Electromagnetic Inspection and Visual Assessment Report

30-Inch Raw Water Transmission Main

Report Prepared for:

City of Denton

Prepared by:

Pure Technologies U.S. Inc.
(Revised DRAFT – September 6, 2017)

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Quality Assurance and Quality Control Statement

By my signature, I attest that this report has been prepared and reviewed in accordance with the Pure Technologies U.S. Inc. Quality Assurance and Quality Control procedures:

September 6, 2017

Brian Ellis, P.E. P.G., Project Manager Date

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Executive Summary

The City of Denton contracted the services of Pure Technologies U.S. Inc. (Pure Technologies) to perform a condition assessment of the 30-Inch Raw Water Transmission Main (the pipeline). Pure Technologies performed a robotics electromagnetic inspection and visual assessment of the pipeline from February 21 to March 2, 2017. Due to data collection issues, a section of the pipeline was re-inspected on May 23, 2017. The re-inspection was from Station 337+54 to Station 359+49, and from Station 1889+00 to Station 1897+27 (approximately 1,800 feet, 56 pipes). No distress associated with broken bar wraps or cylinder anomalies were detected in the re-inspected section. The pipeline is comprised of 30-inch bar wrapped pipe (BWP). Several sections of the pipeline have been bypassed and relocated due to the Denton County Transportation Authority (DCTA) expansion of rail service in the proximity of the pipeline. This report details the results from the electromagnetic inspection and visual condition assessment. The inspection is part of the City of Denton's assessment approach to make informed pipeline management decisions.

The inspection spanned a total of 1,319 pipes, covering a cumulative distance of 8.62 miles (45,504 ft). Of these pipes, two (2) pipes were identified with five (5) broken bar wraps, and 12 pipes exhibited steel cylinder anomalies. Table ES.1 and ES.2 provide a summary of the correlated inspection data.

Table ES.1: Pipes with Cylinder Anomalies in the 30-Inch Raw Water Transmission Main

Pure Reference Number (Pipe)	Piece Number	Low Station	Cylinder Anomaly Positional Range (feet)	Cylinder Anomaly Area (sq.-inches)	Cylinder Anomaly Type	Visual Condition Assessment (Distance from insertion)
2480	747	187+42	25.5-26.0	40	Type 1	Discoloration and areas of carbonate staining (706 feet).
2498	729	193+90	27.0-27.5	50	Type 1	Visual anomaly at 5:00 position (63 feet). Water approx. 1-foot deep, Robotics fully submerged (25 feet).
2536	696	205+07	14.0-14.5	50	Type 1	Longitudinal crack along invert, 30 feet in length (starts at 1,036 feet and ends at 1,066 feet).
3270	3	448+53	12.0-12.5	40	Type 1	Circumferential cracking and areas of carbonate staining (1,945 feet).
2202	1021-SP	89+93	20.5-21.0		Type 2	Discoloration from 8:00 to 11:00 position, 3 feet length (65 feet).
2912	347	328+54	30.5-32.0		Type 2	Carbonate staining at the crown (2,357 feet)

Table ES.1: Pipes with Cylinder Anomalies in the 30-Inch Raw Water Transmission Main

Pure Reference Number (Pipe)	Piece Number	Low Station	Cylinder Anomaly Positional Range (feet)	Cylinder Anomaly Area (sq.-inches)	Cylinder Anomaly Type	Visual Condition Assessment (Distance from insertion)
3252	21	442+05	26.5-27.5		Type 2	Carbonate staining at the 11:00 position (1,295 feet), Poor visibility.
2102	1120	54+29	0.5-2.0		Feature-Like	Discoloration from 2:00 to 5:00 position, approx. 6 feet in length, extends across joint. Joint spall at invert (3,270 feet)
2812	446	292+92	13.0-15.0		Feature-Like	Large area of discoloration from invert, across 9:00 position to crown (1,245 feet)
3243	30	438+81	27.5-28.5; 31.0-32.0		Feature-Like	Robotics platform fully submerged, no visibility.

Notes:
Cylinder Anomaly Positional Range – represents the portion of the pipe affected by the anomalous signal. Signal position is measured from low station.
Type 1 Anomaly: Anomalies observed in the data are consistent with cylinder wall loss observed in testing on pipes at other sites.
Type 2 Anomaly: Anomalies observed in the data is not indicative of cylinder wall loss based on findings observed in testing on pipes at other sites.
Feature-Like Anomaly: Anomalies in the pipe that have characteristics of a possible undocumented feature.

Table ES.2: Pipes with Broken Bar Wraps in the 30-Inch Raw Water Transmission Main

Pure Reference Number (Pipe)	Piece Number	Low Station	Break Position (feet)	Number of Broken Bar Wraps by Region	Total Number of Broken Bar Wraps	Visual Condition Assessment (Distance from insertion)
2034	1188	29+82	13.0	5	5	No visual deficiencies observed
2871	387	314+14	23.0	5	5	Areas of carbonate staining; 8:00 position (890 feet), 2:30 position (897 feet), poor visibility

1.1 Conclusions

Pure Technologies' inspection and condition evaluation of the pipeline concluded that:

1. Of the 1,319 pipes inspected, only two (2) pipes were identified with an electromagnetic signature representative of five (5) broken bar wraps.

2. Ten (10) pipes were identified to have anomalous signals likely caused by a change in the pipe cylinder and categorized based on the cylinder anomalies electromagnetic signature observed in the collected data. Based on the information shown in Table ES.1:

   - Four (4) pipes are categorized to have Type 1 cylinder anomalies

     - Type 1 Anomaly: Anomalies observed in the data are consistent with cylinder wall loss observed in testing on pipes at other sites.

   - Three (3) pipes are categorized to have Type 2 cylinder anomalies

     - Type 2 Anomaly: Anomalies observed in the data is not indicative of cylinder wall loss based on findings observed in testing on pipes at other sites.

   - Three (3) pipes are categorized to have feature-like cylinder anomalies.

     - Feature-Like Anomaly: Anomalies in the pipe that have characteristics of a possible undocumented feature.

3. Bases on the visual condition assessment, numerous pipes exhibited visual deficiencies such as internal cracking, liner and joint spalling, carbonate staining and discoloration.

   - Longitudinal cracking was noted at several locations in the pipe; along the invert, the crown, and the springlines. A few pipes had a combination of longitudinal cracking at these locations.

     - Cracks or fractures that appear greater than 1/16" of an inch (0.0625 inches) wide in the inner concrete lining could be an indication of excessive loading conditions or changes in the structural integrity of the pipe. These cracks could allow water to infiltrate and contact the steel cylinder, which may accelerate any existing cylinder corrosion.

   - Several pipes exhibited circumferential cracking; a few pipes had multiple cracks, and there were a few sections where the circumferential cracking intersected the longitudinal cracks.

   - Areas of carbonate staining and liner discoloration was typical throughout.

   - An accumulation of suspected biological growth was detected at the invert of a few gate valves.

1.2 Recommendations

Pure Technologies provides the following recommendations for the short and long-term management of the pipeline. The recommendations were based on the electromagnetic inspection data analysis and visual condition evaluation to develop an accurate condition assessment of the pipeline for the City of Denton.

1. The pipes shown in Table ES.3 were identified with broken bar wraps and with cylinder anomalies during the inspection. These pipes were ranked based on the current condition only (likelihood of failure). Additional factors; location, environmental impact, redundancy, proximity to buildings or roadways, etc. (consequence of failure criteria) was not considered for the pipe prioritization and outside of the project scope. The City of Denton should consider an excavation and verification program to further investigate pipes of highest risk, based on the likelihood and consequence of failure.

Table ES.3: Prioritization of Inspected Pipes Identified with Distress

Pure Reference Number (Pipe)	Low Station	Broken Bar Wraps	Cylinder Anomaly Area (square-inch)	Cylinder Anomaly Type	Visual Condition Assessment	Ranking
2034	29+82	5			No visual deficiencies observed	1
2871	314+14	5			Areas of carbonate staining	1
2536	205+07	0	50	Type 1	Longitudinal crack along invert	2
3270	448+53	0	40	Type 1	Circumferential cracking and areas of carbonate staining	3
2480	187+42	0	40	Type 1	Discoloration and areas of carbonate staining.	4
2498	193+90	0	50	Type 1	Visual anomaly at 5:00 position	5
2202	89+93	0		Type 2	Discoloration	6
2912	328+54	0		Type 2	Carbonate staining at the crown	6
3252	442+05	0		Type 2	Carbonate staining at the 11:00 position.	6
2812	292+92	0		Feature-Like	Large area of discoloration	7
2102	54+29	0		Feature-Like	Discoloration, Joint spall at invert	8
3243	438+81	0		Feature-Like	Robotics platform fully submerged, no visibility.	9

2. The four (4) pipes with Type 1 cylinder anomalies (possible cylinder deterioration) detected should be further investigated; excavated for field verification and forensic analyses, to identify if repairs or replacements are warranted.

3. Pipes with wide internal cracks should be thoroughly investigated to determine if repairs are required. If the cracks are greater than 1/16 of an inch (0.0625 inches) this is considered a fracture, and therefore should be point repaired with mortar, grout or approved equivalent in accordance with current bar wrapped pipe manufacturing recommendations. Several pipes exhibited longitudinal cracking. Additional details are provided in Appendix D - Inspection pipe list with visual assessment observations.

4. Joints missing mortar should be repaired with mortar, grout or approved equivalent in accordance with current bar wrapped pipe manufacturing recommendations. The joint of pipe 2255 (Pure reference number), Piece number 971 exhibited areas of missing mortar at the time of the inspection. Additional details are provided in Appendix D - Inspection pipe list with visual assessment observations.

5. The origin of the suspected biological accumulation should be further investigated.

6. Based on the level of distress detected during the electromagnetic inspection, Pure Technologies recommends that another inspection of the pipeline be conducted in five (5) years to determine if pipes with existing deficiencies exhibited an increase in distress (broken bar wraps or cylinder anomalies) or if new distress developed.

7. Transient pressure monitoring should be implemented on the pipeline to identify operational issues that cause transients. The device should be capable of monitoring and recording short duration pressure transients at a rate of 20 measurements per second or better. Reducing pressure transients will minimize the potential for on-going incremental damage to the pipeline.

8. An asset management program should be developed to extend the serviceability of the pipeline, reduce the risk of future failures, and prevent the loss of valuable resources. A comprehensive graphical information system (GIS) could be developed to assist the City of Denton with the overall management of the pipeline, such that each individual pipe is a unique asset. GIS provides an accurate spatial representation of the alignment, the location of each individual pipe, and a geographic database of pipeline information. Any repairs and condition information collected can be included for each individual pipe in the GIS database. This provides valuable assessment data that can be updated or analyzed and will allow the pipeline to be selectively managed when repairs or replacements are required.

2. Project Background

The inspected portion of the 30-inch Raw Water Transmission Main (the "pipeline") is composed of 30-inch bar wrapped pipe (BWP). Several sections of the pipeline were bypassed and relocated with 42-inch and 30-inch BWP. The 42-inch relocation section was necessitated by the expansion of Interstate 35, while the 30-inch relocation were dictated by the extension of the adjacent Denton County Transit Authority (DCTA) rail line. Based on the email correspondence received from the City of Denton on April 21, 2017 it is our understanding that in addition to the DCTA's four (4) relocated sections, the City of Denton (COD) had also replaced some sections of the pipeline with Class 200, bar wrapped pipe. Below is a summary of the replacement pipe sections, per the information provided by the COD.

- In 2000, the Corinth Loop Relocation project was implemented from Station 213+00 to Station 215+00, approx. 256 linear feet of 30-inch, Class 150 bar wrapped pipe (B303).
- In 2010, near Station 337+00 toward the water plant, approximately 60-feet of pipeline was replaced between Mahill Road and Pockrus Road.
- Also in 2010, there was approximately 80-feet of pipeline that was replaced near Station 92+00 towards the COD, northwest of Overly Drive.
- In 2012, on the east side of I35, a leak was identified that resulted in approximately 50-feet of pipeline being replaced from Station 13+00 toward the COD.
- In 2015, the COD replaced two (2) pipes, each 32-feet in length (west of I35) because of a deteriorated connection the contractor found during the Interstate 35 East relocation.

The original 30-inch pipes were manufactured by U.S. Pipe and Foundry Co. in 1974 while the 42-inch relocation pipes were manufactured by Hanson Pipe and Products, Inc. in 2015. The manufacturing details for the 30-inch relocation sections were not available at the time of this report. The pipeline is owned and operated by the City of Denton.

A map of the inspected section of the pipeline is shown below (Figure 1.1).

