ILI-Based Approach to Assess SSWC

Christopher Davies[1], Cameron Cooper[1], Lee Sellers[2]
[1]ROSEN Group, [2]Energy Transfer Company

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Abstract

In response to the discovery of Selective Seam Weld Corrosion (SSWC) on a 12 inch natural gas pipeline, an in-line inspection (ILI) was completed using an ultra-resolution circumferential magnetic flux leakage tool. The closer sensor configuration of this system allowed for a more detailed recording of the magnetic leakage profile ensuring that the peak value of flux leakage is recorded within complicated corrosion morphologies such as SSWC.

Through an optimized evaluation process, all corrosion anomalies considered to be associated with the longitudinal weld were subject to detail review. The review provides a thorough understanding of the different signal characteristics and likelihood classifications of 'likely', 'possible' and 'unlikely' SSWC are assigned. The initial evaluation process resulted in the identification of 23 'Likely' SSWC anomalies and 35 'Possible' SSWC anomalies. All remaining corrosion anomalies associated with the longitudinal weld were classified as 'Unlikely' SSWC. Classification is critical as it pertains to integrity management. Understanding the pipeline's susceptibility to SSWC, the detection capability of the ILI system and the confidence of likelihood classifications allows for process driven discrimination between SSWC and 'general corrosion' in the area of the longitudinal weld.

Validation of the evaluation and classification was achieved through a structured dig program. A total of 3 excavations were performed on the pipeline, which targeted a total of 24 anomalies associated with the longitudinal weld. Evidence of SSWC was observed for 11 of the 13 'Likely' SSWC classifications. Of the five (5) 'Possible' SSWC calls investigated, three (3) were confirmed to be SSWC. No evidence of SSWC was observed for the 'Unlikely' SSWC classification subject to infield investigation. The results of these excavations were used to reclassify all remaining anomalies associated with the longitudinal weld.

A critical aspect of the likelihood classification process is iteratively incorporating information from field investigations. This paper presents the close collaborative efforts performed by a pipeline company and an ILI service provider, to help manage the threat of SSWC on a 12 inch pipeline. It is intended to present an ILI based approach to assess SSWC, and share recent experience with the industry on a targeted approach in managing the threat of SSWC.

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Introduction

The pipeline industry has become increasingly focused on selective seam weld corrosion (SSWC) in both gas and liquid pipelines. This threat has been specifically listed in the changes made to the gas transmission regulations in 2020 by the US Department of Transportation (Code of Federal Regulations CFR Tittle 49 Part 192), which defines SSWC as a threat that must be explicitly discounted (confirmed as not present) or assessed (defects identified, mitigated and managed safely) on a pipe segment. It lists ILI tools (Section §192.921 (a) (1)) as an appropriate method to manage the threat of SSWC [1, 2].

Consequently, in response to the discovery of SSWC, an ILI of a 12 inch natural gas pipeline was performed in March 2022 using an ultra-resolution circumferential magnetic flux leakage tool (MFL-C Ultra) configured to detect axial volumetric anomalies. This system provides high-resolution data of narrow, axial anomalies leading to an improved capability over standard resolution MFL-C systems.

A total of 204 individual corrosion anomalies considered to be associated with the longitudinal seam weld were reported by the 2022 MFL-C Ultra data set. All individual corrosion anomalies were subject to an advanced review of the ILI signal data to understand the different signal characteristics and assign SSWC likelihoods of 'likely', 'Possible' and 'Unlikely' SSWC, leading to focused remediation.

SSWC, sometimes referred to as metal loss preferentially affecting a detected longitudinal seam[1], is an axially orientated pattern of narrow corrosion centered on the longitudinal weld seam of welded pipe. While corrosion can be in the region of the seam weld, the axially orientated corrosion is deeper in the longitudinal weld zone than the surrounding pipe body. SSWC tends to have a relatively high length/width ratio and a localized area of maximum depth, described often as a 'V' shape. For the purposes of choosing appropriate ILI to detect, classify, and size SSWC, it is best to classify it as axial grooving or slotting as per the Pipeline Operators Forum (POF) categories for corrosion [3]. When ILI detects corrosion associated with the longitudinal weld, identifying the appropriate response can be challenging. SSWC is an environmentally assisted, time dependent threat that normally effects autogenous welded pipe such as electric resistance weld (ERW) and electric flash welded (EFW) seams. An example of SSWC found in the field within ERW pipe material, alongside a cross section of a weld is provided in Figure 1 and Figure 2.

