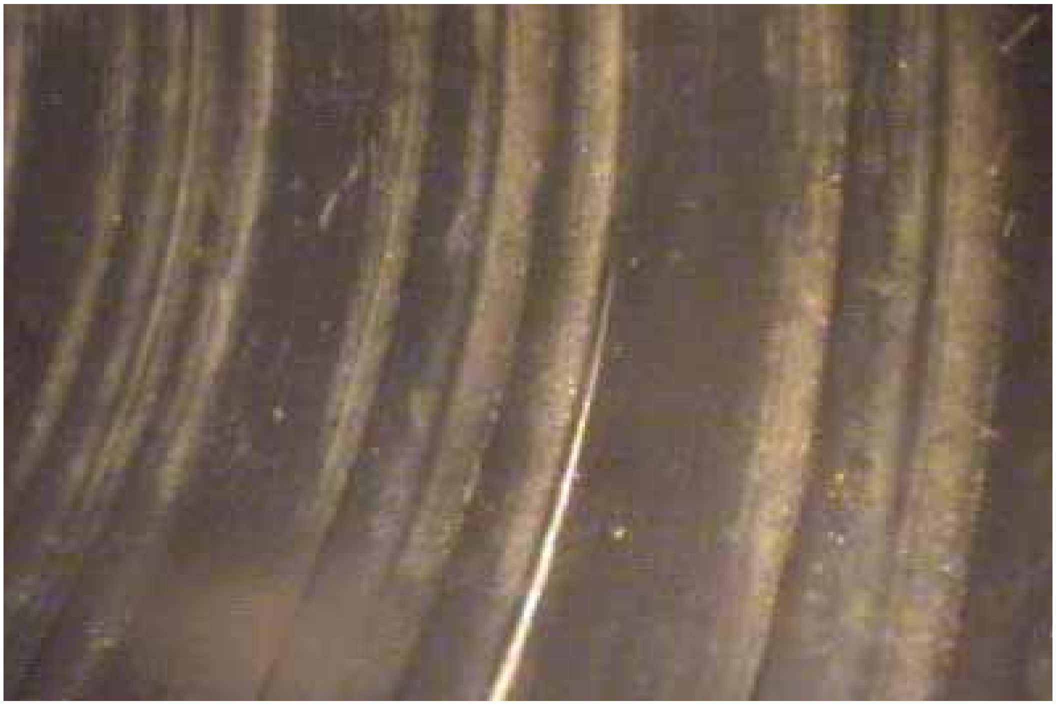
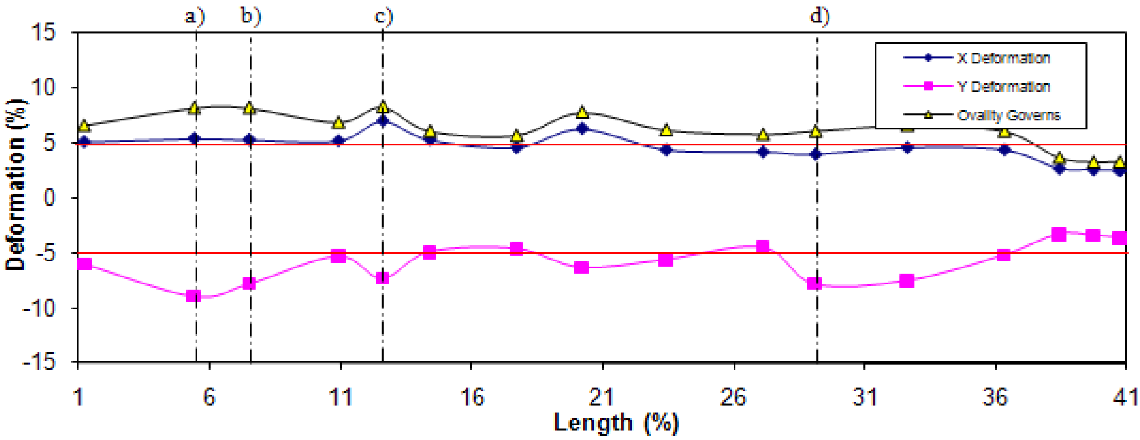


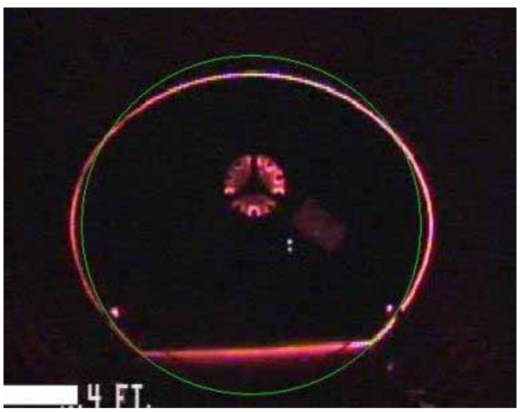
Figure 422 Cracking/fracture failure for Pipeline No. 8 (Site No. 7: West Island Road)

Figure 423 Cracking/fracture failure for Pipeline No. 8 (Site No. 7: West Island Road)

Figure 424 Joint displacement failure for Pipeline No. 8 (Site No. 7: West Island Road)

Pipeline No. 9 (Site No. 8 Kinross Road)

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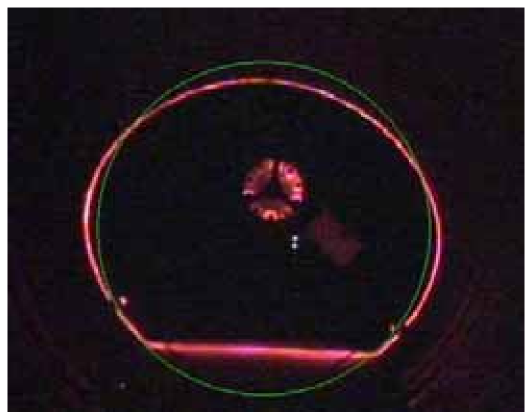
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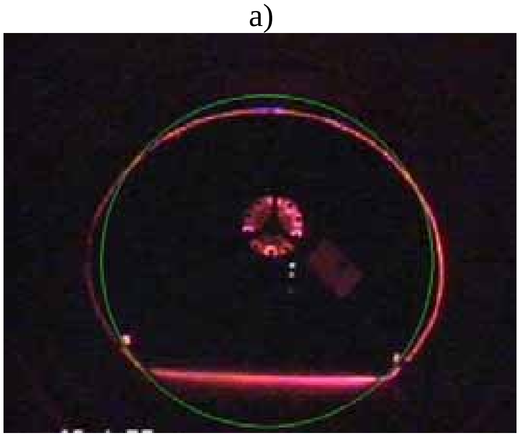

c)

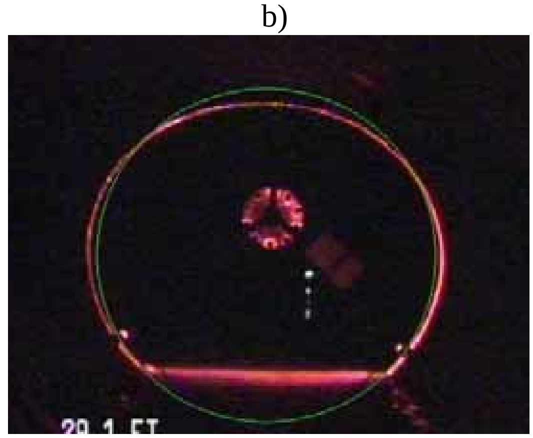
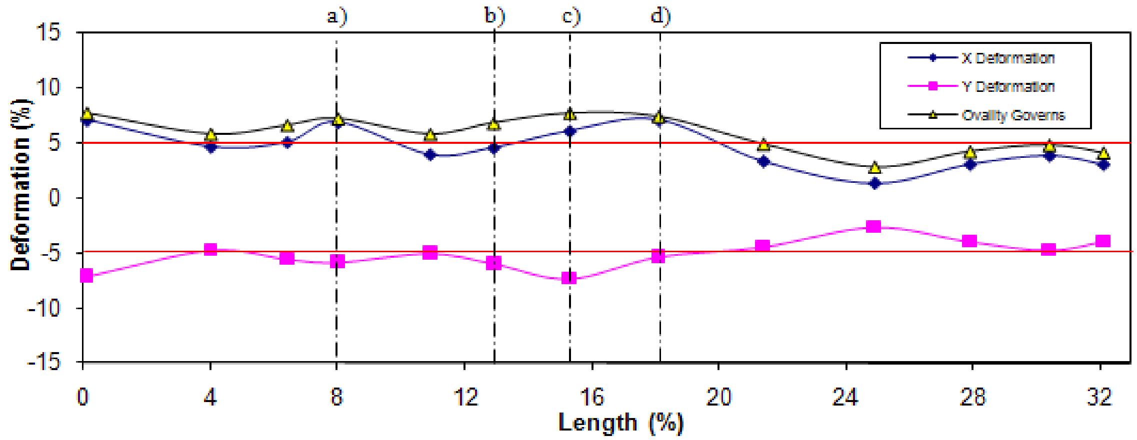
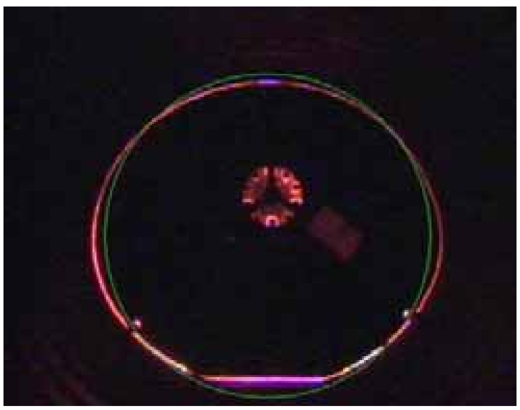

d)

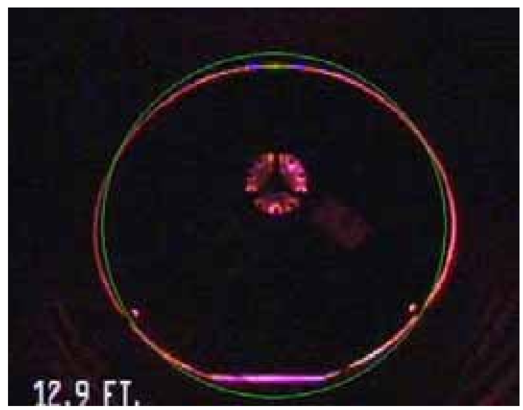
Figure 425 Horizontal and vertical deformation of Pipeline No. 9 (Site No. 8: Kinross Road)

Figure 426 Cracking/fracture failure for Pipeline No. 9 (Site No. 8: Kinross Road)

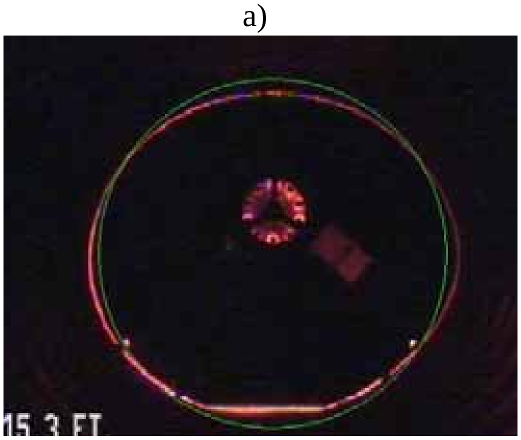
Pipeline No. 10 (Site No. 8 Kinross Road)




a)



b)



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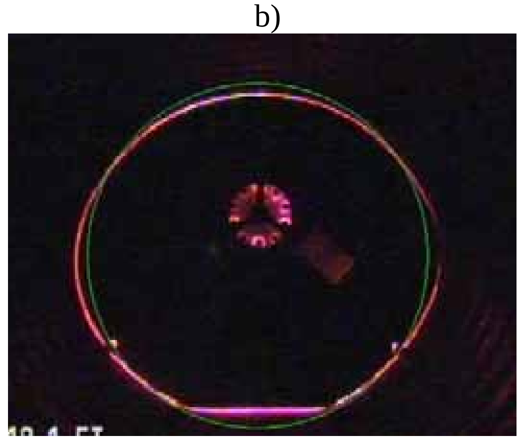
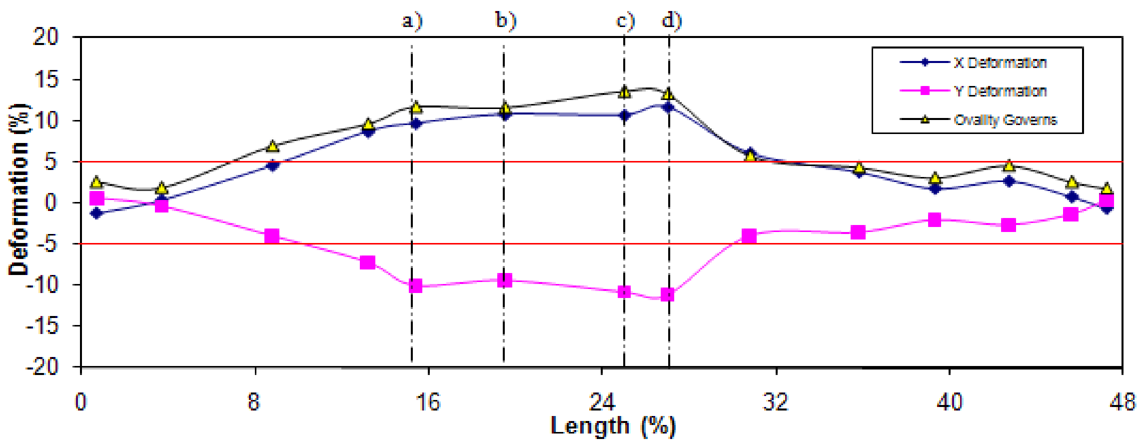
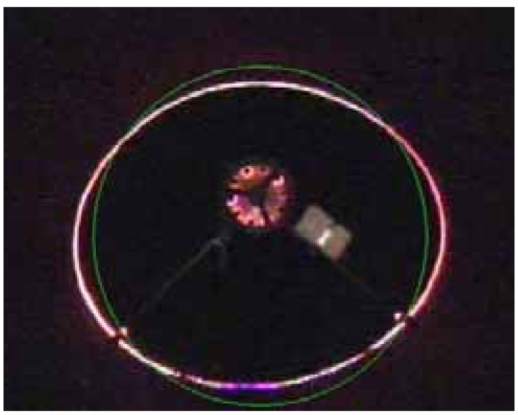

d)

Figure 427 Horizontal and vertical deformation of Pipeline No. 10 (Site No. 8: Kinross Road)

Pipeline No. 11 (Site No. 8 Kinross Road)

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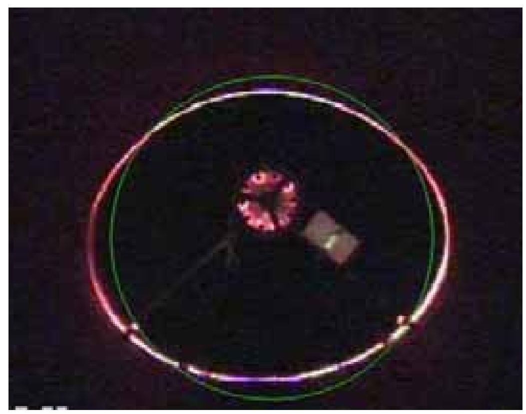
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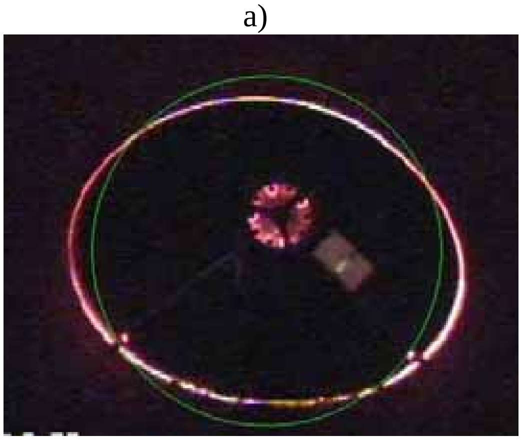

c)

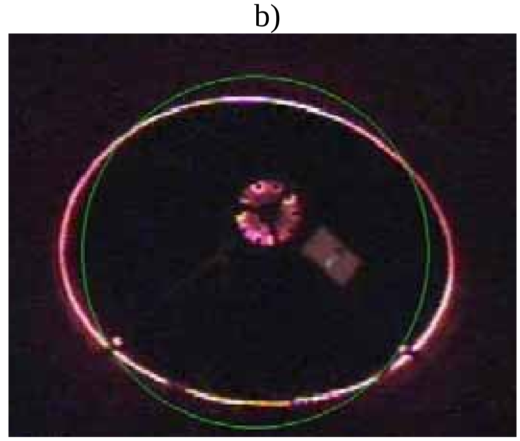
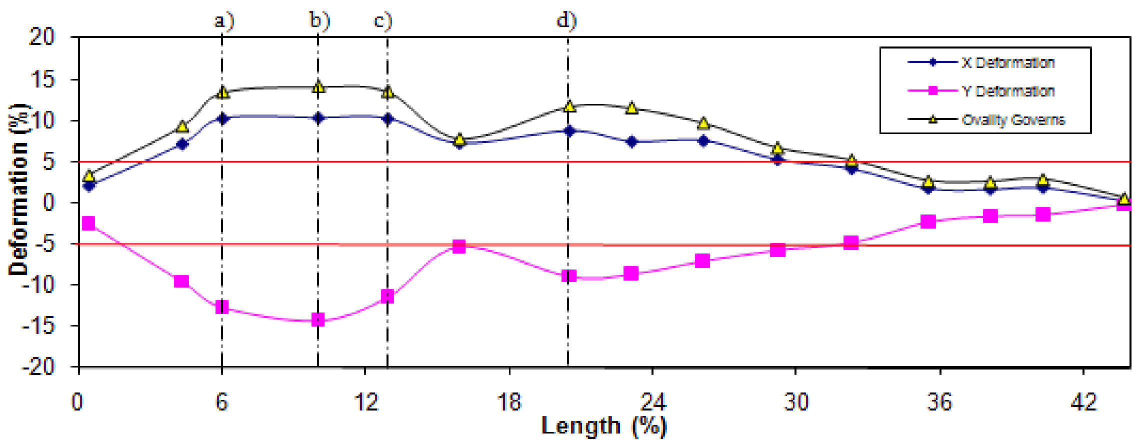

d)

Figure 428 Horizontal and vertical deformation of Pipeline No. 11 (Site No. 8: Kinross Road)

Pipeline No. 12 (Site No. 8 Kinross Road)



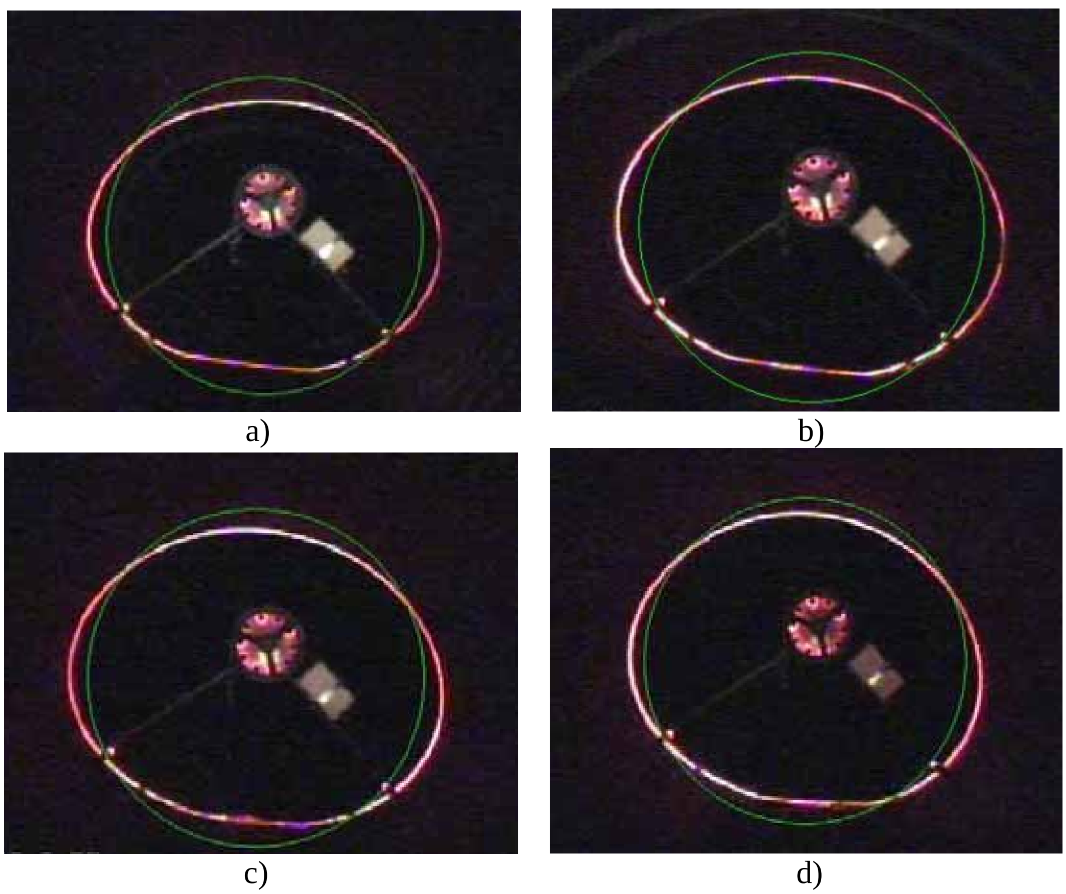
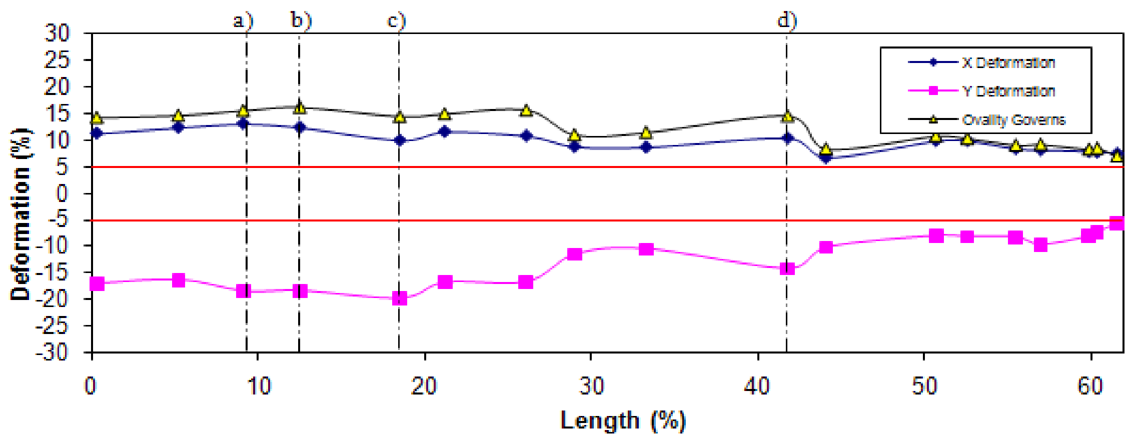
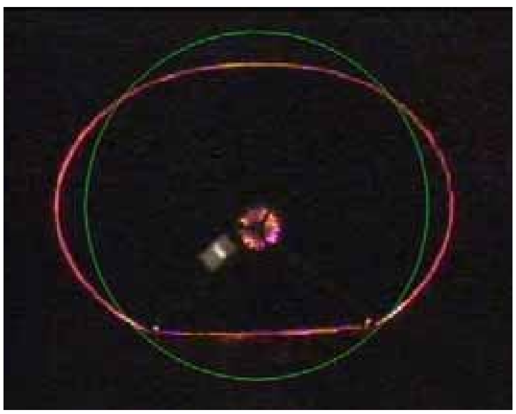
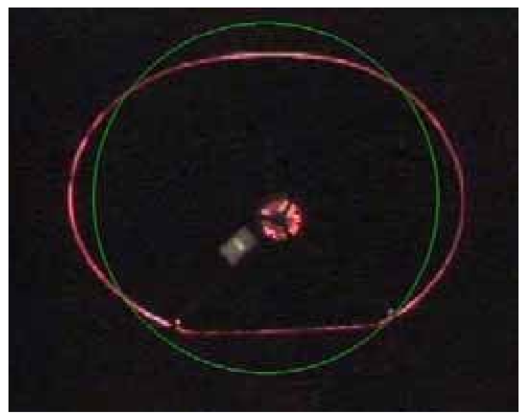


Figure 429 Horizontal and vertical deformation of Pipeline No. 12 (Site No. 8: Kinross Road)

Pipeline No. 13 (Site No. 8 Kinross Road)




a)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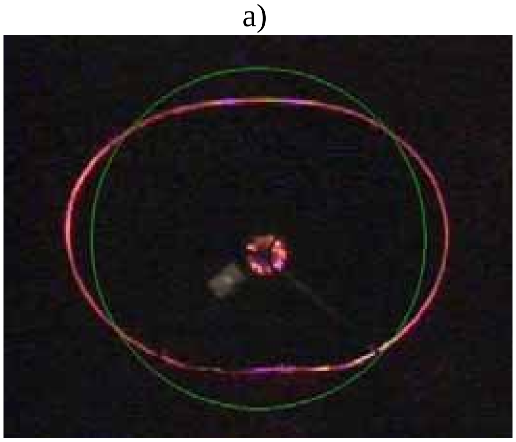

c)

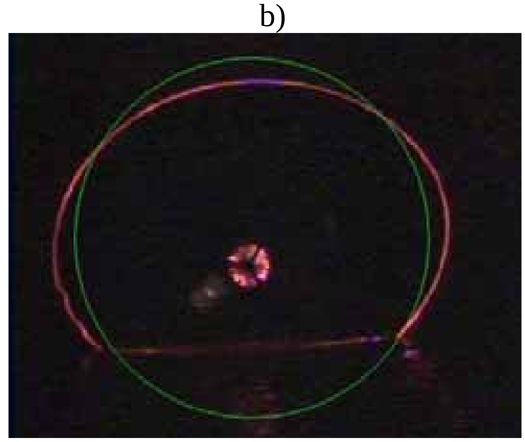

d)

Figure 430 Horizontal and vertical deformation of Pipeline No. 13 (Site No. 8: Kinross Road)

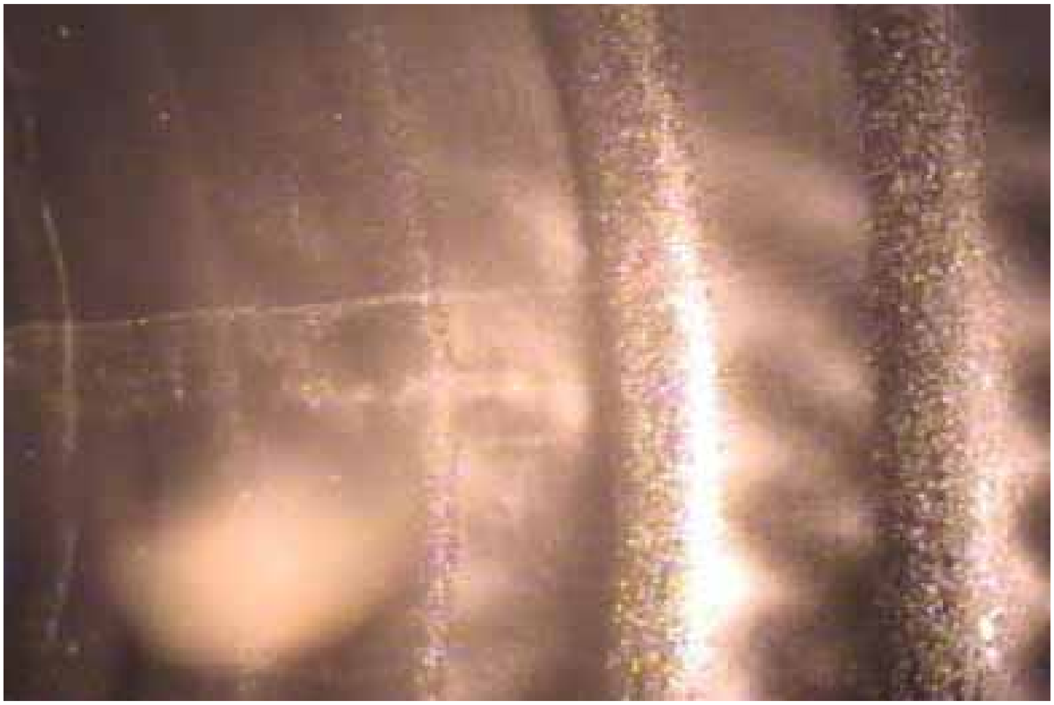


Figure 431 Buckling failure for Pipeline No. 13 (Site No. 8: Kinross Road)

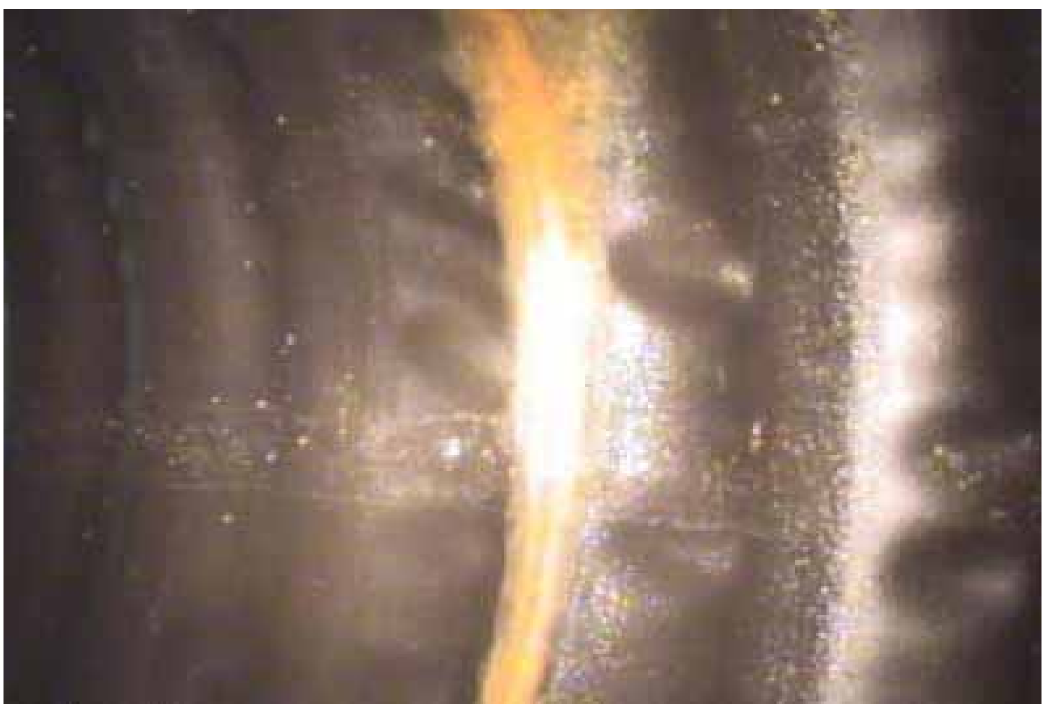


Figure 432 Buckling and corrugation growth failure for Pipeline No. 13 (Site No. 8: Kinross Road)

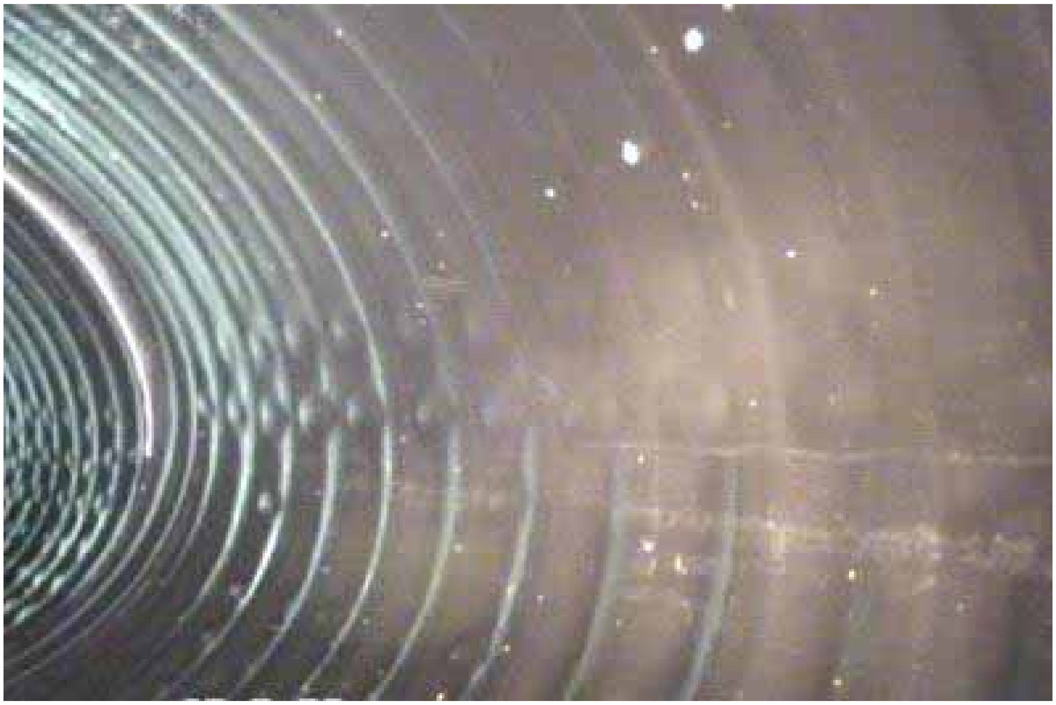


Figure 433 Buckling and corrugation growth failure for Pipeline No. 13 (Site No. 8: Kinross Road)

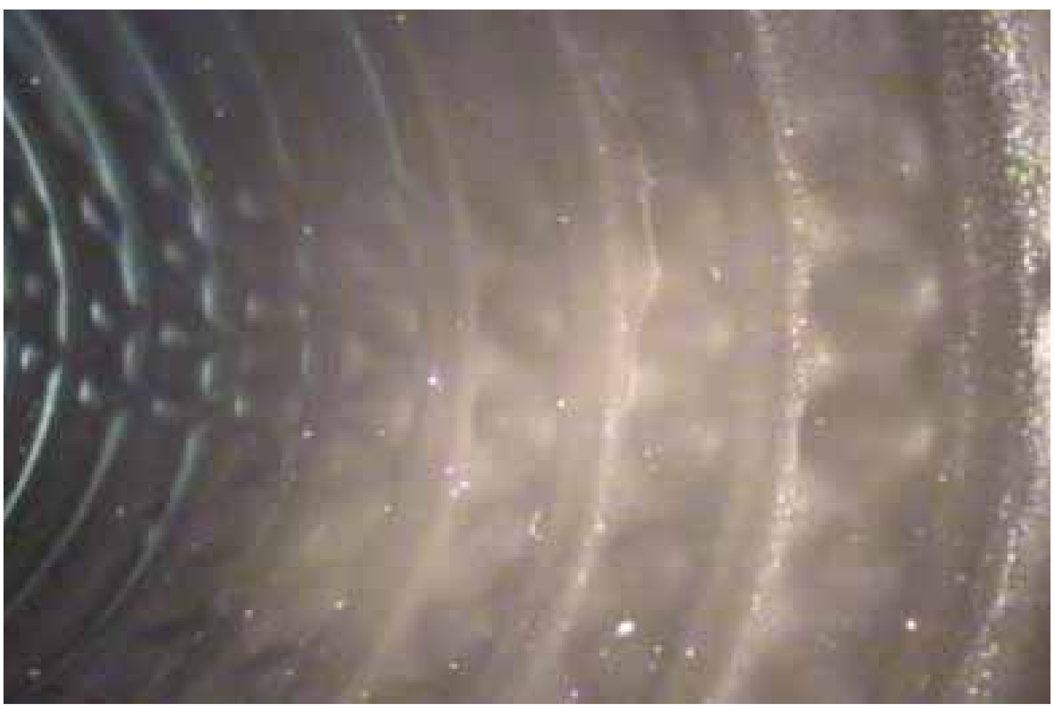


Figure 434 Buckling and corrugation growth failure for Pipeline No. 13 (Site No. 8: Kinross Road)

Figure 435 Cracking/fracture failure for Pipeline No. 13 (Site No. 8: Kinross Road)