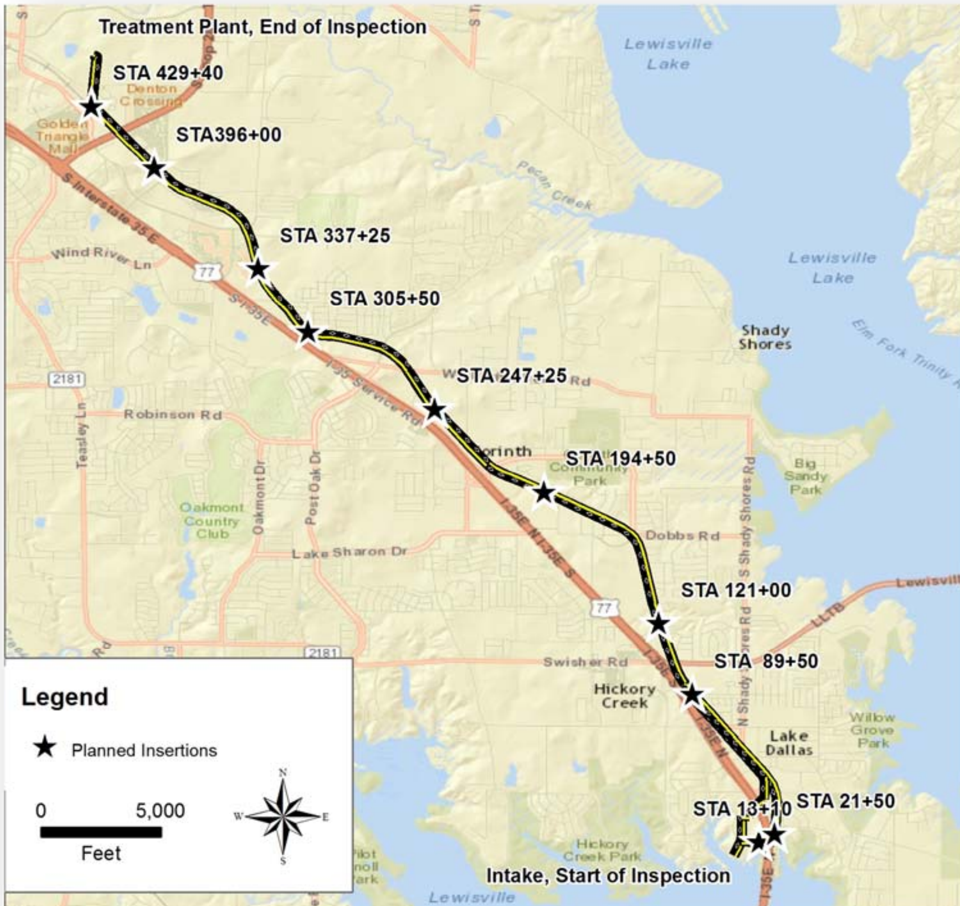


Figure 1.1: Inspection Limits

In general, the inspection moved from upstream (US) to downstream (DS). A general outline of the inspection schedule is provided in Table 1.1.

Table 1.1 Inspection Schedule			
Date	**Insertion Station**	**Approximate Upstream Station**	**Approximate Downstream Station**
2/21/2017	21+50	18+07	61+50
2/22/2017	89+50	60+72	121+58
2/23/2017	121+00, 194+50	121+00	194+50
2/24/2017	194+50, 247+25	194+50	247+25

2/25/2017	247+25, 305+50	247+25	337+70
2/27/2017	337+25, 396+00	337+25	420+53
2/28/2017	429+40	429+40	Plant
3/1/2017	6+25	0+78	13+10
3/2/2017	18+07, 247+25	18+07, 263+90	13+10, 247+25
5/23/2017[A]	337+70	337+70	367+70

[A]*Section re-inspected due to data collection issues during original inspection.*

2.1 Project Scope

To provide the City of Denton with comprehensive inspection data and internal video including a visual assessment of the pipeline. Pure Technologies utilized the following investigative techniques to collect condition data on the pipeline:

- Pure Robotics® electromagnetic inspection platform
- Closed Circuit Television (CCTV) visual condition assessment

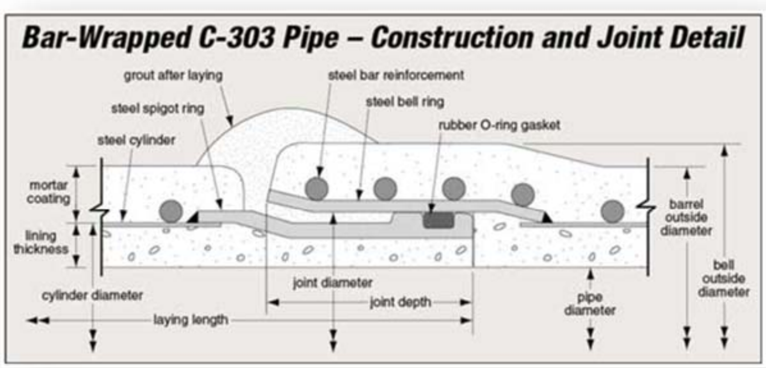


Figure 1.2: AWWA C303 Bar Wrapped Pipe Construction Details [3]

2.2 Document Review

Pure Technologies reviewed the following documents to assess the condition of the pipeline:

- Parallel Raw Water Line, 1974. City of Denton, Texas Water Works System Improvements – *Plan and Profile Drawings* – Bid Number 74-8175. Freeze and Nichols.

- City of Denton, 2015. Submittal Raw Water Relocations. Pressure Pipe Layout Drawings.

2.3 Overview of Bar Wrapped Pipe

The first edition of AWWA C303, Standard for Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type [2] was not approved until 1970; however, BWP has been in use since 1942. BWP is comprised of a welded steel cylinder, and steel reinforcing bars under tension that are wrapped helically around the cylinder to provide additional strength.

The steel cylinder in BWP performs as the main structural component, and as a watertight membrane. An inner cement mortar lining and outer mortar coating provides corrosion protection for the steel components. Pure Technologies conducted field measurements during a new tap installation, which were compared to the AWWA design standards, based on this comparison and our experience, the BWP was determined to be Class C303.

Bar wrapped pipe is usually manufactured in accordance with AWWA C303 using standard sizes that range from 10 inches to 72 inches in diameter. This type of pipe is designed for allowable design pressures up to 400 psi in addition to an external earth load. Figure 1.2 shows the construction and joint details of a typical AWWA C303 pipe.

Although BWP looks similar to lined cylinder pipe (LCP), both behave different structurally, as the design and materials vary significantly. LCP is a concrete prestressed pipe that remains in compression due to a spirally wound prestressing wire, and is not designed in such a way that the steel cylinder plays a significant role in the structural integrity of the pipe. In BWP, the steel cylinder is a main structural component that affects the load carrying capacity of the pipe

In BWP, mild steel is used for the steel cylinder and the reinforcing bars. Lined cylinder pipe uses mild steel for the cylinder but high strength steel is utilized for the prestressing wire, which is wrapped under high tension. Thus, the bars in BWP and the wire in LCP or PCCP respond differently to environmental conditions that facilitate corrosion. The mild steel bars in BWP are thicker in diameter and wrapped under lower tension than LCP, meaning that corrosion takes a longer period of time to compromise the strength of the reinforcing bars.

There are two (2) important aspects to note regarding the deterioration of BWP:

1. Deterioration can begin on the bars or on the steel cylinder.
2. The integrity of the mortar coating is essential to protect the steel against corrosion and premature failure.

3. Electromagnetic Inspection Results

3.1 Introduction

Electromagnetic data was collected on February 21 to March 2, 2017 for the pipeline. The inspected section spanned an overall distance of 8.62 miles. Due to the insertion method of the robotic tool, pipes located at access points were not fully inspected. Below are Pure Technologies' resources used to perform the inspection, as well as the inspection schedule (Table 2.1).

Table 2.1: Inspection Summary				
On-Site Staff	M. Wieder, J. Hollis, J. Purkiss, J. Wroblski			
Analysts	J. Suryadi, E. Ng			
Project Manager	B. Ellis			
Tool	Pure Robotics®			
Inspection Dates	**Diameter (inches)**	**Start Station**	**End Station**	**Distance[A]**
February 21 to March 2, 2017, and May 23, 2017	30	0+56	12+48	0.24 miles
	42	10+02	15+43	0.10 miles
	30	18+11	450+35	8.28 miles
Total Distance				**8.62 miles**

[A]Distance may not correspond to station due to number of reloation sections.

A summary of the total number of pipes that had electromagnetic signatures consistent with broken bar wraps and pipes that exhibited cylinder anomalies is shown below (Table 2.2).

Table 2.2: Summary of Inspected Pipes					
Pipeline	**Diameter (inches)**	**Number of Inspected Pipes**	**Pipes with Broken Bar Wraps**	**Pipes with Cylinder Anomalies**	**Relocation Pipes**
Raw Water Transmission Main	30	1,301	2	10	152
	42	18	0	0	18
Total		**1,319**	**2**	**10**	**170**

A summary of the number of pipes with 5 broken bar wraps, 10 to 15 broken bar wraps, and 15 broken bar wraps or more detected during the inspection is presented in Table 2.3.

Table 2.3: Summary of Pipes with Broken Bar Wraps					
Pipeline	**Diameter (inches)**	**Length (feet)**	**Pipes with 5 Broken Bar Wraps**	**Pipes with 10 to 15 Broken Bar Wraps**	**Pipes with more than 15 Broken Bar Wraps**
Raw Water Transmission Main	30	44,963	2	0	0
	42	541	0	0	0
Total		**45,504**	**2**	**0**	**0**

3.2 Comparison and Correlation to the Pipe Laying Schedule

The original data from section from Station 346+54 to Station 359+49 and the relocation section from approximate Station 1889+00 to approximate Station 1894+80 was not analyzed due to an error in the data collection during the original inspection. Pure Technologies remobilized the Station 337+70 on May 23, 2017 and inspected approximately 3,000 feet downstream (towards the plant) to recollect this section of data.

3.3 Calibration

Effective analysis of electromagnetic data requires knowledge of how the electromagnetic signal behaves when no broken bar wraps are present (i.e., the baseline condition) and being able to compare that baseline condition to the data signal received when there are broken bar wraps on the pipe.

As the data signal is sensitive to the properties of a particular pipe (i.e., bar diameter and spacing, cylinder thickness, etc.), pipes with the same diameter, but with different design specifications, exhibit different signal properties, or “baselines”. Additionally, these pipes will display data signals that respond differently when broken bar wraps are present.

To understand how the data signal responds in varying conditions, Pure Technologies performs calibration scans on pipes similar to the inspected pipe. The calibration process involves scanning a pipe or set of pipes with properties (i.e., diameter, bar class, bar gauge, etc.) that are as close as possible to the properties of the in-situ pipe. These representative pipes are initially scanned to establish the baseline signal. Pure Technologies uses this information to assess signal variation due to the pipe properties alone.

Once the baseline signal has been established, additional scans are performed on the pipe while varying the number and layout of broken bar wraps to determine:

- The resolution of the system when the number of broken bar wraps changes, and
- The optimal system settings that should be used for that particular pipe.

A calibration curve is created from this information and incorporated into Pure Technologies' analysis software. At this point, an experienced data analyst can measure a distress signal and compare it to the calibration curve to quantify the number of broken bar wraps represented by that signal. The distressed regions of each inspected pipe are then identified, measured, and compared against the calibration curves to quantify the number of broken bar wraps in each distressed region.

As the calibration process was not performed on any of the pipes from the pipeline, the calibration curve was calculated using mathematical modeling based on Pure Technologies' in-depth knowledge of calibration scans from other projects.

Variations in pipe properties do not affect the ability of the electromagnetic inspection equipment to locate broken bar wraps, but the variations will affect the accuracy of the quantification of distress. If calibration tests are done on any pipes from the pipeline at a future date, the resulting calibration curve can be applied to the data signal from this inspection to refine the calculated number of broken bar wraps for the distressed pipes.

3.4 Electromagnetic Inspection Results

Of the 1,319 pipes inspected in the pipeline, 2 pipes had electromagnetic anomalies consistent with broken bar wraps. The distressed pipes are presented in Table 2.4.

The Pure Reference Number is the unique pipe number assigned by Pure Technologies for reference only, and does not correlate with existing pipeline information. The stationing shown in the table is the low station for the pipe.

The Break Position of the region with broken bar wraps is measured from the low station of the distressed pipe to the center of the distress region and was rounded to the nearest 0.5 feet.

The Number of Broken Bar Wraps by Region have each been rounded to the nearest 5 broken bar wraps. Regions with fewer than 5 broken bar wraps are reported as having 5 broken bar wraps, which implies that regions shown as containing 5 broken bar wraps may be overestimated.

Table 2.4: Pipes with Broken Bar Wraps							
Pure Reference Number	**Piece Number**	**Low Station**	**Pipe Length (feet)**	**Pipe Class**	**Break Position (feet)**	**Number of Broken Bar Wraps by Region**	**Total Number of Broken Bar Wraps**
2034	1188	29+82	36	150	13.0	5	5
2871	387	314+14	36	100	23.0	5	5

3.5 Pipes with Cylinder Anomalies

The electromagnetic analysis of the pipeline identified ten (10) pipes with anomalous signals that do not resemble the characteristics of broken bar wraps.

The anomalous signals observed have been categorized as cylinder anomalies. These signals respond differently than the established baseline (undamaged) electromagnetic signal and indicate a region of the cylinder where a manufacturing feature or corrosion of the cylinder is the most likely source of the anomaly. These pipes with cylinder anomalies have been further categorized by anomaly type based on the electromagnetic signature observed in the collected data:

1. Type 1 Anomaly: Anomalies observed in the data are consistent with cylinder wall loss observed in testing on pipes at other sites.
2. Type 2 Anomaly: Anomalies observed in the data is not indicative of cylinder wall loss based on findings observed in testing on pipes at other sites.
3. Feature-Like Anomaly: Anomalies in the pipe that have characteristics of a possible undocumented feature.

Testing for cylinder anomalies involves forming various anomaly sizes and arrangements while using a variety of instrument configurations to conduct the scans. Cylinder anomalies may encompass variations that cause a decrease or increase of the cylinder thickness. There is currently no quantification process for reporting cylinder anomalies. Unlike broken bars which result in the same size of signal change regardless of circumferential position, the size of signal change for cylinder anomalies will vary based on its proximity to the exciter or detector. The Enhanced Electromagnetic Pure Robotics array was used to observe the size, shape, and position of this anomaly. Further details for these pipes are provided in Appendix C.

The pipes with these anomalous signals are listed in Tables 2.5, 2.6 and 2.7.