[1] Corrosion that "preferentially" affects the long seam is corrosion that is of and along the weld seam that is classified as selective seam weld corrosion (SSWC) [1].

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Figure 1: Confirmed SSWC in ERW pipe material

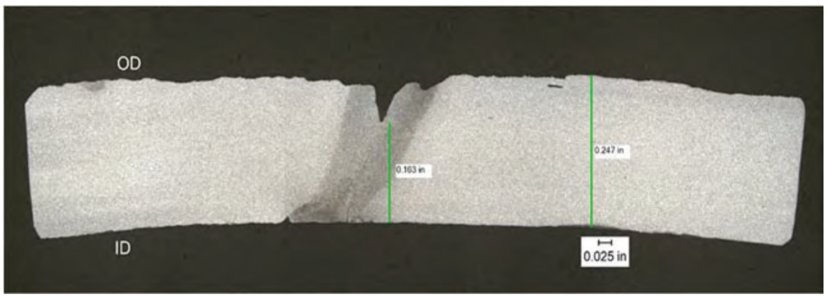

Figure 2: Cross section of confirmed SSWC in ERW pipe material

Susceptibility to SSWC

The 12 inch pipeline was constructed in 1952, predominately (99%) from low–frequency electric resistance welded (LF-ERW) pipe material conforming to API 5L Grade X42 of unknown pipe manufacture. The majority of the pipeline has a nominal wall thickness (wt.) of 0.250 inch, with sections of 0.312 inch, 0.375 inch and 0.5 inch also present.

The provided pipeline information along with the results from historic verification data and material testing, were used to establish an understanding of SSWC susceptibility. The pipeline is clearly susceptible as evidenced by the historical discovery of SSWC, however understanding the susceptibility of the pipeline to SSWC is helpful as it shapes the way corrosion on the long seam initiates and grows. SSWC has typically been observed in older vintage pipes, mainly due to the technology limitations and quality control issues used in manufacturing methods before 1970. Historical weld techniques such as direct-current electric resistance welding (DC-ERW), LF-ERW and electric flash welding (EFW) are more prone to SSWC when compared to other modern manufacturing processes such as submerged arc welding (SAW and DSAW). Literature shows that a number of factors associated with vintage pipe manufacturing and steels may also be responsible for promoting SSWC [4, 5, 6, 7]:

- A galvanic reaction between the base metal and the seam weld material
- Inclusions and chemistry segregation in the weldment
- Crevices formed between inclusions and steel

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- Quantity and profile of Manganese Sulfide inclusions
- Significant presence of Carbon (when the mechanism is not controlled by Sulfur)
- Absence of post-weld heat treatment (PWHT).

Flaws in vintage electric welded pipes have been documented to produce a quantifiably larger percentage of flaws in the seam weld compared to modern techniques. ERW pipe with a high Sulfur content exceeding 0.01% and a carbon content greater than 0.1 by weight is known to be more susceptible to SSWC [8]. Previous material testing performed on the predominant pipe population of the 12 inch pipeline i.e. 1952, LF-ERW, 0.250 inch, Grade X42 pipe, confirmed a maximum recorded Sulfur value of 0.041% and a Carbon weight up to 0.26%.

In addition to detection and sizing of pipeline anomalies, the pipeline information recorded by the ILI system can also be used to characterize the types of pipes contained within a pipeline. The pipeline diagnostic plot shown in **Figure 3**, which is based on an analytical assessment of ILI data in combination with existing documentation and historical pipe data provides enhanced information for integrity assessment and threat management. Figure 3 showcases the characteristic variables of joint length, SMYS and wall thickness of all pipes along the pipeline with respect to log distance and elevation. The anomalies reported by the 2022 MFL-C ILI and those earmarked as verified are also shown in Figure 3.