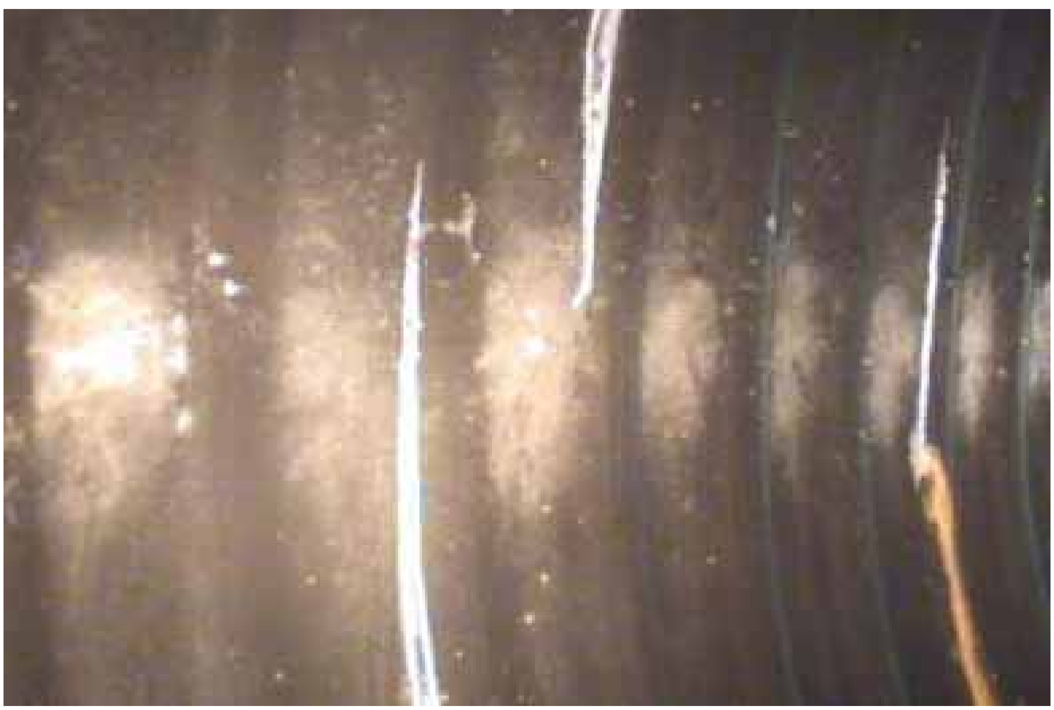


Figure 436 Cracking/fracture and corrugation growth failure for Pipeline No. 13 (Site No. 8: Kinross Road)

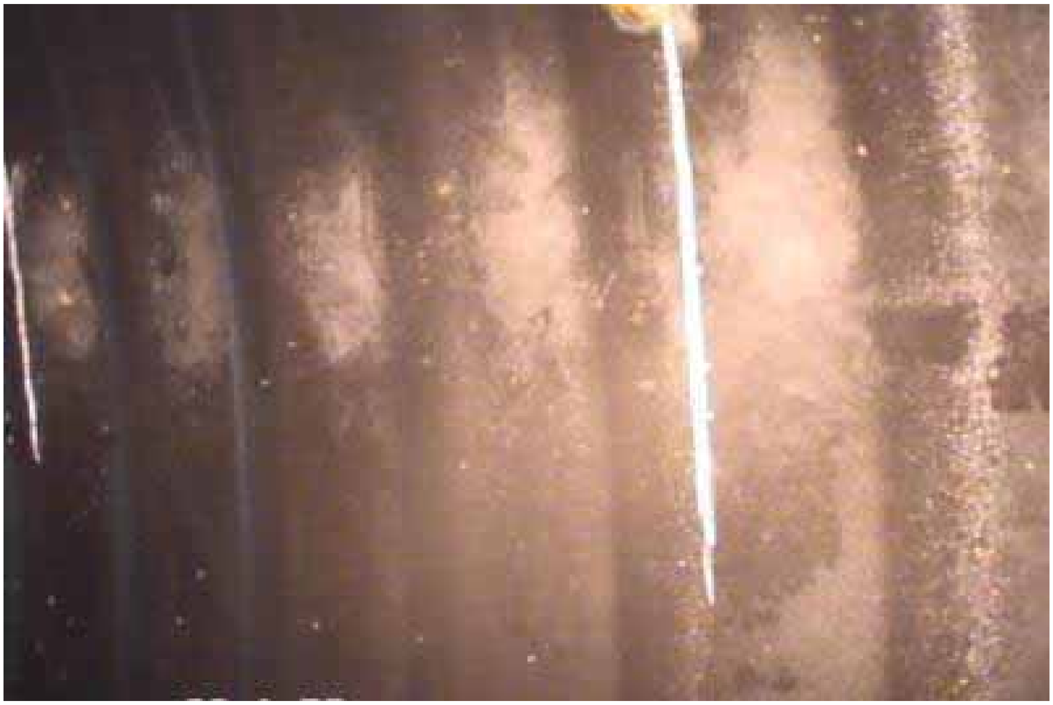


Figure 437 Cracking/fracture and corrugation growth failure for Pipeline No. 13 (Site No. 8: Kinross Road)

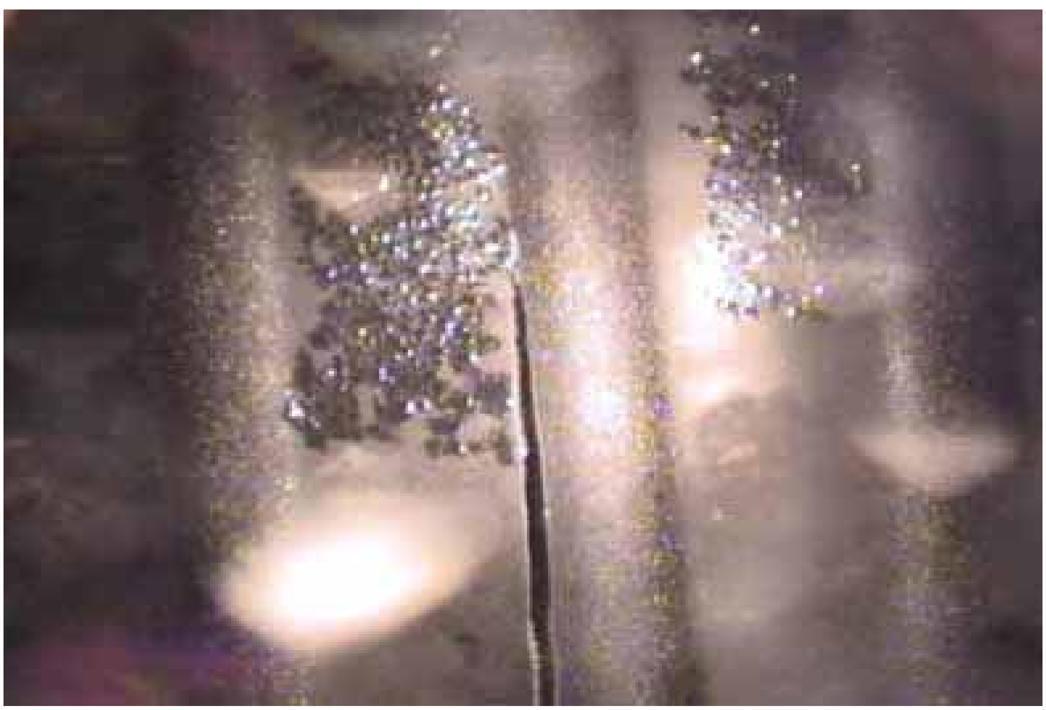


Figure 438 Cracking/fracture failure for Pipeline No. 13 (Site No. 8: Kinross Road)

Pipeline No. 14 (Site No. 8 Kinross Road)

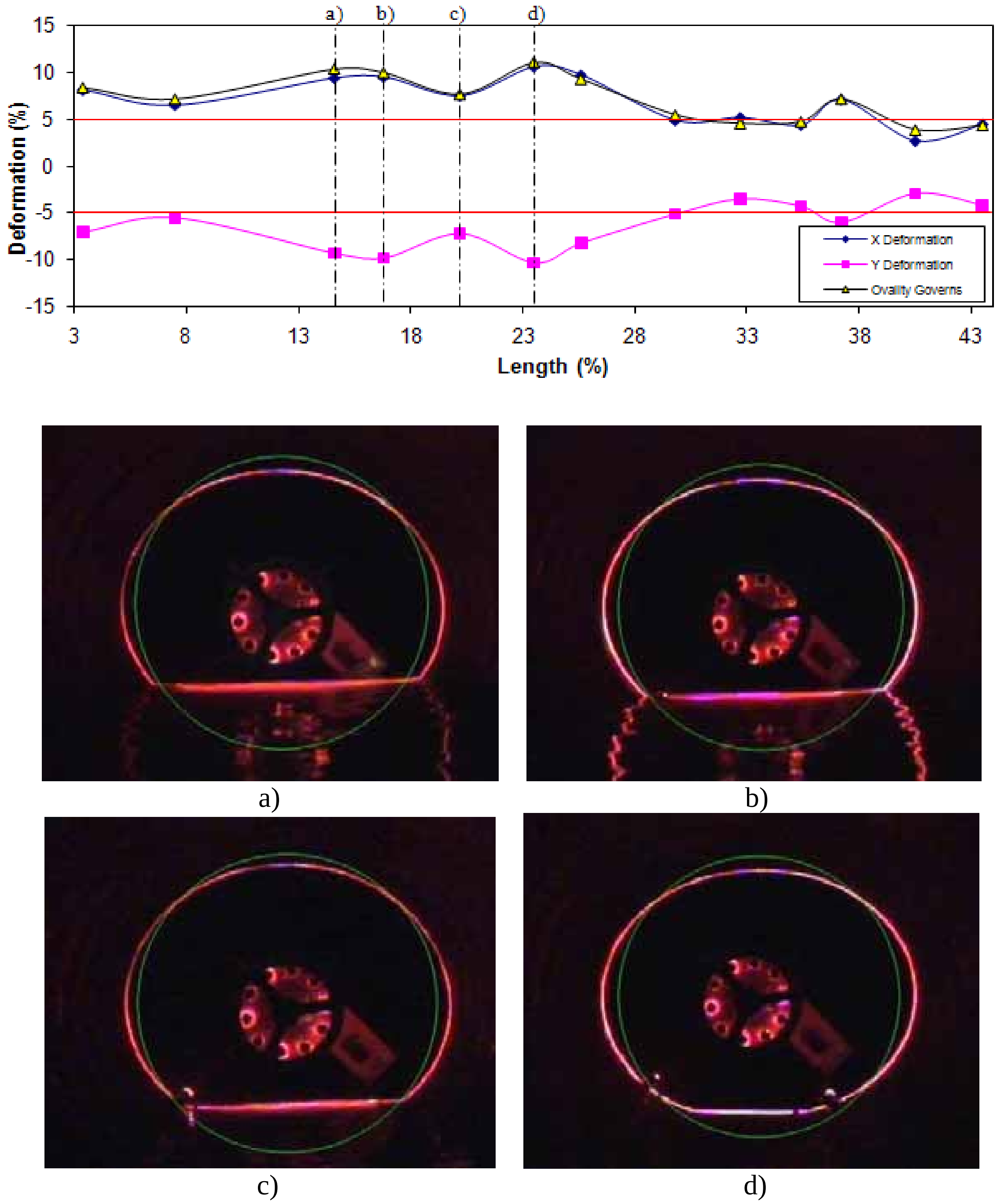
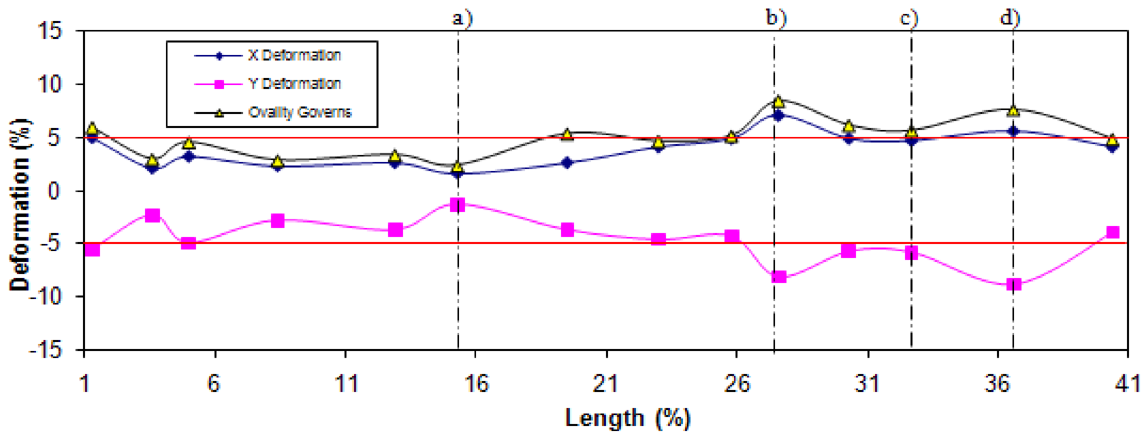
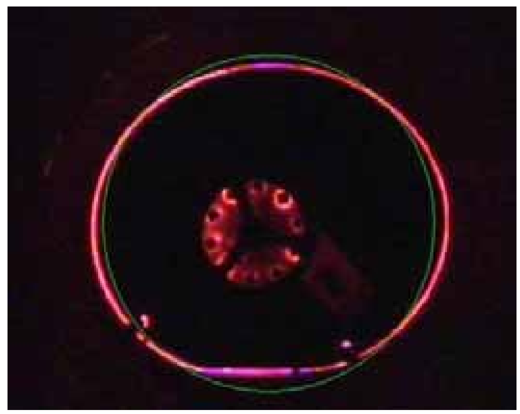


Figure 439 Horizontal and vertical deformation of Pipeline No. 14 (Site No. 8: Kinross Road)

Pipeline No. 15 (Site No. 8 Kinross Road)




a)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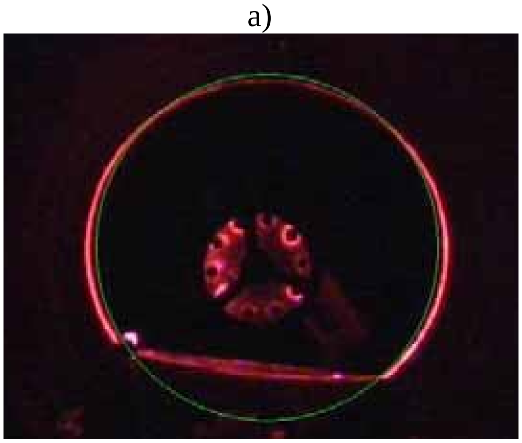

c)

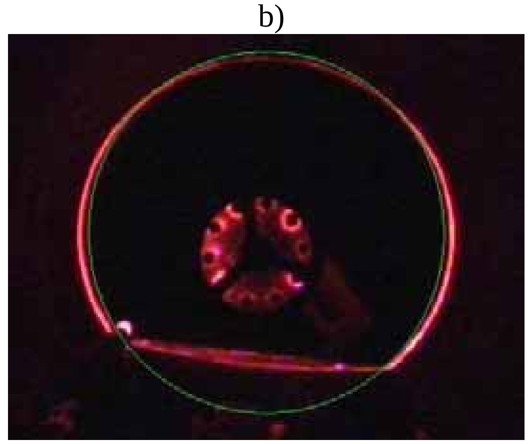
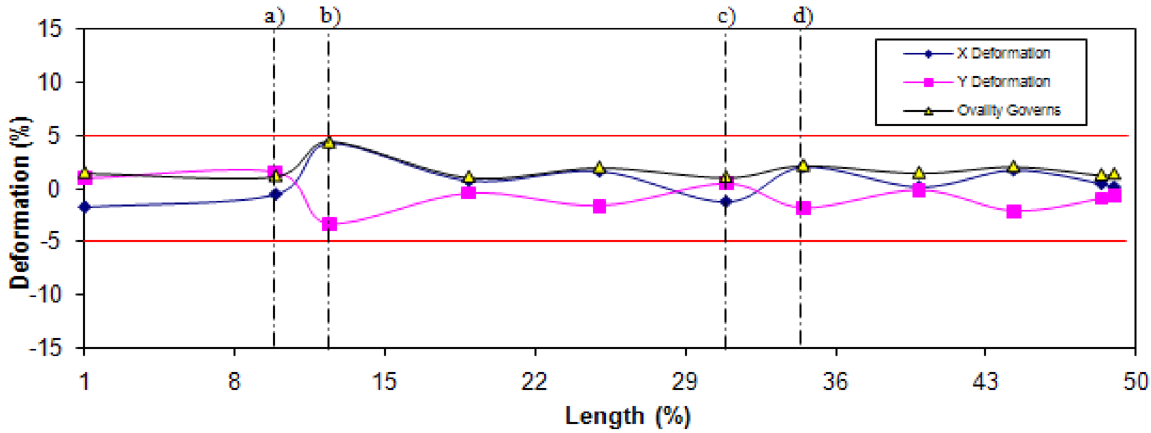

d)

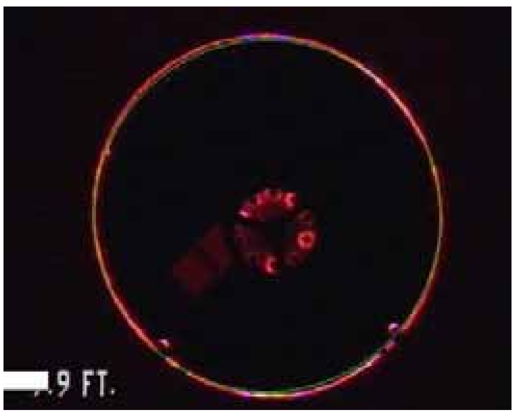
Figure 440 Horizontal and vertical deformation of Pipeline No. 15 (Site No. 8: Kinross Road)

Pipeline No. 16 (Site No. 9 Driveway off Main Street L'Anse)

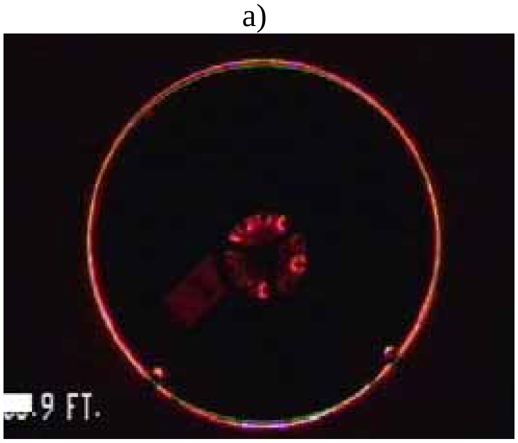
Figure 441 Corrugation growth failure for Pipeline No. 16 (Site No. 9: Driveway off Main St. L'Anse)

Pipeline No. 17 (Site No. 10 L'Anse)




a)


b)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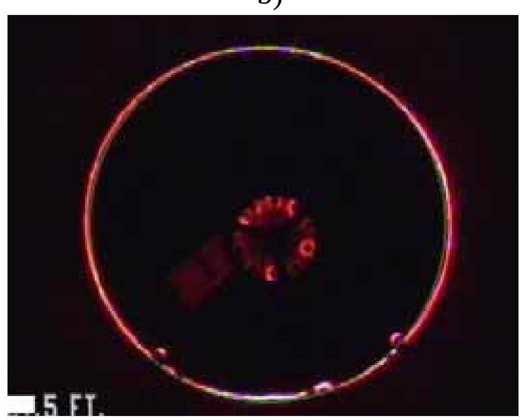
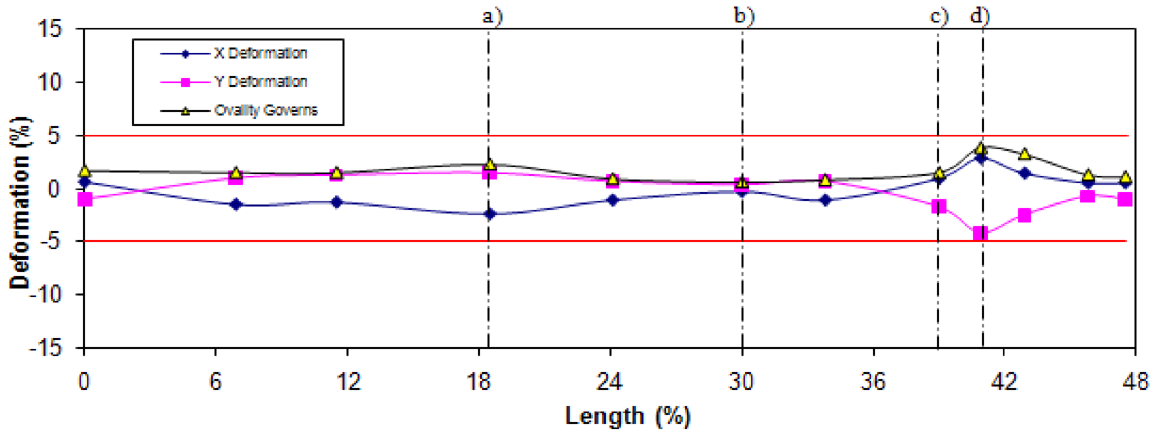
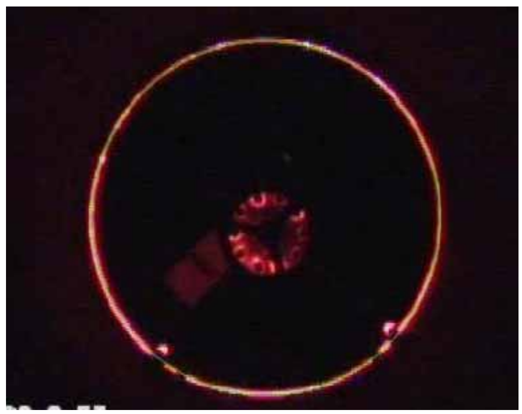

d)

Figure 442 Horizontal and vertical deformation of Pipeline No. 17 (Site No. 10: L'Anse)

Pipeline No. 18 (Site No. 10 L'Anse)




a)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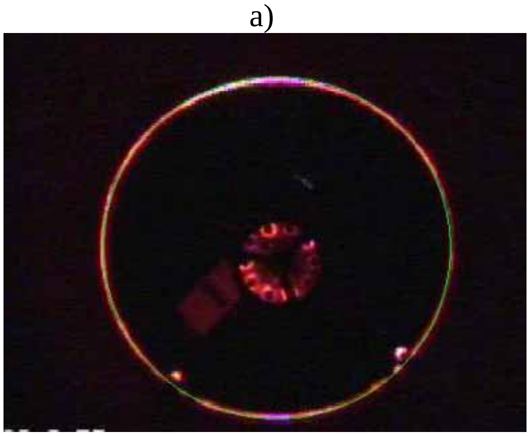
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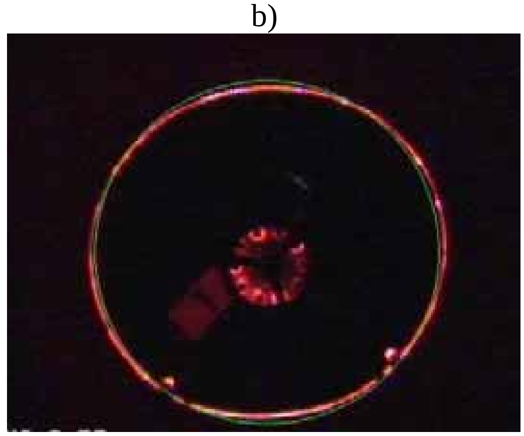
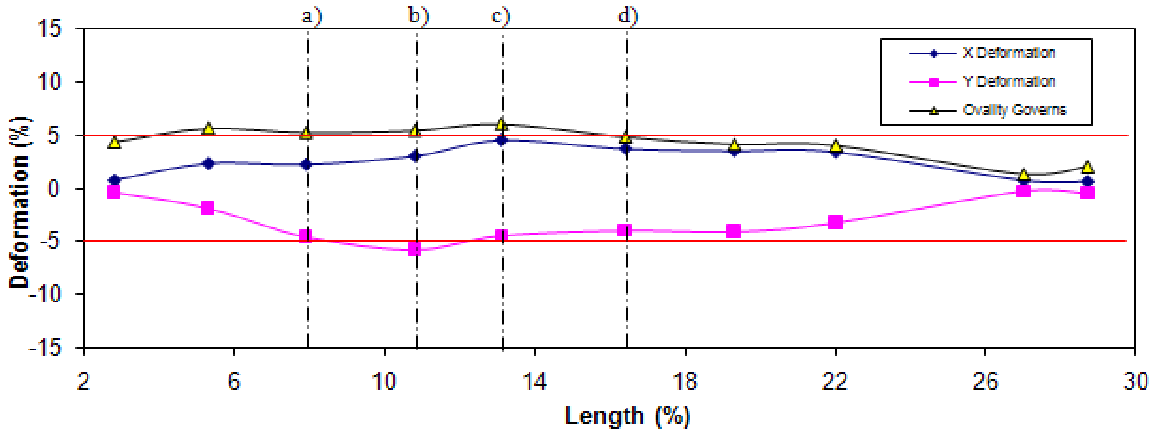
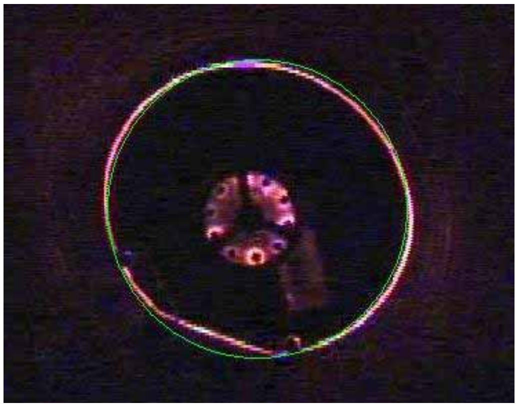

d)

Figure 443 Horizontal and vertical deformation of Pipeline No. 18 (Site No. 10: L'Anse)

Pipeline No. 19 (Site No. 11 Houghton County-North Laird Heights)

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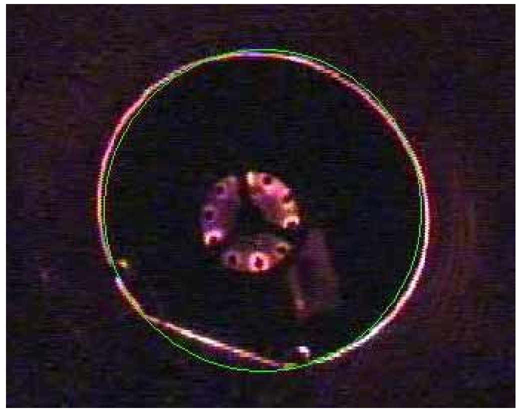
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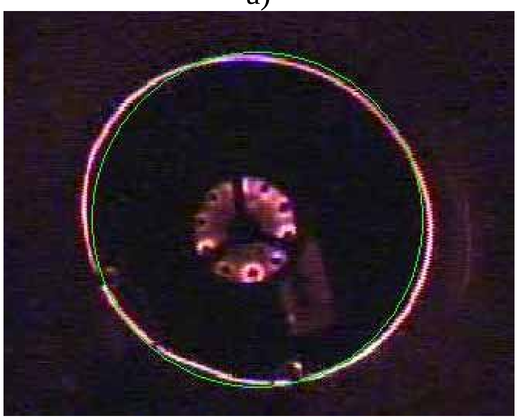
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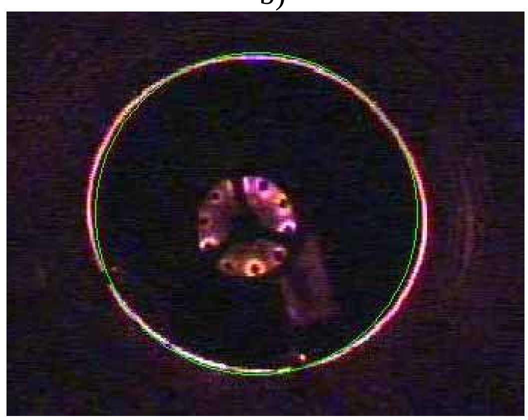
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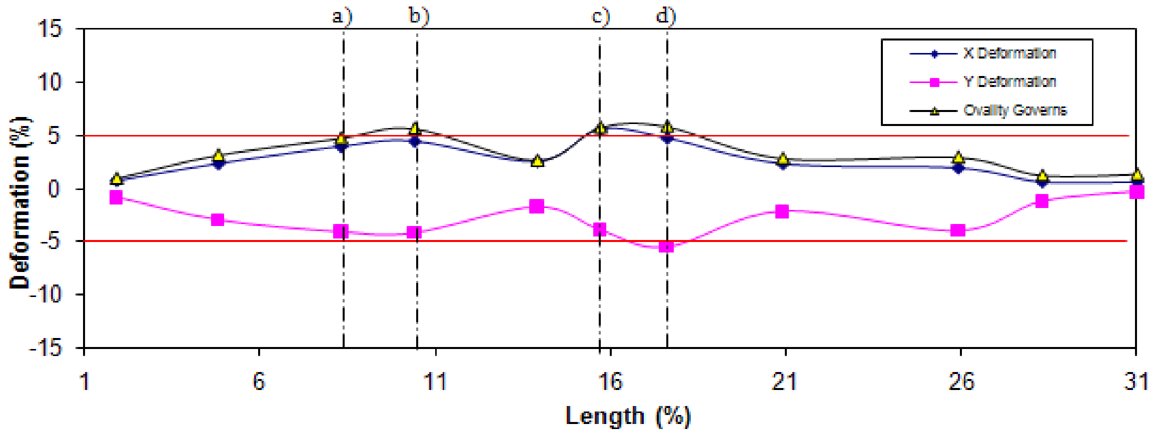
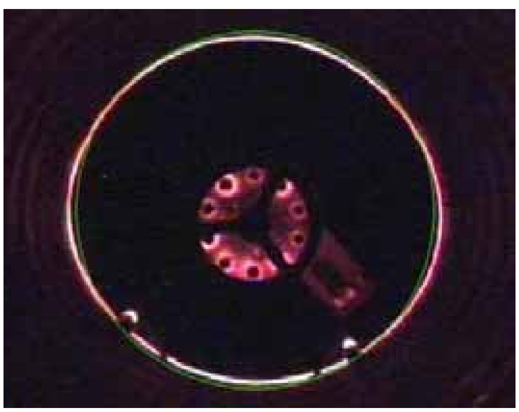
Figure 444 Horizontal and vertical deformation of Pipeline No. 19 (Site No. 11: Houghton County-North Laird Heights)

Pipeline No. 20 (Site No. 11 Houghton County-North Laird Heights)

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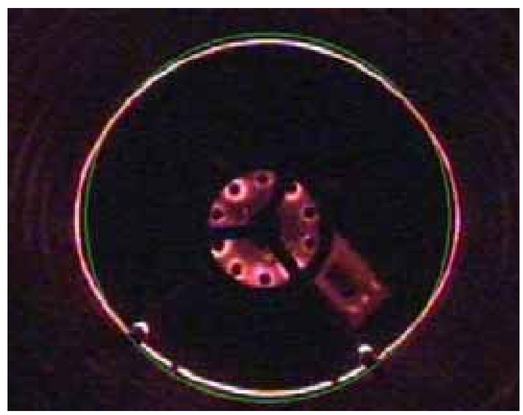
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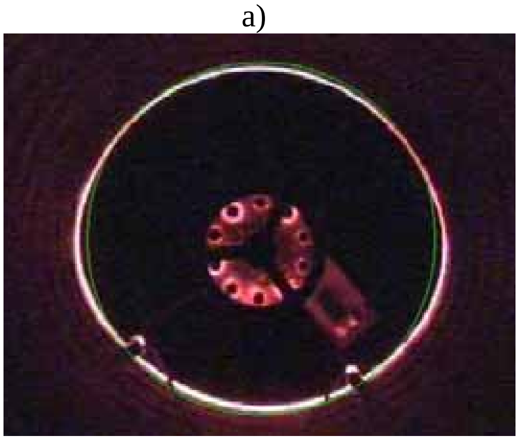
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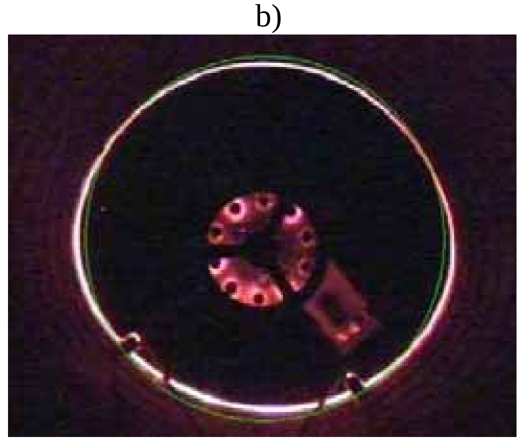

d)

Figure 445 Horizontal and vertical deformation of Pipeline No. 20 (Site No. 11: Houghton County-North Laird Heights)

Pipeline No. 21 (Site No. 11 Houghton County-North Laird Heights)

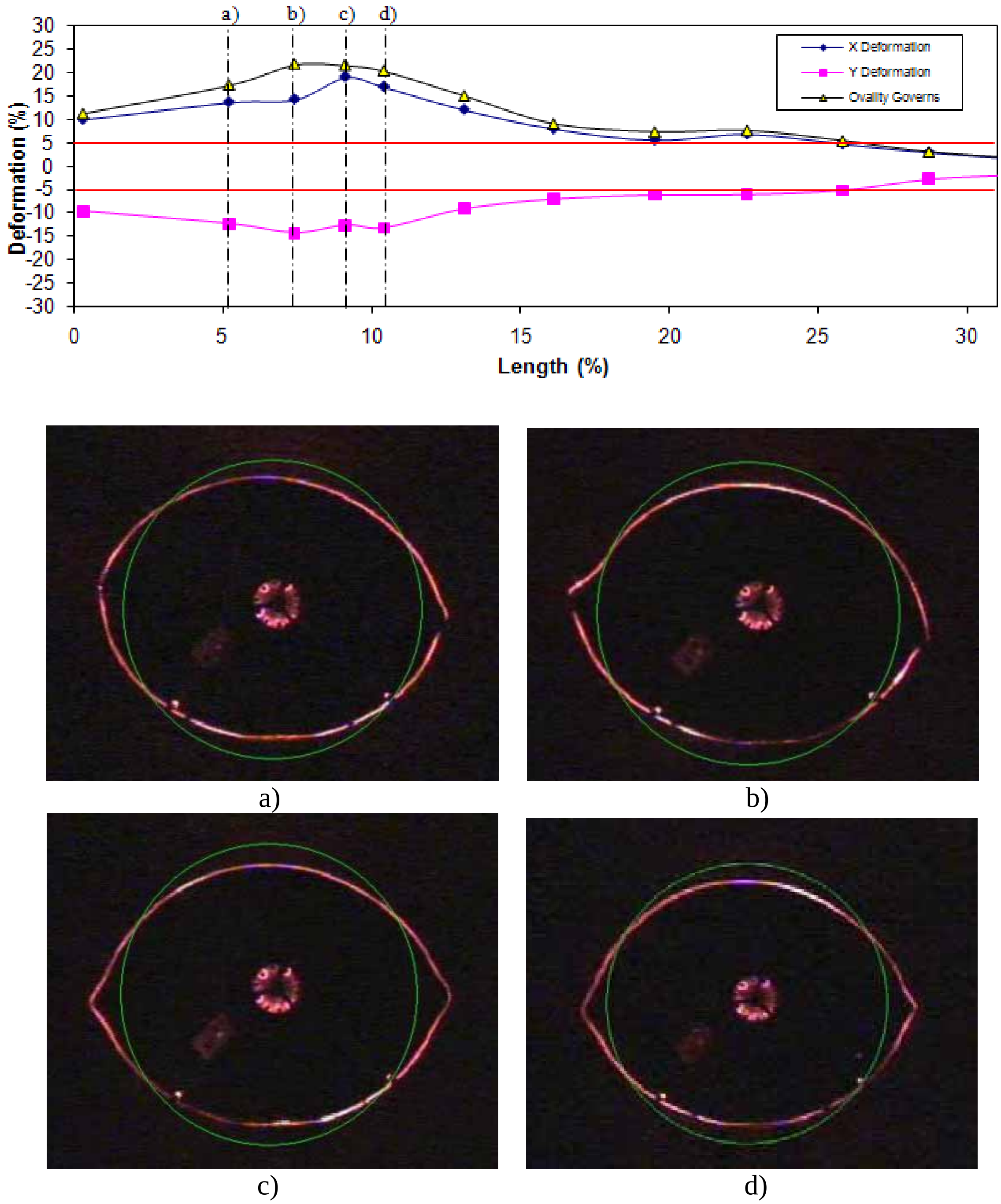


Figure 446 Horizontal and vertical deformation of Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