Table 2.5: Pipes with Type 1 Cylinder Anomalies						
Pure Reference Number	Low Station	Pipe Length (feet)	Pipe Class	Cylinder Anomaly Positional Range[A] (feet)	Cylinder Anomaly Area (square-inch)	Circumferential Clock Position of Anomaly (facing high station)
2480	187+42	36	100	25.5-26.0	40	5 to 8 o'clock
2498	193+90	36	100	27.0-27.5	50	8 to 10 o'clock
2536	205+07	36	100	14.0-14.5	50	9 to 11 o'clock
3270	448+53	36	100	12.0-12.5	40	4 to 8 o'clock

[A]*Cylinder Anomaly Positional Range – represents the portion of the pipe affected by the anomalous signal. Signal position is measured from low station.*

Table 2.6: Pipes with Type 2 Cylinder Anomalies					
Pure Reference Number	Low Station	Pipe Length (feet)	Pipe Class	Cylinder Anomaly Positional Range[A] (feet)	Circumferential Clock Position of Anomaly (facing high station)
2202	89+93	36	150	20.5-21.0	3 to 9 o'clock
2912	328+54	36	100	30.5-32.0	10 to 3 o'clock
3252	442+05	36	100	26.5-27.5	11 to 1 o'clock

[A]*Cylinder Anomaly Positional Range – represents the portion of the pipe affected by the anomalous signal. Signal position is measured from low station.*

Table 2.7: Pipes with Feature-like Cylinder Anomalies					
Pure Reference Number	Low Station	Pipe Length (feet)	Pipe Class	Cylinder Anomaly Positional Range[A] (feet)	Circumferential Clock Position of Anomaly (facing high station)
2102	54+29	36	150	0.5-2.0	Full circumference
2812	292+92	36	100	13.0-15.0	10 to 2 o'clock
3243	438+81	36	100	27.5-28.5; 31.0-32.0	11 to 2 o'clock

[A]*Cylinder Anomaly Positional Range – represents the portion of the pipe affected by the anomalous signal. Signal position is measured from low station.*

3.6 Relocation Pipe Sections

Several sections of the pipeline were bypassed and relocated. The inspected relocation sections are listed in Table 2.8.

Table 2.8: Replacement / Relocation Sections in the 30-Inch Raw Water Transmission Main

Start Station[A]	End Station[A]	Diameter (inches)	Length (feet)	Replacement / Relocation
10+02	15+43	42	541	Relocation
13+00	13+50	30	50	Replacement
92+00	92+80	42	80	Replacement
213+00	215+56	30	256	Replacement
337+00	337+60	30	60	Replacement
1725+00	1730+01	30	544	Relocation
1793+85	1805+00	30	1,140	Relocation
1809+50	1814+48	30	563	Relocation
1889+00	1905+00	30	1,619	Relocation

[A]Station numbers are approximated from plan and profile drawings due to unavailability of pipe laying schedules.
[B]Station numbers are approximated based on pipe replacement information provided by the City of Denton.

4. Visual Assessment Results

4.1 CCTV Technology

4.2 Methodology

The Pure Robotics® multi-sensor inspection platform, equipped with the electromagnetic inspection tool and CCTV pan-tilt-zoom camera. The robotics tool collects valuable, comprehensive structural information of the pipeline and is capable of high-resolution videos and images of the pipeline interior. The camera is designed for use in lower light environments. In addition to the camera lights, the robotics platform is fitted with variable intensity quartz halogen and high intensity light emitting diode (LED) lighting.

During the inspection, the interior of the pipeline was visually inspected for cracks, spalls, staining, and other indications of distress. The visual inspection also evaluated each of the pipeline joints for deterioration of the mortar. Pipe distress is reported as a clock position in the direction of the inspection, with 12:00 referencing the crown of the pipe, 6:00 referencing the invert, and 3:00 and 9:00 referencing both springline positions. A diagram of this methodology is shown in Figure 3.1.

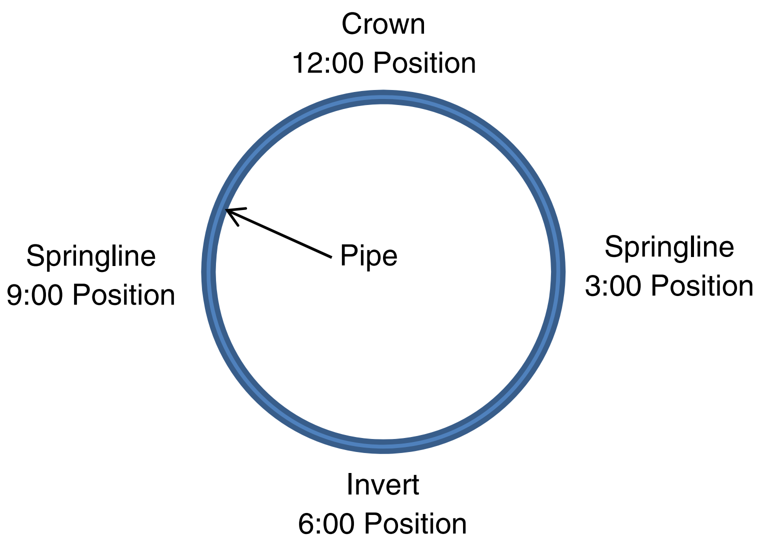


Figure 3.1: Orientation of Visual Observations Identified in the Direction of the Inspection.

While reviewing the CCTV inspection videos, a reviewer has limited ability to closely examine any cracks, spalling or deterioration; therefore, pipes with visual damage are identified based on the physical appearance, size and location of the visual defect inside the pipe as well as review of plan and profile drawings for any unusual external loading conditions around the pipe

4.3 Results

Pure Technologies performed an internal visual assessment of the pipeline using CCTV. This information was then compared to the electromagnetic inspection data

The 12 pipes identified with cylinder anomalies and / or broken bar wraps were visually evaluated for to determine if there was any correlation in the inspection data and internal condition of the pipe.

The robotics inspection identified lower elevations of the pipeline that were not able to be fully dewatered. In some of these sections, the CCTV video was unclear and difficult to assess the internal condition of the pipeline, therefore observations in these areas are made with less certainty.

4.3.1 Visual Assessment – Pipes with Type 1 Anomalies

The electromagnetic inspection identified four (4) pipes with an anomalous signal consistent with cylinder wall loss observed in testing on pipes at other sites. The pipes listed in Table 2.5 are classified as having a Type 1 cylinder anomalies.

The following figures are images taken from the CCTV video that show the internal condition of the pipes in Table 2.5. The video name is provided as reference for each image.

A visual assessment of these pipes concluded areas of carbonate staining, discoloration and cracking.

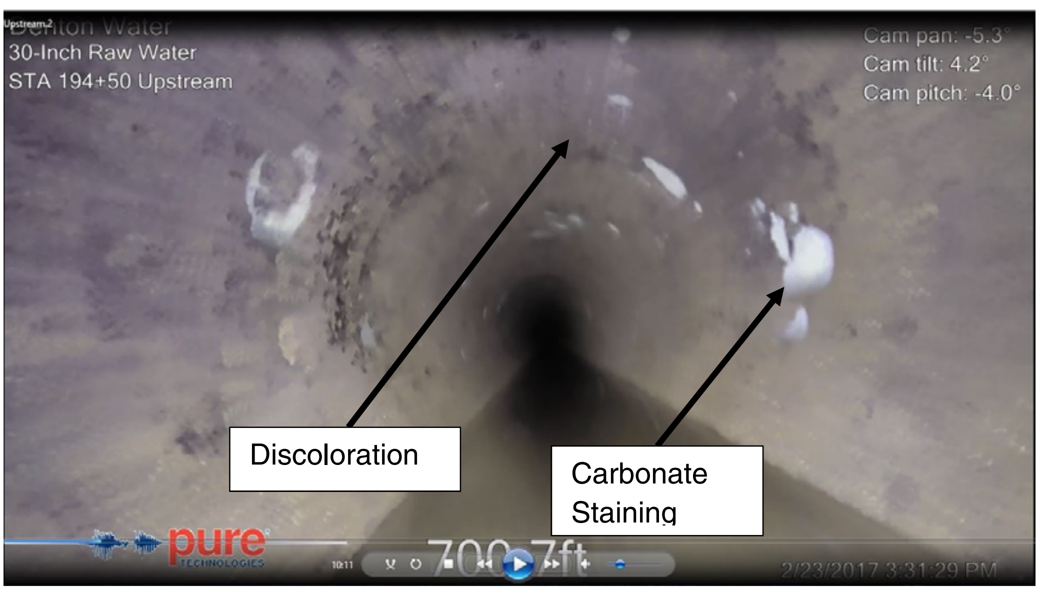


Figure 3.2: Pipe 2480, Areas of discoloration and carbonate staining, 706 feet from insertion (Station 194+50, Upstream, Video 2)

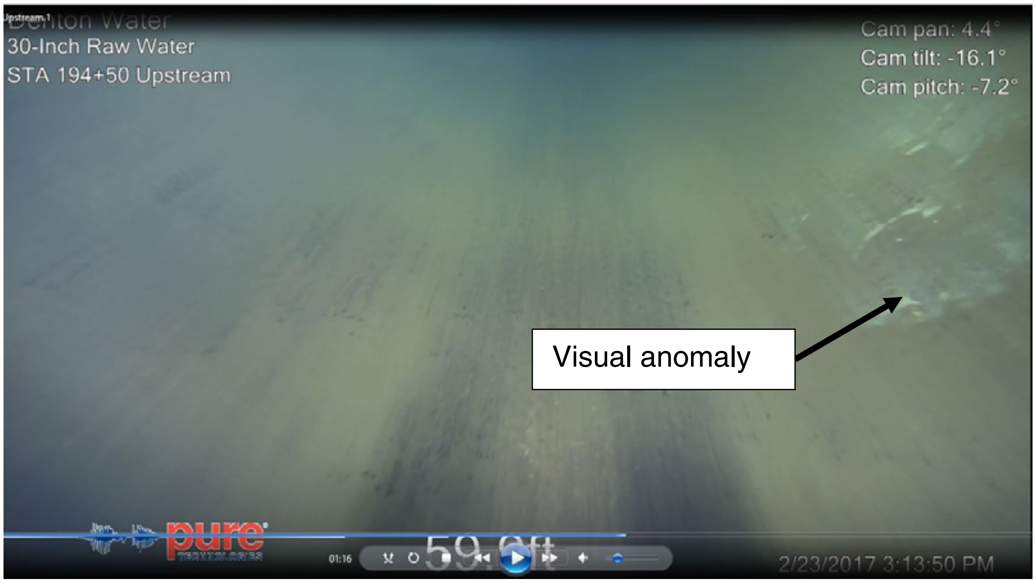


Figure 3.3: Pipe 2498, Visual anomaly observed at 5:00 position, 63 feet from insertion (Station 194+50, Upstream, Video 1)

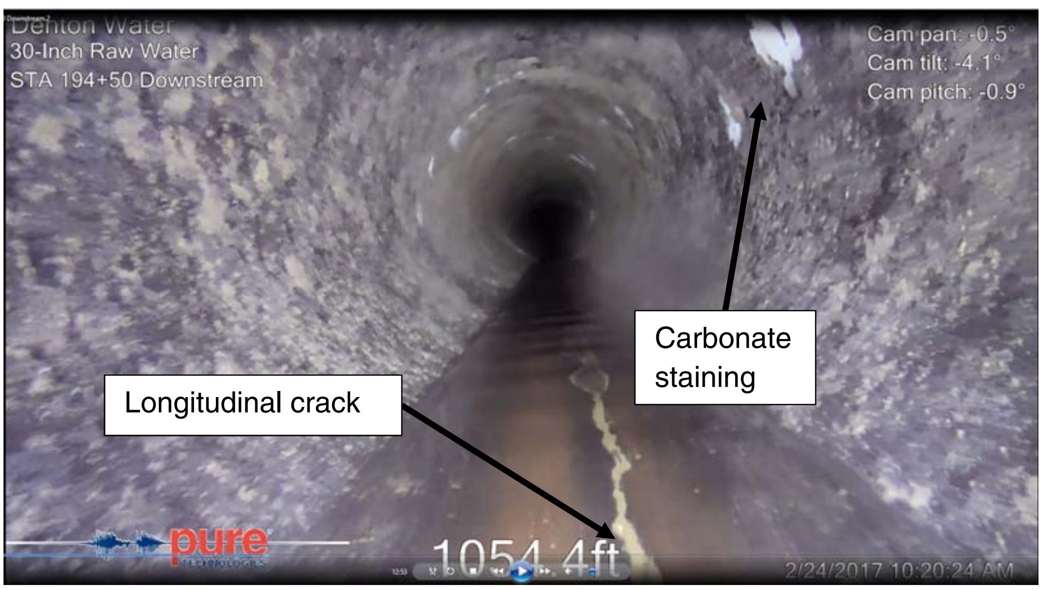


Figure 3.4: Pipe 2536, Longitudinal crack along invert, 30-feet in length, begins at 1,036 feet from insertion (Station 194+50, Downstream, Video 2)

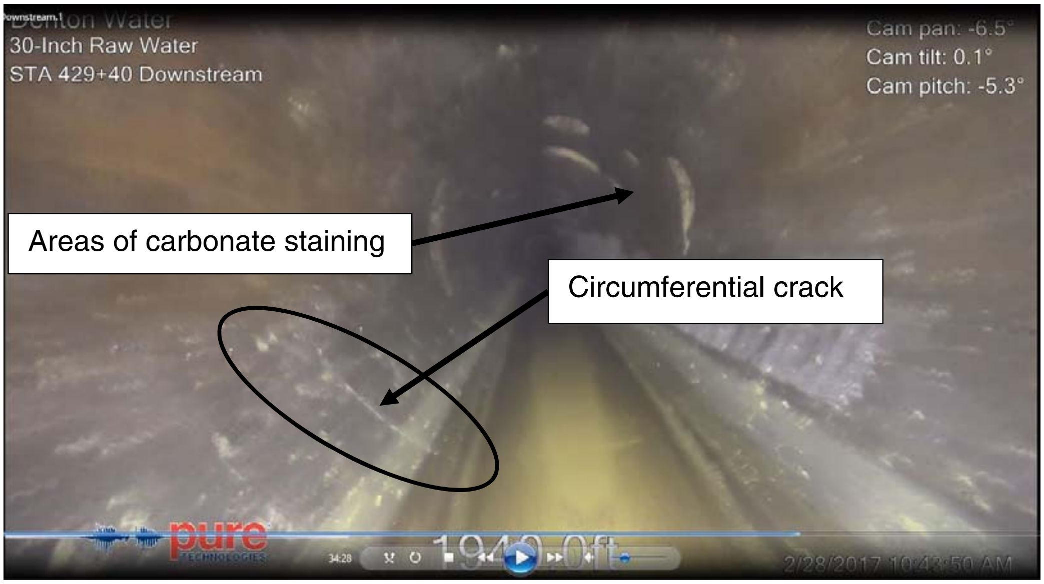


Figure 3.5: Pipe 3270, Circumferential crack, Carbonate staining and discoloration, begins 1,950 feet from insertion, (Station 194+50, Downstream, Video 1)

4.3.2 Visual Assessment – Pipes with Type 2 Anomalies

The electromagnetic inspection also identified three (3) pipes with an anomalous signal not indicative of cylinder wall loss based on findings observed in testing on pipes at other sites. The pipes listed in Table 3.2. are classified as having a Type 2 cylinder anomalies.