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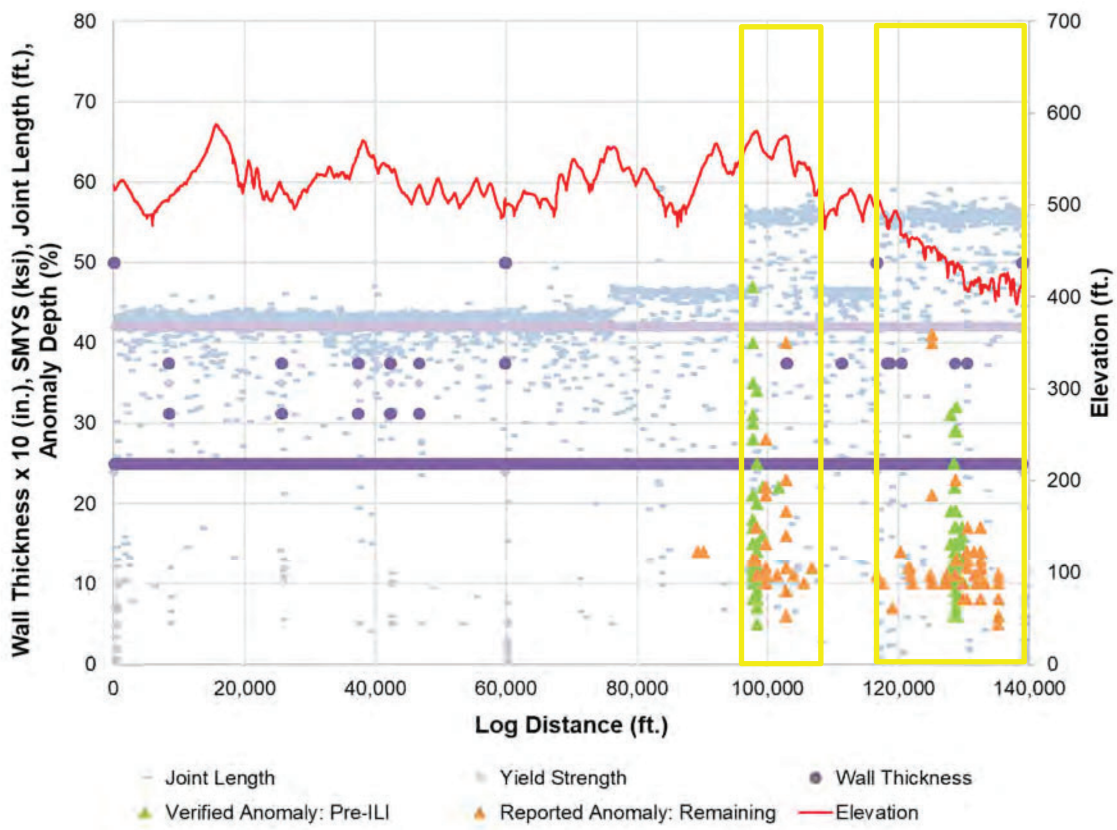

Figure 3: Pipeline diagnostic plot overlaid with reported corrosion anomalies

All reported anomalies were considered to be located within the primary pipe population of LF-ERW pipe material conforming to API 5L Grade X42 with a wall thickness of 0.25 inch. Looking at Figure 3 an observation can be made that 202 of the 204 reported anomalies fall within a distinguishable pipe population which contains measured joint lengths of ~55 feet. This would indicate an increased susceptibility to SSWC for one pipe population reported on the line as outlined in Table 1.

Table 1: Overview of observed pipe populations in relation to joint length and number of anomalies

Approx. Log. Distance (ft.)	Approx. Cumulative Length (ft.)	Joint Length (ft.)	Seam Orientation	Count of Corrosion Anomalies Associated with Long Seam
0 – 76,000	76,000	~42	Randomly distributed around the circumference	0
76,000 – 96,000 108,000 – 118,000	30,000	~46	Top of Line (9:30 to 2:30)	2
96,000 – 108,000 118,000 – 139,000	33,000	~55	Randomly distributed around the circumference	202

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ILI Technology

New ILI systems are now available to help operators differentiate between corrosion that is in the vicinity of the long seam and SSWC. If a clear discrimination between SSWC and general corrosion in the area of the seam weld cannot be established, operators will have limited options and generally have to conservatively treat all reported corrosion as SSWC, triggering an excessive number of repairs. The ILI evaluation process aimed at identifying 'Likely', 'Possible' and 'Unlikely' SSWC has allowed operators to define a structured and optimized response for excavation activities to verify the process and remediate anomalies.