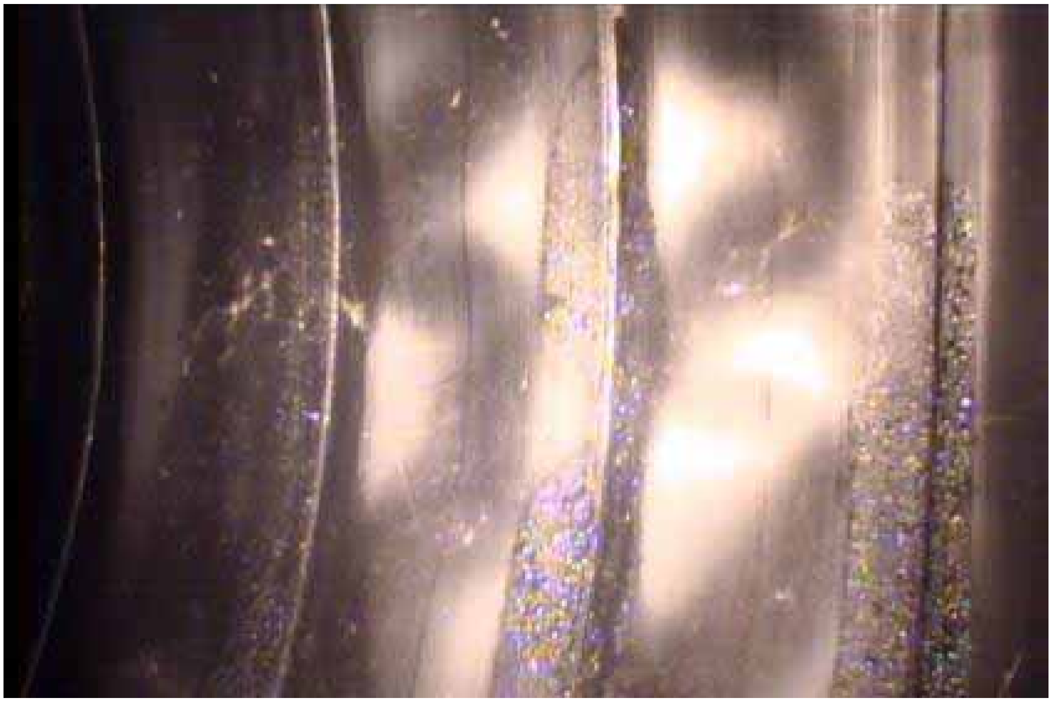


Figure 447 Buckling failure for Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

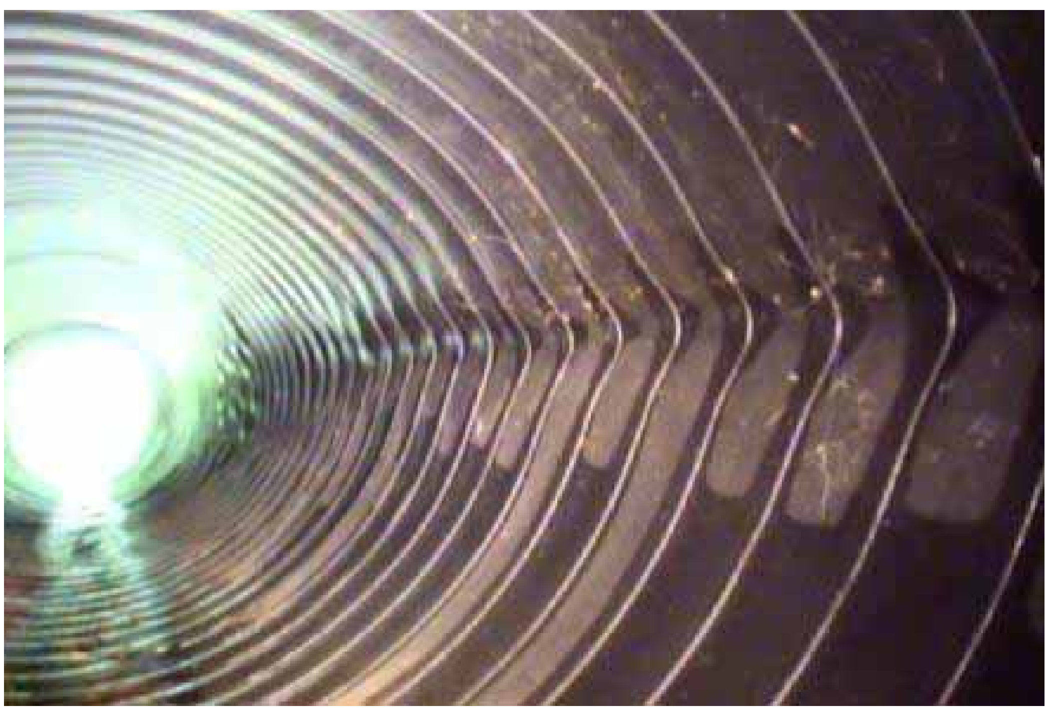


Figure 448 Buckling and corrugation growth failure for Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

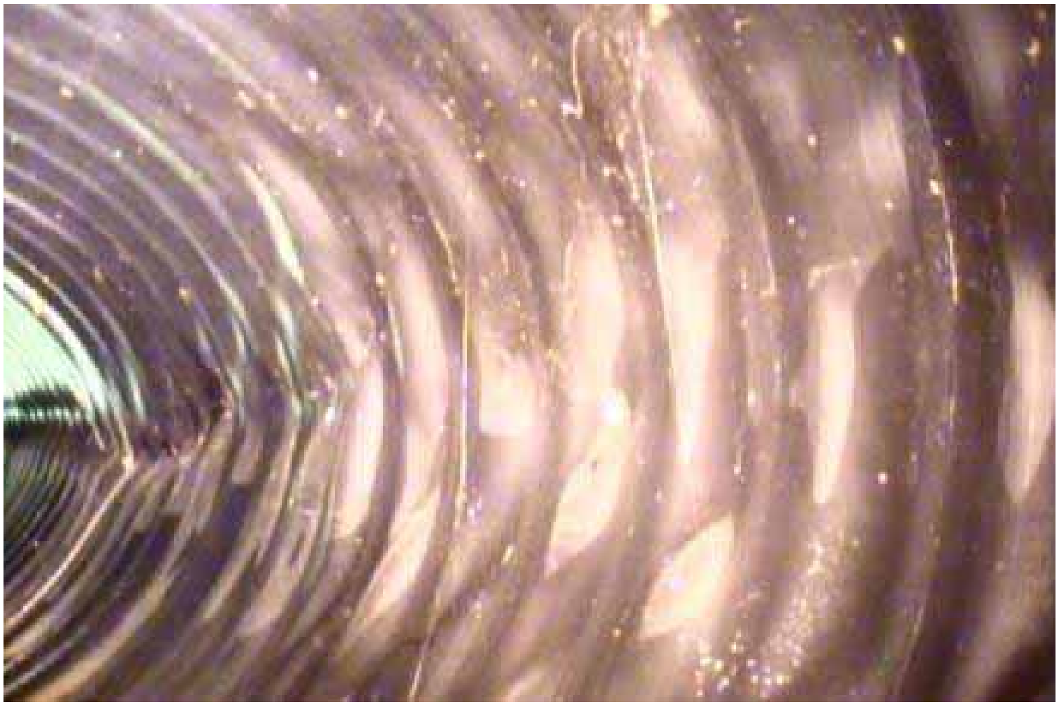


Figure 449 Buckling and corrugation growth failure for Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

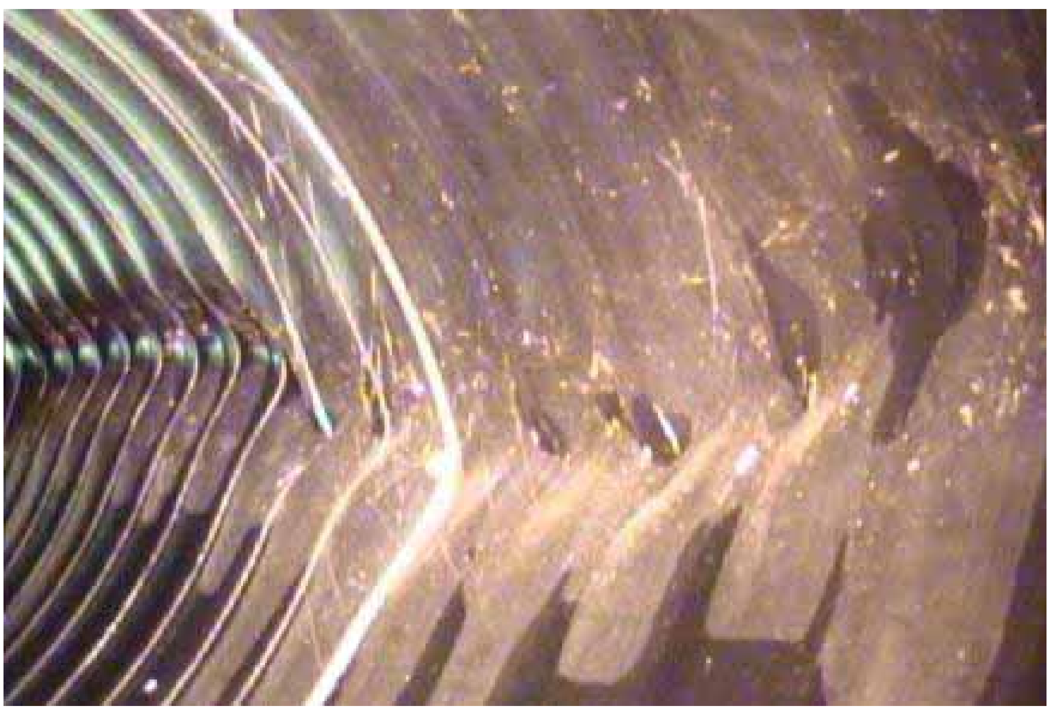


Figure 450 Buckling and corrugation growth failure for Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

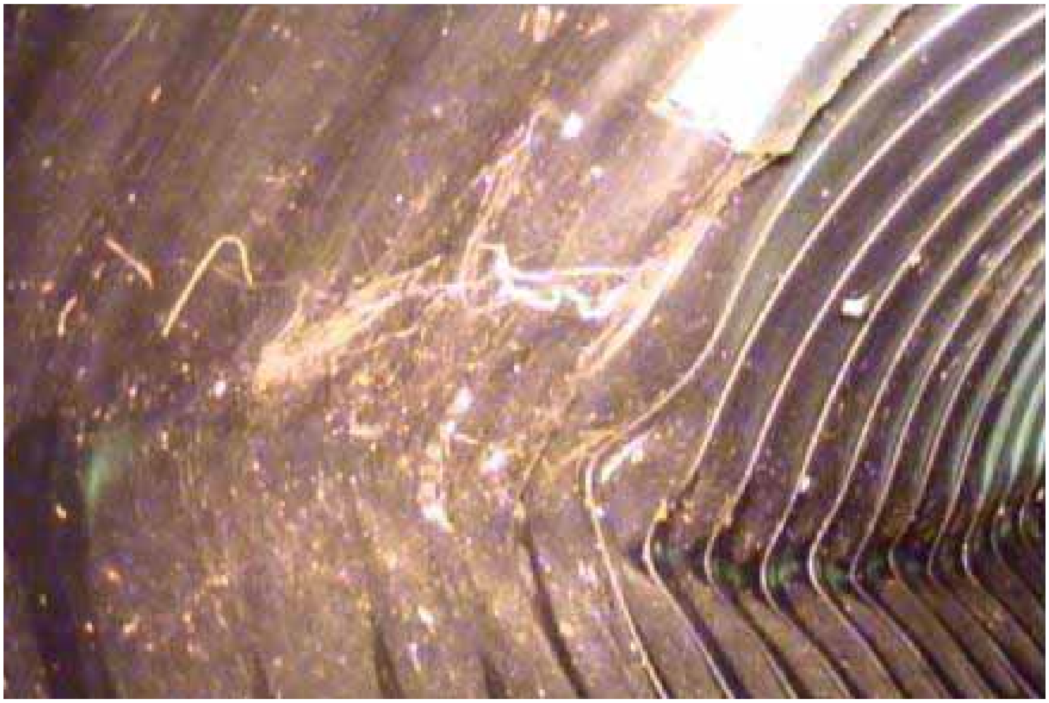
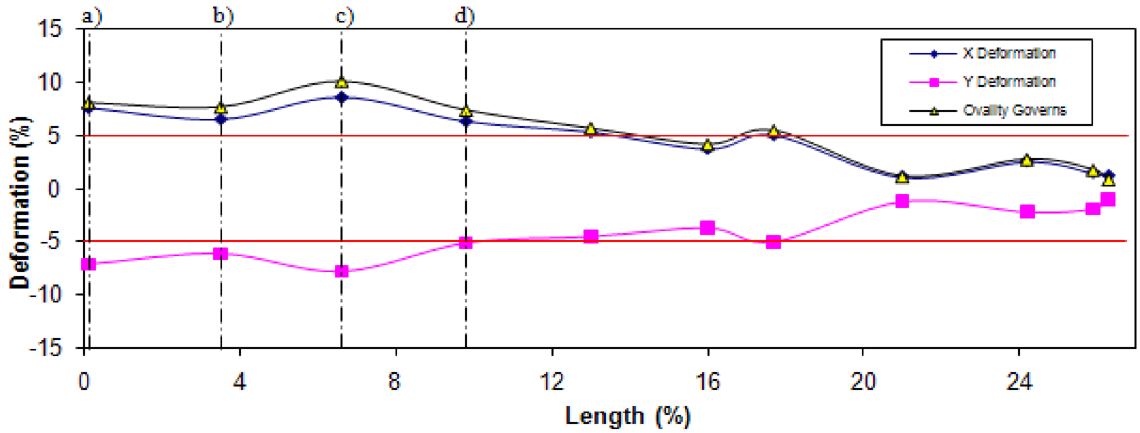
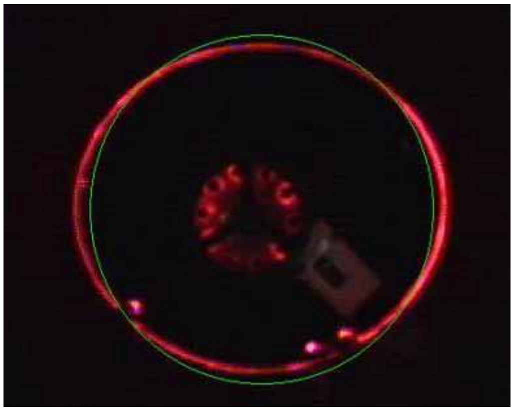


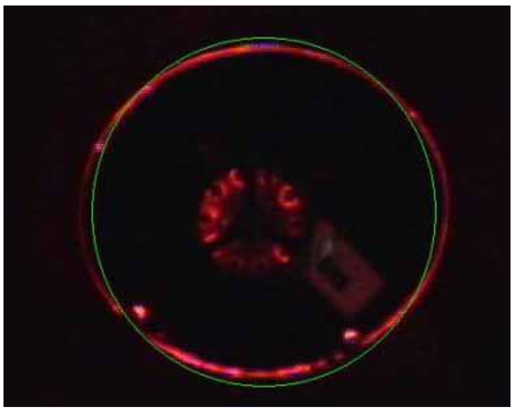
Figure 451 Buckling and corrugation growth failure for Pipeline No. 21 (Site No. 11: Houghton County-North Laird Heights)

Pipeline No. 22 (Site No. 11 Houghton County-North Laird Heights)





a)



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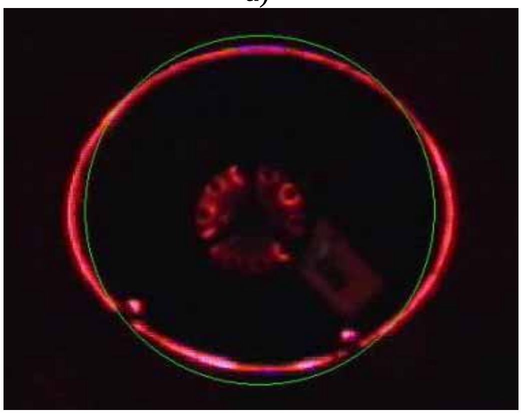
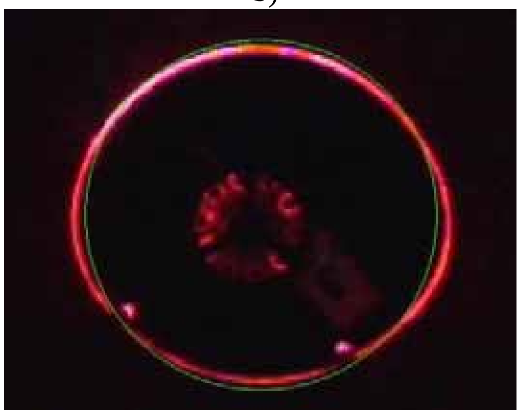


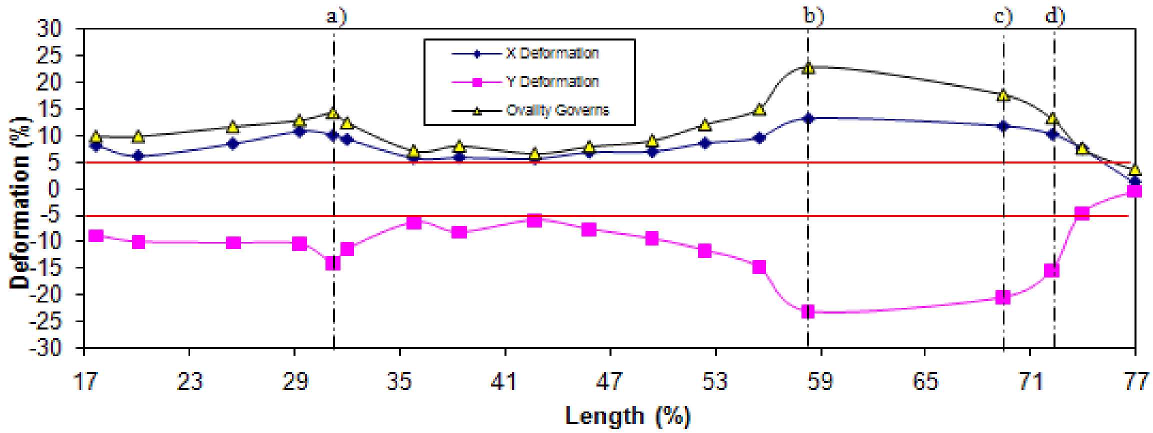
c)

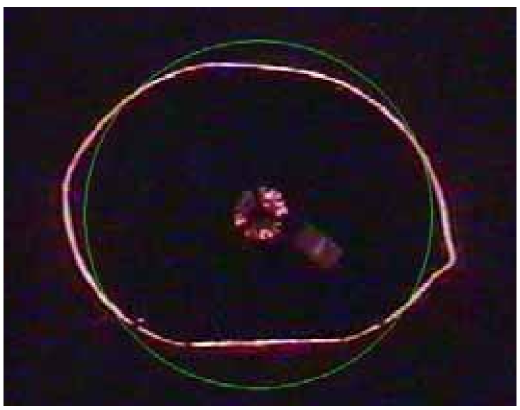
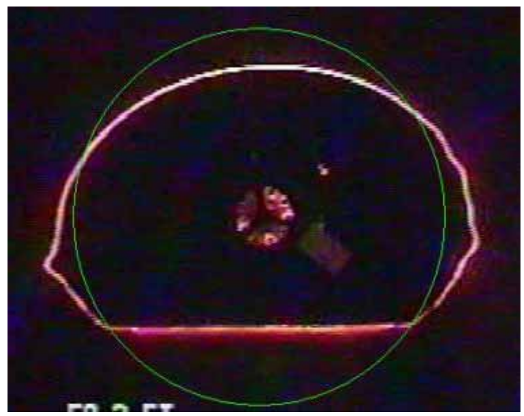


d)

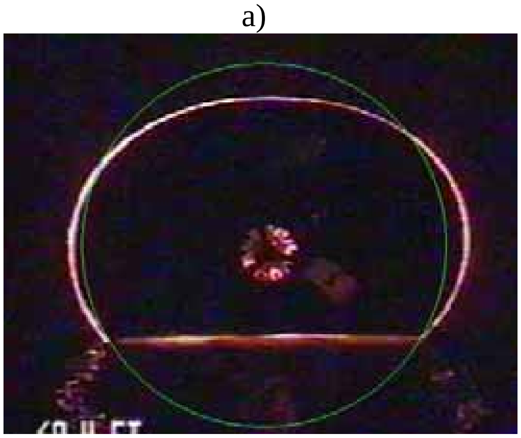
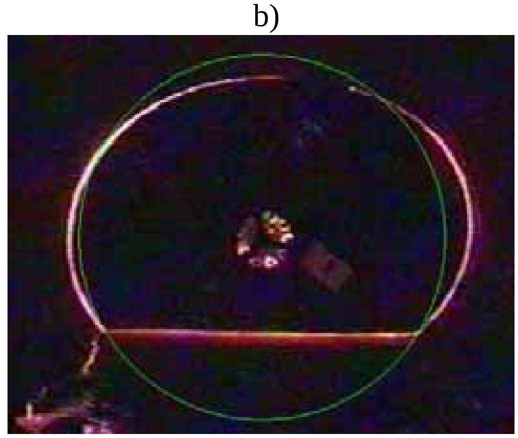
Figure 452 Horizontal and vertical deformation of Pipeline No. 22 (Site No. 11: Houghton County-North Laird Heights)

Pipeline No. 23 (Site No. 12 48th Avenue)



a) b)

c) d)

Figure 453 Horizontal and vertical deformation of Pipeline No. 23 (Site No. 12: 48th Avenue)

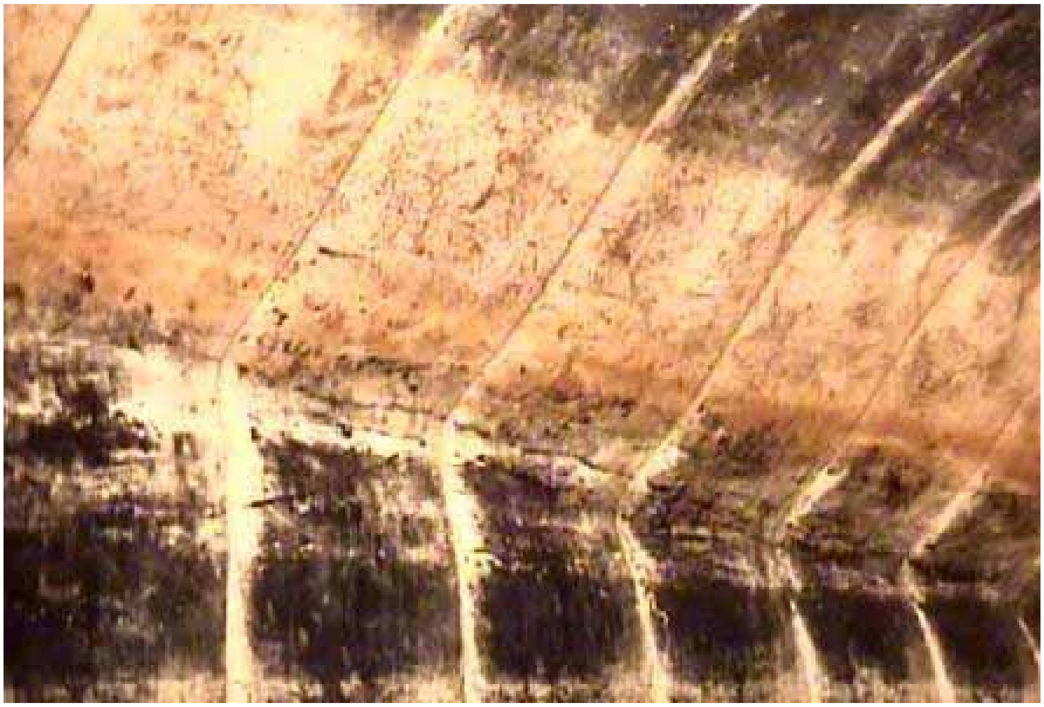


Figure 454 Buckling and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

Figure 455 Buckling and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

Figure 456 Buckling, cracking/fracture, joint displacement, and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

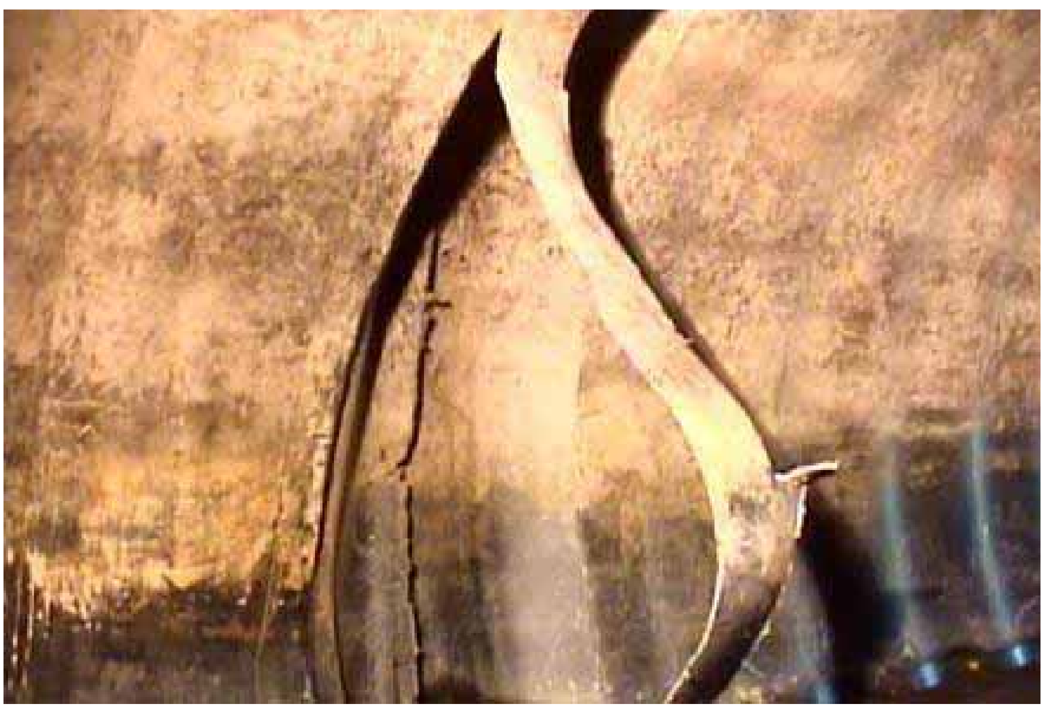


Figure 457 Cracking/fracture, major joint displacement, and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

Figure 458 Buckling and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

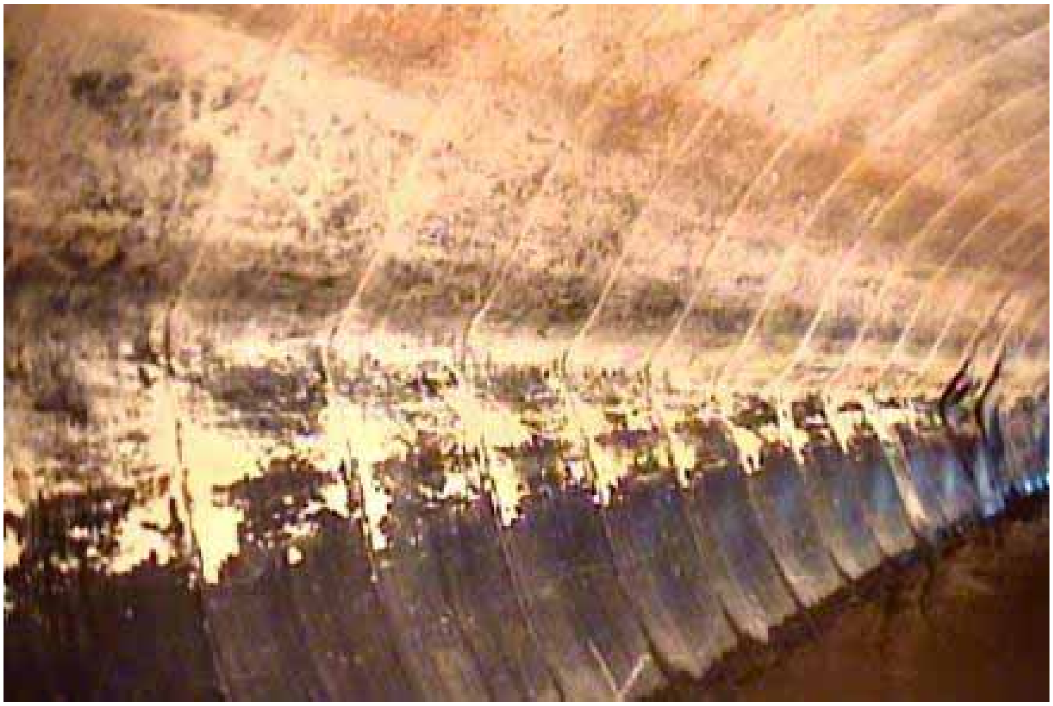
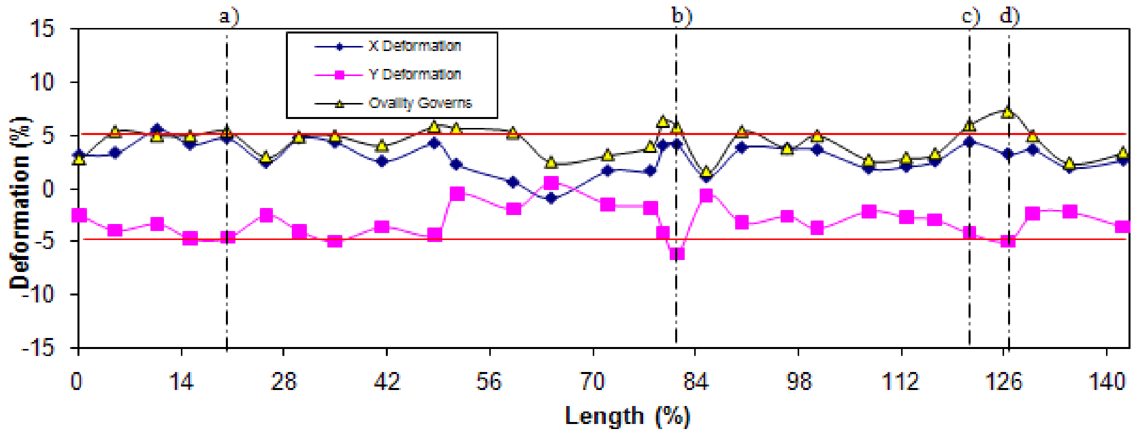
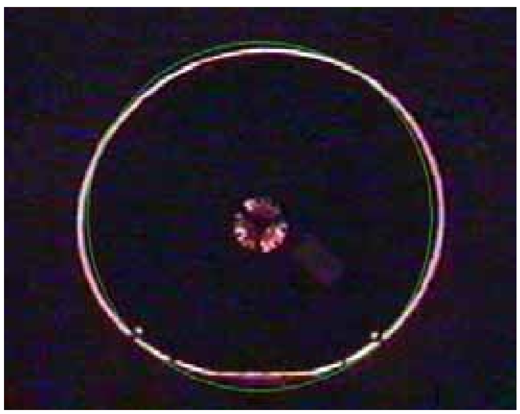


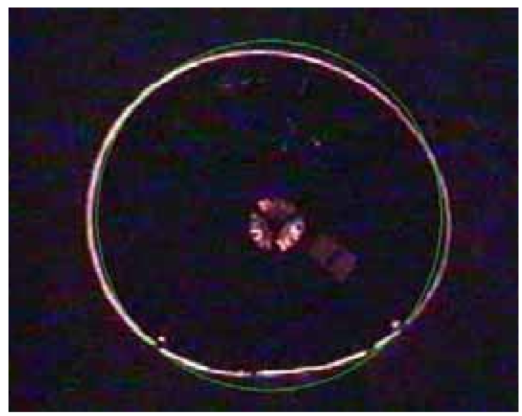
Figure 459 Buckling and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

Figure 460 Excessive deformation, inverse curvature, and corrugation growth failure for Pipeline No. 23 (Site No. 12: 48th Avenue)

Pipeline No. 24a (Site No. 13 Burlinghame Avenue)




a)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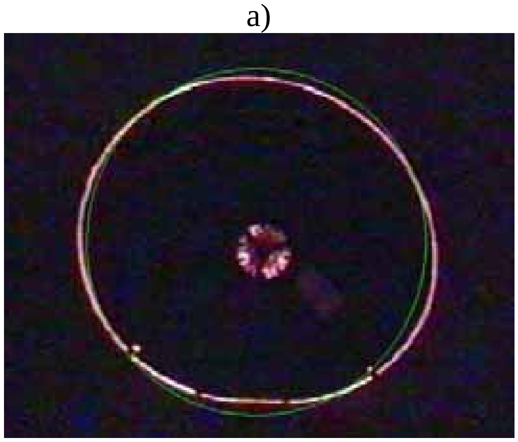

c)

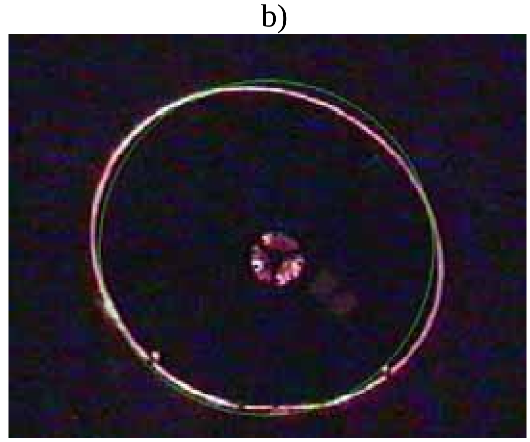
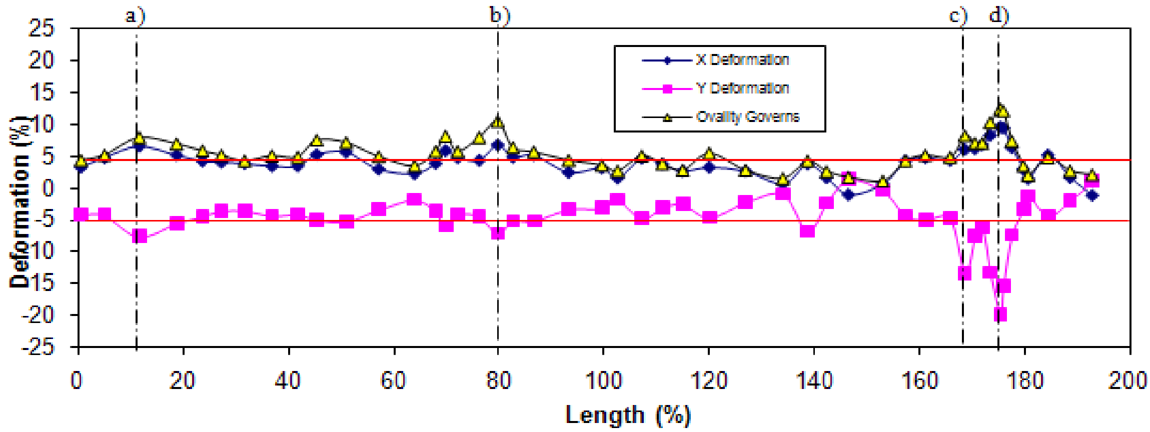
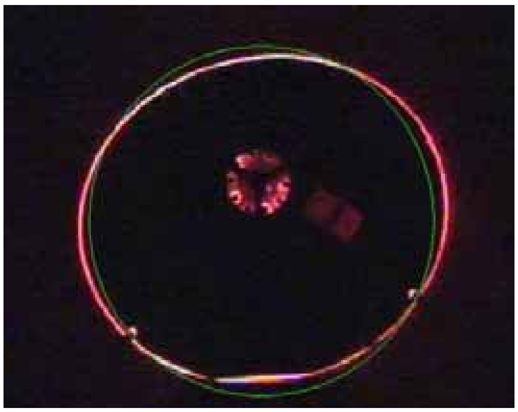

d)

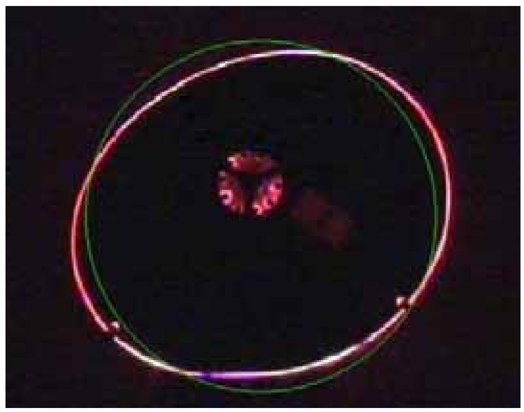
Figure 461 Horizontal and vertical deformation of Pipeline No. 24a (Site No. 13: Burlinghame Avenue)