Table 3.2: Pipes with Type 2 Cylinder Anomalies

Pure Reference Number	Piece Number	Low Station	Pipe Length (feet)	Pipe Class	Cylinder Anomaly Positional Range (feet)
2202	1021-SP	89+93	36	150	20.5-21.0
2912	347	328+54	36	100	30.5-32.0
3252	21	442+05	36	100	26.5-27.5

The following figures are images taken from the CCTV video that show the internal condition of the pipes in Table 3.2. The video name is provided as reference for each image.

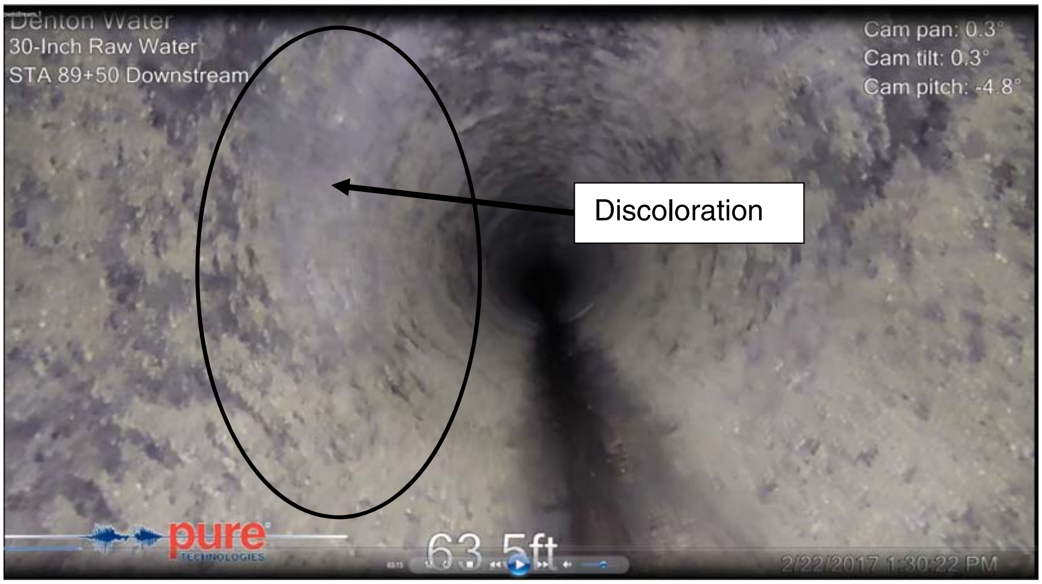


Figure 3.6: Pipe 2202, Discoloration from 8:30 position to 11:30 position, located 67 feet from insertion (Station 89+50, Downstream, Video 1)

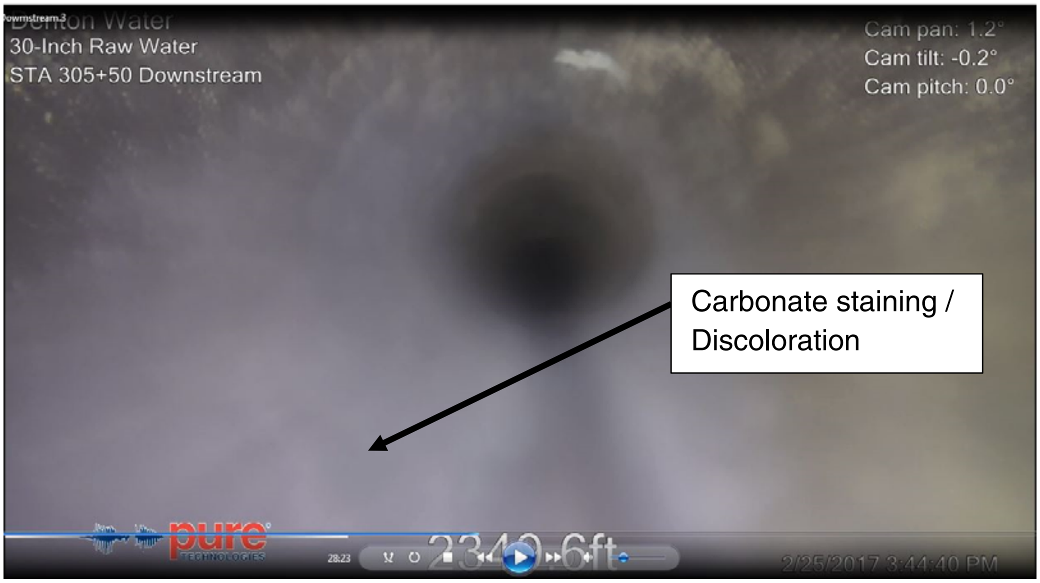


Figure 3.7: Pipe 2912, Carbonate staining / Discoloration, 2,340 feet from insertion (Station 305+50, Upstream, Video 3)

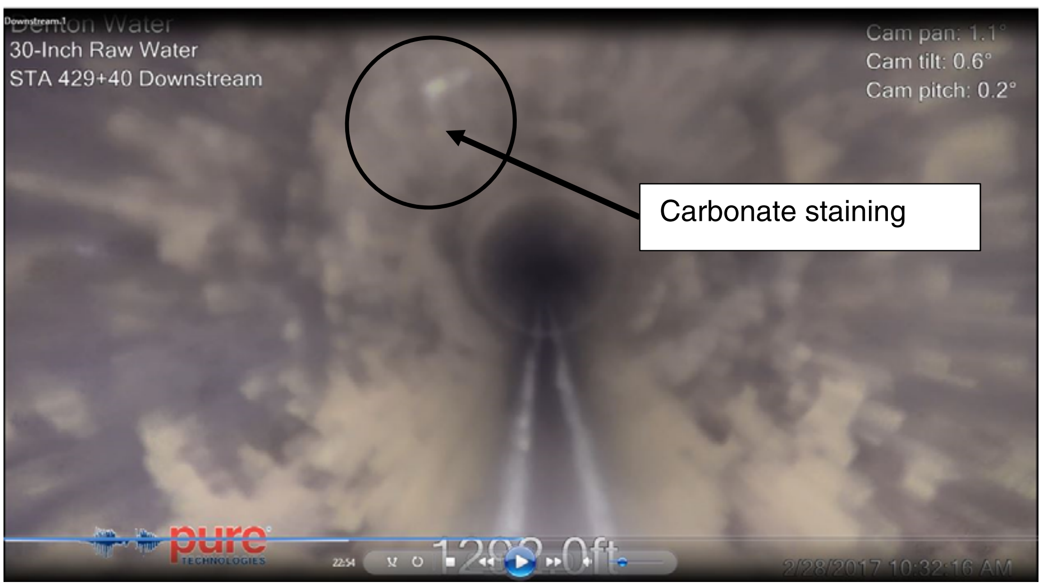


Figure 3.8: Pipe 3252, Area of carbonate staining, 11:00 position, 1,295 feet from insertion (Station 429+40, Downstream, Video 1)

4.3.3 Visual Assessment – Pipes with Feature-Like Anomalies

The electromagnetic inspection also identified three (3) pipes with an anomalous signal with characteristics of a possible undocumented feature. These pipes listed in Table 3.3.

The following figures are images taken from the CCTV video that show the internal condition of the pipes in Table 3.3. The video name is provided as reference for each image.

Table 3.3: Pipes with Feature-like Cylinder Anomalies

Pure Reference Number	Piece Number	Low Station	Pipe Length (feet)	Pipe Class	Cylinder Anomaly Positional Range (feet)
2102	1120	54+29	36	150	0.5-2.0
2812	446	292+92	36	100	13.0-15.0
3243	30	438+81	36	100	27.5-28.5; 31.0-32.0

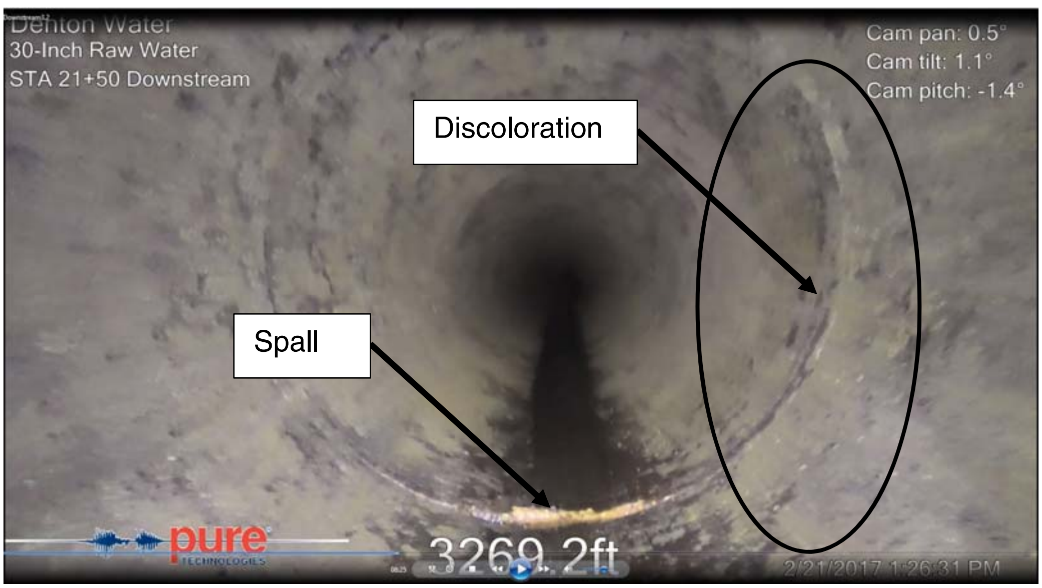


Figure 3.9: Pipe 2102, Discoloration, 2:00 to 5:00 position, 6 feet in length, 3,270 feet from insertion Joint spall at invert, (Station 21+50, Downstream, 3.2 Video)

Figure 3.10: Pipe 2812, Large Discoloration, from invert across 9:00 position to crown, 1,245 feet from insertion (Station 305+50, Upstream, Video 3)

4.3.4 Visual Assessment – Pipes with Broken Bar Wraps

The robotics inspection identified two (2) pipes with an electromagnetic signature representative of broken bar wraps. These pipes are listed in Table 3.4.

Table 3.4: Pipes with Broken Bar Wraps

Pure Reference Number	Piece Number	Low Station	Break Position (feet)	Number of Broken Bar Wraps by Region	Total Number of Broken Bar Wraps	Visual Condition Assessment (Distance from insertion)
2034	1188	29+82	13.0	5	5	No visual deficiencies observed
2871	387	314+14	23.0	5	5	Areas of carbonate staining; 8:00 position (890 feet), 2:30 position (897 feet), poor visibility

Based on the Station 21+50 Downstream 3.1 CCTV Video, no internal visual deficiencies were observed in Pipe 2034.

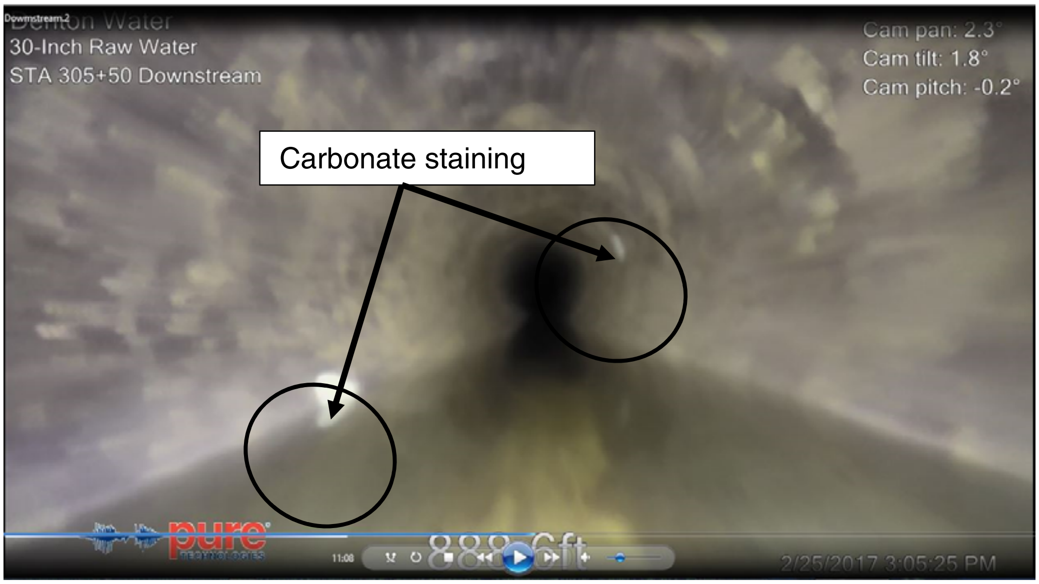


Figure 3.11: Pipe 2871, Areas of carbonate staining, 2:30 and 8:00 positions, 895 feet from insertion (Station 305+50, Downstream, Video 2)

4.3.5 Visual Assessment – Overview

A detailed review of the robotics inspection videos identified pipes with visual deficiencies consisting one or combination of the following; longitudinal cracking, circumferential cracking, areas of carbonate staining, leaching, or discoloration and spalling at the joints or liner.