Understanding the morphology of threats like SSWC is key to selecting the appropriate ILI configuration. ILI systems like the MFL-C tool are available to detect, size and identify axially oriented corrosion, such as axial grooving or slotting corrosion. However, SSWC can be very narrow, especially near the tip of the 'V' shaped anomaly. Standard MFL-C technology has limited capability in discriminating SSWC from 'general corrosion' associated with the weld. A higher resolution is helpful to better characterize corrosion near the long seam since it records a more detailed response of the magnetic leakage profile. This is achieved by the use of a MFL-C Ultra tool. The main differences between the two tools types are summarised below in Table 2.

Table 2: MFL-C vs MFL-C Ultra

	MFL-C	**MFL-C Ultra**
Sensor Spacing (Circumferential Resolution)	2.9 mm (0.114 inch)	1.6 mm (0.063 inch)
Number of Channels per Carrier	8	45 (fully tri-axial)
Sampling distance	2.5 mm (0.098 inch)	1 mm (0.039 inch)

The reduced sensor spacing and increased number of channels increases the probability of recording the peak value of flux leakage within complex corrosion morphologies. This is demonstrated in Figure 4 which presents a comparison of the signal response recorded by a MFL-C and a MFL-C Ultra tool for an anomaly with a reported metal loss depth of 64% wt.

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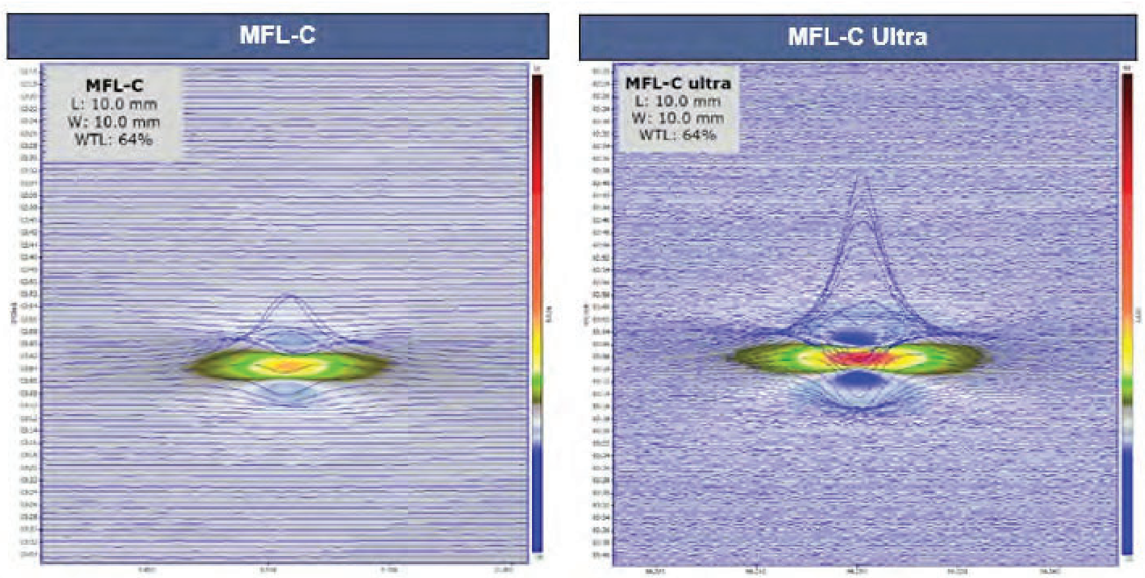

Figure 4: Comparison of signal response between MFL-C (left) and MFL-C Ultra (right)

Anomaly Classification and Prioritization

115 of the 204 individual corrosion anomalies reported by the 2022 ILI considered to be associated with longitudinal weld were confirmed as being subject to previous investigation/repair. The remaining 89 individual metal loss corrosion anomalies were subject to further detailed review and analysed to understand their interaction with the seam weld. This detailed review included a range of considerations, such as the plausibility of corrosion morphology, tool dynamics, homogeneity of the magnetic field, circumferential profile of the signal data, and comparison of signal responses with infield investigation. The main objective of the advanced analysis was to assign likelihood classifications of likely, possible and unlikely SSWC. The distinction of each classification is given below:

- Likely' SSWC meets all requirements of the signal response evaluation process and is considered confident identification of SSWC.
- 'Possible' SSWC meets most of the evaluation requirements, but without sufficient confidence to be distinguished as 'Likely' or 'Unlikely' SSWC.
- 'Unlikely' SSWC is not considered to be SSWC. These anomalies show no characteristics of being SSWC in the signal data.