Pipeline No. 24b (Site No. 13 Burlinghame Avenue)

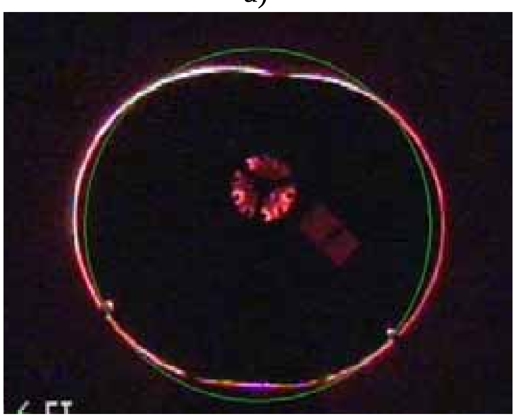




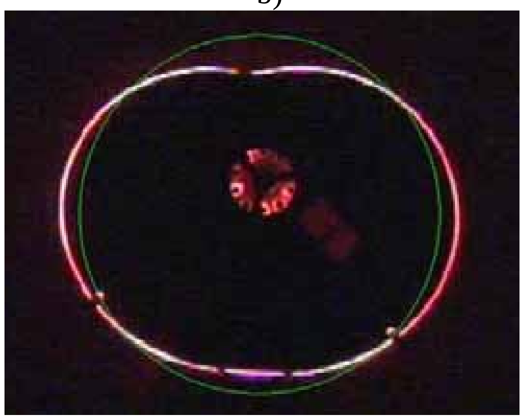
a)



b)



c)



d)

Figure 462 Horizontal and vertical deformation of Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

Figure 463 Cracking/fracture failure for Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

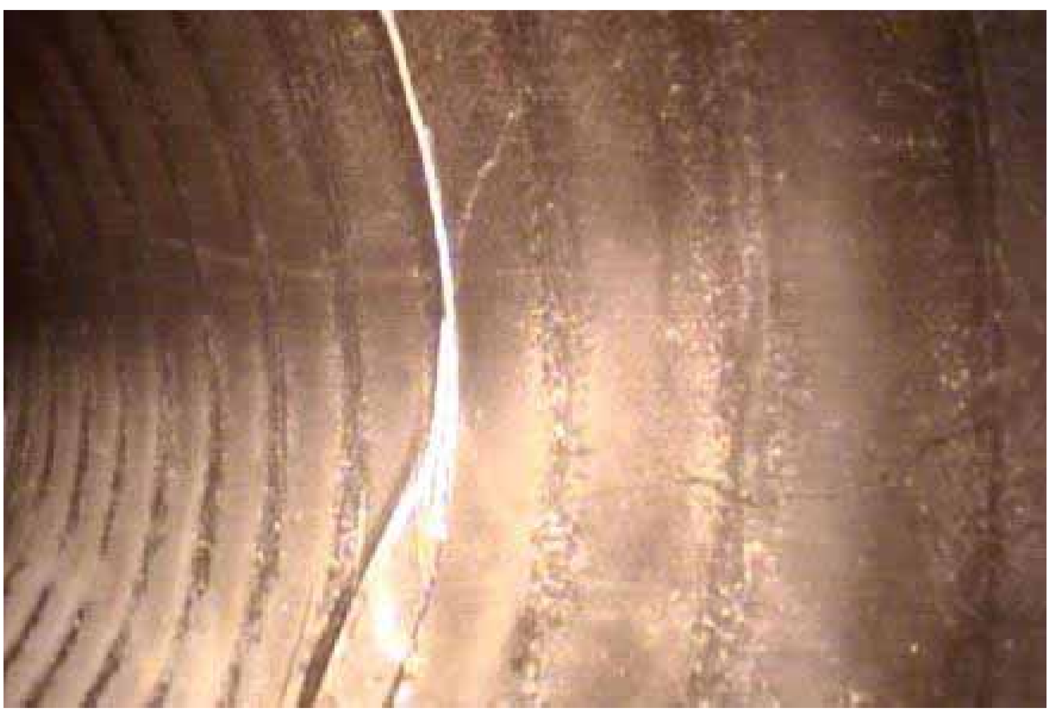


Figure 464 Cracking/fracture and corrugation growth failure for Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

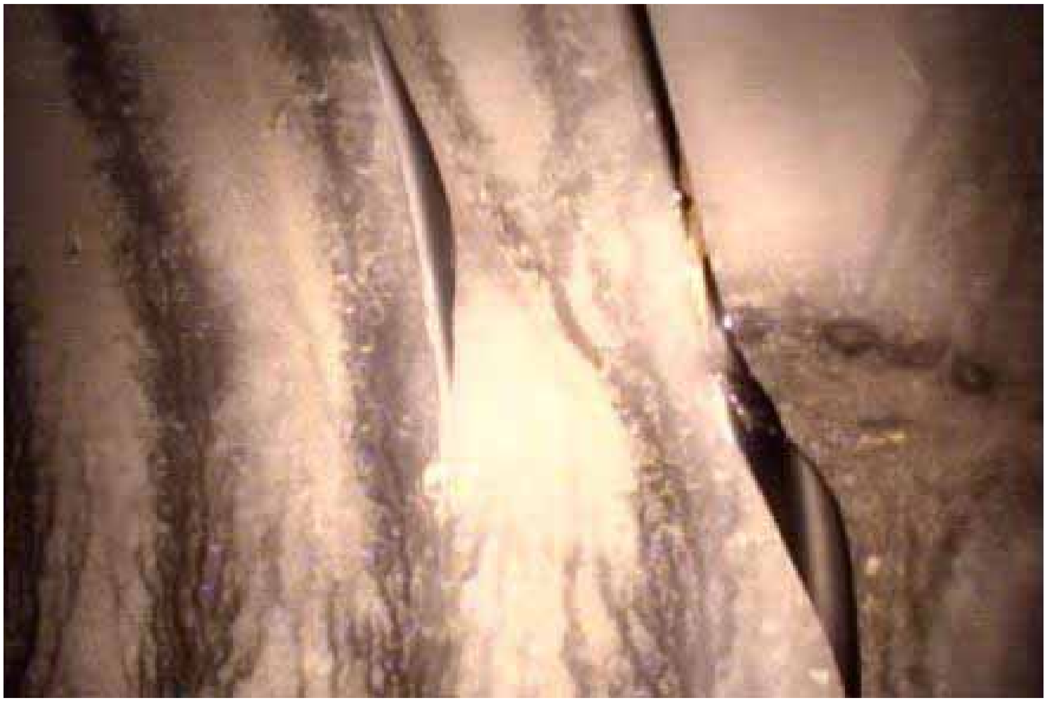


Figure 465 Cracking/fracture, buckling, and corrugation growth failure for Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

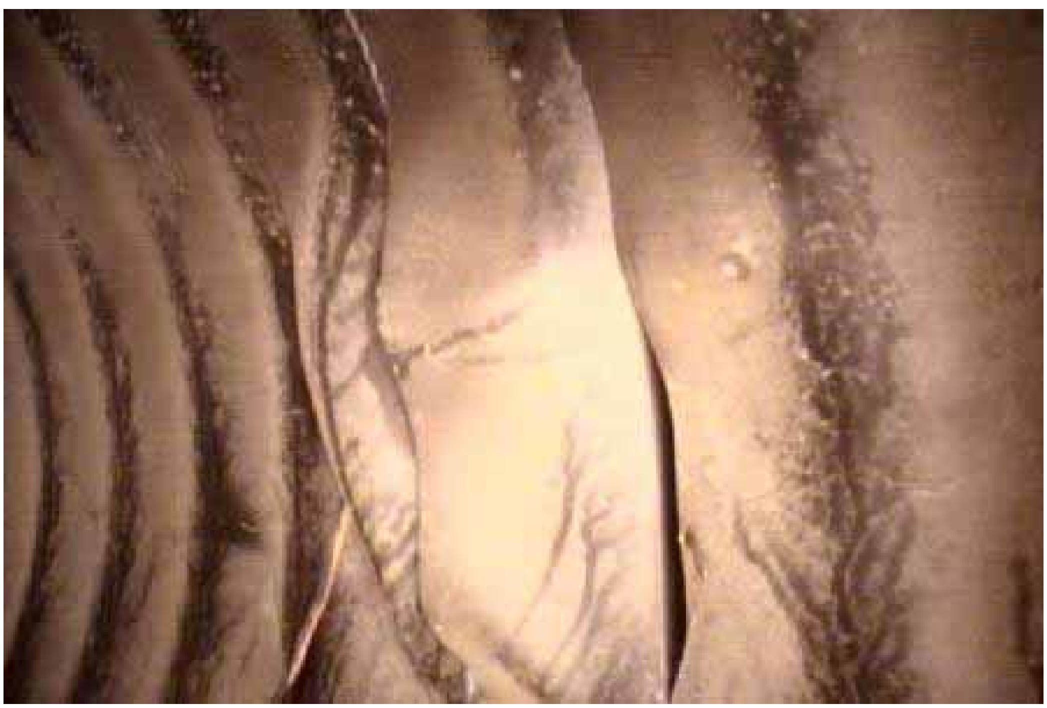


Figure 466 Cracking/fracture, buckling, and corrugation growth failure for Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

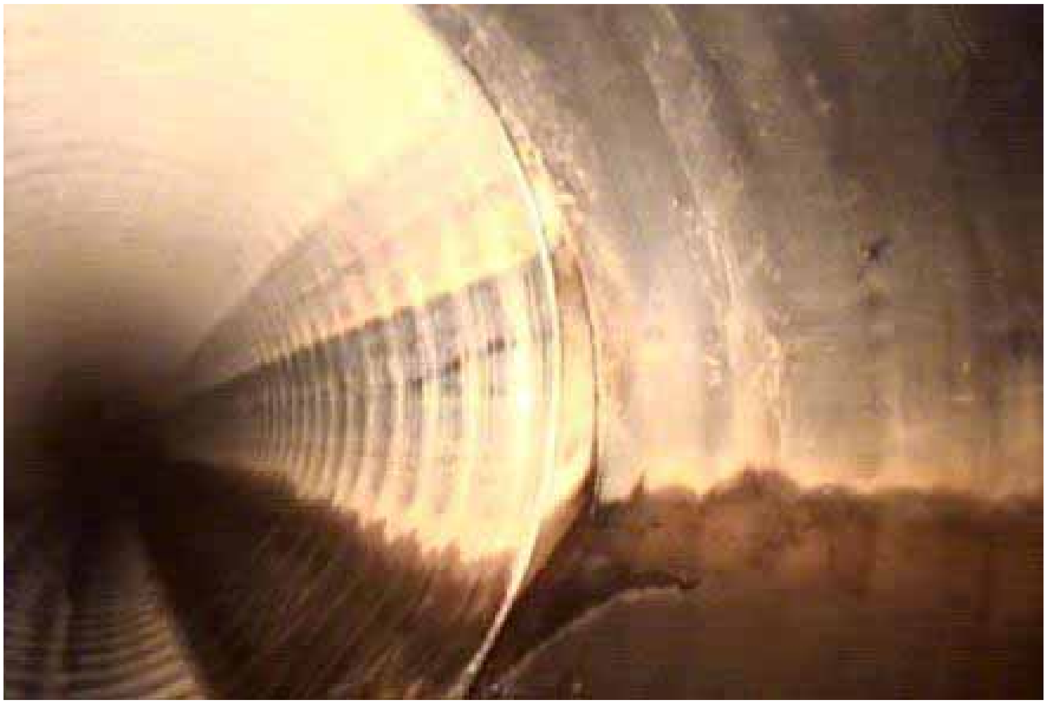
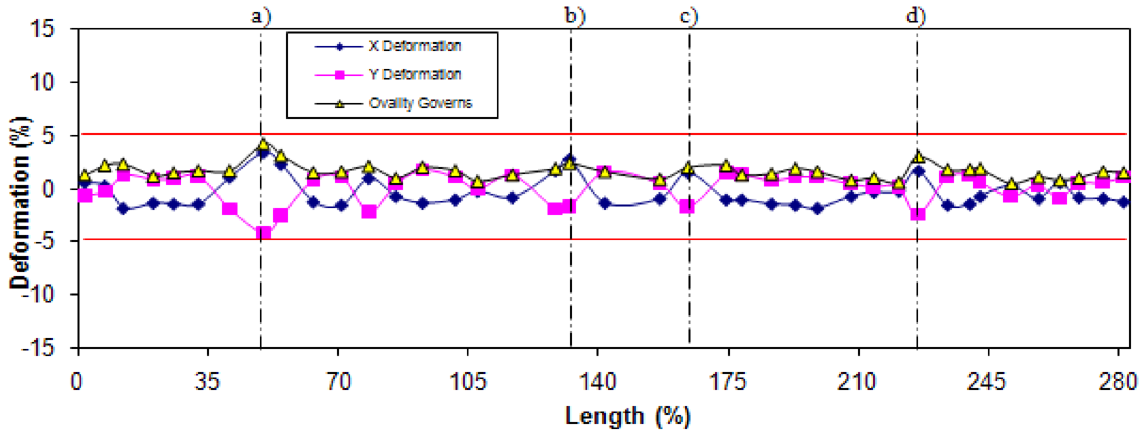
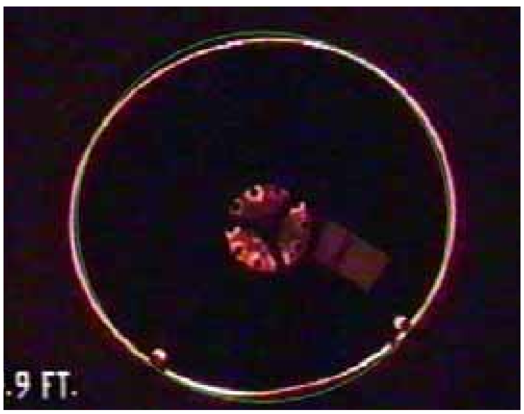
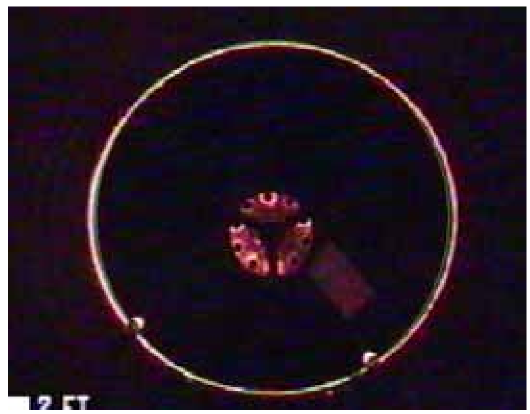


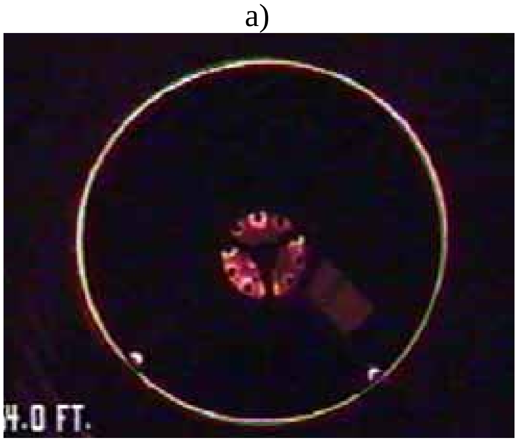
Figure 467 Joint displacement and corrugation growth failure for Pipeline No. 24b (Site No. 13: Burlinghame Avenue)

Pipeline No. 25 (Site No. 14 Downtown Grand Rapids)




a)


b)


c)

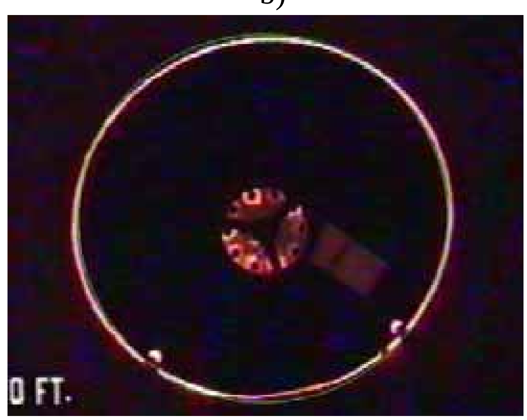
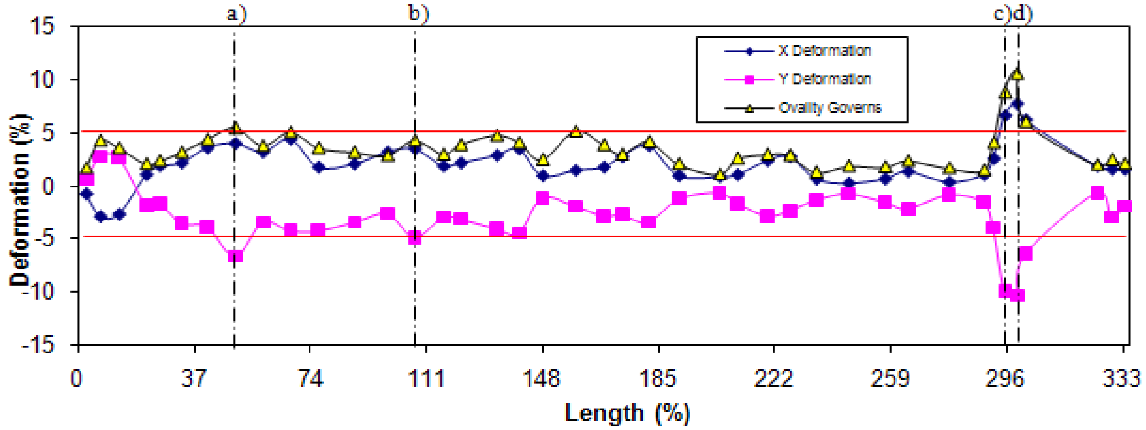
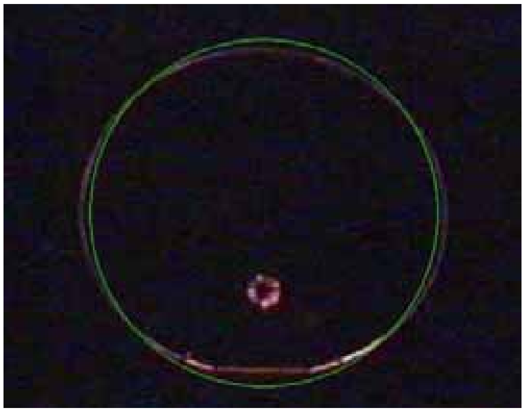

d)

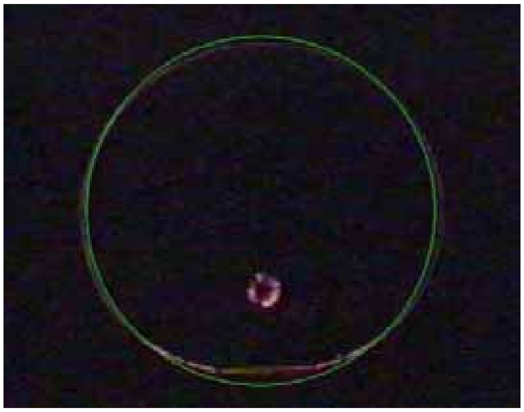
Figure 468 Horizontal and vertical deformation of Pipeline No. 25 (Site No. 14: Downtown Grand Rapids)

Pipeline No. 26 (Site No. 15 Greenville)

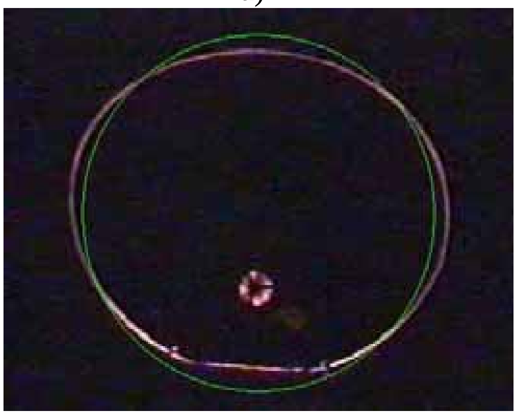




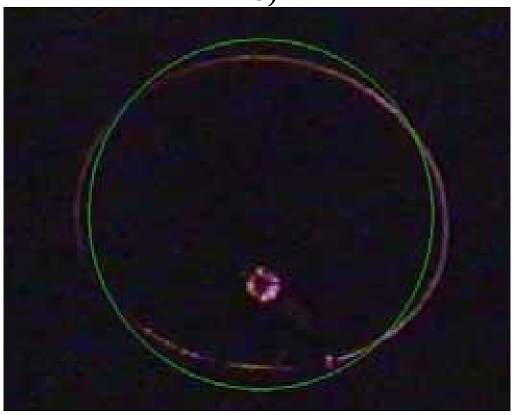
a)



b)



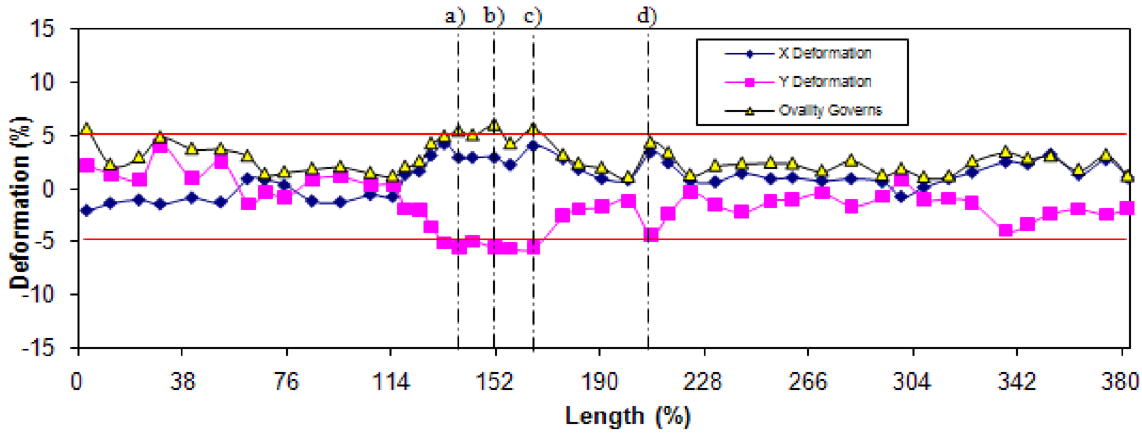
c)

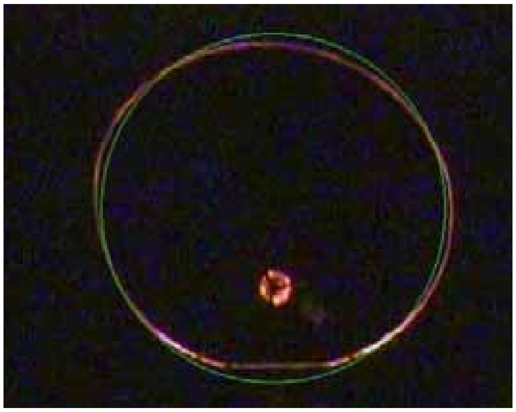


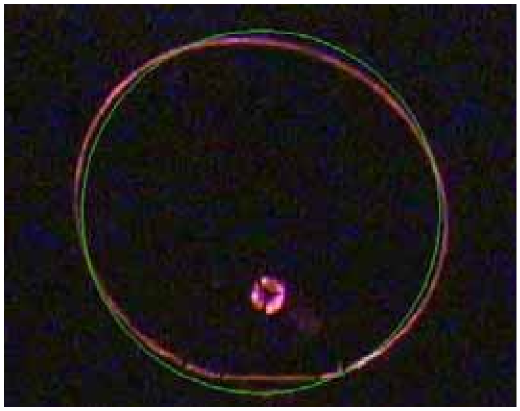
d)

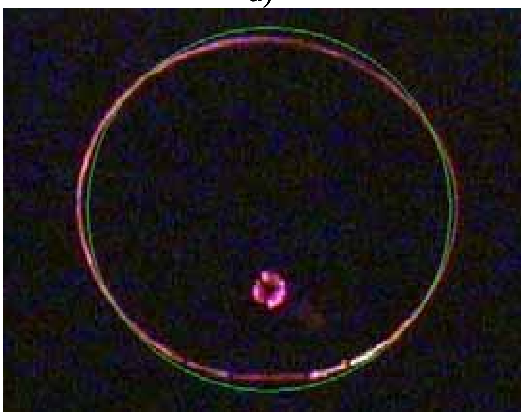
Figure 469 Horizontal and vertical deformation of Pipeline No. 26 (Site No. 15: Greenville)

Pipeline No. 27 (Site No. 15 Greenville)




a)


b)


c)

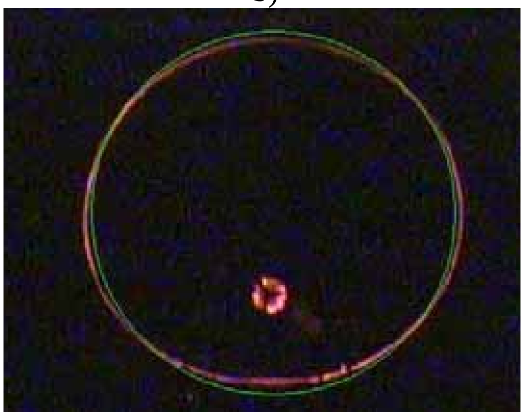
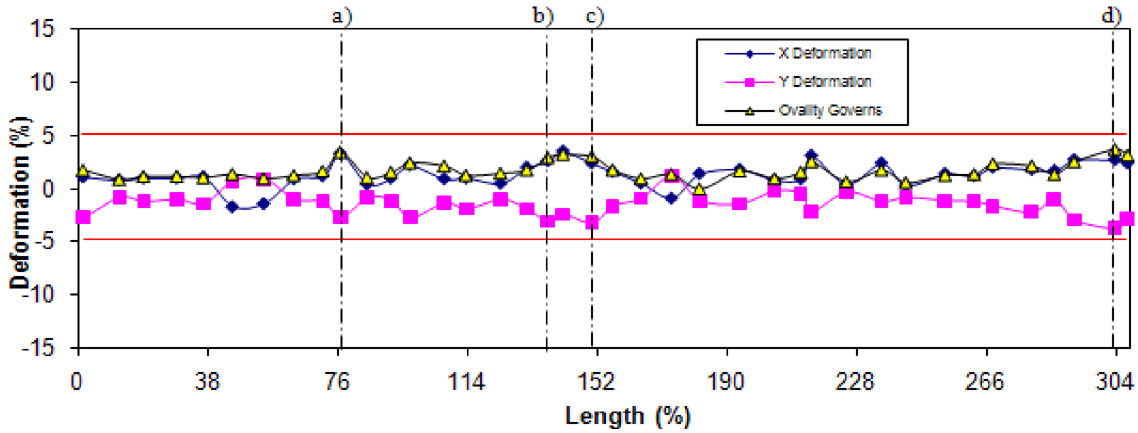
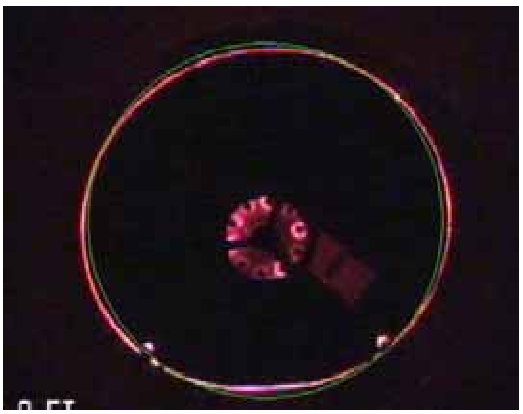
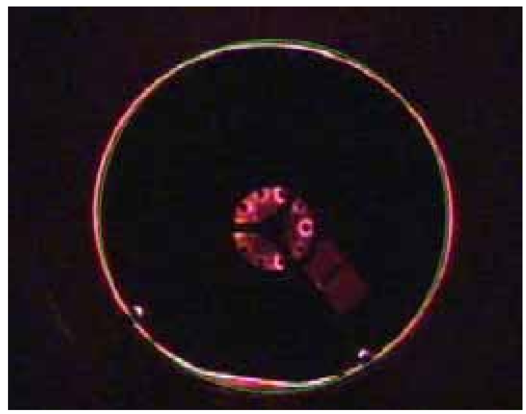

d)

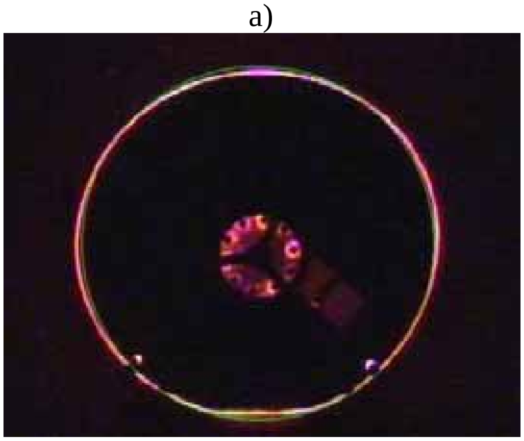
Figure 470 Horizontal and vertical deformation of Pipeline No. 27 (Site No. 15: Greenville)

Pipeline No. 28 (Site No. 16 Knapp and M44)




a)


b)


c)

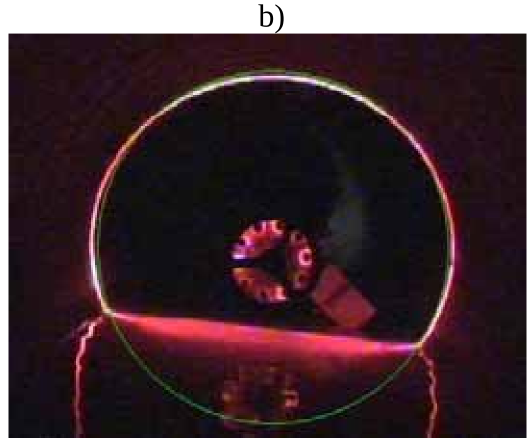
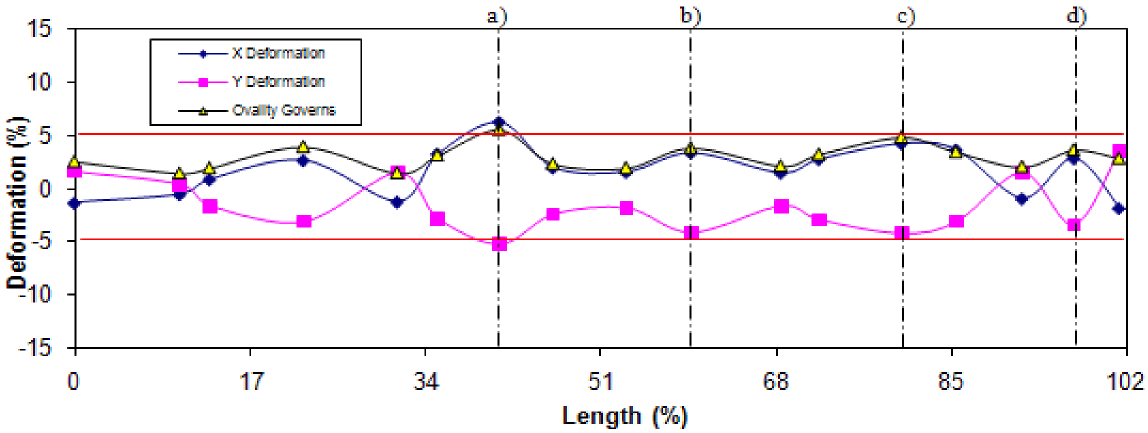
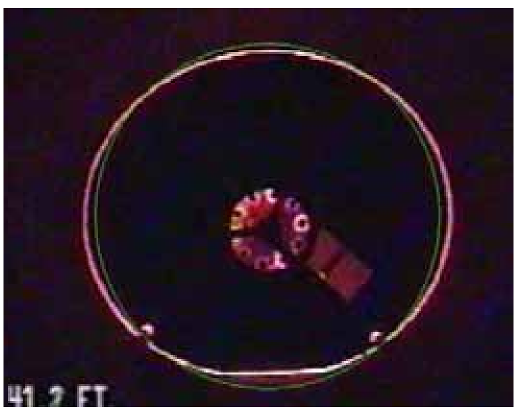

d)

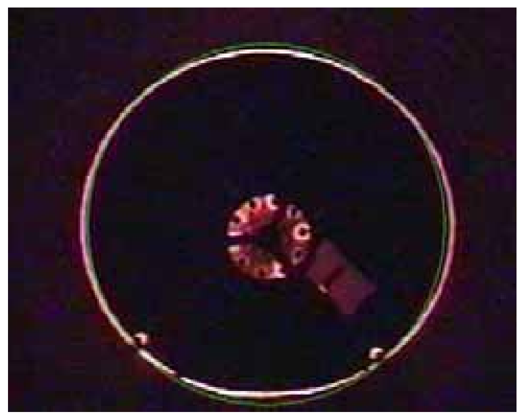
Figure 471 Horizontal and vertical deformation of Pipeline No. 28 (Site No. 16: Knapp and M44)

Pipeline No. 29 (Site No. 16 Knapp and M44)

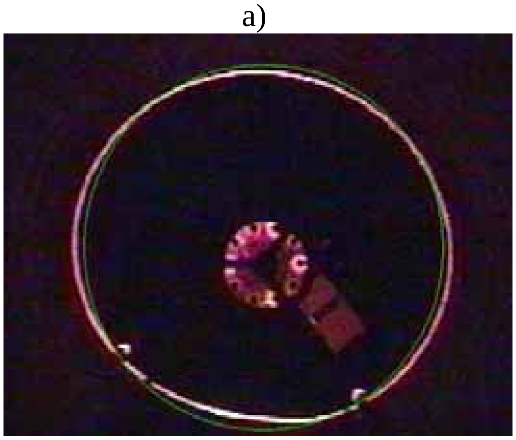




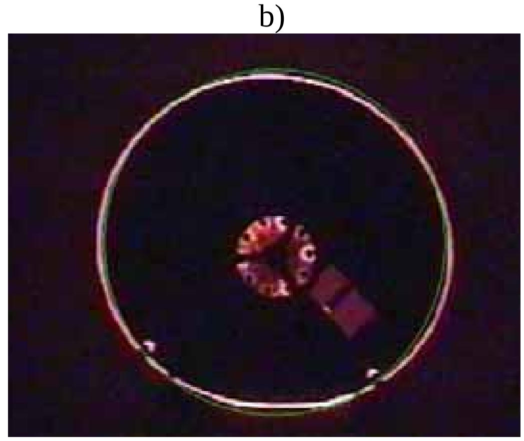
a)



b)



c)



d)

Figure 472 Horizontal and vertical deformation of Pipeline No. 29 (Site No. 16: Knapp and M44)

Appendix 10 – State of Florida

In this appendix, the layout and specification of different site numbers and locations and pipeline sizes and length with the inspection date are shown for state of Florida. Following that, summary of different observed damages and deformations are shown. Comparison of maximum deformations for each pipeline and deformation of pipelines along length with snapshots of 4 different sections are shown in figures. Deformation graphs include vertical, horizontal and ovality deformations of the pipelines. Views of notable damage or failure modes are then followed for each pipeline.