Longitudinal cracking or fractures found in bar wrapped pipe are of concern and generally the result of pipe deflection often caused by excessive external loading, but also attributed to internal pressures exceeding the design pressure of the pipe.

For example, longitudinal cracking along the crown may be a result from excessive overburden stress or overloading. Similarly, longitudinal cracking along the invert could be due to poor pipe bedding. Other causes could be related to manufacturing defects, or loss of pipe strength caused by corrosion of the steel cylinder or broken bar wraps, which causes separation between the inner lining and steel cylinder.

Longitudinal cracking is an indication of advanced deterioration, where in some cases the structural integrity of the pipe may be affected.

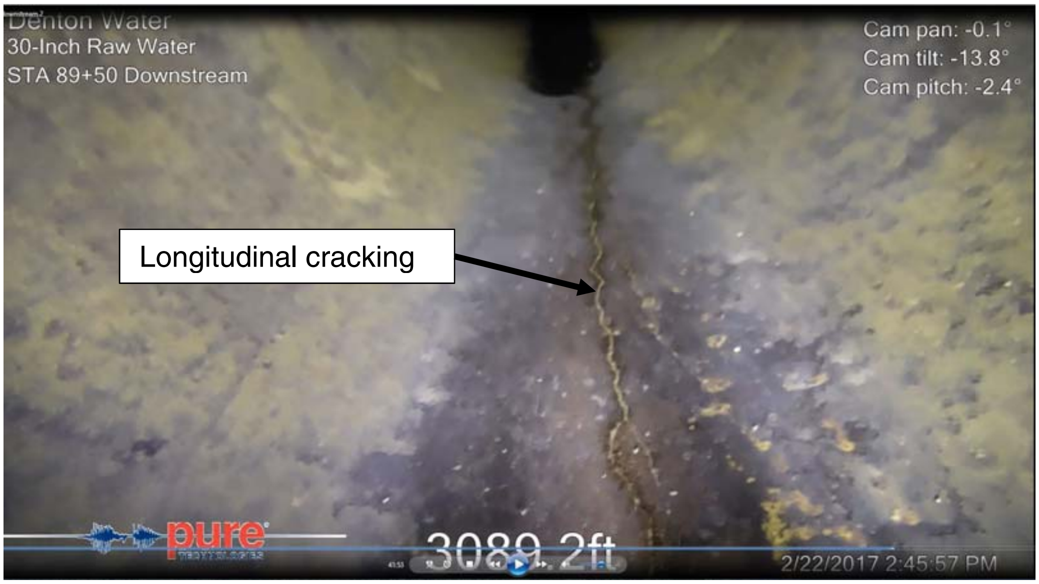


Figure 3.12: Pipe 2289, Longitudinal cracking along invert 3090 feet from insertion (Station 89+50, Downstream, Video 2)

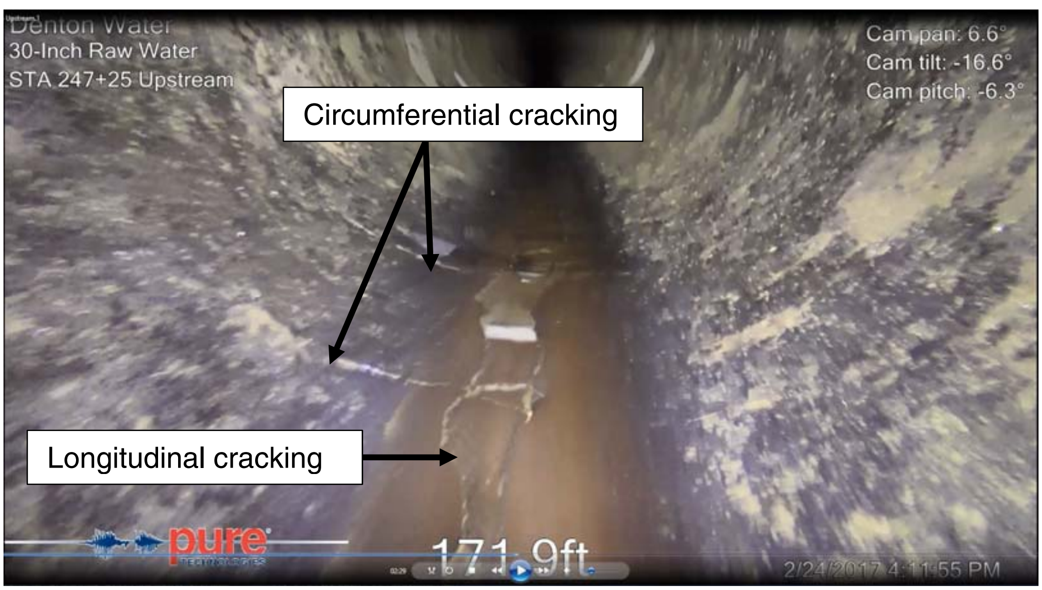


Figure 3.13: Pipe 2652, Longitudinal cracking along invert with intersecting circumferential cracks 180 feet from insertion (Station 247+25, Upstream, Video 2)

Figure 3.14: Pipe 2652, Longitudinal cracking along invert and crown

170 feet from insertion (Station 337+25, Downstream, Video 1

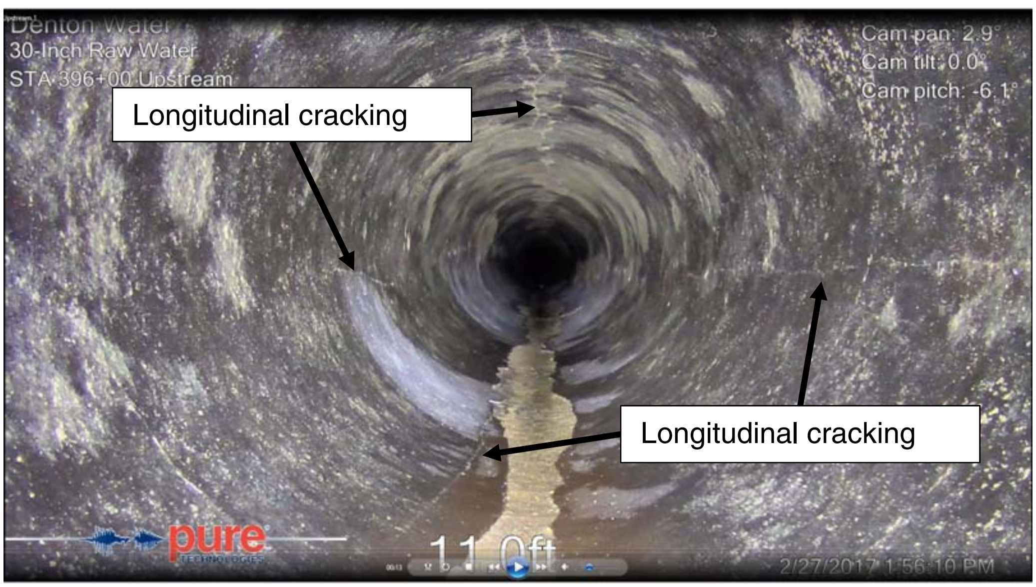


Figure 3.15: Longitudinal cracking along invert, crown and at each springline

Piece number 156-SP insertion (Station 396+00, Upstream, Video 1)

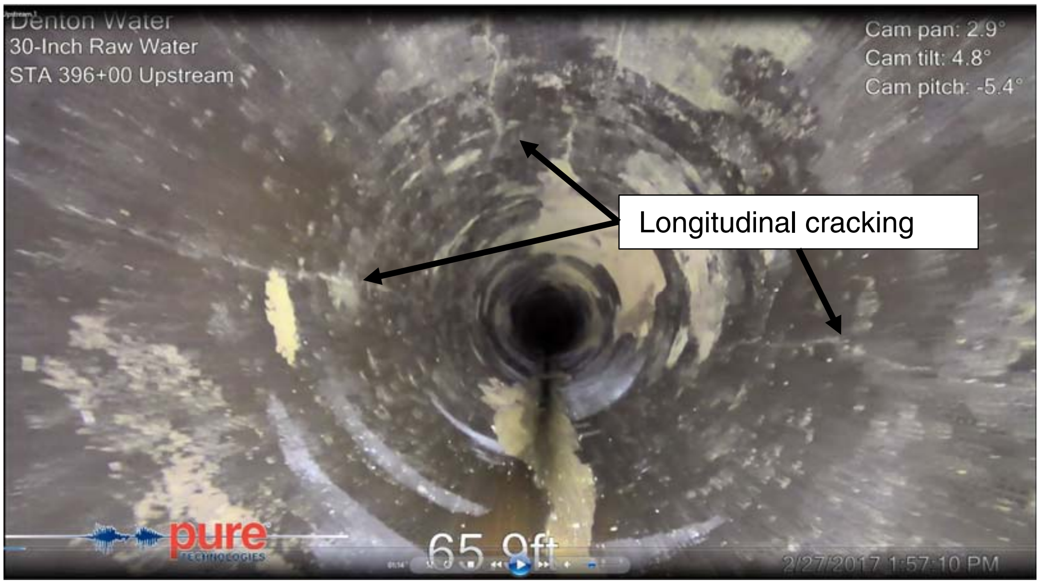


Figure 3.16: Pipe Number 3115, Longitudinal cracking along crown and at each springline Located 66 feet from insertion, (Station 396+00, Upstream, Video 1)

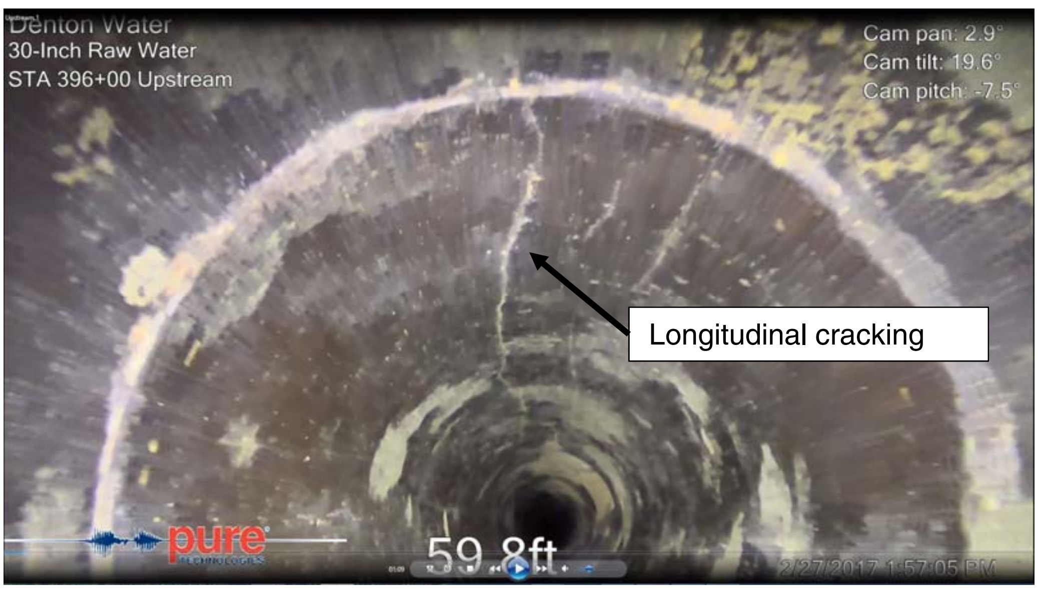


Figure 3.17: Pipe Number 3116, Longitudinal cracking along crown full length of pipe Located 60 feet from insertion, (Station 396+00, Upstream, Video 1)

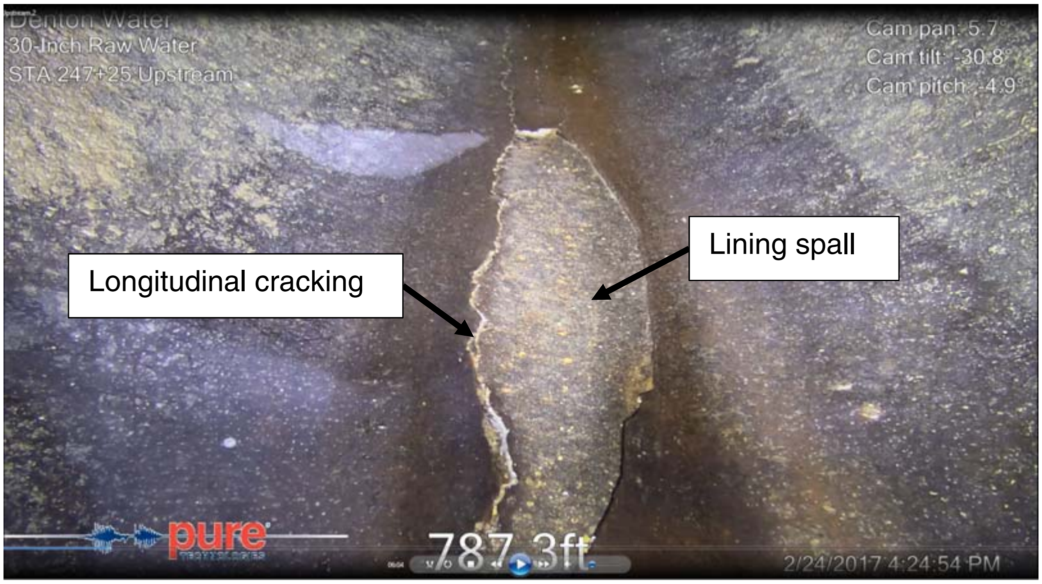


Figure 3.18: Pipe 2506, Longitudinal crack with lining spall at invert, 787 feet from insertion (Station 247+25, Upstream, Video 2)