The likelihood classification allows a systematic discrimination between SSWC and general corrosion that is close to or crossing the longitudinal weld. The classification process is used to create a prioritized list of anomalies for in-field verification and remediation. The verification stage is a crucial aspect of the evaluation process as findings from the field are to be documented and fed back into the evaluation process. The morphology of confirmed SSWC anomalies, can be used to further refine

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the likelihood classifications of all remaining anomalies along the pipeline. Those anomalies confirmed as SSWC are then used as a 'blueprint' to ensure confidence in ILI classifications.

In this case corrosion anomalies that had been subject to previous infield investigation and that still remain on the pipeline at the time of 2022 ILI, under repairs, were utilized in the evaluation process. This allowed for further scrutiny of the remaining anomalies considered to be associated with the long seam. The signal response of those areas confirmed as SSWC showed a pronounced difference in amplitude between the target metal loss anomaly and the surrounding signal data. The verified findings were leveraged to help refine the initial SSWC classification (see Figure 5, Figure 6 and Figure 7).

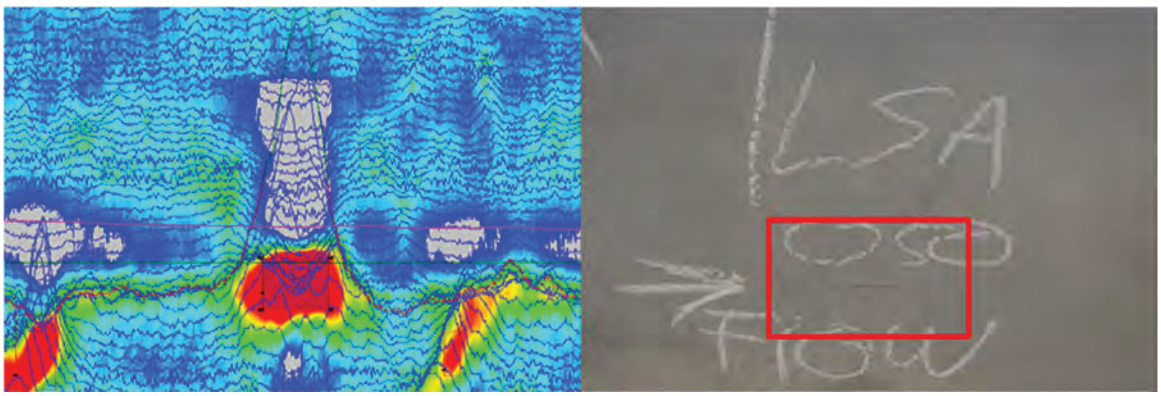

Figure 5: MFL-C Ultra signal response (left), confirmed SSWC in-situ circa 2011 (right)