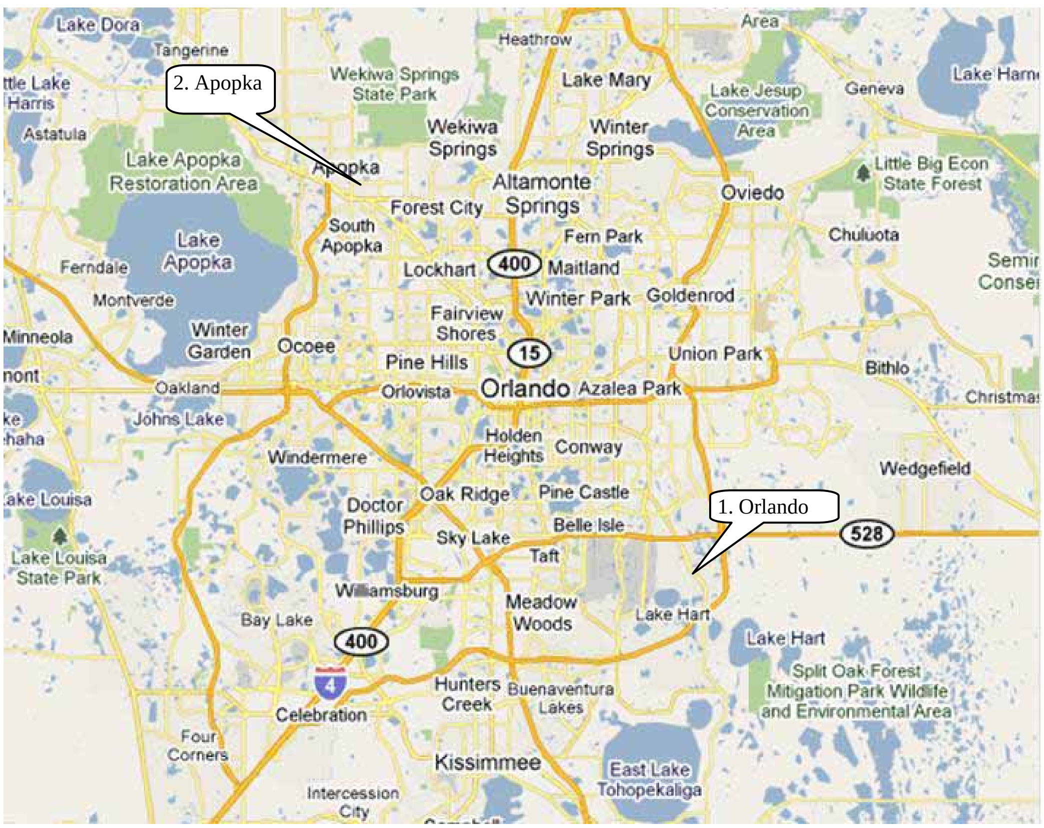


Figure 473 Layout of site locations

Table 331 Specification of Project Sites

Site Number	Site Location	Pipeline Number	Pipeline Diameter (in.)	Inspection date	Length (ft)
1	Orlando	1	24	7/2/2010	470
		2	42	7/2/2010	485
		3	36	7/2/2010	485
		4	30	7/2/2010	540
		5	18	7/2/2010	95
		6	24	7/3/2010	500
		7	36	7/3/2010	195
		8	42	7/3/2010	290
		9	42	7/3/2010	215
2	Apopka	10	18	7/4/2010	260
		11	24	7/4/2010	330
		12	24	7/4/2010	75
		13	30	7/8/2010	310
		14	20	7/4/2010	60
		15	18	7/4/2010	95

Table 332 Summary of different observed damages for different pipes at different site locations

Site Number	Site Location	Pipeline Number	Cracking	Excessive Deformation	Inverse Curvature	Major Joint Displacement	Corrugation Growth	Buckling
1	Orlando	1				✓	✓	
		2		✓		✓	✓	
		3	✓	✓		✓	✓	✓
		4	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
		5	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
		6		✓	✓	✓	✓	
		7	✓	✓		✓	✓	✓
		8	✓	✓		✓	✓	✓
		9		✓		✓	✓	✓
2	Apopka	10	✓			✓	✓	✓
		11	✓	✓	✓	✓	✓	
		12		✓		✓	✓	
		13	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
		14		✓		✓	✓	
		15		✓		✓	✓	
Percentage of pipelines experiencing failure mode			42%	83%	17%	100%	100%	42%

N.A. : Laser video data not collected

Table 333 Comparison and Summary of Deformation of pipelines

Site Number	Site Location	Pipeline Number	X Def (%)	Y Def (%)	Ovality (%)	Max Def (%)
1	Orlando	1	4.8	4.4	4.9	4.9
		2	4.0	7.2	6.3	7.2
		3	4.4	7.6	3.2	7.3
		4	N.A.	N.A.	N.A.	N.A.
		5	N.A.	N.A.	N.A.	N.A.
		6	5.7	5.5	3.9	5.7
		7	2.5	6.2	4.1	6.2
		8	3.7	5.1	4.5	5.1
		9	2.5	5.3	3.6	5.3
2	Apopka	10	3.8	4.3	5.1	5.1
		11	5.8	10.3	8.4	10.3
		12	3.0	5.7	5.5	5.7
		13	N.A.	N.A.	N.A.	N.A.
		14	4.1	6.7	5.7	6.7
		15	3.9	5.5	4.7	5.5
	Max		5.8	10.3	8.4	10.3
	Min		2.5	4.3	3.2	4.9
	Average		4.0	6.2	5.0	6.3

N.A. : Laser video data not collected

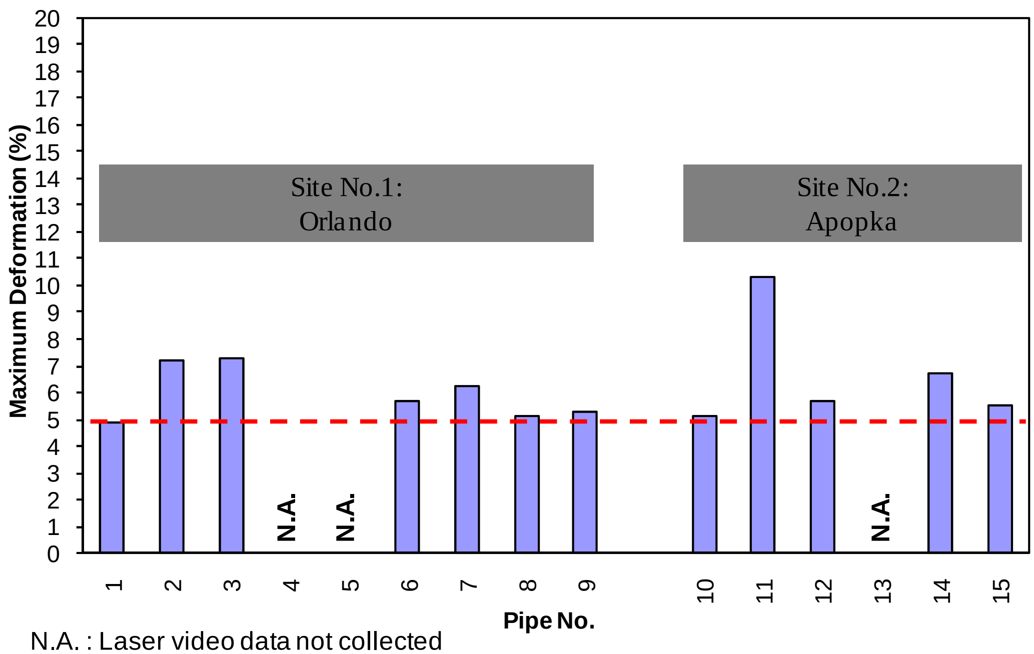
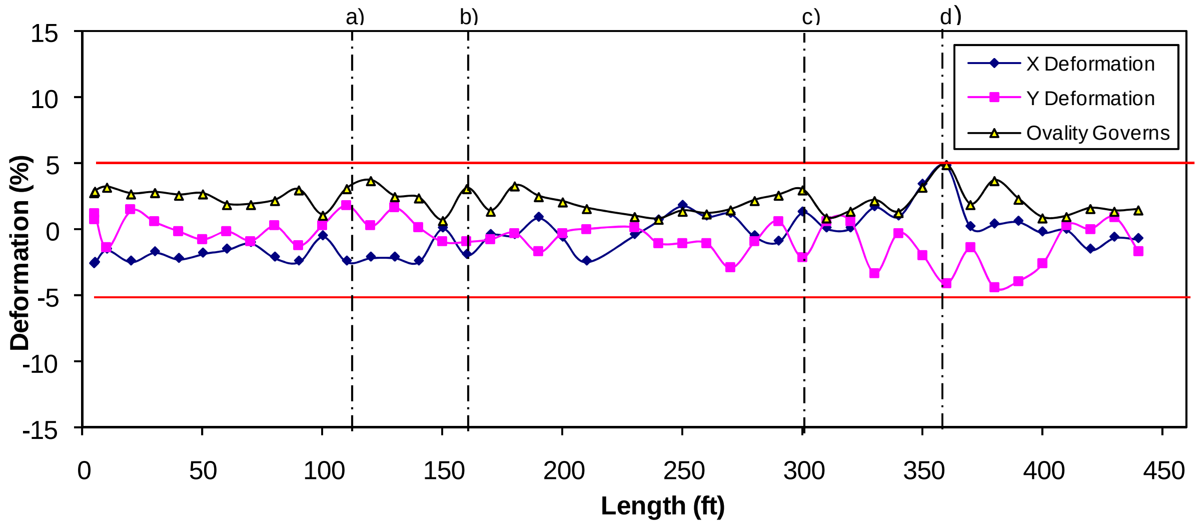
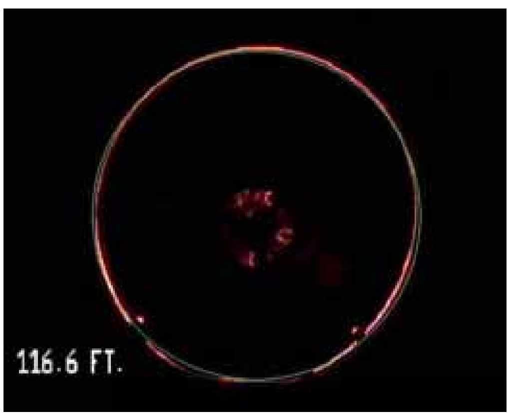


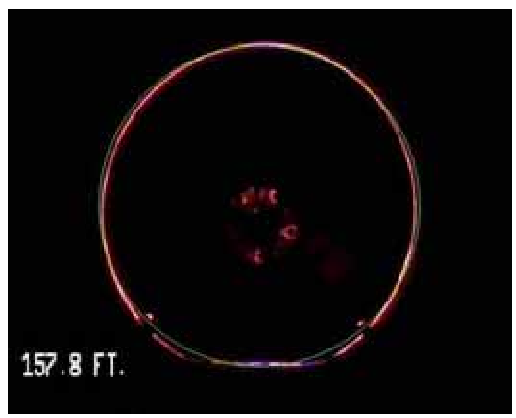
Figure 474 Comparison of Maximum deformations calculated for pipelines tested in different site locations

Pipeline No. 1 (Site No. 1: Orlando)

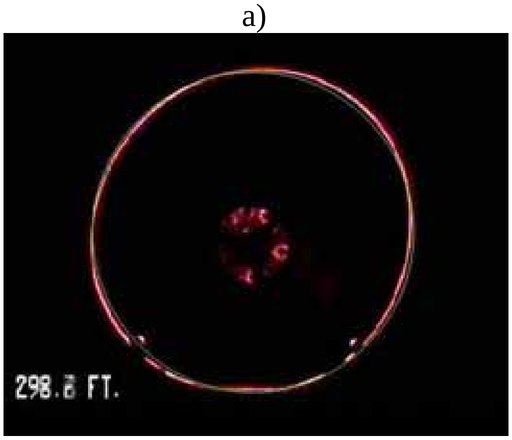




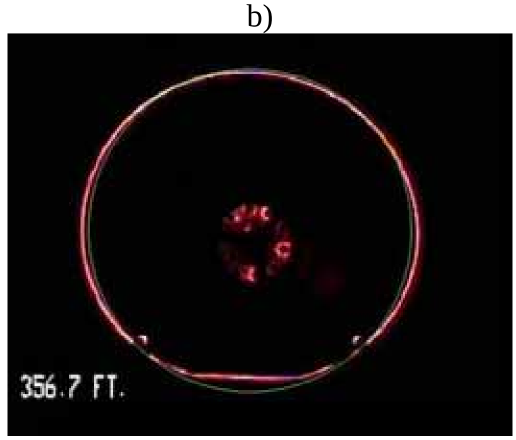
a)



b)



c)



d)

Figure 475 Horizontal and vertical deformation of the pipeline No. 1 (Site No. 1: Orlando)

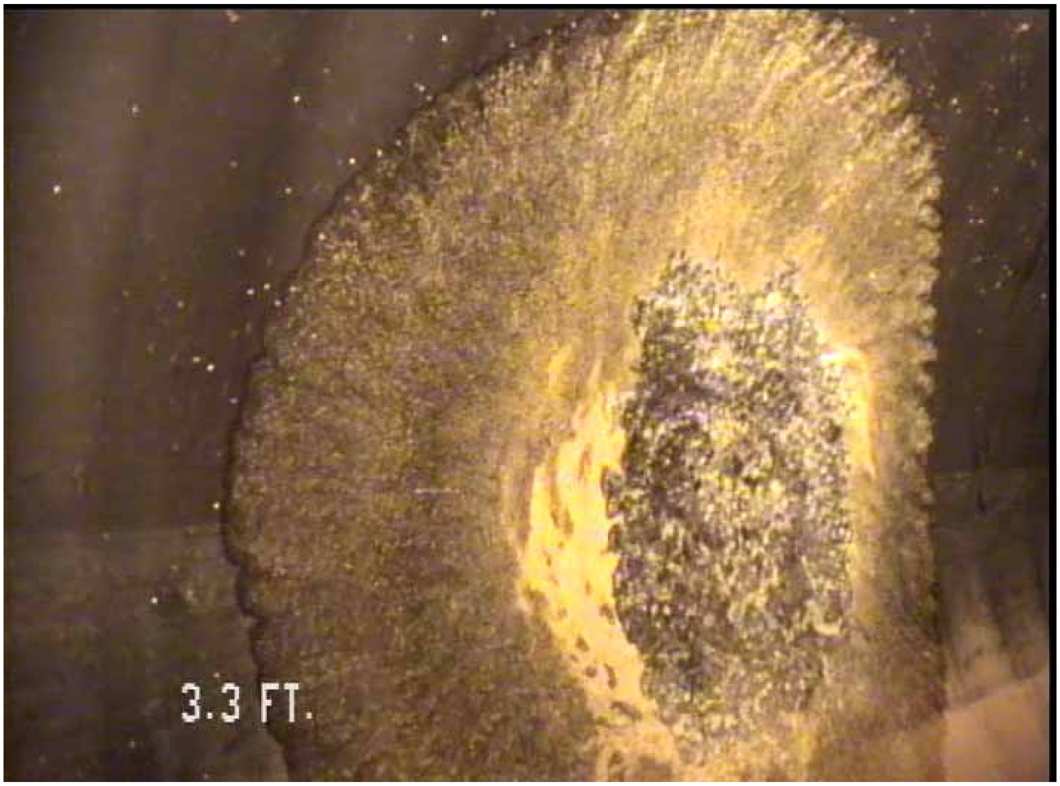


Figure 476 View of the oxidation damage for pipeline No. 1 (Site No. 1: Orlando)

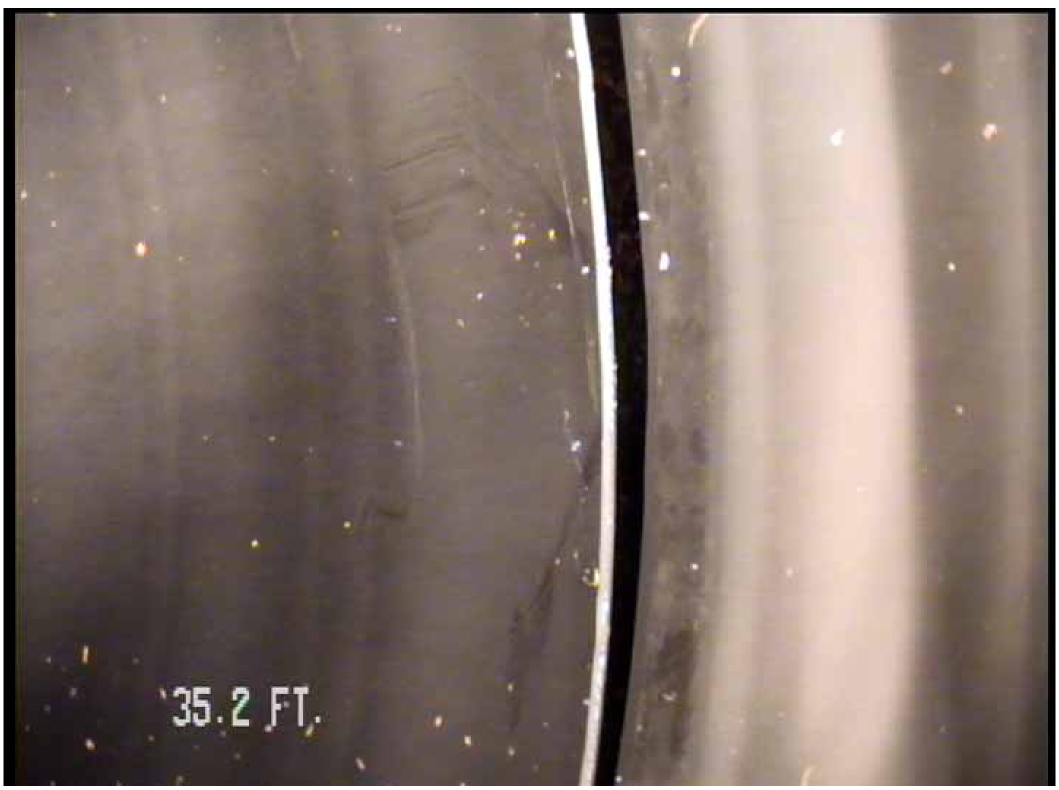


Figure 477 View of the major joint displacement failure for pipeline No. 1 (Site No. 1: Orlando)

Figure 478 View of the major joint displacement failure for pipeline No. 1 (Site No. 1: Orlando)

Figure 479 View of excessive deformation and corrugation growth failures for pipeline No. 1 (Site No. 1: Orlando)

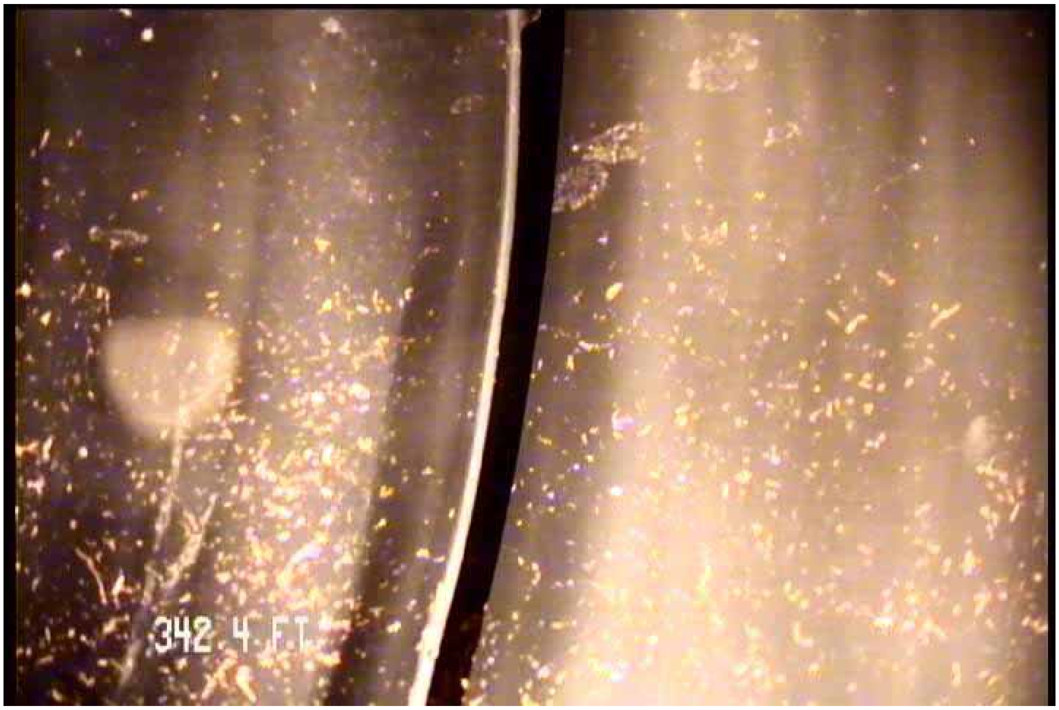
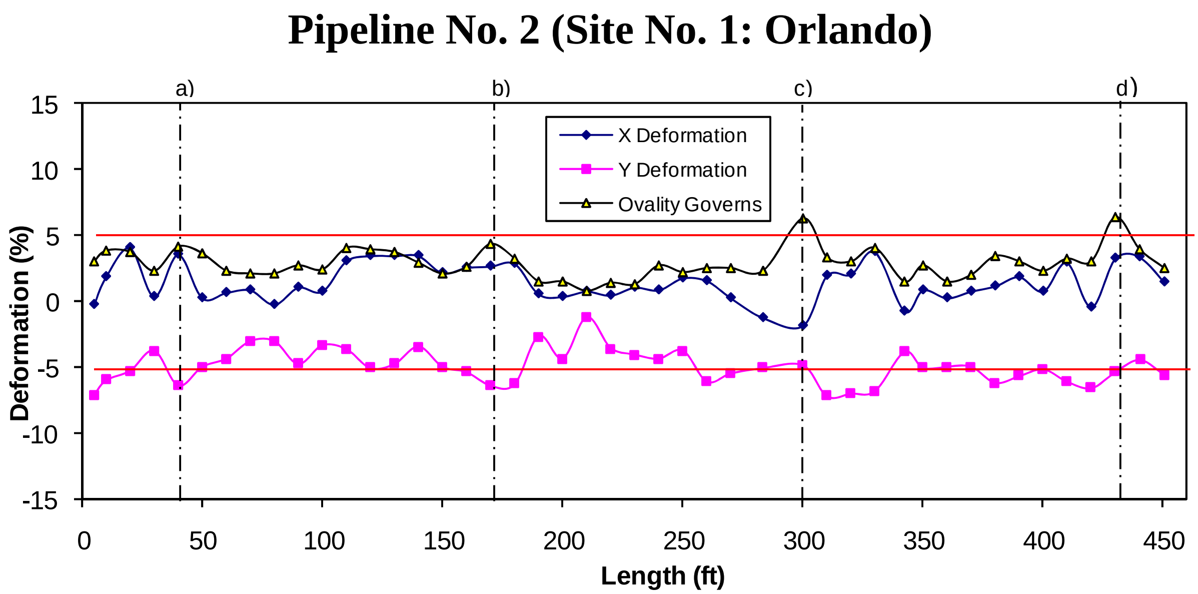


Figure 480 View of major joint displacement failure for pipeline No. 1 (Site No. 1: Orlando)



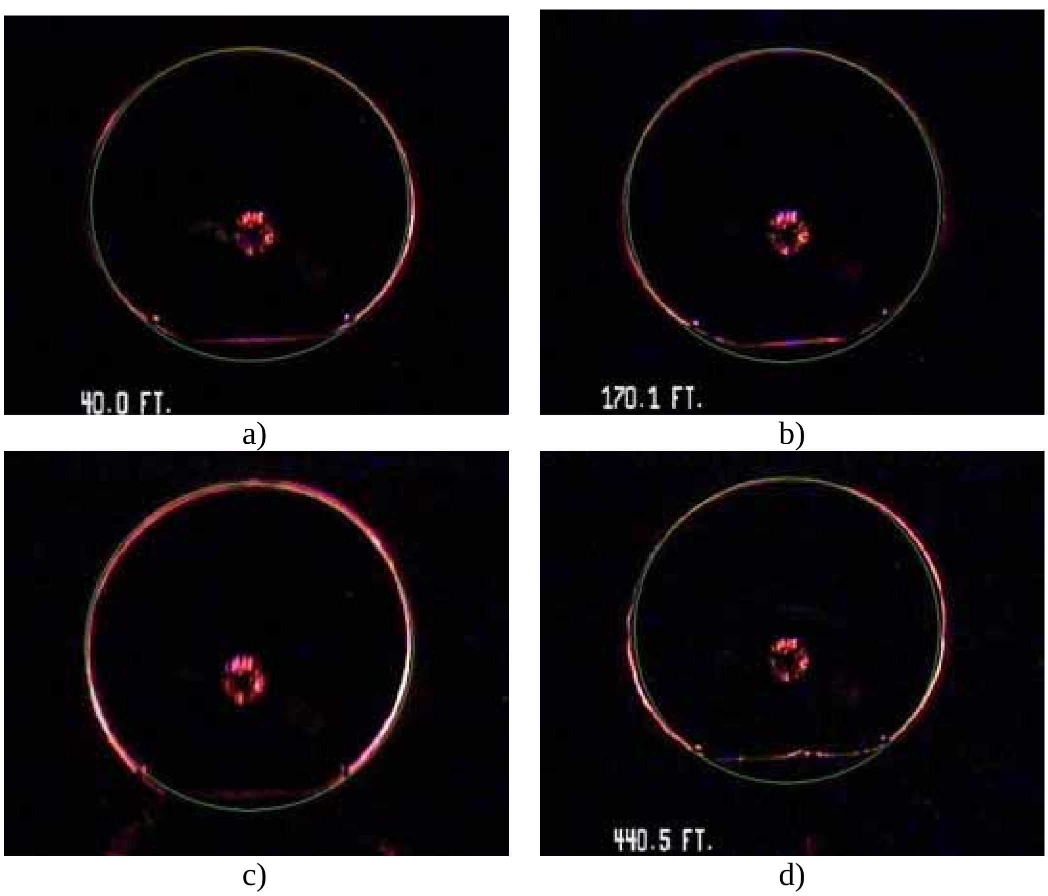


Figure 481 Horizontal and vertical deformation of the pipeline No. 2 (Site No. 1: Orlando)

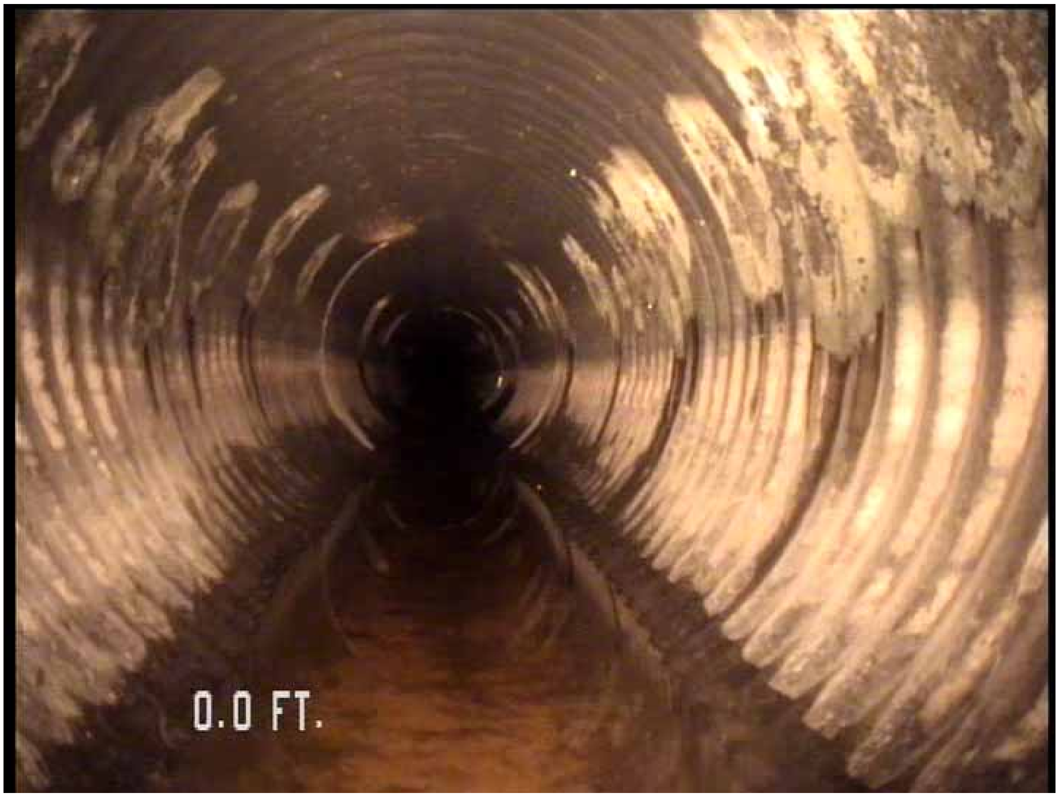


Figure 482 View of the corrugation growth failure for pipeline No. 2 (Site No. 1: Orlando)

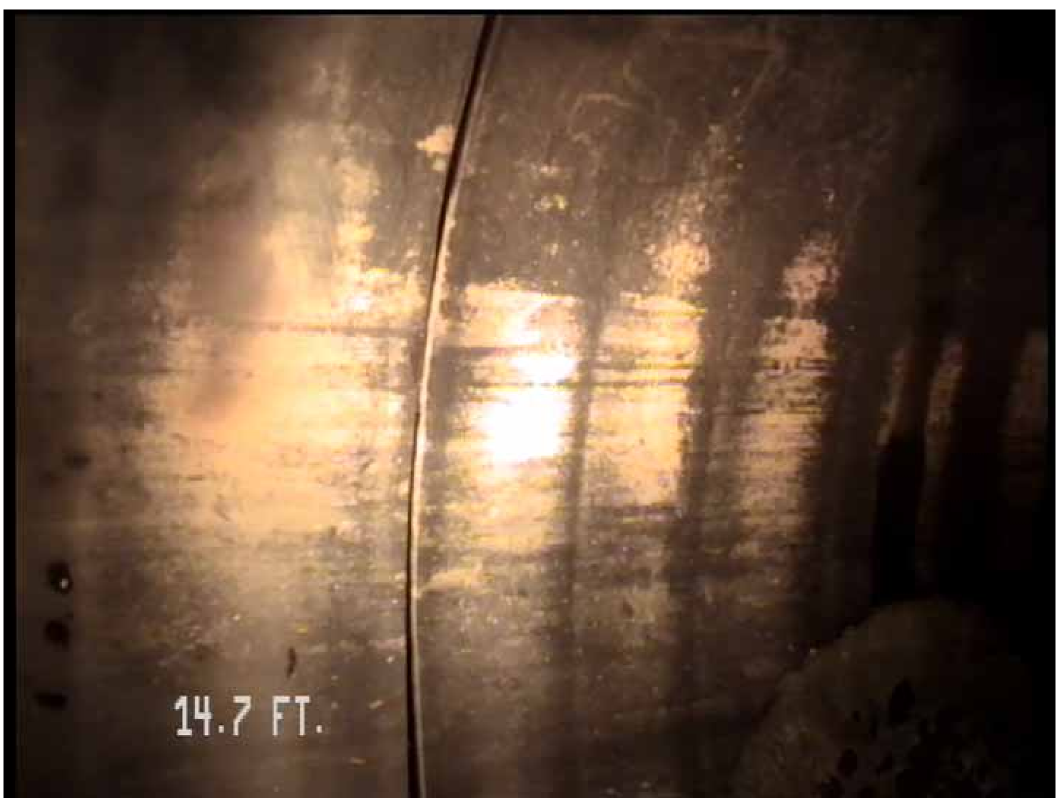


Figure 483 View of the minor joint displacement failure for pipeline No. 2 (Site No. 1: Orlando)

Figure 484 View of the leaking at the joint for pipeline No. 2 (Site No. 1: Orlando)

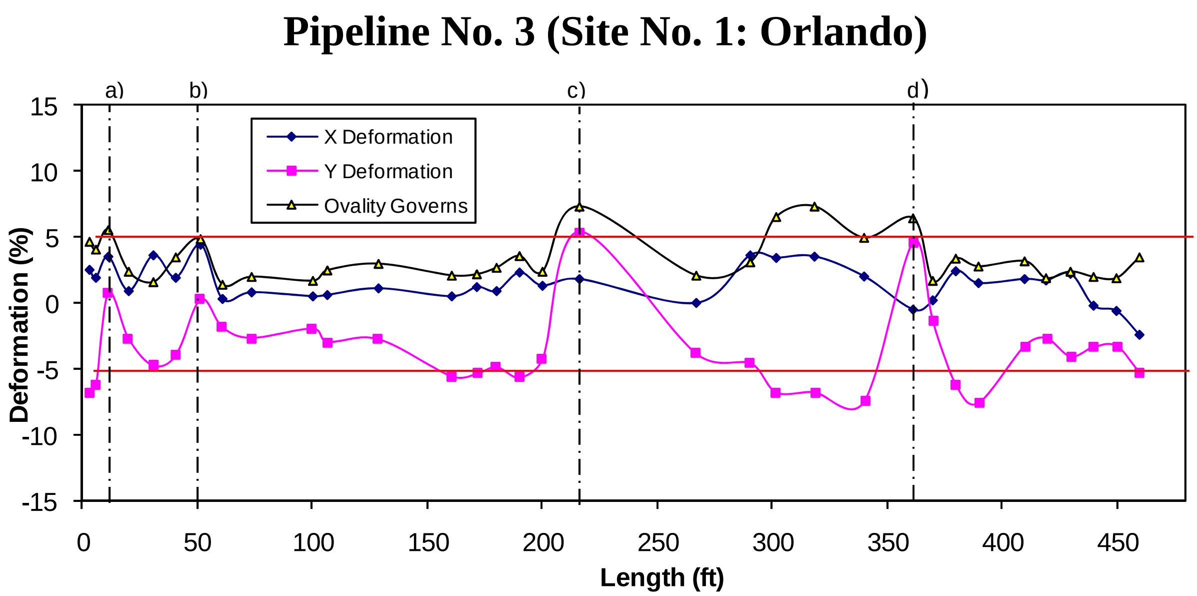
Figure 485 View of the corrugation growth failure for pipeline No. 2 (Site No. 1: Orlando)

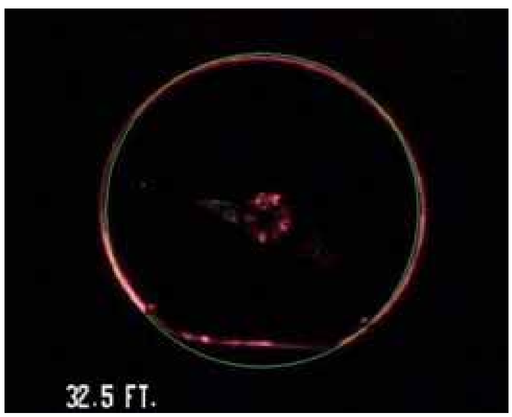
Figure 486 View of the major joint displacement failure for pipeline No. 2 (Site No. 1: Orlando)

Figure 487 View of the major joint displacement failure for pipeline No. 2 (Site No. 1: Orlando)

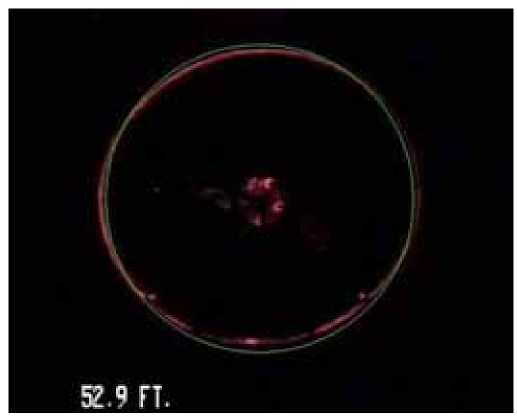
Figure 488 View of major joint displacement failure for pipeline No. 2 (Site No. 1: Orlando)

Figure 489 View of the corrugation growth failure for pipeline No. 2 (Site No. 1: Orlando)

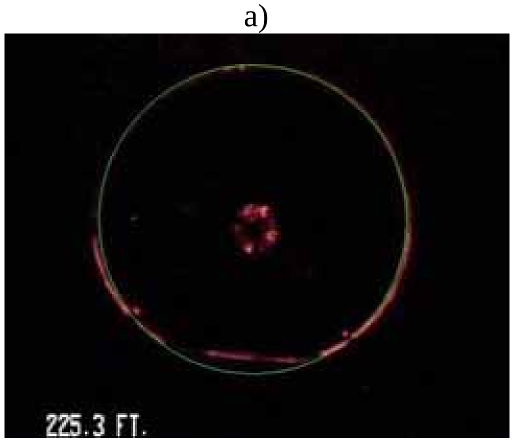




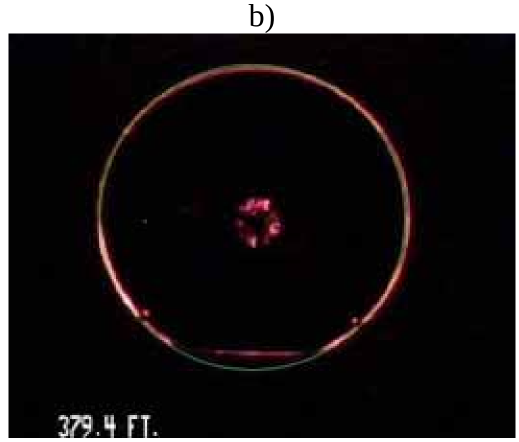
a)



b)



c)



d)

Figure 490 Horizontal and vertical deformation of the pipeline No. 3 (Site No. 1: Orlando)

Figure 491 View of the corrugation growth failure for pipeline No. 3 (Site No. 1: Orlando)