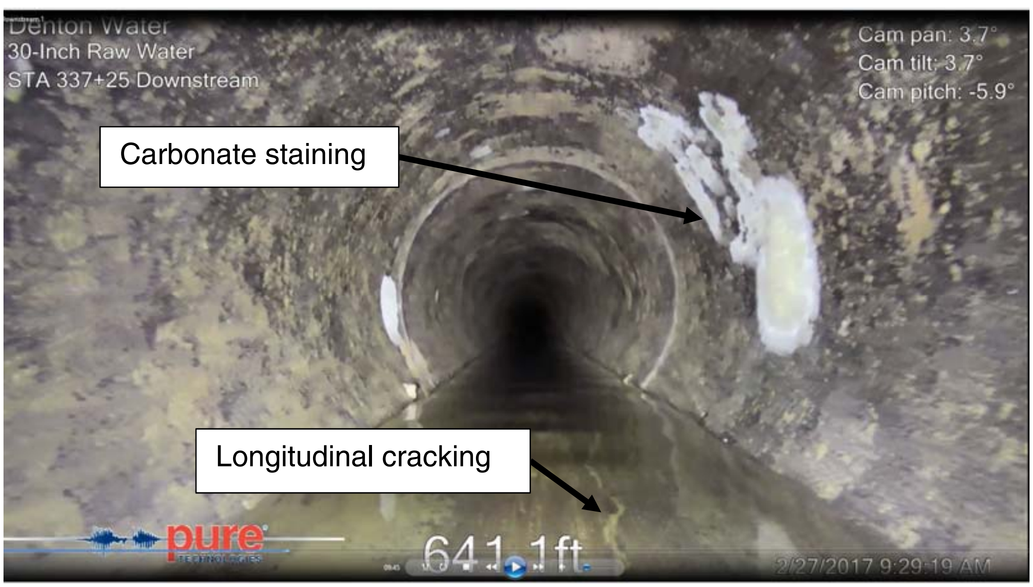


Figure 3.19: Pipe 2955, Longitudinal crack along invert, areas of carbonate staining, 641 feet from insertion (Station 337+25, Downstream, Video 1)

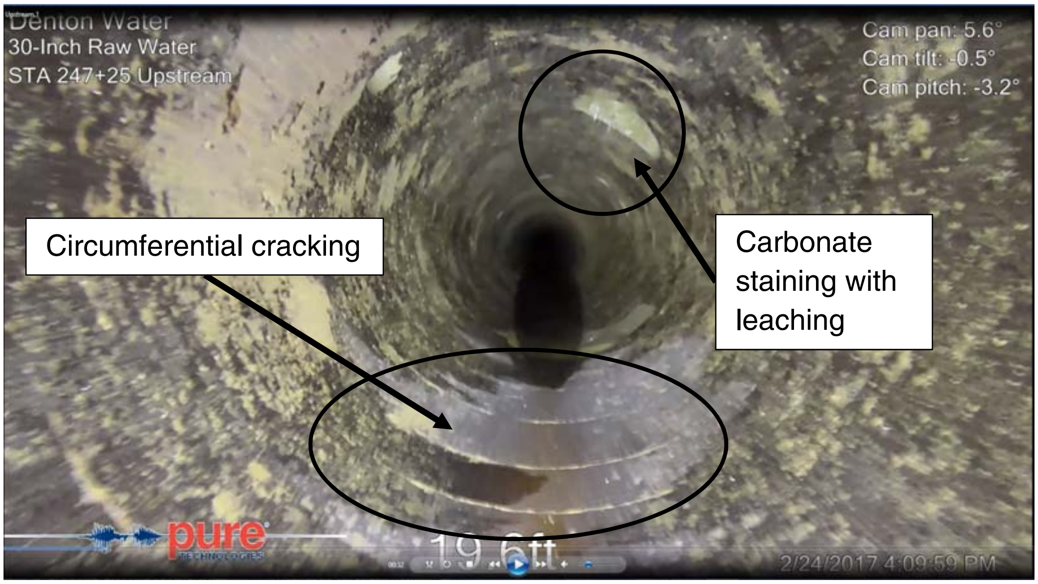


Figure 3.20: Pipe 2655, Circumferential cracking, Carbonate staining with leaching at 2:00 position, 20 feet from insertion (Station 247+25, Upstream, Video 1)

Typically, circumferential cracking is not of concern, and generally does not relate to the structural integrity of the pipe, unless there is a correlation with the electromagnetic inspection. None of the pipes circumferential cracking correlated to the electromagnetic inspection data. A few pipes had numerous circumferential cracks throughout the pipe length.

Figure 3.21: Pipe number N/A, Typical gate valve, 770 feet from insertion (Station 194+50, Downstream, Video 2), Pipe laying schedule unavailable

Figure 3.22: Pipe 2267, General view of top outlet, 2,294 feet from insertion (Station 89+50, Downstream, Video 2)

Figure 3.23: Pipe 2255, Joint missing mortar, 1,975 feet from insertion (Station 89+50, Downstream, Video 1),

Pure Technologies considers moderate spalling to be when the spall depth is greater than 0.5 inches but the underlying steel joint ring is not exposed. Severe spalls typically expose or nearly expose the joint ring and are considered in need of repair. The joints were not physically measured during the inspection, therefore it not possible to determine the depth and severity of spalls.

Figure 3.24: Pipe 2506, Gate valve, Suspected biological accumulation at invert, 240 feet from insertion (Station 194+50, Downstream, Video 1)

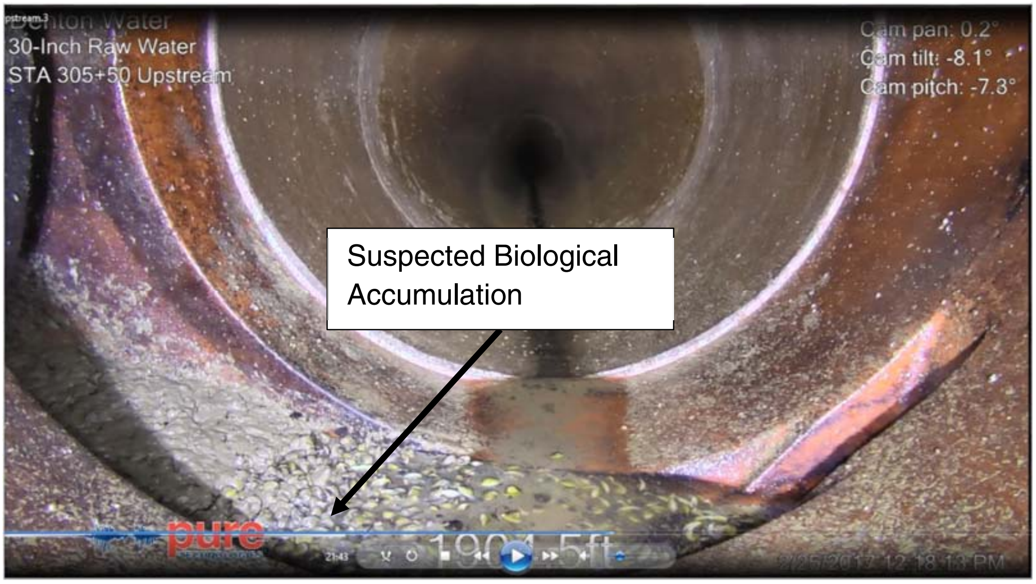


Figure 3.25: Pipe Number N/A, Gate valve, suspected biological accumulation at invert, 1,902 feet from insertion (Station 305+50, Upstream, Video 3), Laying schedules unavailable

Figure 3.26: Pipe 3272, Gate valve, accumulation of debris, side outlet, 2,000 feet from insertion (Station 429+40, Downstream, Video 1)

Figure 3.27: Butterfly valve, 2,125 feet from insertion towards Rapid Mix Basin (Station 429+40, Downstream, Video 1) end of inspection

Figure 3.28: Pipe 2771, Gate valve and outlets, 210 feet from insertion (Station 279+00, Upstream, Video 1)

5. References

References for Bar Wrap Pipe

1. Ameron. Concrete Cylinder Pipe Design Manual. U.S.A. 1988
2. American Water Works Association. AWWA C303, Concrete Pressure Pipe, Bar-Wrapped, Steel-Cylinder Type. Denver: AWWA; 2008.
3. American Water Works Association. Manual of Water Supply Practices M9. Third Edition. Denver. 2008.
4. American Concrete Pipe Association, Concrete Pipe Design Manual, Vienna: ACPA; 2007.

APPENDIX A

Glossary & Abbreviations

AV:	Air Valve
BO:	Blow off
BWP:	Bar Wrapped Pipe
ECP:	Embedded Cylinder Pipe
EL:	Elbow
EM:	Electromagnetic
LCP:	Lined Cylinder Pipe
OL:	Outlet
MH:	Manhole
NSS:	Non-Shorting Strap
PCP:	Prestressed Concrete Pipe
PCCP:	Prestressed Concrete Cylinder Pipe
RCP:	Reinforced Concrete Pipe
RCCP:	Reinforced Concrete Cylinder Pipe
SP:	Short Pipe Length
SS:	Shorting Strap
STD:	Standard Pipe Length
TO:	Turn Out
VS:	Vent Structure
PW:	Pumping Well

Amplitude: A component of the data signal produced during pipeline inspection, amplitude is an indication of signal strength.

Anomalous Pipe: A pipe that produces a data signal that cannot be interpreted as distressed or distress-free due to some irregularity. This irregularity may be due to unexplained signal influence during the inspection process or due to the properties of the pipe itself.

Calibration: A controlled inspection of a pipe similar to the in-situ pipe that is performed to determine the expected signal response. The data signal recorded while inspecting the in-situ pipes is then compared to this signal to estimate number of broken bar wraps. Calibration typically requires the destructive testing of a removed pipe.

Distressed Pipe: A pipe that exhibits electromagnetic anomalies consistent with broken bar wraps. The amount of distress can be estimated by comparing the distress signal with the signal obtained during the calibration process.

Distressed Region: A section of pipe that exhibits electromagnetic anomalies consistent with broken bar wraps. There may be one or more regions of distress in any distressed pipe.

Downstream: In the direction of water flow.

Feature: Fixtures in the pipeline that affect the inspection (e.g., Manholes, Air Valves, Tees, Elbows).

Feature Pipe: Pipes with features that may be used to locate distressed pipes. The feature pipes cannot be analyzed for distress at or near the feature due to the signal distortion caused by the presence of the feature.

Joint: An area of the pipeline where two pipe ends are fixed together. Typically, pipe ends are joined spigot to bell; however, special pipes are available that join two bells ends or two spigot ends.

Phase: A component of the data signal produced during pipeline inspection, phase is a representation of the signal's travel time.

Rank: Listing of pipes with respect to the total number of broken bar wraps in the pipe (descending order).

Pipe: Single section of pipe, from bell end to spigot end.

Upstream: Against the direction of water flow.

APPENDIX B

Electromagnetic Inspection Technology

Primary Focus of Electromagnetic Inspection

Assessing the condition of a PCCP transmission main is a challenging task that is best performed using a combination of non-destructive testing technology, internal visual inspection and sounding (in embedded cylinder pipe), engineering science, and experiential judgment. The primary goal of an inspection is to provide an understanding of the condition of the structural component that provides the pipe's strength—the prestressing bar. An electromagnetic inspection provides a non-destructive method of evaluating the baseline condition of the prestressing bar. Electromagnetic inspections ascertain a magnetic signature for each pipe to identify anomalies that are produced by zones of broken bar wraps. Various characteristics associated with an anomaly (length, magnitude, phase shift, etc.) are evaluated to provide an estimate of the number of broken bar wraps. This inspection method is able to quantify the amount of bar wrap damage and is the best method of determining the baseline condition of a pipeline.

Background and Theory of Electromagnetic Inspection

For many years, it has been possible to exploit the concept of eddy currents to measure structural properties in metals. The application of a time-varying magnetic field to metal structures can create internal electric currents as free electrons are driven by the field along discontinuities in the metal itself. Many applications of this phenomenon have been developed to detect damaged sections in steel and iron pipelines.

For PCCP, a different mechanism exists that can be used to determine the structural condition of the pipe. Eddy currents that are generated in a bar wrap can flow along the length of the bar wrap, generating a solenoidal field (see *Figure B.1*). If the current is interrupted by a break in the prestressing bar, the field will be affected.

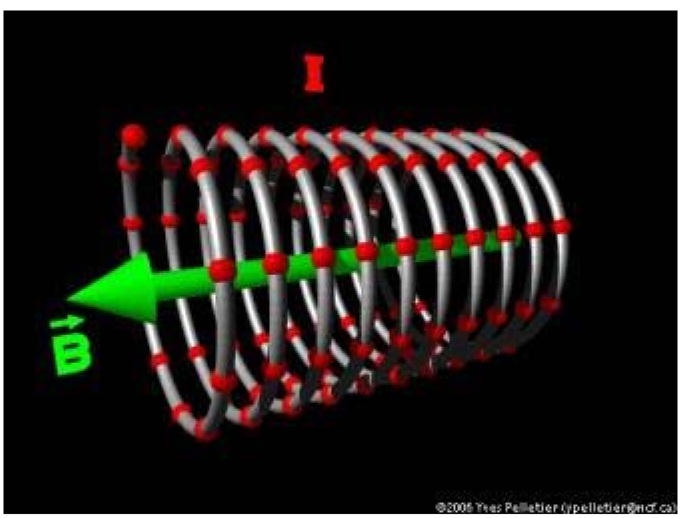


Figure B.1: Electric currents induced by time-varying magnetic field

The electromagnetic system used by Pure Technologies generates eddy currents in the bar wrap and detects where the field is altered by the presence of breaks in the prestressing bar.