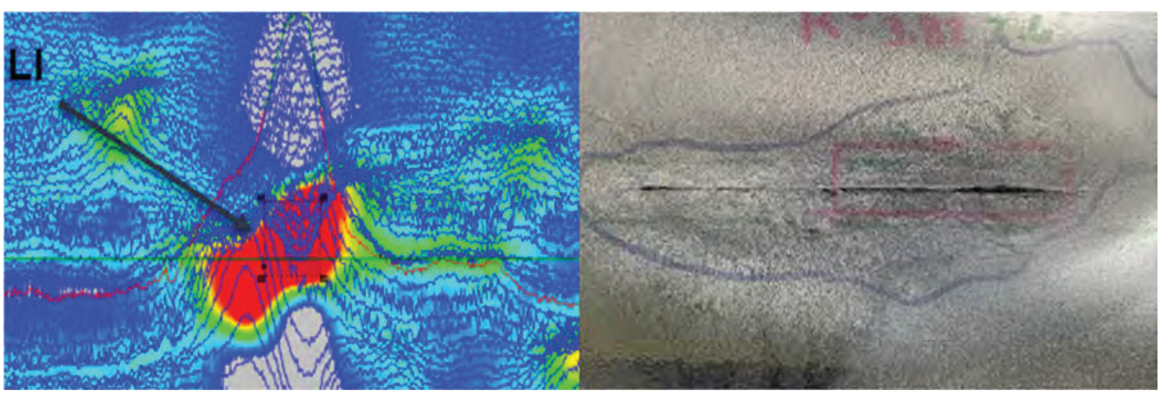

Figure 6: MFL-C Ultra signal response (left), confirmed SSWC in-situ circa 2021 (right)

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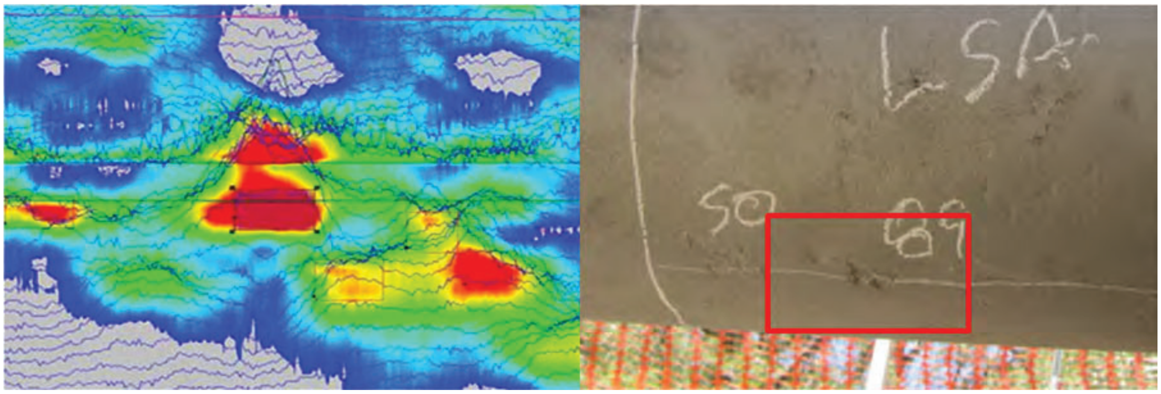

Figure 7: MFL-C Ultra signal response (left), confirmed general corrosion in-situ circa 2011 (right)

The ILI data evaluation process helped differentiate anomalies from 'general corrosion' and prioritize 'likely' and 'possible' SSWC anomalies regardless of dimensions. Anomaly classifications were established, identifying and prioritizing a total of 58 SSWC anomalies (23 'Likely', 35 'Possible'), with the remaining 31 seam weld corrosion anomalies being classified as 'Unlikely' SSWC.

In parallel to the ILI evaluation process, metal loss anomalies associated with the longitudinal seam weld were prioritized based on severity, location (i.e. pipeline routing and class locations), susceptibility, sizing characteristics and the number of anomalies within the same joint to help prioritize anomalies for verification and on-going remediation.

The aim of the prioritized listing was to identify the order in which anomalies should be investigated i.e. acting on the most significant threats whilst also collecting the necessary and most useful information from the field to develop a robust future integrity management plan. A critical aspect of this process was iteratively incorporating information from field investigations to ensure confidence in the likelihood classifications, whilst also mitigating the threat of SSWC.

Six (6) locations were prioritized for post-ILI investigation, encompassing 46 individual corrosion anomalies considered to be associated with the longitudinal weld (19 'Likely', 19 'Possible' and 8 'Unlikely'). These 46 anomalies were located in eight (8) joints within the primary susceptible pipe population. The anomalies suggested for investigation are highlighted in **Figure 8**.