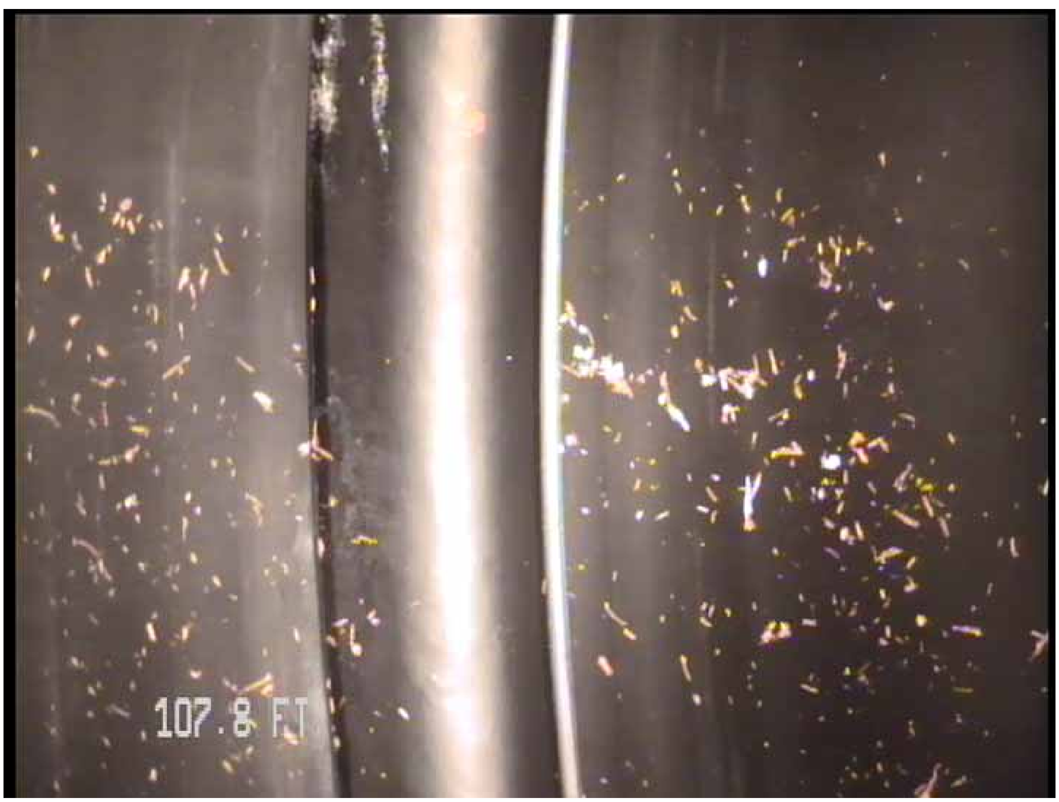


Figure 492 View of the major joint displacement failure for pipeline No. 3

(Site No. 1: Orlando)

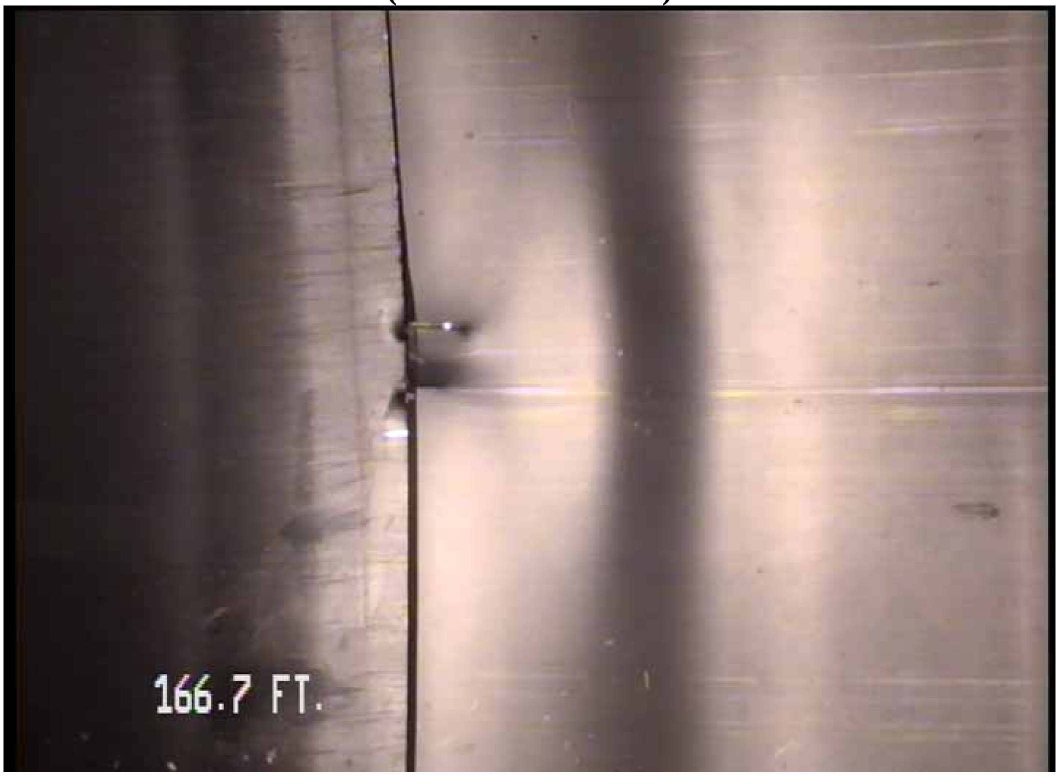


Figure 493 View of the cracking and buckling failures for pipeline No. 3 (Site No. 1: Orlando)

Figure 494 View of the cracking/leaking failures for pipeline No. 3

(Site No. 1: Orlando)

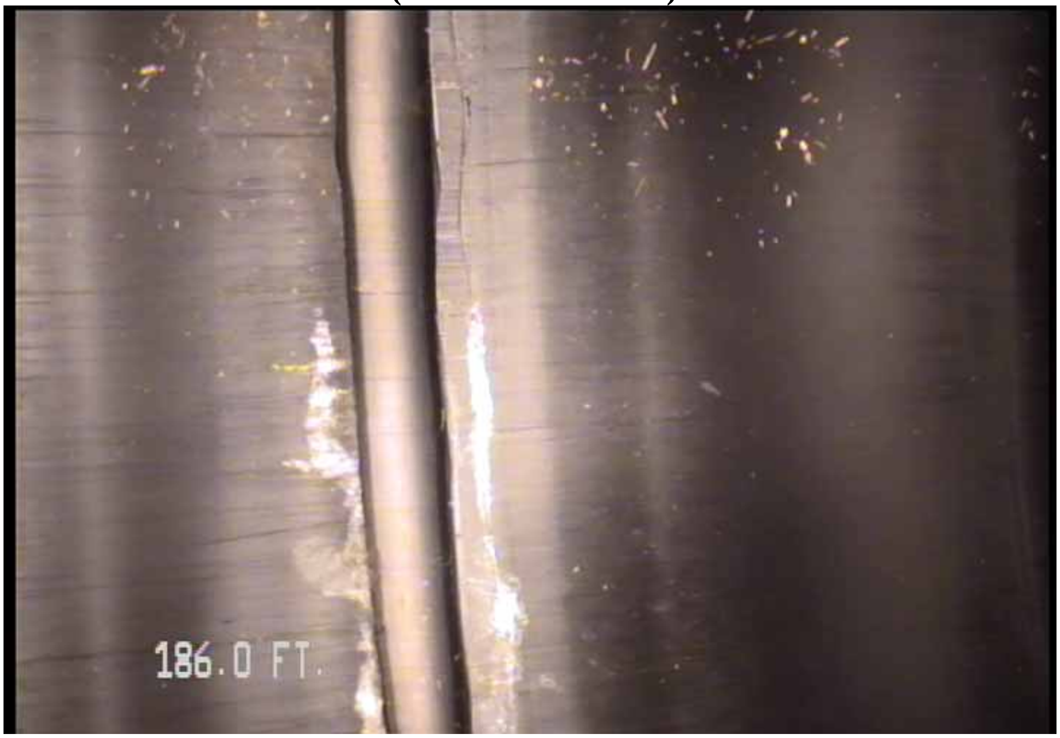


Figure 495 View of the major joint displacement failure for pipeline No. 3 (Site No. 1: Orlando)

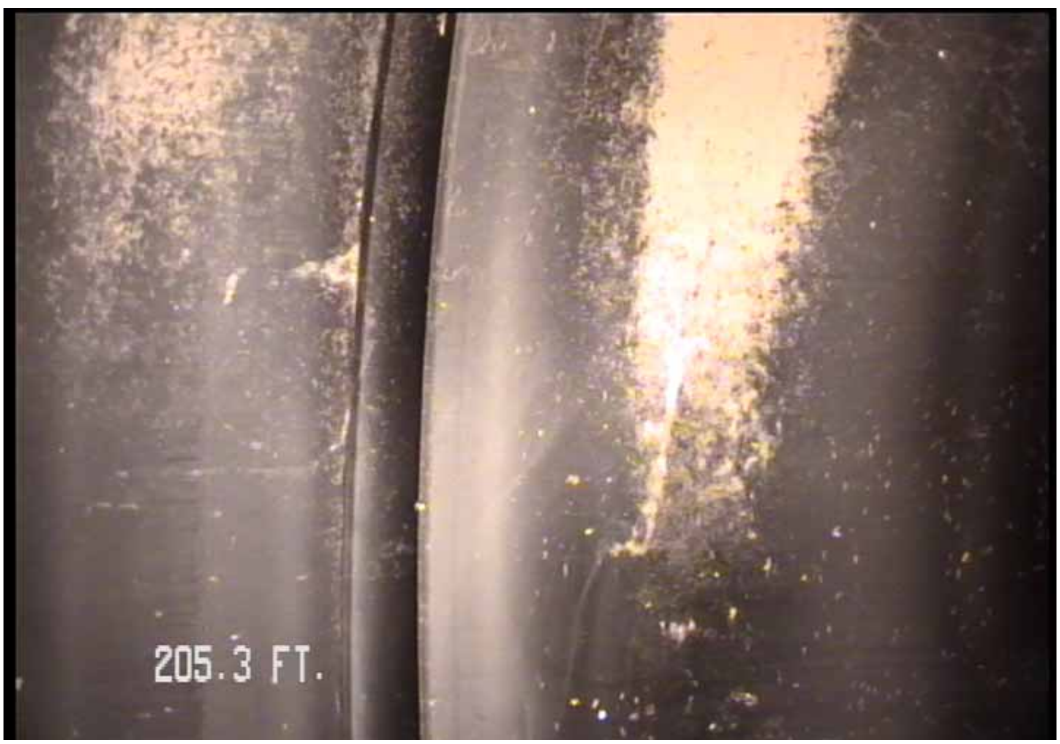


Figure 496 View of the major joint displacement failure for pipeline No. 3 (Site No. 1: Orlando)

Figure 497 View of the corrugation growth failure for pipeline No. 3 (Site No. 1: Orlando)

Figure 498 View of the buckling failure for pipeline No. 3 (Site No. 1: Orlando)

Figure 499 View of the corrugation growth failure for pipeline No. 3 (Site No. 1: Orlando)

Figure 500 View of the leaking at the joint for pipeline No. 3 (Site No. 1: Orlando)

Figure 501 View of the joint for pipeline No. 3 (Site No. 1: Orlando)

Figure 502 View of the excessive deformation, corrugation growth and buckling failures for pipeline No. 3 (Site No. 1: Orlando)

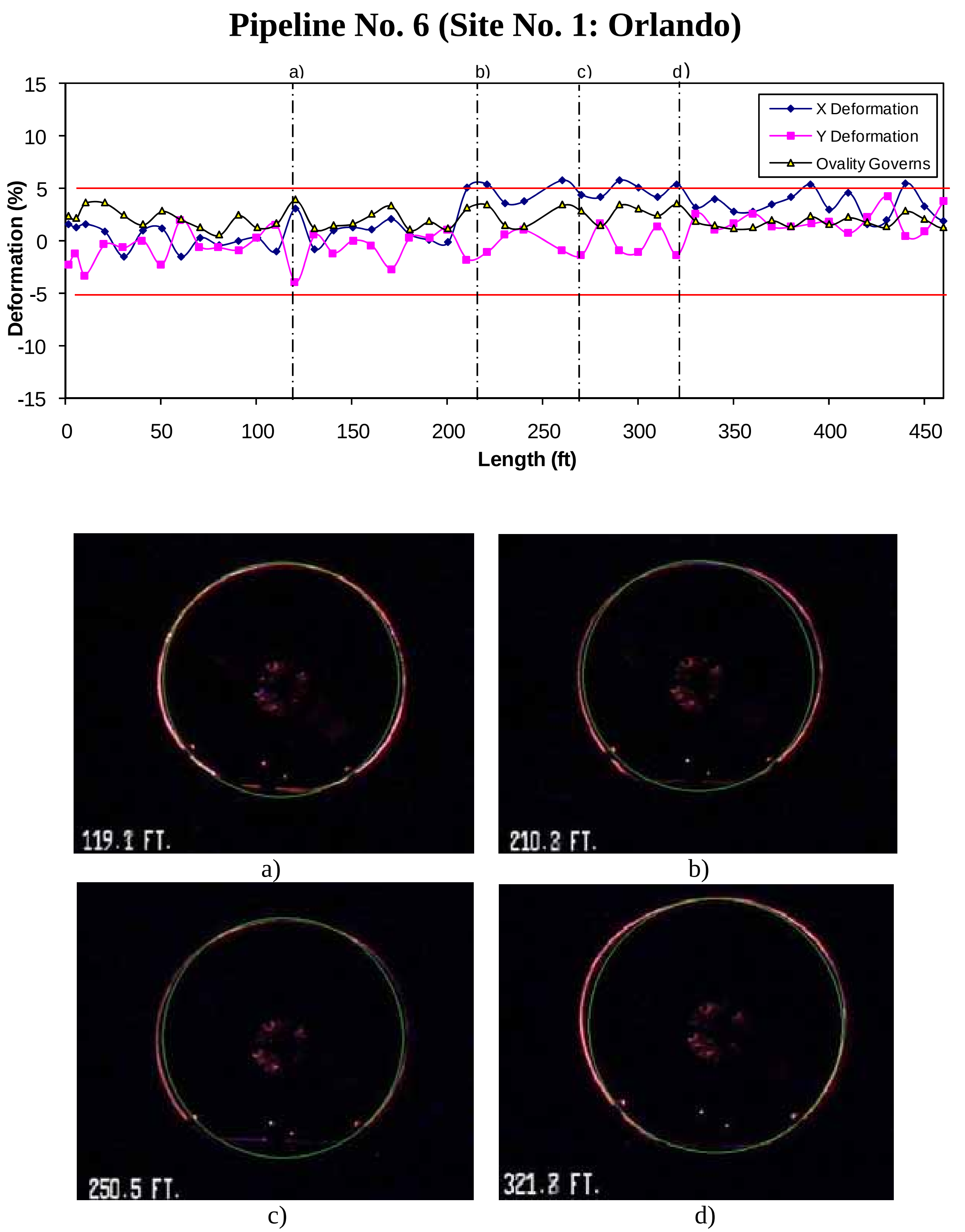


Figure 503 Horizontal and vertical deformation of the pipeline No. 6 (Site No. 1: Orlando)

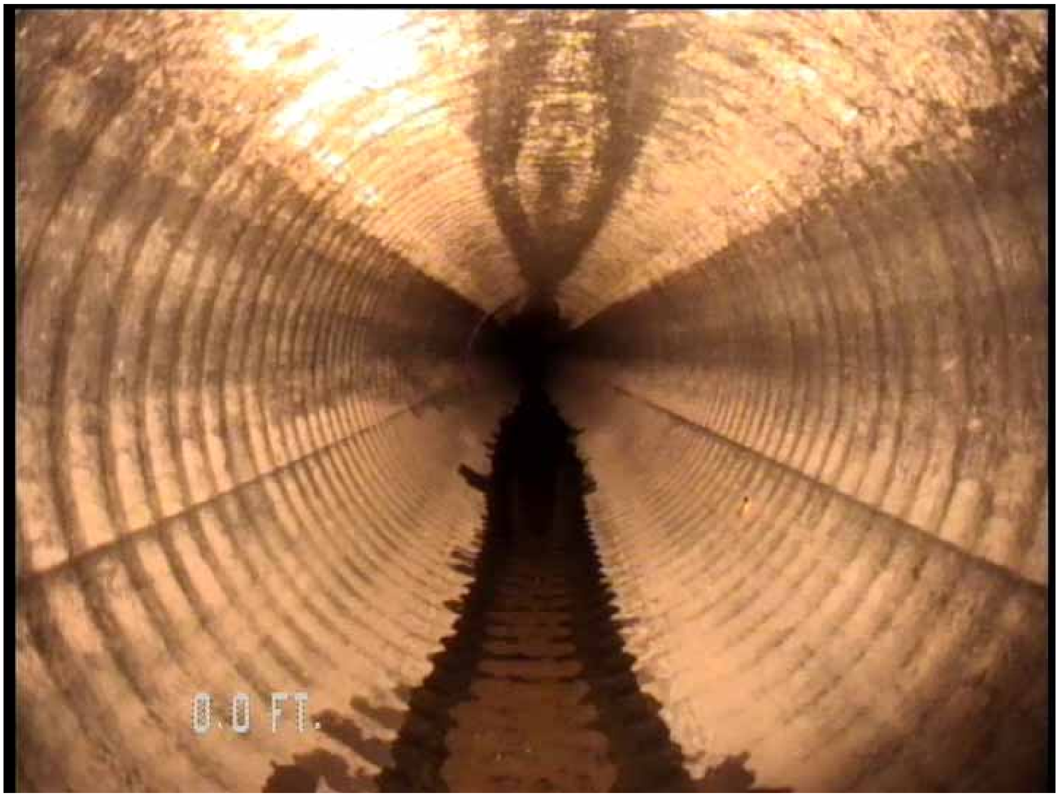


Figure 504 View of the corrugation growth failure for pipeline No. 6 (Site No. 1: Orlando)

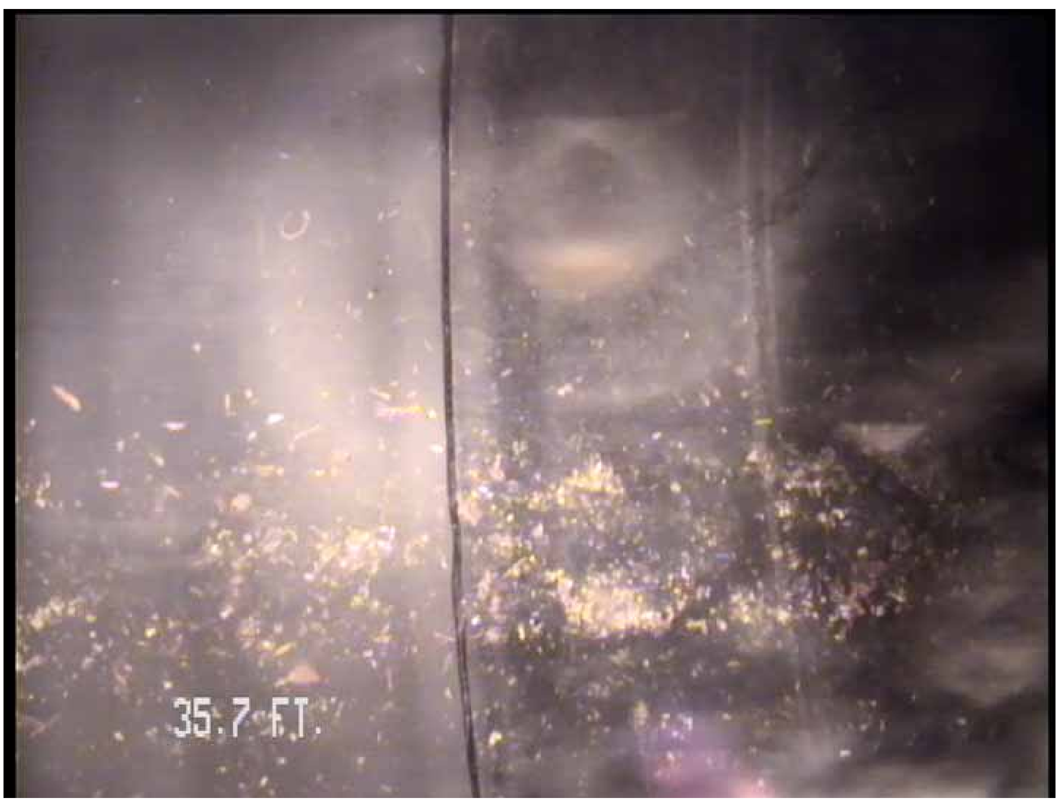


Figure 505 View of the joint for pipeline No. 6 (Site No. 1: Orlando)

Figure 506 View of the minor joint displacement failure for pipeline No. 6 (Site No. 1: Orlando)

Figure 507 View of the major joint displacement failure for pipeline No. 6

(Site No. 1: Orlando)

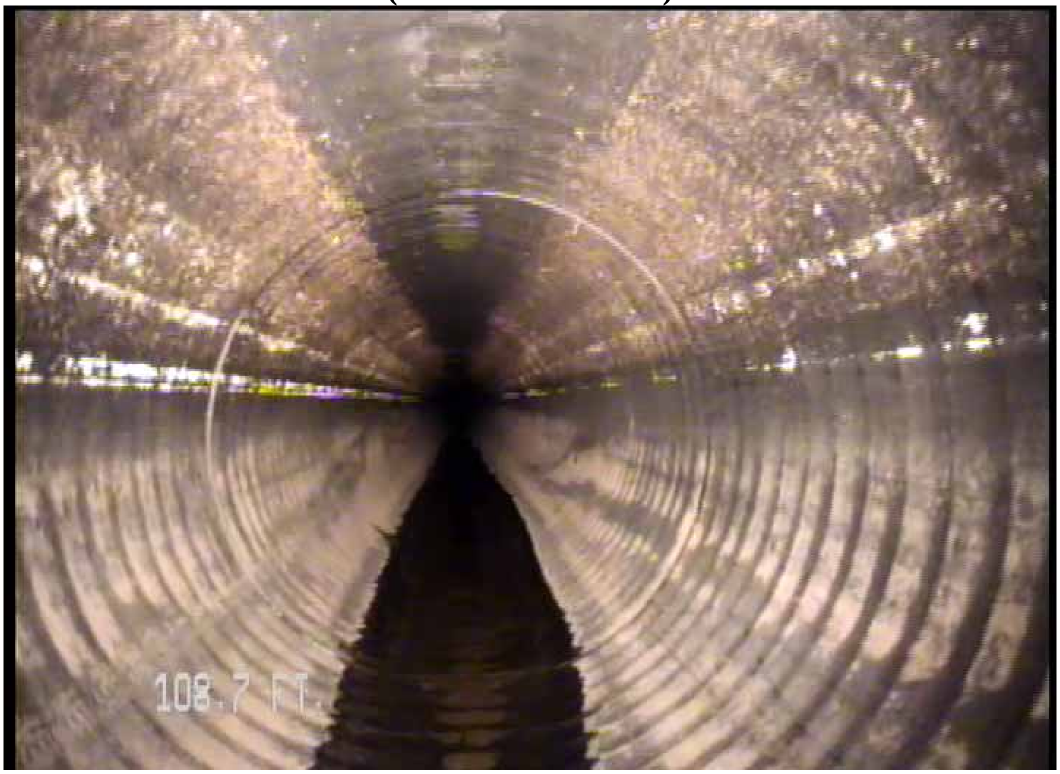


Figure 508 View of the corrugation growth failure for pipeline No. 6 (Site No. 1: Orlando)

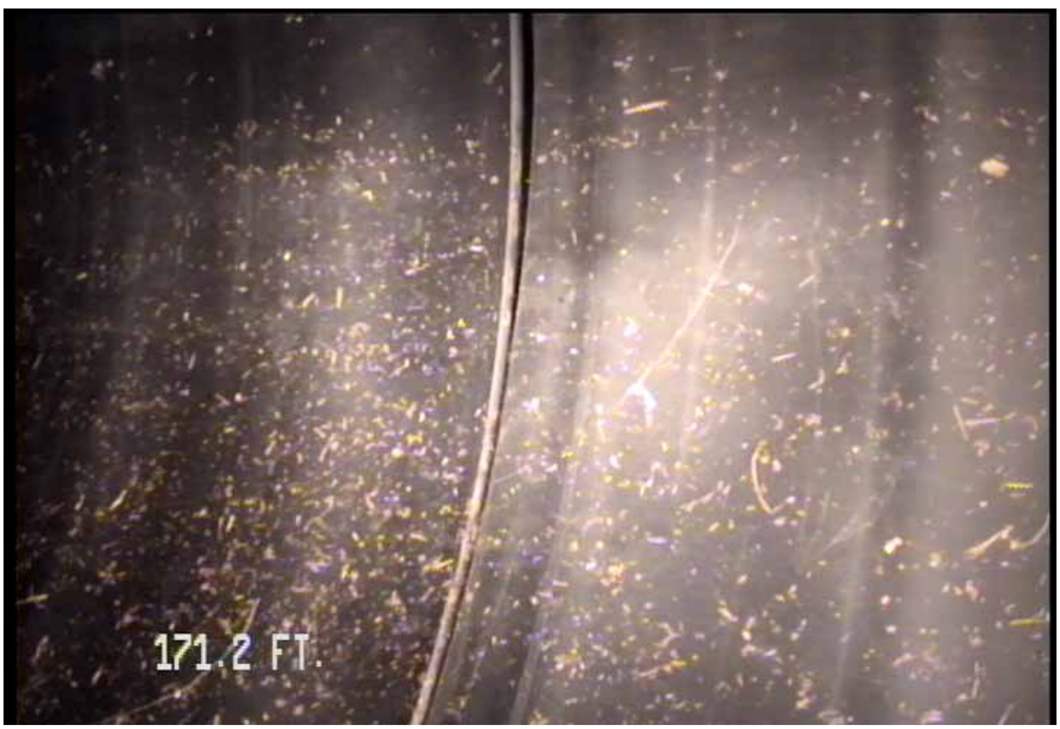


Figure 509 View of the minor joint displacement failure for pipeline No. 6 (Site No. 1: Orlando)

Figure 510 View of the minor joint displacement failure for pipeline No. 6 (Site No. 1: Orlando)

Figure 511 View of the joint for pipeline No. 6 (Site No. 1: Orlando)

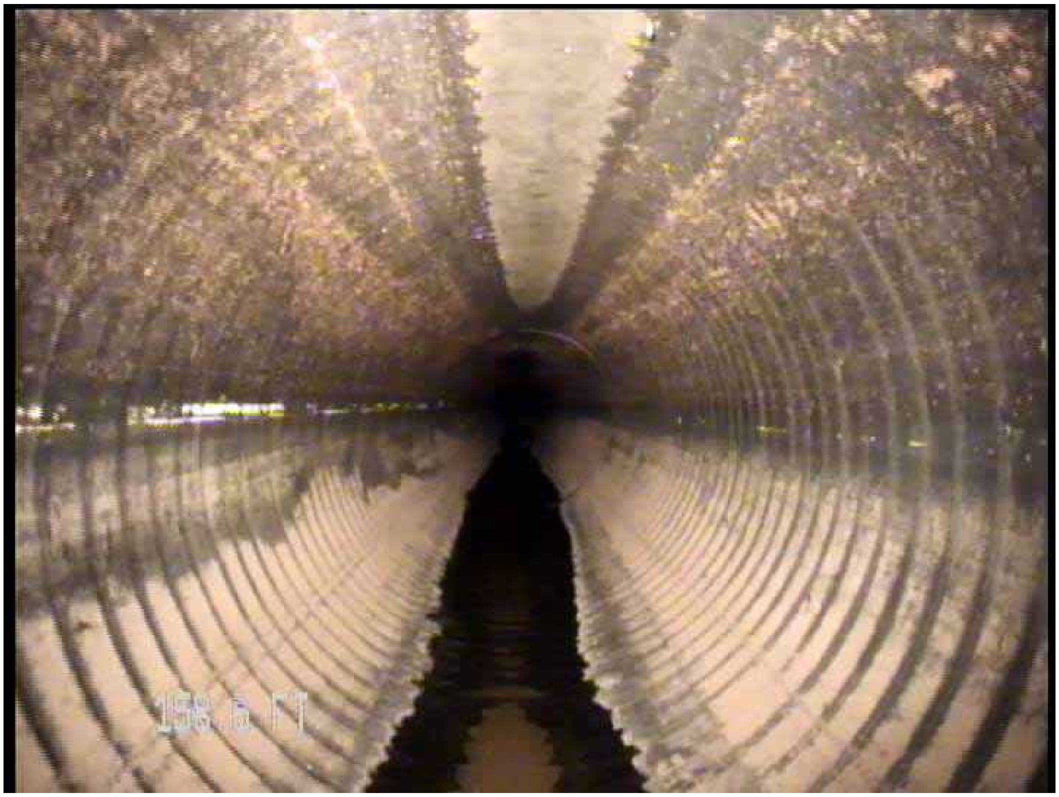
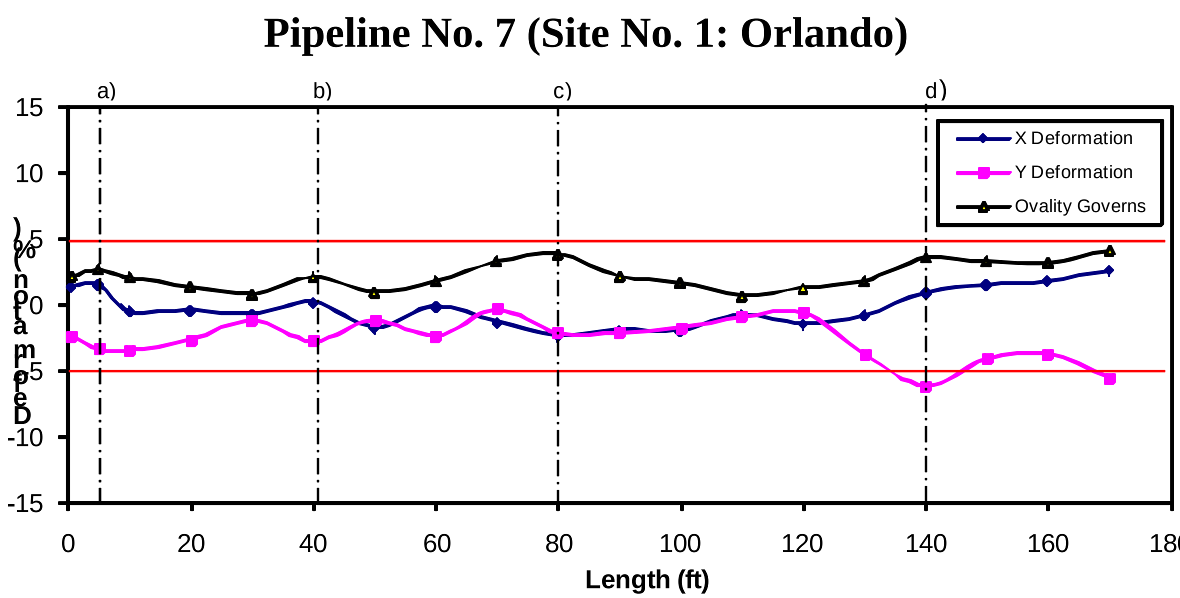
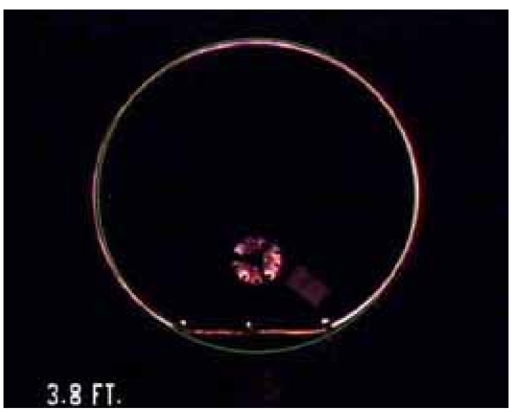


Figure 512 View of the corrugation growth failure for pipeline No. 6 (Site No. 1: Orlando)

Figure 513 View of the corrugation growth failure for pipeline No. 6 (Site No. 1: Orlando)





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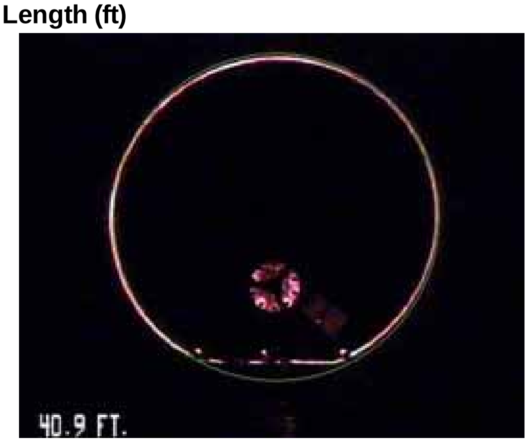
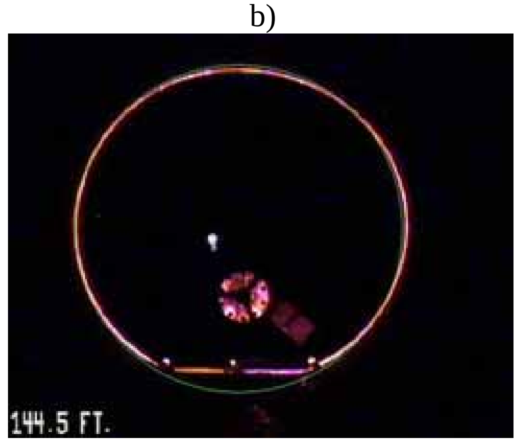


b)

c)



d)

Figure 514 Horizontal and vertical deformation of the pipeline No. 7 (Site No. 1: Orlando)

Figure 515 View of the minor joint displacement failure for pipeline No. 7 (Site No. 1: Orlando)

Figure 516 View of corrugation growth failure for pipeline No. 7 (Site No. 1: Orlando)

Figure 517 View of the minor joint displacement and buckling failure for pipeline No. 7 (Site No. 1: Orlando)

Figure 518 View of the buckling failures for pipeline No. 7 (Site No. 1: Orlando)

Figure 519 View of the minor joint displacement and buckling failures for pipeline No. 7 (Site No. 1: Orlando)

Figure 520 View of the buckling failure at the joint for pipeline No. 7 (Site No. 1: Orlando)