To create an electric current in the prestressing bar, the Pure Technologies electromagnetic system generates a magnetic field inside a PCCP. A signal generator outputs a low frequency alternating electric current (typically less than 100 Hz) into a coil of bar (known as an exciter coil) positioned near the inner surface of the pipe. The magnetic field generated by this coil extends through the concrete core, steel cylinder, and finally into the prestressing bar wraps. As the coil travels along the length of the pipe, the field moves as well, creating a localized magnetic field that then generates eddy currents in the bar. As long as there are no breaks in the bar wrap, the current will flow uniformly along the bar; however, where a broken bar wrap exists, a discontinuity in the current forms. As the magnetic field passes over the section of the broken bar, currents are generated that form opposing magnetic field lines.

Detectors are placed on the opposite side of the pipe from the exciter coil to record the variations in the magnetic field that are created when broken bar wraps interrupt the current flow. Analyzing and interpreting the response of the magnetic field allows for estimates of the number of broken bar wraps and the approximate location of the broken bar wraps along the length of the pipe.

Analysis Considerations

Electromagnetic inspections detect electromagnetic anomalies, or differences, in the expected induced field of a PCCP. Anomalies that are consistent with broken bar wraps are of particular importance; however, the induced field of interest is small and other interference can mask or distort the size and shape of the electromagnetic signal, affecting the ability to detect and quantify broken bar wraps. The accuracy of the broken bar wrap detection and quantification process on any given pipe depends on a number of factors including, but not necessarily limited to:

- Accuracy and completeness of the information supplied by the client
- Type and configuration of pipe being inspected
- Availability of relevant calibration information
- Type, complexity, location, and number of distressed regions on a given pipe
- Inspection conditions observed in the pipe during the data collection period

Accuracy and completeness of the information supplied by the client. The inspection system is sensitive to all magnetic properties of a pipe, including cylinder thickness and composition, bar spacing and diameter, and the number of bar wraps. Pure Technologies uses the information provided by the client to perform the analysis. Drawings that indicate the exact location of pipe features and varying pressure classes are used to correlate the inspection data. Drawings that indicate how each class of pipe is constructed (cylinder thickness, bar diameter and spacing, shorting strap or non-shorting strap, etc.) are used to identify and quantify regions of distress. Discrepancies in the drawings and the data may affect the accuracy of the analysis.

Unknown or sealed appurtenances along the pipeline. Although most appurtenances exhibit a signal that is different and distinguishable from broken bar wraps, in some cases, the signals are similar and an appurtenance could be misinterpreted as broken bar wraps if it is not listed on the drawings and not visible during the inspection.

Existence of ferromagnetic (steel) materials near the pipeline. When extra steel is located in close proximity to the pipeline, it can cause a signal distortion that may mask broken bar wraps or could cause anomalies that may be misinterpreted as broken bar wraps.

Previously repaired pipes. There are a variety of methods used to repair distressed PCCP. Some of these methods allow electromagnetic inspections to be conducted on the repaired pipe while others do not. Internal carbon fiber repairs do not appear to distort the electromagnetic signal and to date, successful repeat inspections have been performed on these repaired pipes and updated quantities of broken bar wraps have been provided for them. Conversely, external tendon repairs, internal or external steel bands, steel slip lining, and internal joint seals can all affect the electromagnetic signal. Consequently, analysis cannot be provided for these types of repaired pipes.

Changes in bar diameter and bar pitch. Broken bar wraps are estimated by measuring the physical length of an anomaly and entering it into a mathematical model known as a calibration curve. Calibration curves are based on either field testing of a similar pipe or mathematical modeling based on an extensive database of calibration test data and finite element analysis. In the case of mathematical modeling, the bar diameter and pitch information are critical factors in the calculations. If this information is not correct, the quantity of broken bar wraps will likely be incorrectly estimated. Typically, it is unknown if there are any pipes affected by this issue, as only excavation and forensic analysis can reveal variations in bar properties.

Changing distance of the bar wrap and steel cylinder. If, during manufacturing of the pipe, there is variation in the distance of the prestressing bar and the steel cylinder, the resultant signal during an electromagnetic inspection may vary, possibly mimicking broken bar wraps. Typically, it is unknown if there are any pipes affected by this issue as only excavation and forensic analysis can reveal manufacturing defects.

Discontinuities or variations such as abnormal welding in liner construction. These discontinuities can mask actual damage or mimic damage where none exists. This situation could cause over or under estimation of the number of broken bar wraps.

Proximity to power lines. In some cases, power lines can cause distortion in the signal due to the stray magnetic fields. This can limit the effectiveness of the analysis if the distortion is too severe. This interference is rare but is noted for completeness of this document.

Motion. Impacts, uneven pipe floor, excessive debris, and vibration all produce distortion which can cause overestimation of broken bar wraps or may mask actual damage. The inspection crew takes every effort to move the tool smoothly to ensure optimum data quality. Detailed field notes document excessive cart motion for analysis consideration, reducing the possibility of misinterpretation due to excessive motion. In addition, a sensitive accelerometer is integrated into the design of the cart, which allows analysts to determine where there was excessive cart motion and identify anomalous signals due to motion.

Type and Configuration of Pipe Being Inspected

The sensitivity to broken bar wraps is affected by the type of pipe being inspected. The following information on detection limits is based on previous calibration testing performed by Pure Technologies.

Bar Wrapped Pipe (AWWA C-303).

Bar wrapped pipe is similar in form to PCCP (AWWA C-301) but with several important distinctions. The primary difference is that the pipes use ¼-inch or thicker steel bars rather than the thinner prestressing bar for the structural support on the pipe.

Feature Pipes. The electromagnetic technology is able to detect distressed regions in some feature pipes; however, due to the impact of the feature on the signal, results are presented with less certainty for regions of the pipe near fittings, manholes, blow off valves, or other features.

Short Pipes. As the joint effect span is constant regardless of the pipe length, its overall effect on a pipe will increase as the length of the pipe decreases. This means that for short pipes, a shorter length along the barrel of the pipe will remain unaffected by the joint signal and thus be analyzable. In addition, as short pipes typically make up a small portion of the pipe inventory inspected, there are not as many baselines (background signals) available for comparison. This makes the identification of distress on shorter pipes more challenging.

Details of Estimates of Broken Bar Wraps

Break Position. The data signal for a distressed region will vary along the length of a given pipe. Small numbers of broken bar wraps in the middle of a pipe are easier to detect and measure than distress at the joint. Low to moderate quantities of broken bar wraps within approximately 18 inches of the joint may be difficult to identify and quantify due to the increased presence of steel at the joint and the distress signal may be overcome by the much larger effect of the joint steel. Small quantities of broken bar wraps near the joint may not be detected and the accuracy of those that are detected may be less than those closer to the center of the pipe. Additionally, broken bar wraps are more difficult to detect and quantify at the bell end of the pipe than at the spigot end of the pipe, since a portion of the bell section will overlap the spigot end. The number of broken bar wraps required for the signal to be detectable and quantifiable depends on the pipe type (embedded cylinder pipe (ECP), lined cylinder pipe (LCP), or non-cylinder pipe (NCP)), joint configuration, proximity of the center of the break region to the joint, and whether it is the bell or spigot end. Because of this, the estimated number of broken bar wraps near the center of a pipe will be provided with greater confidence than broken bar wraps near the joints, especially near the bell end.

End Effects. End effects refer to changes in the data signal near the end of a pipe (bell or spigot) that are due to a variety of installation methods of the pipe joint itself. End effects do not refer to distress at the joint. Beveled spigots, pulled joints, mitered joints, butt straps, closure pieces, steel fittings, etc., will all affect the data signal at the end of a pipe in some way. Research in this specific area has provided methods for analysts to determine if the signal is due to an end effect, or true end distress. The differences are subtle and examination of client records can provide the additional information necessary to conclude whether a particular data signal represents end effects or end distress. In the case where both end effects and end distress exist, quantification is more challenging.

Non-contiguous Broken Bar Wraps. This occurs when broken bar wraps are scattered amongst non-broken bar wraps. Non-contiguous broken bar wraps are often the result of hydrogen embrittlement as opposed to corrosion, which results in a continuous region of broken bar wraps as the corrosion typically starts at a point and grows with time.

During the inspection, a broad magnetic field is projected onto the prestressing bar (several inches wide); therefore, it is difficult to analyze individual prestressing bar wraps. When broken bar wraps are separated by non-broken bar wraps, the non-broken bar wraps can be masked by the distress signals and may appear broken depending on the distance from the broken and non-broken prestressing bar wraps. The distance from the broken bar wraps required for the non-broken bar wraps to be distinguishable depends on the pipe properties and the total number of broken bar wraps. Non-contiguous broken bar wraps may lead to an anomaly that is larger than the actual associated prestressing bar damage.

The estimated number of broken bar wraps in any report normally assumes a region of consecutive broken bar wraps exist for each break region. This assumption is the only assumption that can be made without additional information, which may be obtained from field verification. It is possible that some or all of the break regions on any distressed pipe will contain intermittent or scattered broken bar wraps instead of consecutive broken bar wrap. In this case, the estimated number of broken bar wraps may be overestimated.

Background Signal Variations. The electromagnetic data signal is sensitive not only to physical differences in pipeline properties (bar diameter and spacing, cylinder thickness, etc.), but it is also sensitive to any magnetic differences in the steel components of the pipe. Pipe manufacturers may use different material suppliers for the various components of the pipes within a pipeline. Even though two pipes are manufactured exactly the same physically, if the steel for the cylinder and the prestressing bar come from different suppliers, they will likely have slightly different magnetic properties, which will result in variations in the background signals.

Much like the human fingerprint, every pipe in a pipeline, no matter how alike they are supposed to be, will exhibit a slightly different background signal. Since distress is quantified by measuring the distressed pipe signal relative to a background signal, any variations in background signals can affect the accuracy of the distress measurement and ultimately the estimate of the number of broken bar wraps.

Number of Break Regions. Results are predicted with greater accuracy for pipes containing single distressed regions than for pipes containing multiple distress regions. As the number of distress regions per pipe increases, or as these regions become closer together, the complexity of the interpretation increases. In some cases, distress regions can interact with each other from an electromagnetic standpoint to create signals of varying complexity. In cases where the distress signal spans a wide region, a specific break position may not be provided. Instead the length of the damage zone will be shown and an approximate range of suspected broken bar wraps will be given.

Significantly distressed pipes (where most or all of the bar wraps are broken along the entire length of a pipe) are sometimes difficult to distinguish from pipes that just have different properties than the pipes around them. Determining if the signal change is due to changing pipe properties or significant distress is partially dependent on the accuracy and completeness of the information made available by the client, but there are also specific checks in the analysis methodology that are applied to make this distinction.

Other Factors

There are often overlaps amongst the key issues listed above and there may or may not be other factors related to these issues that decrease the level of confidence in the results presented in the report. Wide variations in manufacturing processes may not impact the structural performance of the pipe but can significantly affect the electromagnetic properties. The list of factors includes ones that are known, unknown, controllable, and uncontrollable. Some can be confirmed during excavation or inspection and some can be eliminated by studying construction records, although errors in these records are common. In all cases, every effort is made to consider the various factors during analysis; however, it should be noted that the results provide an estimate of the broken bar wraps in a pipe section based on all the information available and assuming that the signal changes are caused by discontinuity in the prestressing bar.

APPENDIX C

Enhanced Electromagnetic Pipe Diagrams

Enhanced Electromagnetic Pipe Diagrams

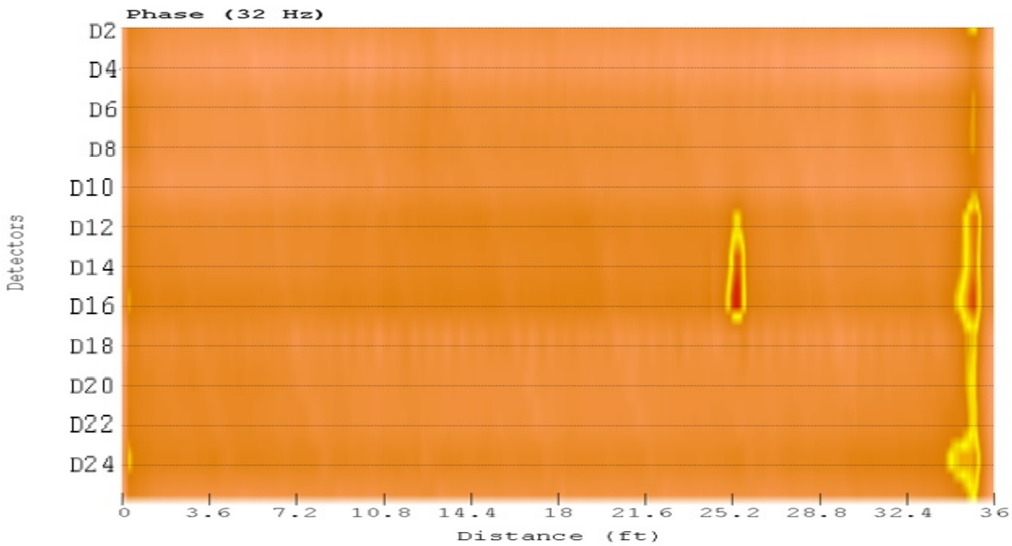
The graphs on the following pages illustrate the recorded electromagnetic inspection data for each of the pipes identified to have localized cylinder anomalies.

The best method of understanding these data sets is to imagine each pipe split down the length of the pipe at the crown and rolled out flat. The x-axis represents the distance, in feet, from the low joint of the pipe. The y-axis denotes D1 through D24, corresponding to the 24 detector coils on the enhanced electromagnetic Pure Robotics tool. D1 represents the detector coil located at the crown of the pipe while D12 represents the detector coil at the invert of the pipe. In this manner, it is possible to identify the clock position on the pipe where an anomaly is located.