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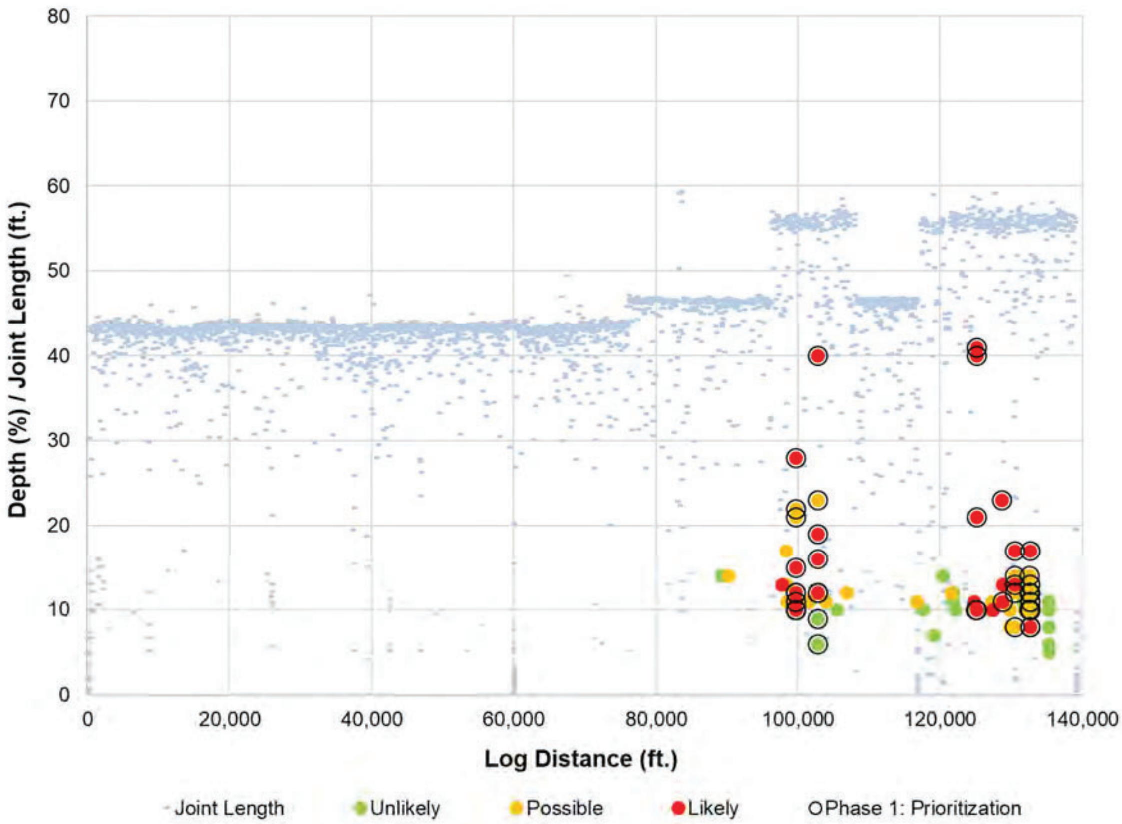

Figure 8: Pipeline diagnostic plot and Phase 1 classification and prioritization of corrosion associated with the seam weld reported by ILI

Although a high priority was assigned to those indications classified as 'Likely' and 'Possible' SSWC, it is equally as important to confirm and verify anomalies characterized as 'Unlikely SSWC'. The 'Likely' and 'Possible' SSWC anomalies included in the initial prioritization also allowed a subset of 'Unlikely' SSWC calls to be scrutinized given their close proximity. Structured excavations on a selection of 'Unlikely' SSWC are essential to the process of SSWC characterization as the information from each anomaly assessed in the field is reviewed against the ILI signal data and a final classification assigned.

In-situ Validation

A structured dig program was performed to permanently remediate 'Likely' and 'Possible' SSWC, and confirm 'Unlikely' SSWC anomalies as true negatives i.e. non SSWC anomalies. An initial set of three (3) excavations were performed targeting 24 individual corrosion anomalies associated with the longitudinal seam weld (13 'Likely', 5 'Possible' and 6 'Unlikely'), that were located in a total of (4) joints. An overview of the 'Likely', 'Possible' and "Unlikely' SSWC anomalies subject to verification are presented in Table 3.