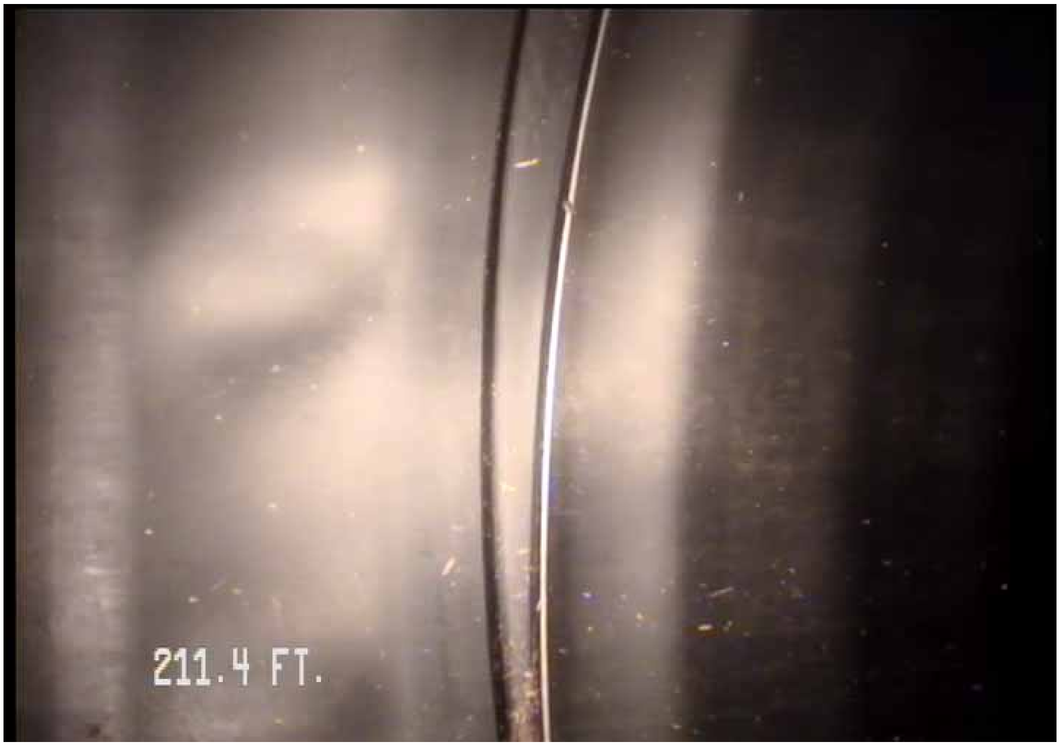
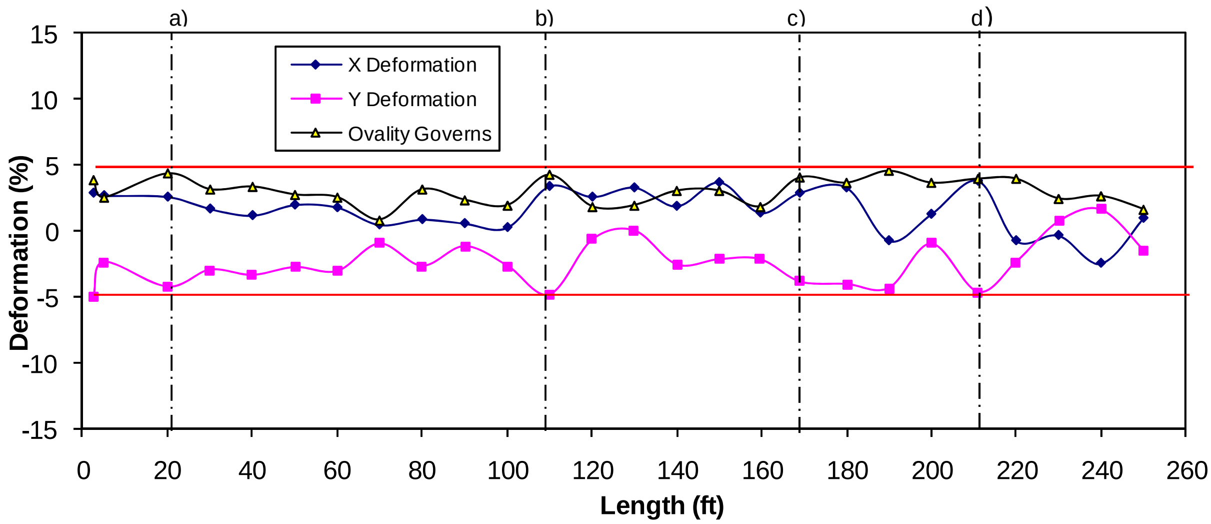
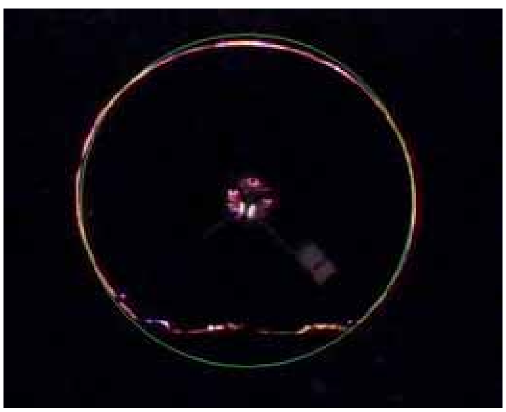
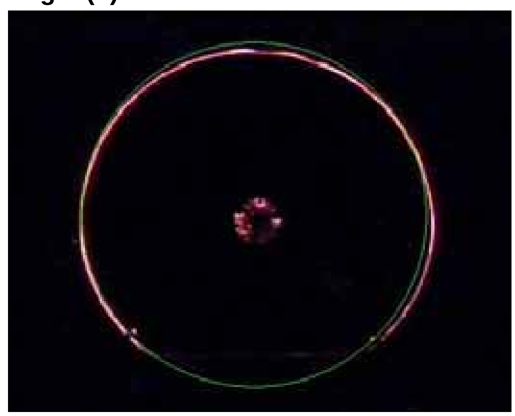


Figure 521 View of the major joint displacement/buckling failures for pipeline No. 7 (Site No. 1: Orlando)

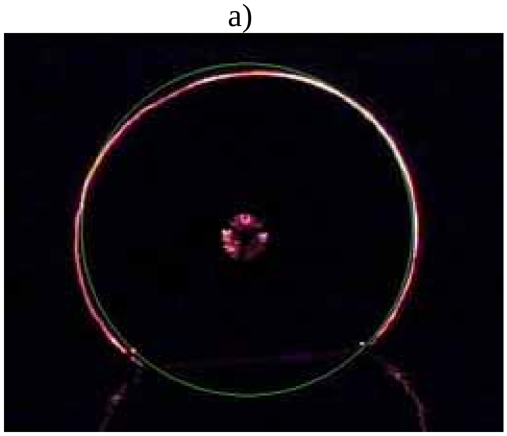
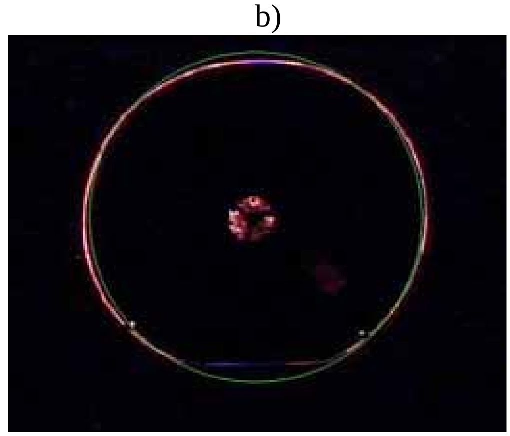
Figure 522 View of the buckling/cracking failures at the joint for pipeline No. 7 (Site No. 1: Orlando)

Pipeline No. 8 (Site No. 1: Orlando)



a) b)

c) d)

Figure 523 Horizontal and vertical deformation of the pipeline No. 8 (Site No. 1: Orlando)

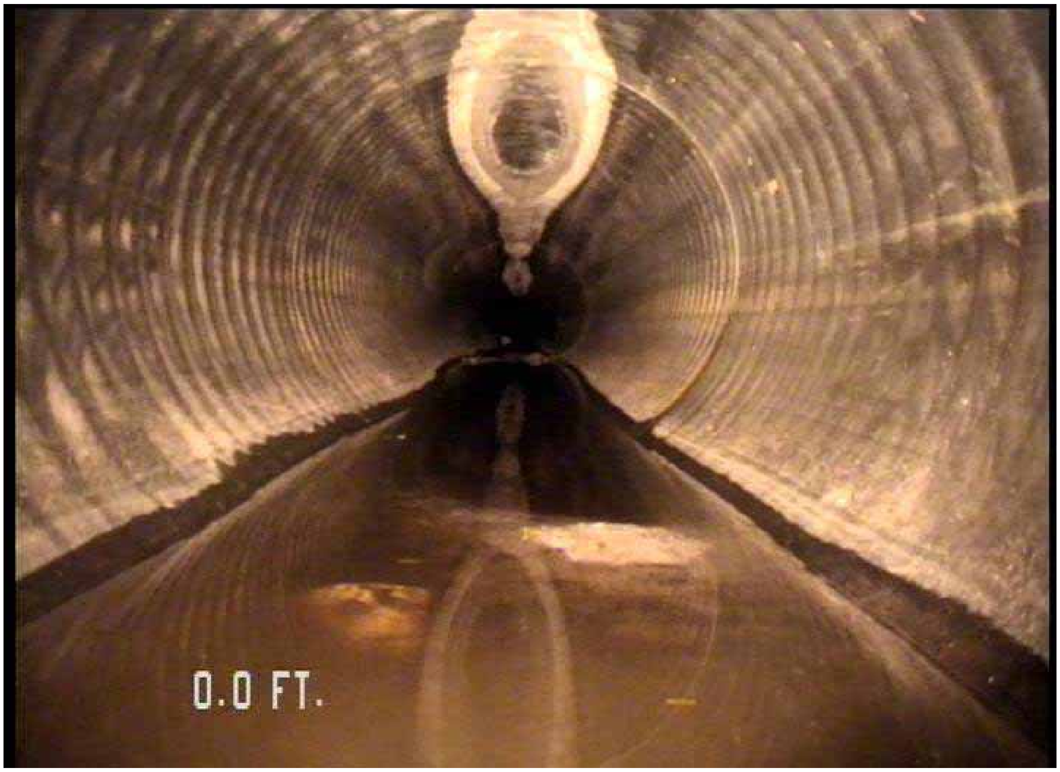


Figure 524 View of corrugation growth failure at the opening of pipeline No. 8 (Site No. 1: Orlando)

Figure 525 View of cracking/leaking failures for pipeline No. 8 (Site No. 1: Orlando)

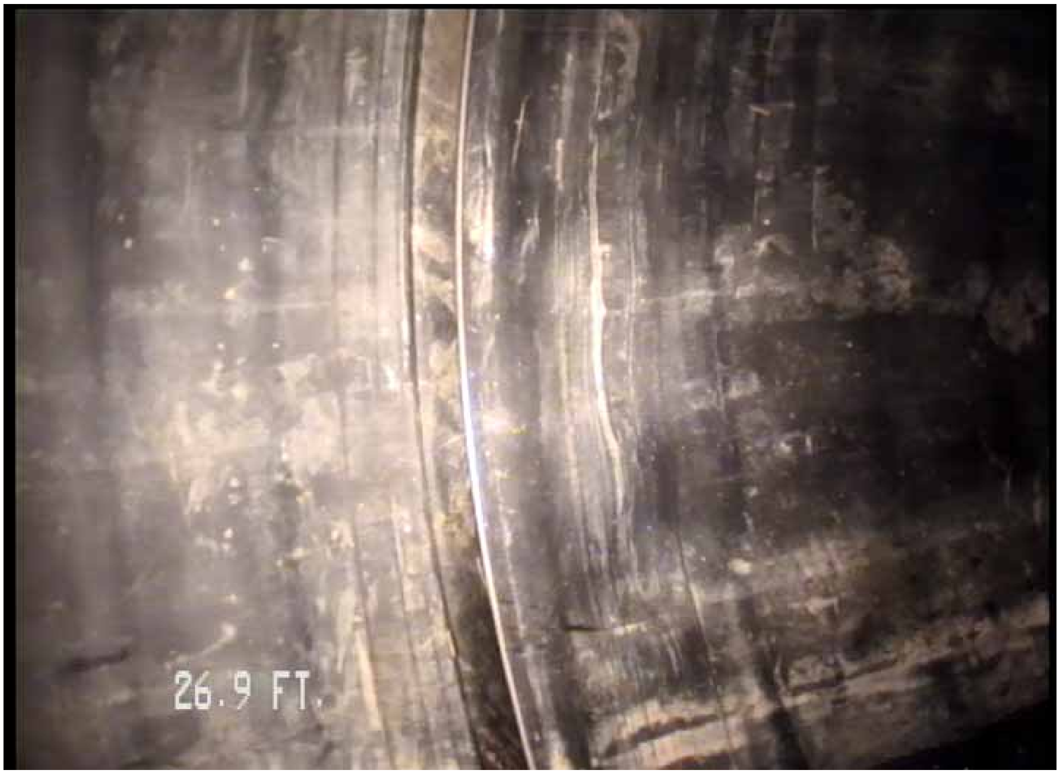


Figure 526 View of major joint displacement and buckling failures for pipeline No. 8 (Site No. 1: Orlando)

Figure 527 View of corrugation growth failure for pipeline No. 8 (Site No. 1: Orlando)

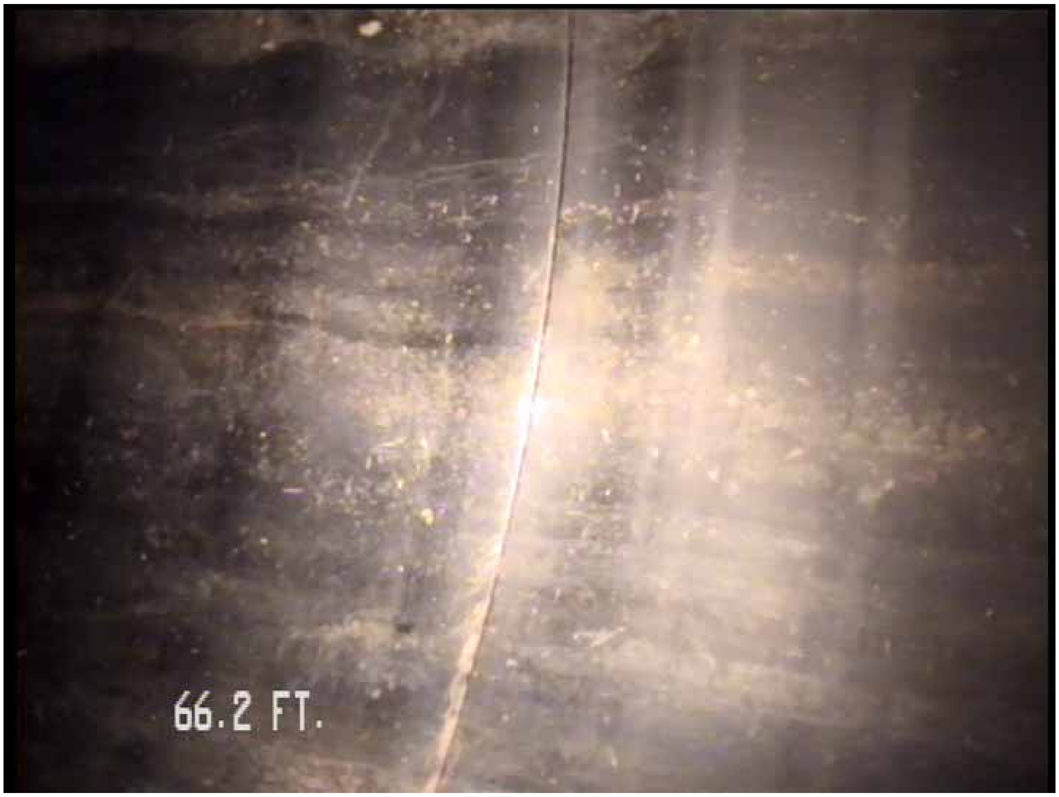


Figure 528 View of joint for pipeline No. 8 (Site No. 1: Orlando)

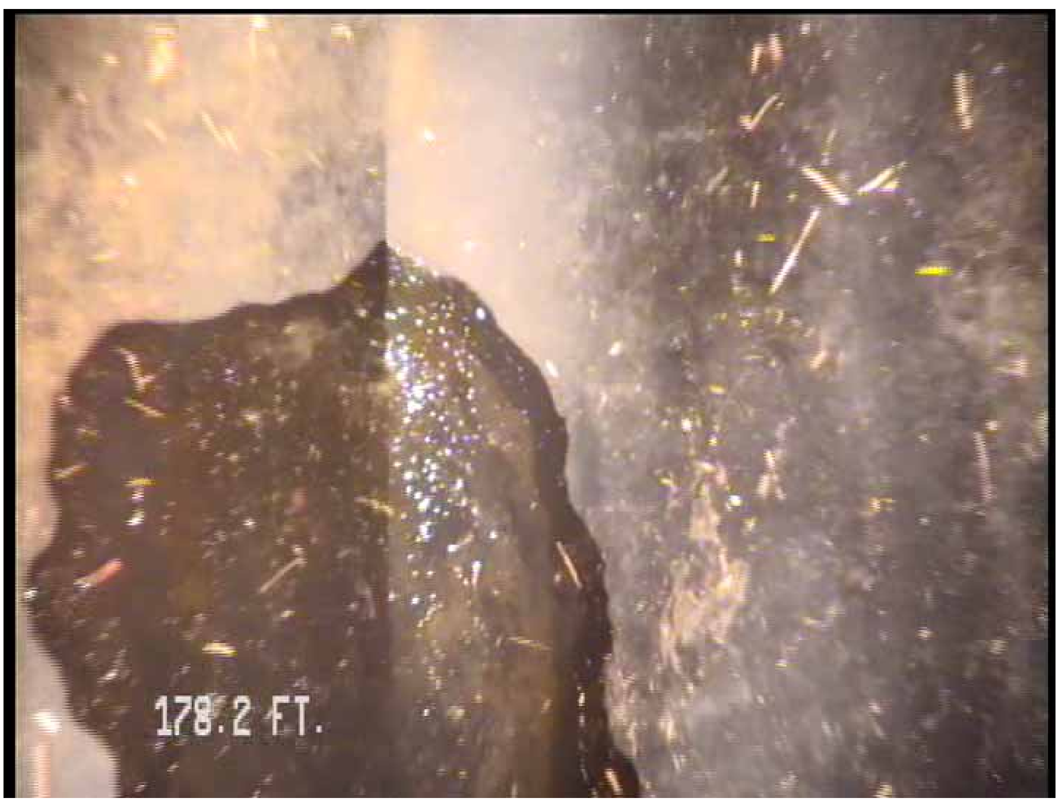
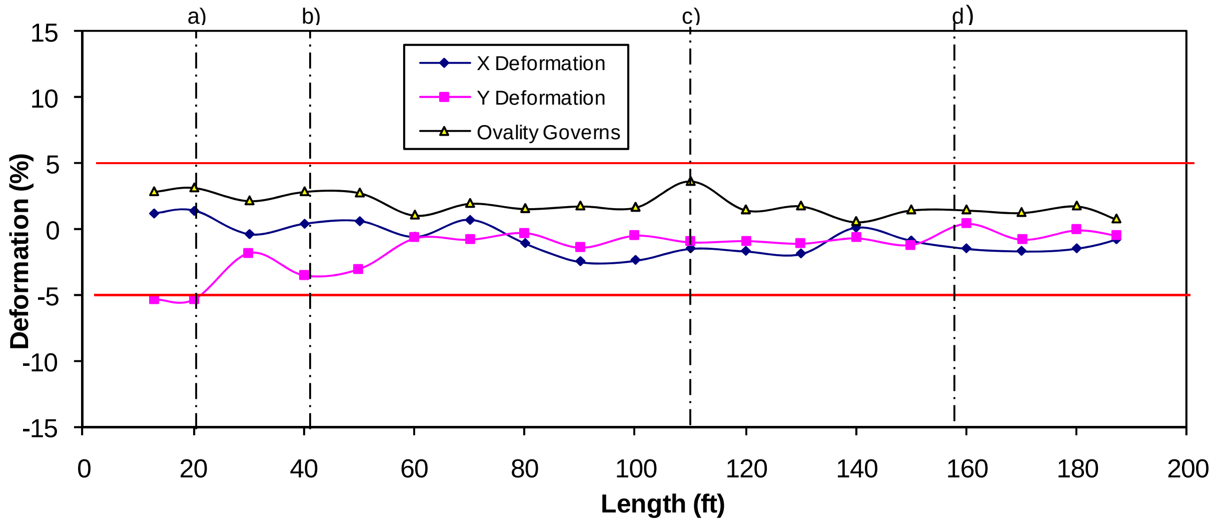


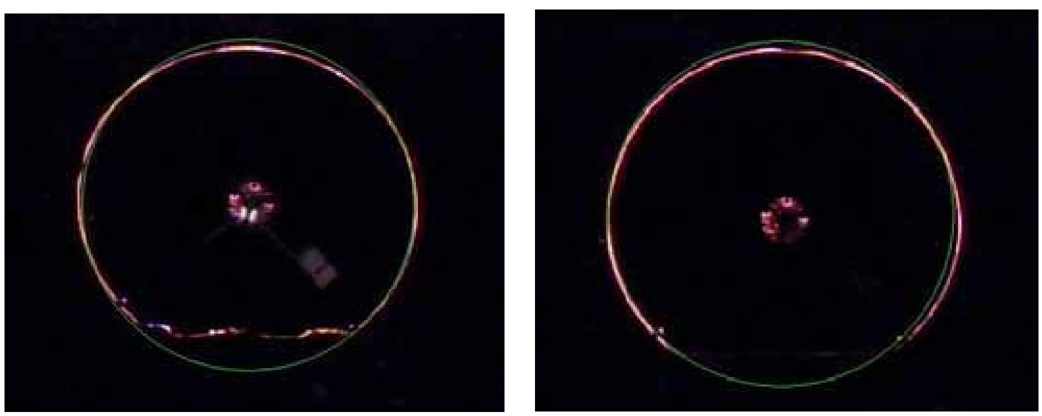
Figure 529 View of cracking/leaking failure for pipeline No. 8 (Site No. 1: Orlando)

Figure 530 View of major joint displacement for pipeline No. 8 (Site No. 1: Orlando)

Figure 531 View of the buckling, corrugation growth failures and dip in line and grade for pipeline No. 8 (Site No. 1: Orlando)

Pipeline No. 9 (Site No. 1: Orlando)





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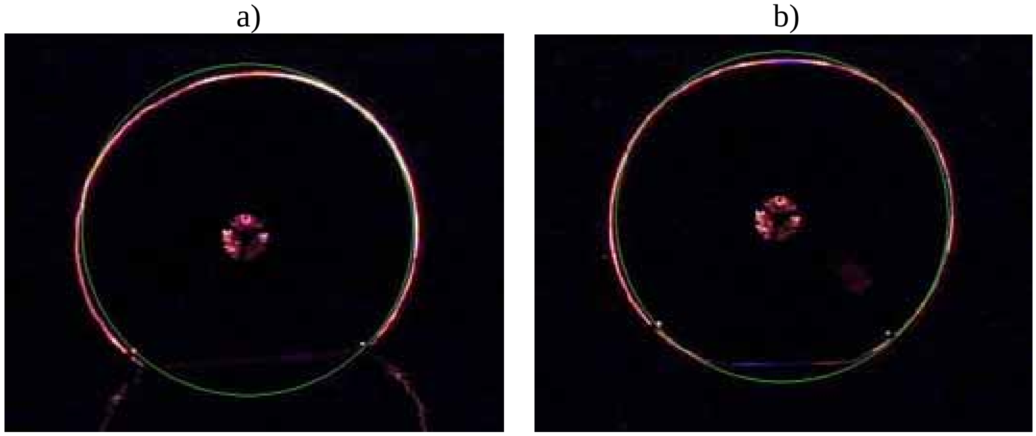


c) d)

Figure 532 Horizontal and vertical deformation of the pipeline No. 9 (Site No. 1: Orlando)

Figure 533 View of the corrugation growth failure at the opening of pipeline No. 9 (Site No. 1: Orlando)

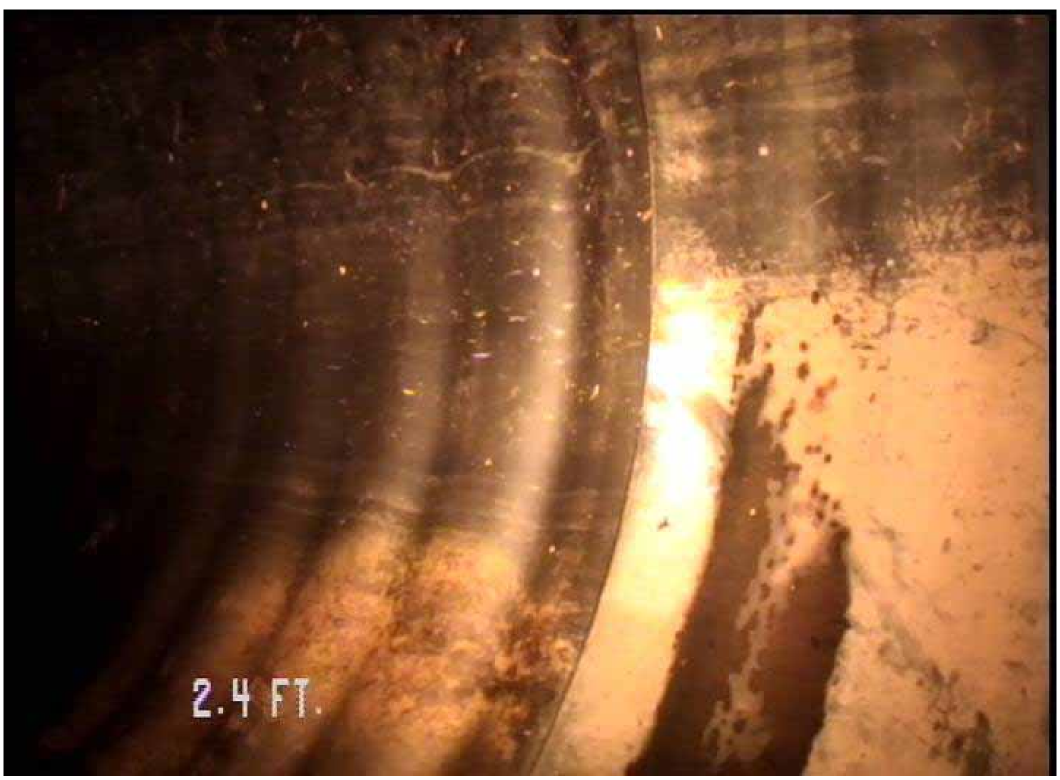


Figure 534 View of the joint for pipeline No. 9 (Site No. 1: Orlando)

Figure 535 View of the corrugation growth for pipeline No. 9 (Site No. 1: Orlando)

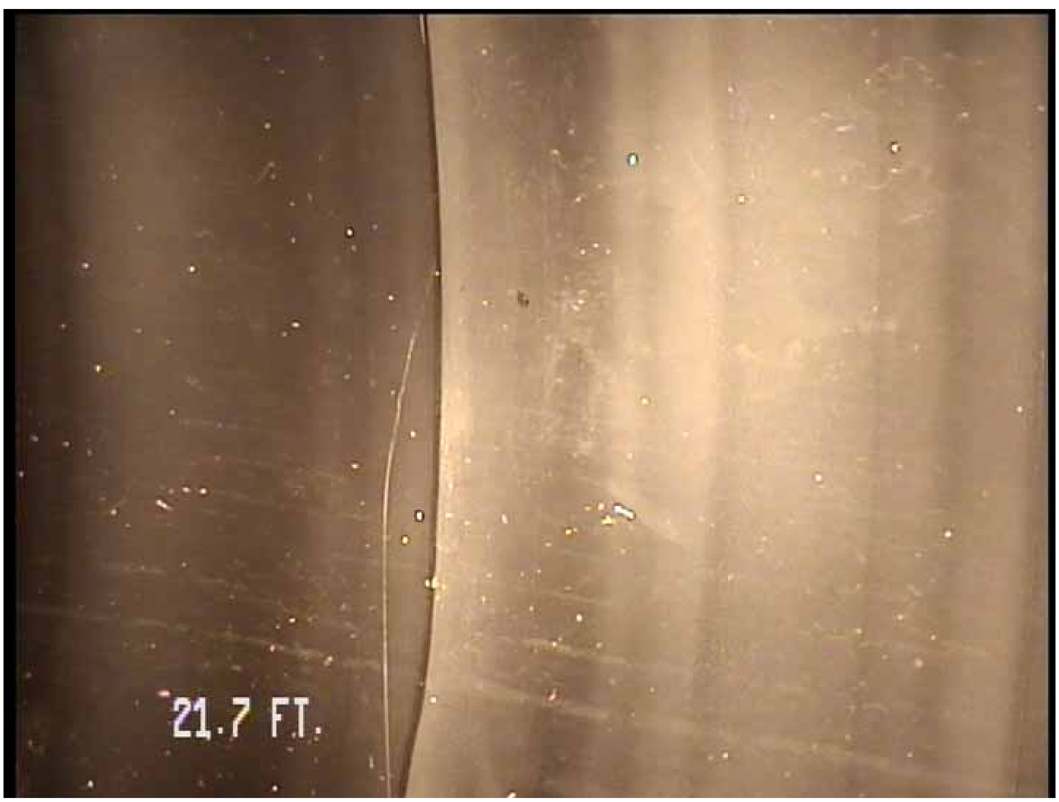


Figure 536 View of the joint for pipeline No. 9 (Site No. 1: Orlando)

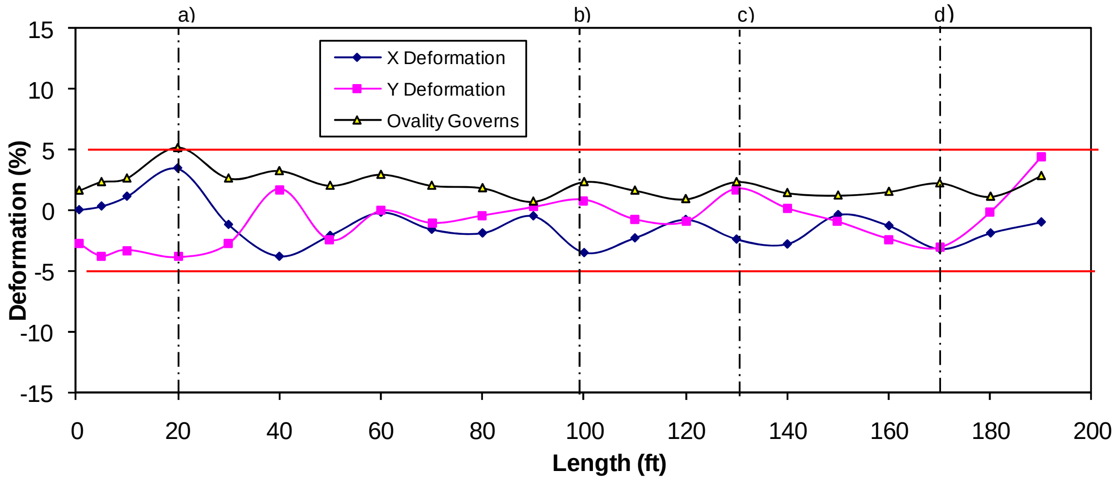
Figure 537 View of the major joint displacement failure for pipeline No. 9 (Site No. 1: Orlando)

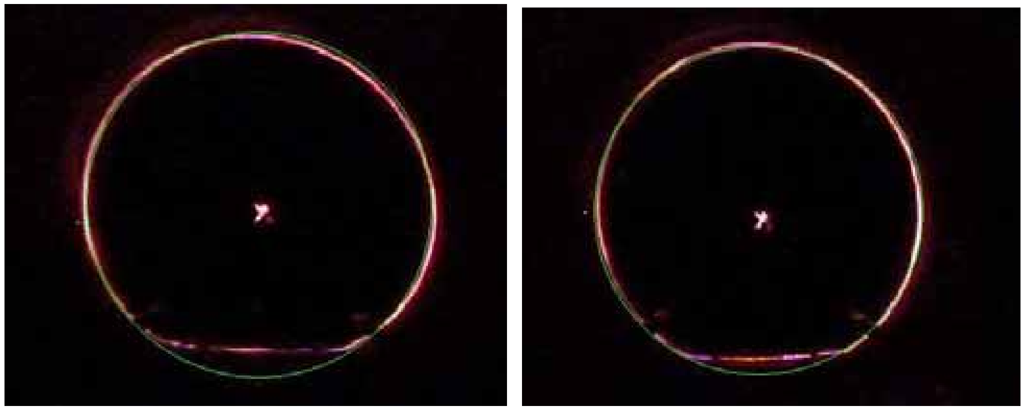
Figure 538 View of the buckling failure for pipeline No. 9 (Site No. 1: Orlando)

Figure 539 View of the minor joint displacement and buckling failures for pipeline No. 9 (Site No. 1: Orlando)

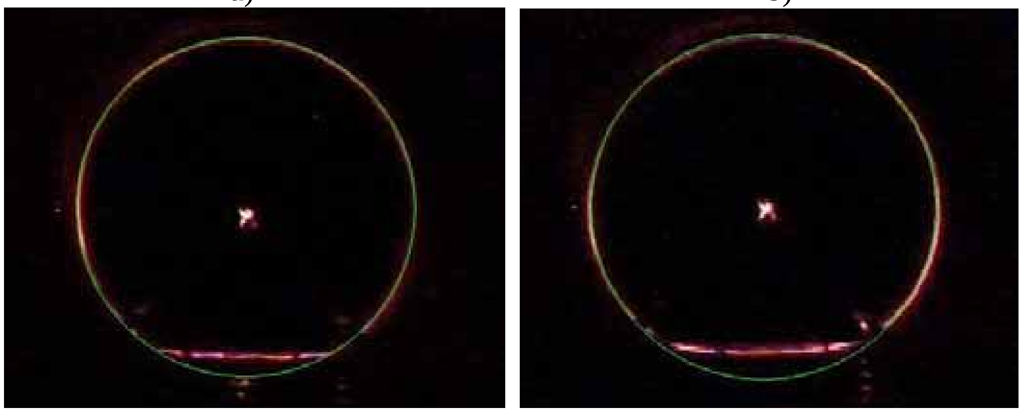
Figure 540 View of corrugation growth failure for pipeline No. 9 (Site No. 1: Orlando)

Pipeline No. 10 (Site No. 2: Apopka)





a) b)



c) d)

Figure 541 Horizontal and vertical deformation of the pipeline No. 10 (Site No. 2: Apopka)

Figure 542 View of the corrugation growth failure for pipeline No. 10 (Site No. 2: Apopka)

Figure 543 View of the corrugation growth, and dip in line and grade for pipeline No. 10 (Site No. 2: Apopka)

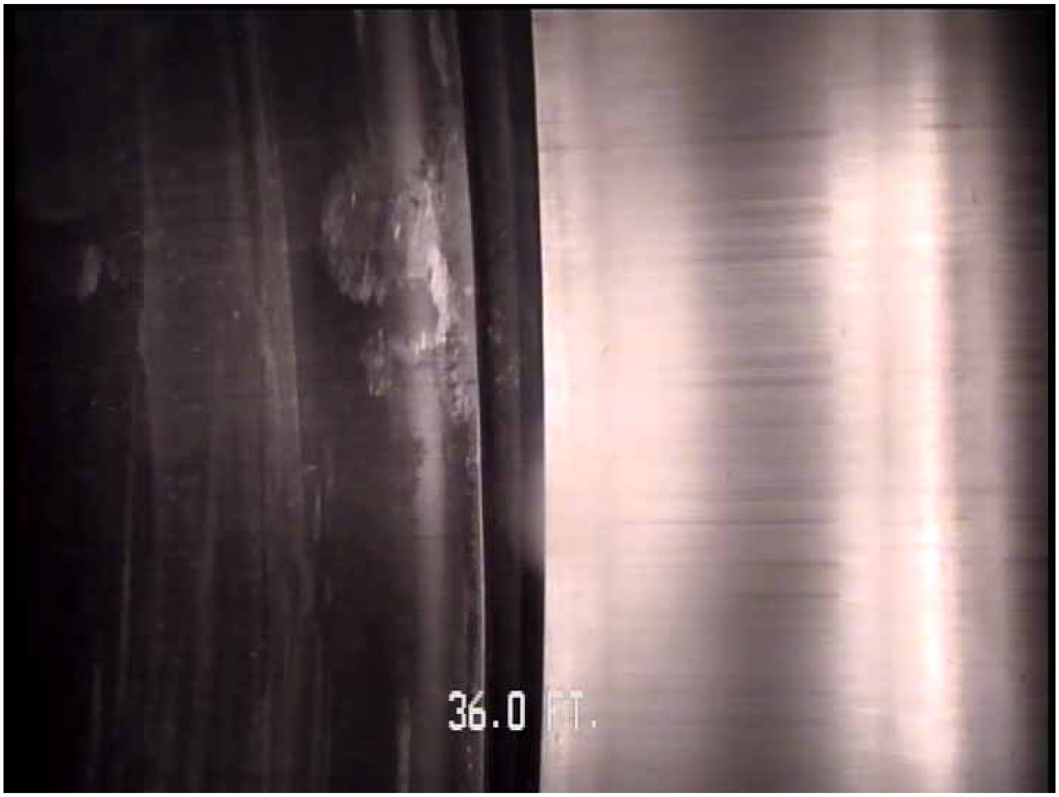


Figure 544 View of major joint displacement failure for pipeline No. 10 (Site No. 2: Apopka)

Figure 545 View of minor joint displacement for pipeline No. 10 (Site No. 2: Apopka)

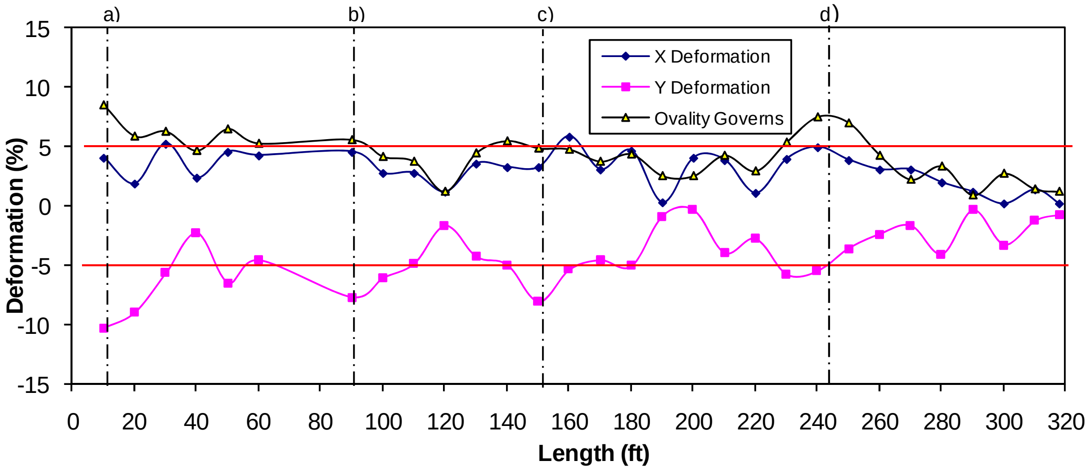
Figure 546 View of the corrugation growth and dips in line and grade for pipeline No. 10 (Site No. 2: Apopka)