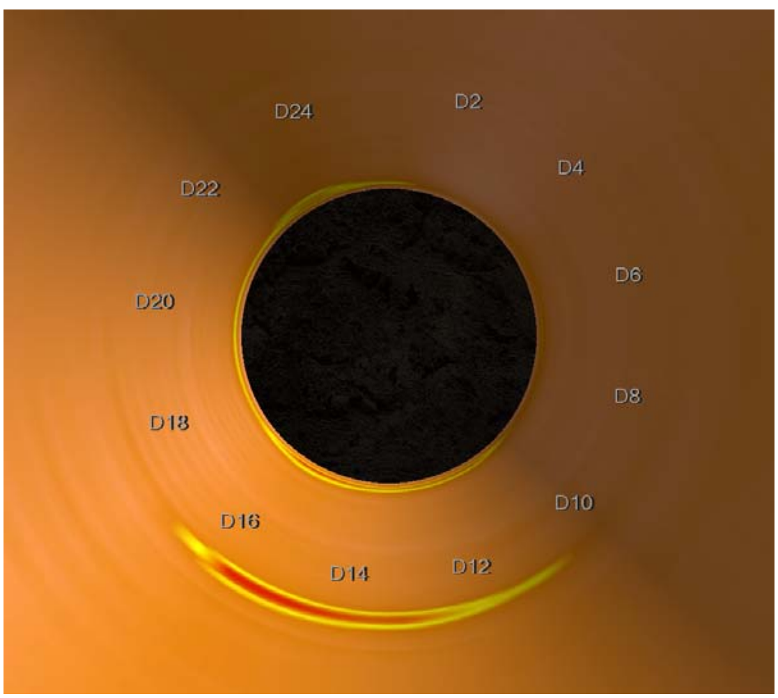
The color in the graph is used to denote the signal strength of the detector. The red or black bars at each end of the graphs denote the joints of the pipe. Since the pipe rollout graphs are difficult to interpret, the data was also rendered onto the inside of a cylinder to assist with illustrating the size, shape, and position of the anomalous area. However, unlike the rollout graphs, the condition of the pipe cannot be fully illustrated with a single viewpoint and several viewpoints need to be utilized to demonstrate all of the characteristics of the anomalous area.

Pure Reference Number 2480:

Pipe rollout map:

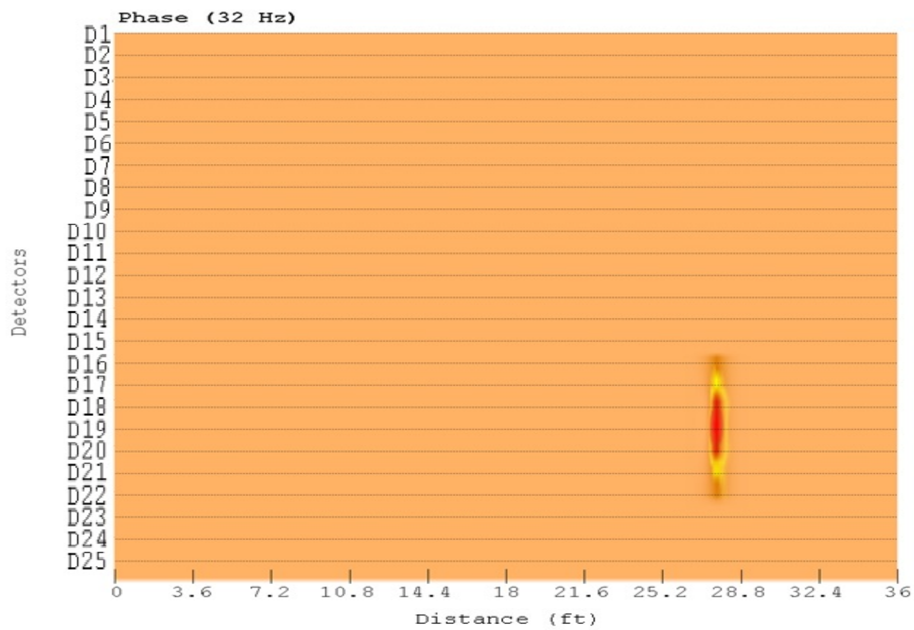


Internal 3D rendering of the pipe illustrating the anomaly size and position:

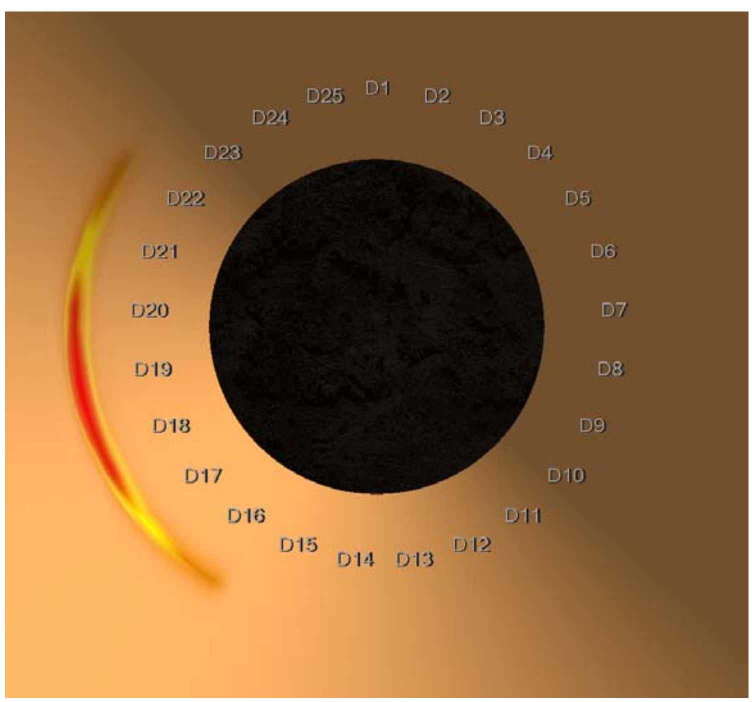


Pure Reference Number 2498:

Pipe rollout map:

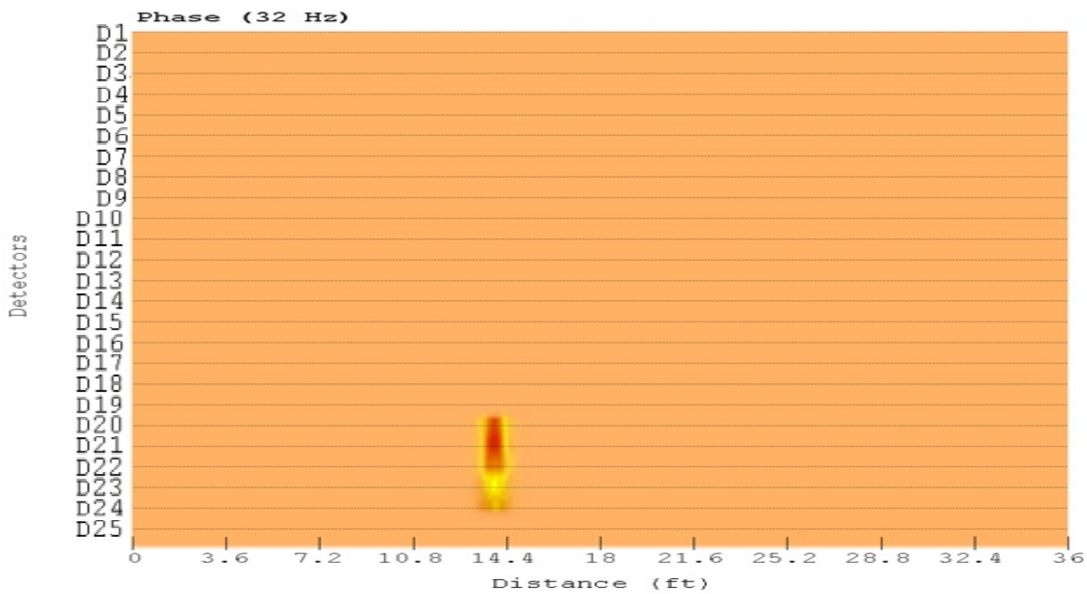


Internal 3D rendering of the pipe illustrating the anomaly size and position:

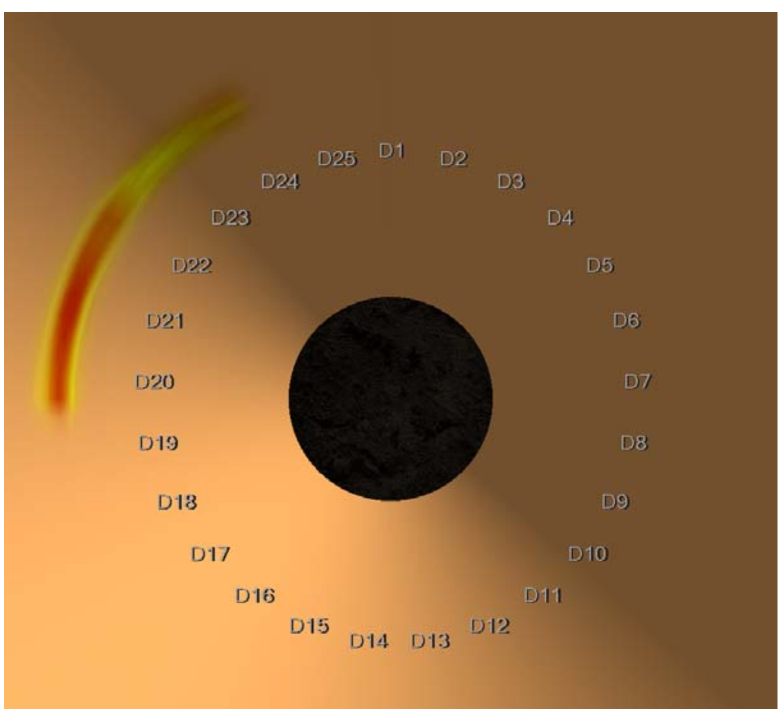


Pure Reference Number 2536:

Pipe rollout map:

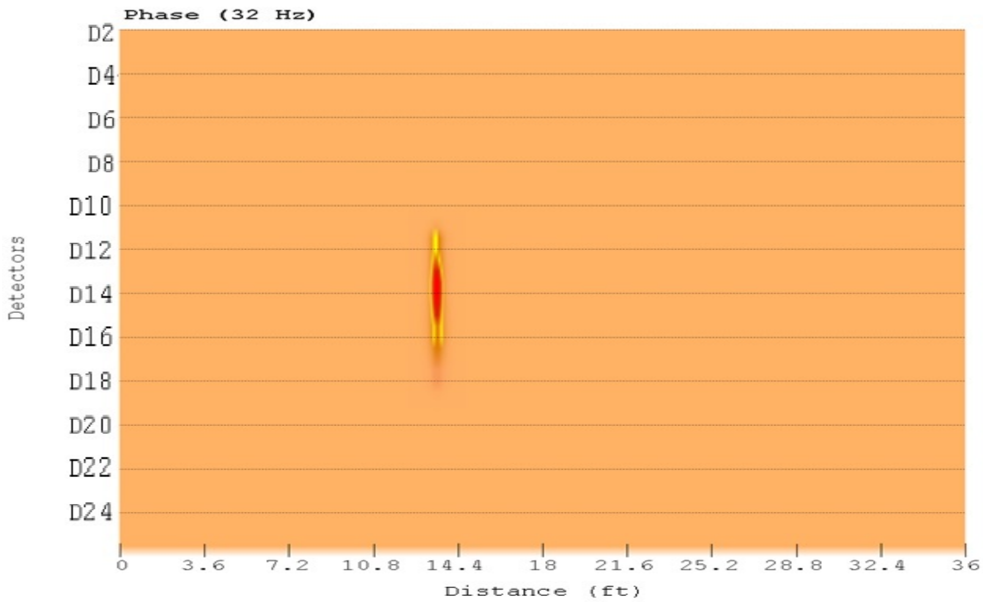


Internal 3D rendering of the pipe illustrating the anomaly size and position:

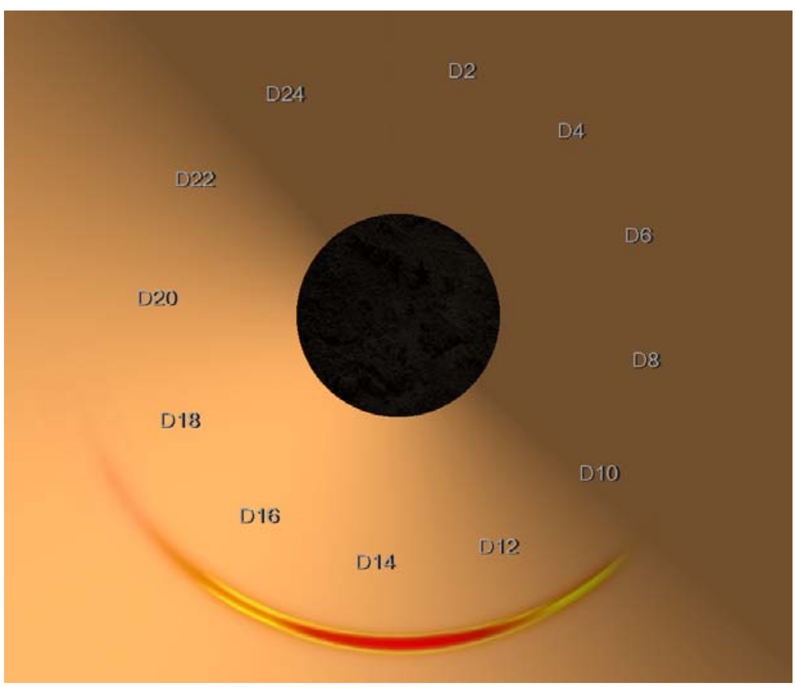


Pure Reference Number 3270:

Pipe rollout map:



Internal 3D rendering of the pipe illustrating the anomaly size and position:



APPENDIX D

Pipe List