Figure 547 View of the corrugation growth failure and dips in line and grade for pipeline No. 10 (Site No. 2: Apopka)

Figure 548 View of the inverse curvature failure for pipeline No. 10 (Site No. 2: Apopka)

Figure 549 Close view of the inverse curvature/crack/fracture failures for pipeline No. 10 (Site No. 2: Apopka)

Pipeline No. 11 (Site No. 2: Apopka)



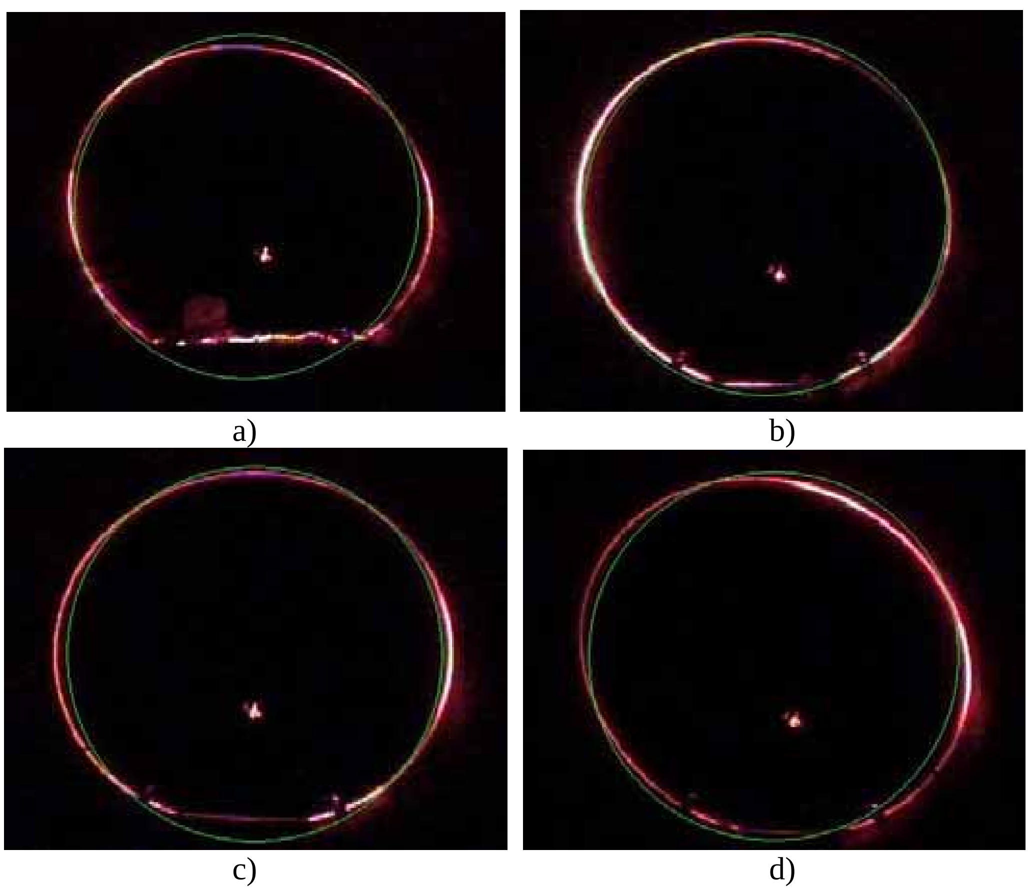


Figure 550 Horizontal and vertical deformation of the pipeline No. 11 (Site No. 2: Apopka)

Figure 551 View of the corrugation growth failure at the opening for pipeline No. 11 (Site No. 2: Apopka)

Figure 552 View of the excessive deformation and corrugation growth failures for pipeline No. 11 (Site No. 2: Apopka)

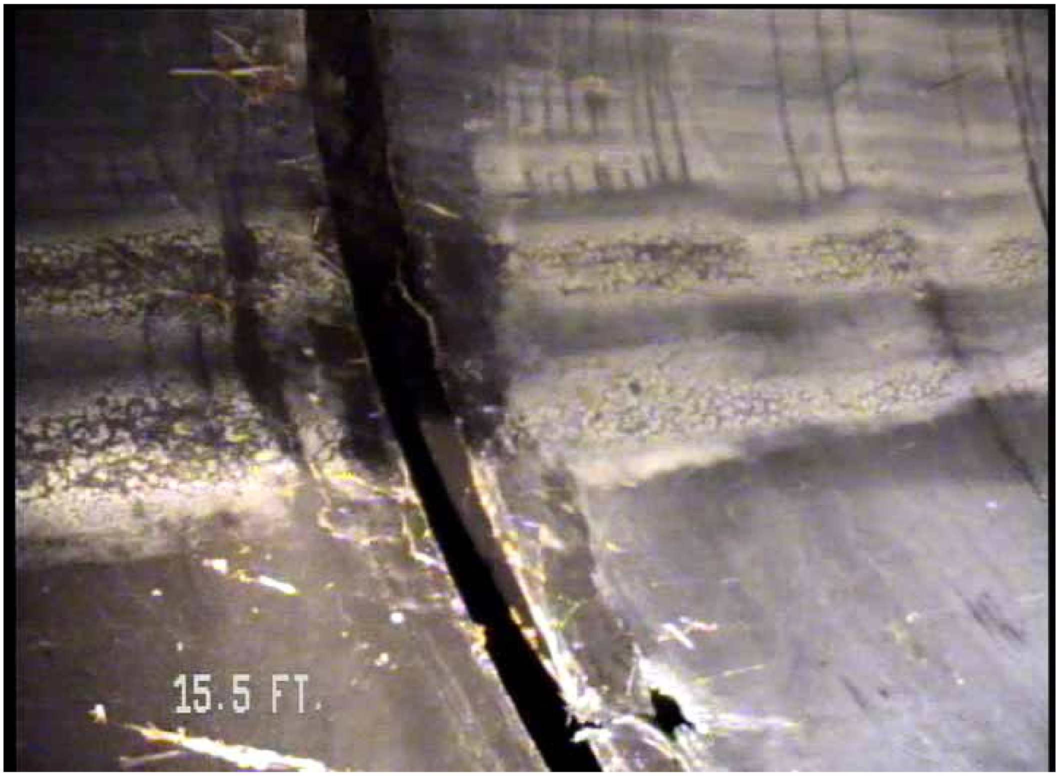


Figure 553 View of the major joint displacement/crack/fracture failures for pipeline No. 11 (Site No. 2: Apopka)

Figure 554 View of the major joint displacement/crack/fracture failures for pipeline No. 11 (Site No. 2: Apopka)

Figure 555 View of corrugation growth failure for pipeline No. 11 (Site No. 2: Apopka)

Figure 556 View of the major joint displacement failure for pipeline No. 11 (Site No. 2: Apopka)

Figure 557 View of corrugation growth/cracking/fracture failures for pipeline No. 11 (Site No. 2: Apopka)

Figure 558 View of cracking/fracture failures for pipeline No. 11 (Site No. 2: Apopka)

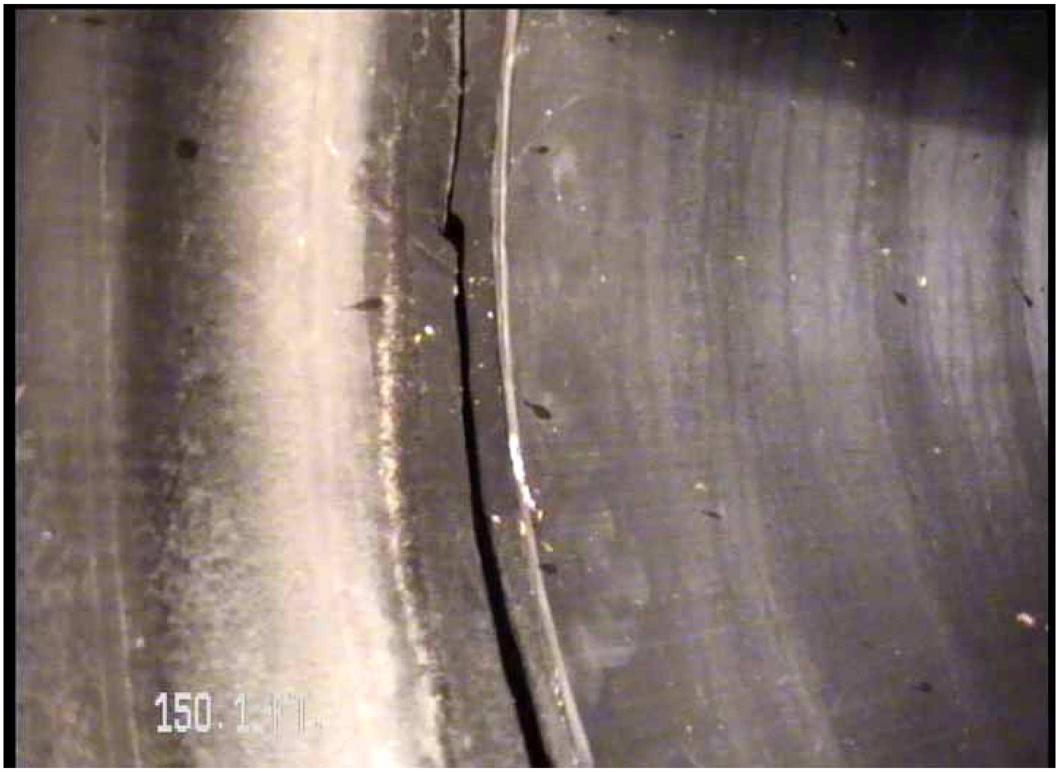


Figure 559 View of the major joint displacement failure for pipeline No. 11 (Site No. 2: Apopka)

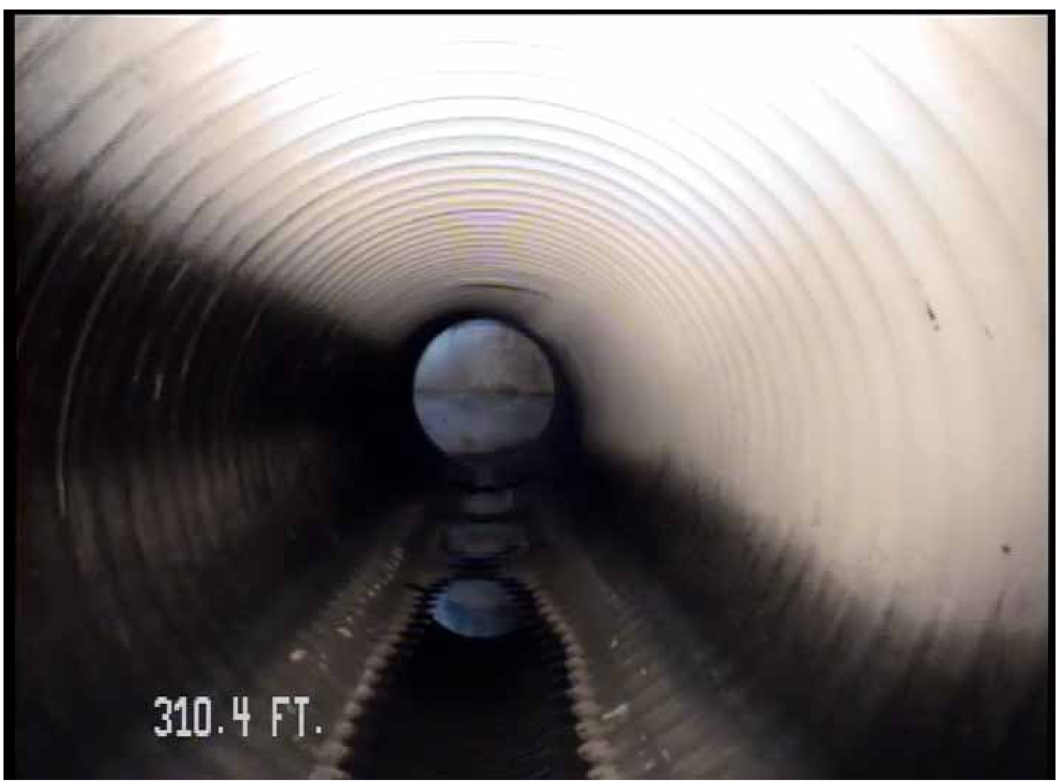
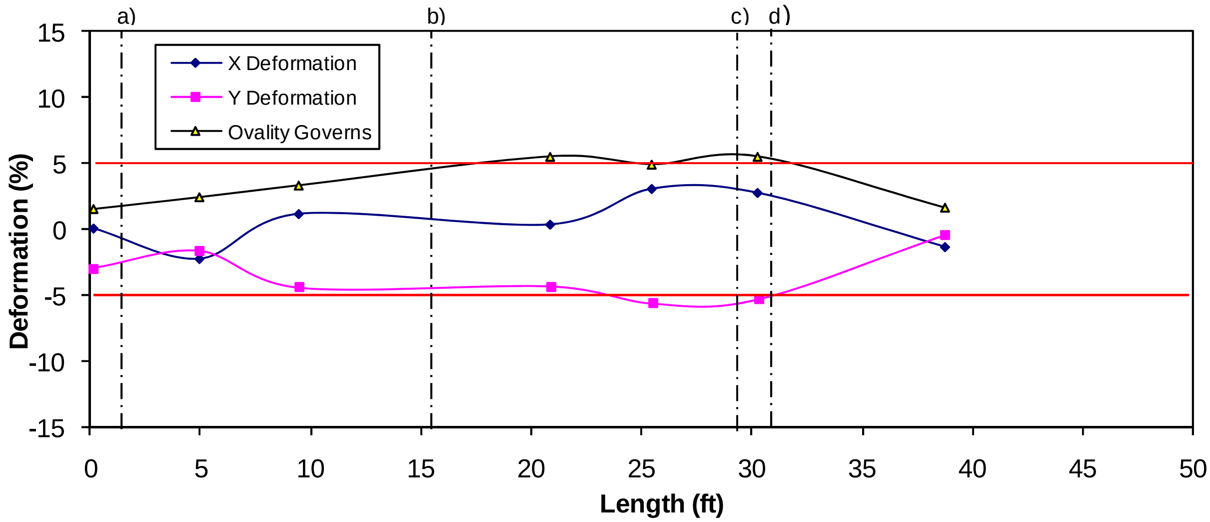


Figure 560 View of corrugation growth failure for pipeline No. 11 (Site No. 2: Apopka)

Pipeline No. 12 (Site No. 2: Apopka)




a)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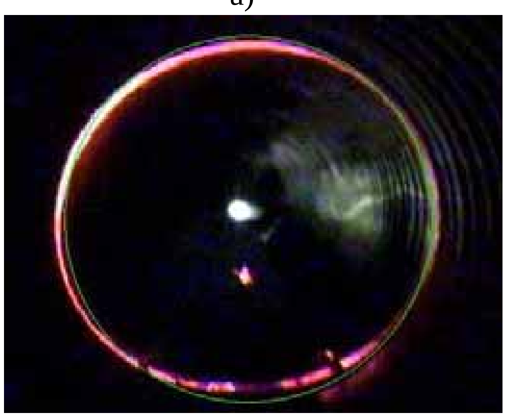
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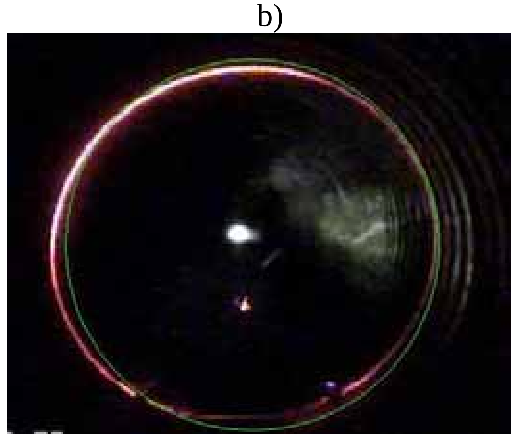

d)

Figure 561 Horizontal and vertical deformation of the pipeline No. 12 (Site No. 2: Apopka)

Figure 562 View of corrugation growth failure at the opening for pipeline No. 12 (Site No. 2: Apopka)

Figure 563 View of major joint displacement failure for pipeline No. 12 (Site No. 2: Apopka)

Figure 564 View of minor joint displacement for pipeline No. 12 (Site No. 2: Apopka)

Figure 565 View of the corrugation growth failure at the end for pipeline No. 12 (Site No. 2: Apopka)

Pipeline No. 13 (Site No. 2: Apopka)

No laser video data.

Figure 566 View of the corrugation growth failure at the opening for pipeline No. 13 (Site No. 2: Apopka)

Figure 567 View of buckling failure at the joint for pipeline No. 13 (Site No. 2: Apopka)

Figure 568 View of minor joint displacement failure for pipeline No. 13 (Site No. 2: Apopka)

Figure 569 View of the excessive deformation, corrugation growth failures and dip in line and grade for pipeline No. 13 (Site No. 2: Apopka)

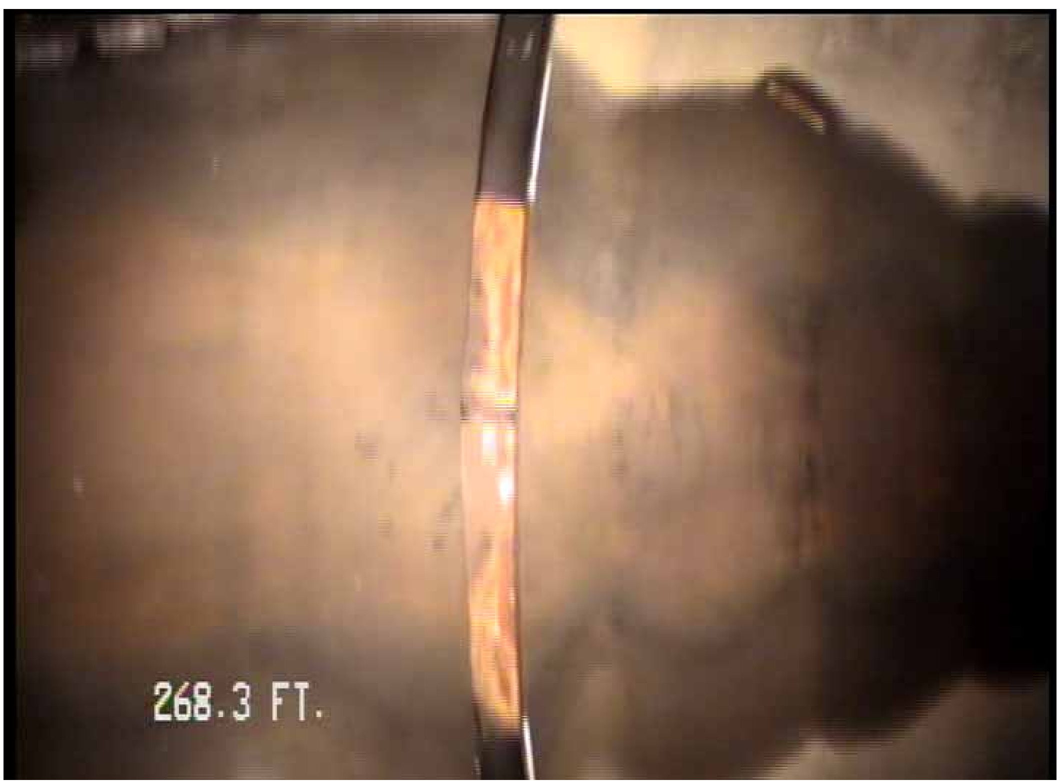
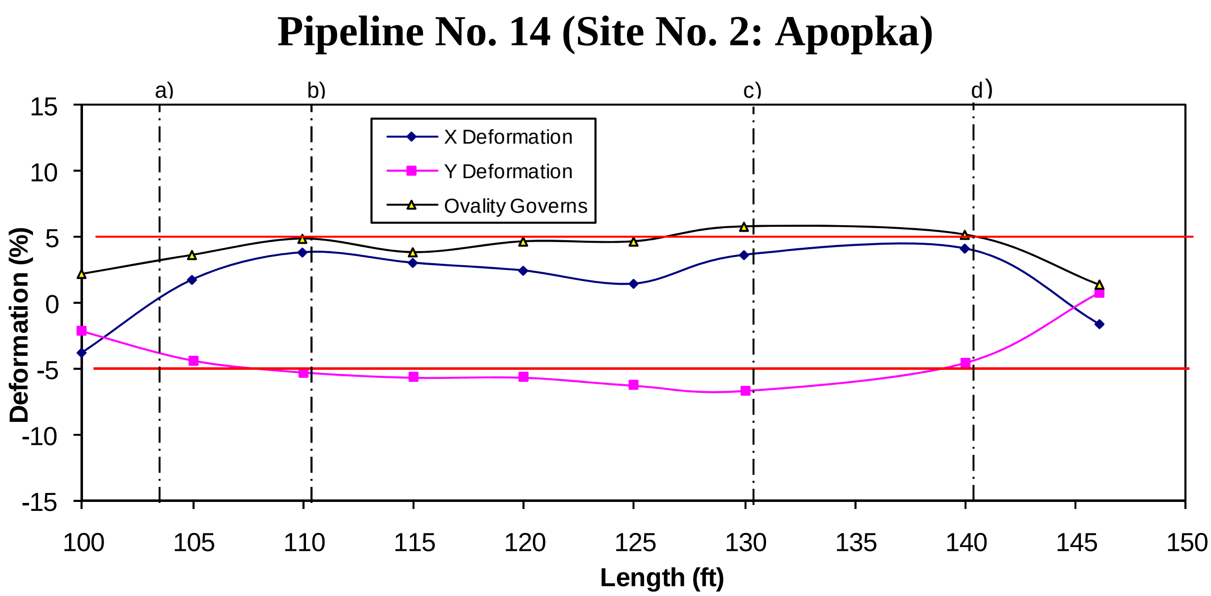


Figure 570 View of the major joint displacement failure for pipeline No. 13 (Site No. 2: Apopka)

Figure 571 View of the corrugation growth failure at the end for pipeline No. 13 (Site No. 2: Apopka)



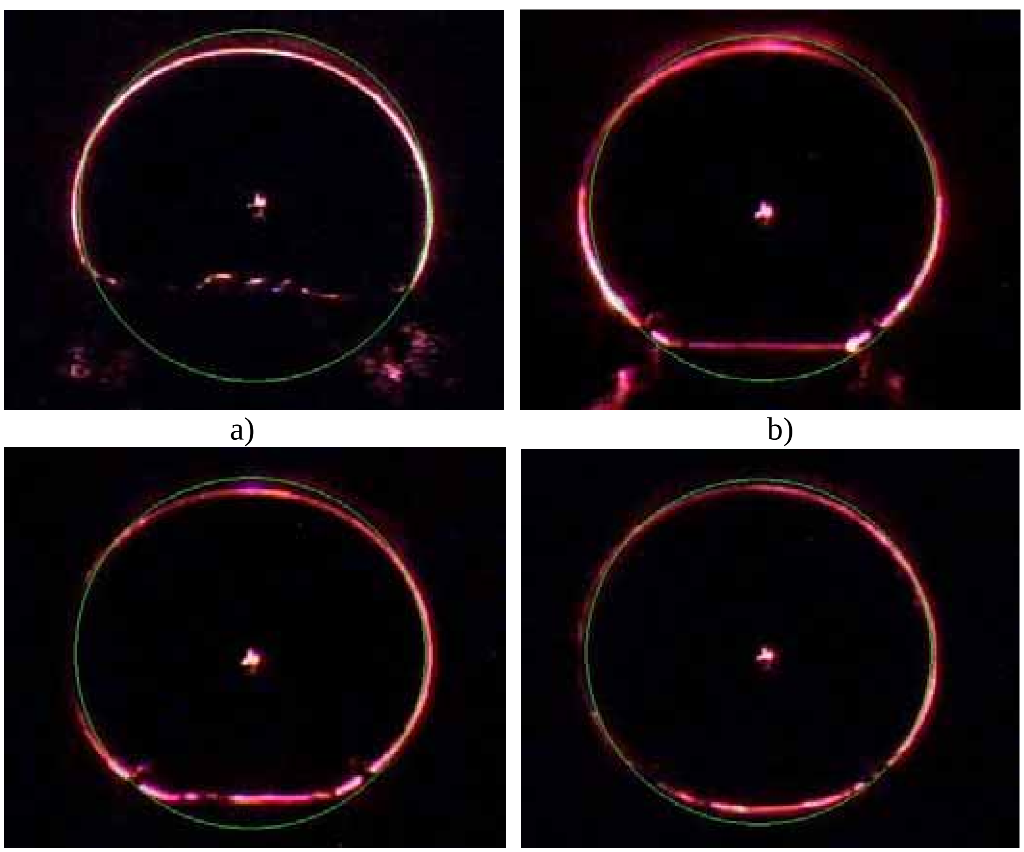

a) b) c) d)

Figure 572 Horizontal and vertical deformation of the pipeline No. 14 (Site No. 2: Apopka)

Figure 573 View of the corrugation growth and heavy build up of sediment at the opening for pipeline No. 14 (Site No. 2: Apopka)

Figure 574 View of the major joint displacement failure for pipeline No. 14 (Site No. 2: Apopka)

Figure 575 View of the major joint displacement failure for pipeline No. 14 (Site No. 2: Apopka)

Figure 576 View of minor joint displacement for pipeline No. 14 (Site No. 2: Apopka)

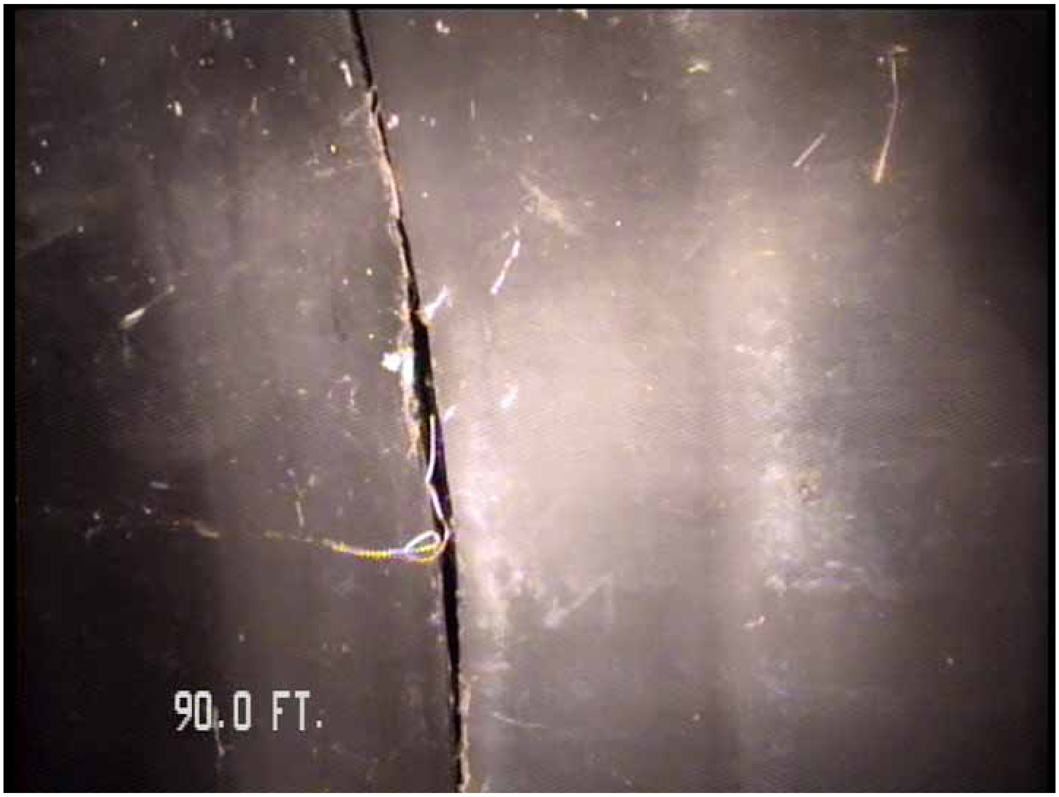
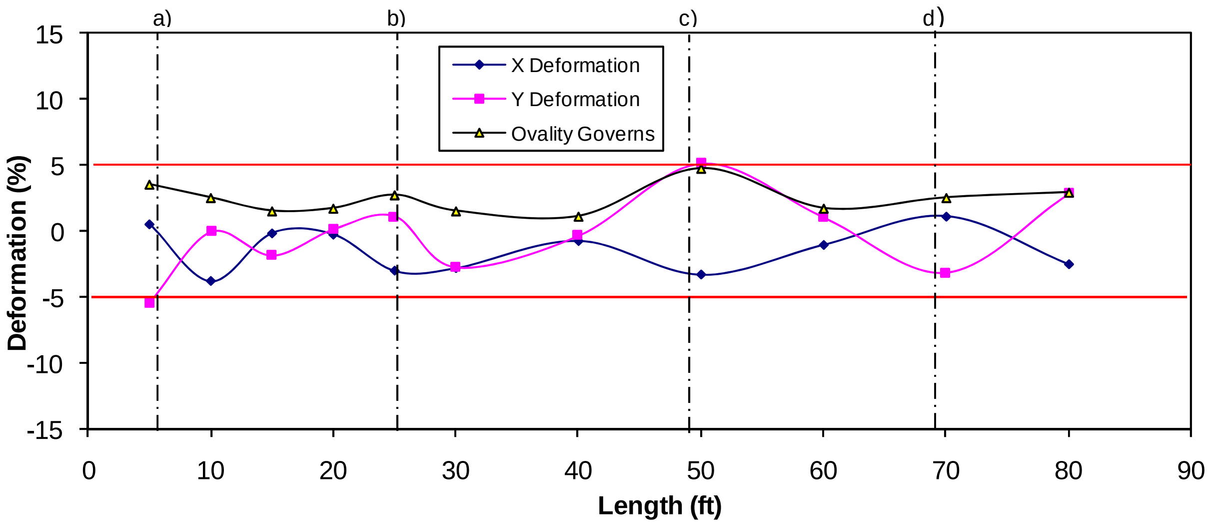
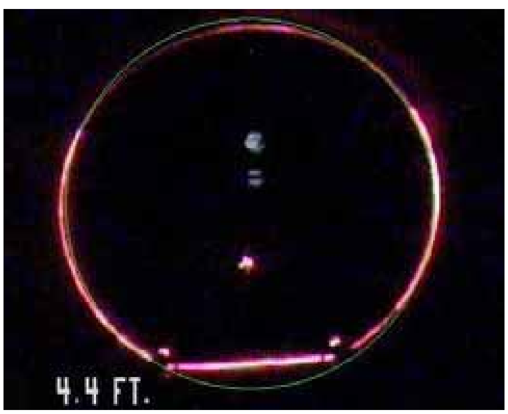


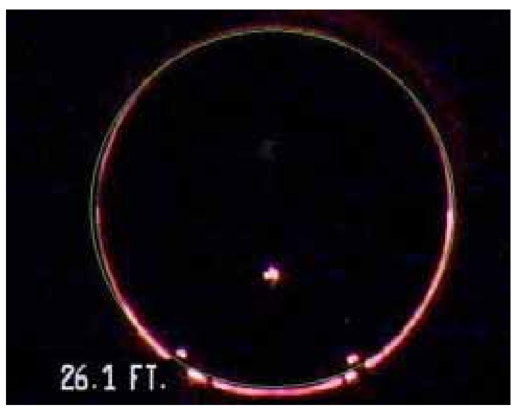
Figure 577 View of minor joint displacement for pipeline No. 14 (Site No. 2: Apopka)

Figure 578 View of the corrugation growth failure at the end for pipeline No. 14 (Site No. 2: Apopka)

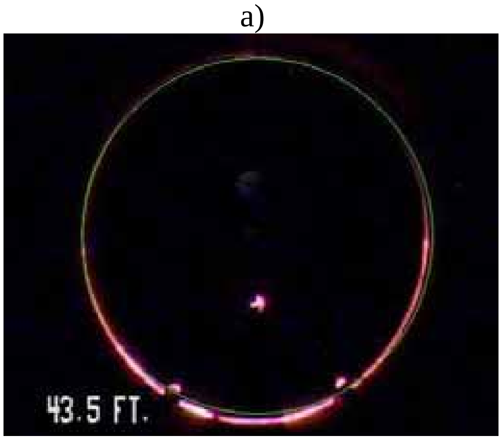
Pipeline No. 15 (Site No. 2: Apopka)

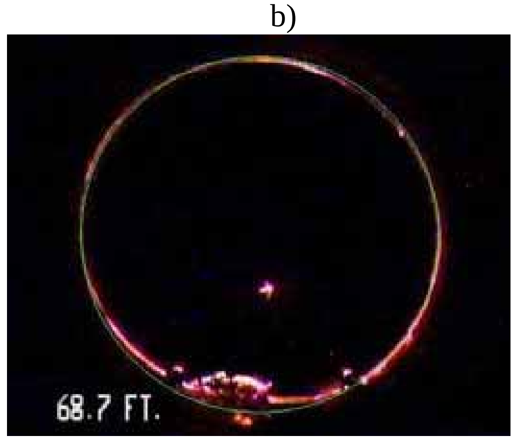






a) b)





c) d)

Figure 579 Horizontal and vertical deformation of the pipeline No. 15 (Site No. 2: Apopka)

Figure 580 View of the corrugation growth failure at the opening for pipeline No. 15 (Site No. 2: Apopka)

Figure 581 View of the excessive deformation, corrugation growth failures and heavy build up of sediment of pipeline No. 15 (Site No. 2: Apopka)

Figure 582 View of major joint displacement failure of pipeline No. 15 (Site No. 2: Apopka)

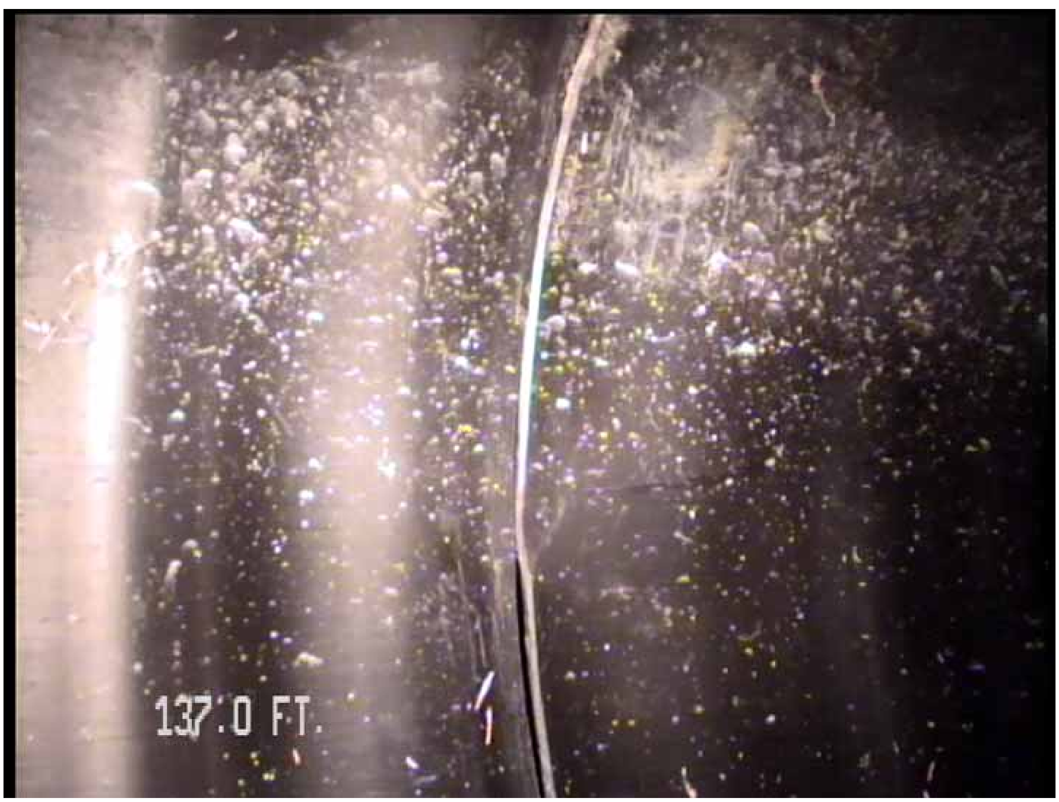


Figure 583 View of minor joint displacement for pipeline No. 15 (Site No. 2: Apopka)

Figure 584 View of corrugation growth failure at the end for pipeline No. 15 (Site No. 2: Apopka)

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