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Table 3: Prioritized corrosion anomalies subject to infield verification

Log. Distance (ft.)	Joint Number	ILI Dimensions		SSWC Classification	Verified Event Type
		Depth (% wt)	Length (inch)		
99643.49	24090	10	0.77	Unlikely	Corrosion
99643.57		10	0.85	Unlikely	Corrosion
99653.35	24100	12	1.83	Likely	SSWC
99654.46		11	1.38	Likely	SSWC
99663.73		15	1.25	Likely	SSWC
99671.35		12	0.72	Unlikely	Corrosion
99681.78		10	0.99	Likely	SSWC
99682.18		28	1.48	Likely	SSWC
99685.60		43	3.00	Possible	Corrosion
99685.81		52	3.50	Possible	SSWC
99685.86		10	0.81	Possible	SSWC
99686.23		10	1.18	Possible	SSWC
102747.27	24720	40	1.35	Likely	SSWC
102747.77		6	0.64	Unlikely	Corrosion
102747.89		9	0.81	Unlikely	Corrosion
102748.31		19	1.27	Likely	SSWC
102748.45		16	1.50	Likely	SSWC
102748.85		23	1.83	Possible	Corrosion
102749.06		12	0.94	Unlikely	Corrosion
102754.17		12	1.17	Likely	SSWC
125077.05	29890	10	0.90	Likely	Corrosion
125079.45		41	1.35	Likely	SSWC
125080.07		21	0.87	Likely	SSWC
125082.28		40	1.23	Likely	Corrosion

Of the 13 ‘Likely’ SSWC anomalies investigated:

- 11 anomalies were confirmed to be SSWC.
- 2 anomalies were confirmed to be general/pitting corrosion directly on the longitudinal weld.

Of the 5 ‘Possible’ SSWC anomalies verified:

- 3 anomalies were confirmed to be SSWC
- 2 anomalies were confirmed to be ‘general corrosion’ crossing or near the longitudinal weld.

Of the 6 ‘Unlikely’ SSWC anomalies investigated all were found to be general corrosion close to or crossing the longitudinal weld. No evidence of SSWC was observed for the ‘Unlikely’ SSWC classifications subject to infield investigation. A summary of those anomalies found to be SSWC for each likelihood classification are presented in Figure 9.

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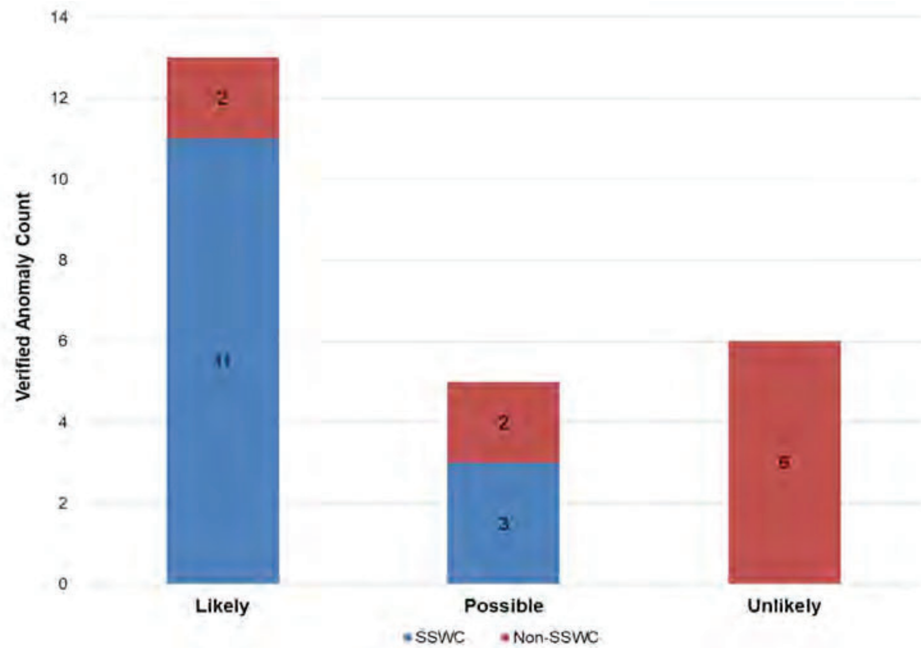

Figure 8: Overview summary of verification results of assigned likelihoods

An example of confirmed SSWC found in the field following the initial classification of 'Likely' SSWC is presented in **Figure 9**, alongside the reported MFL-C Ultra signal responses.

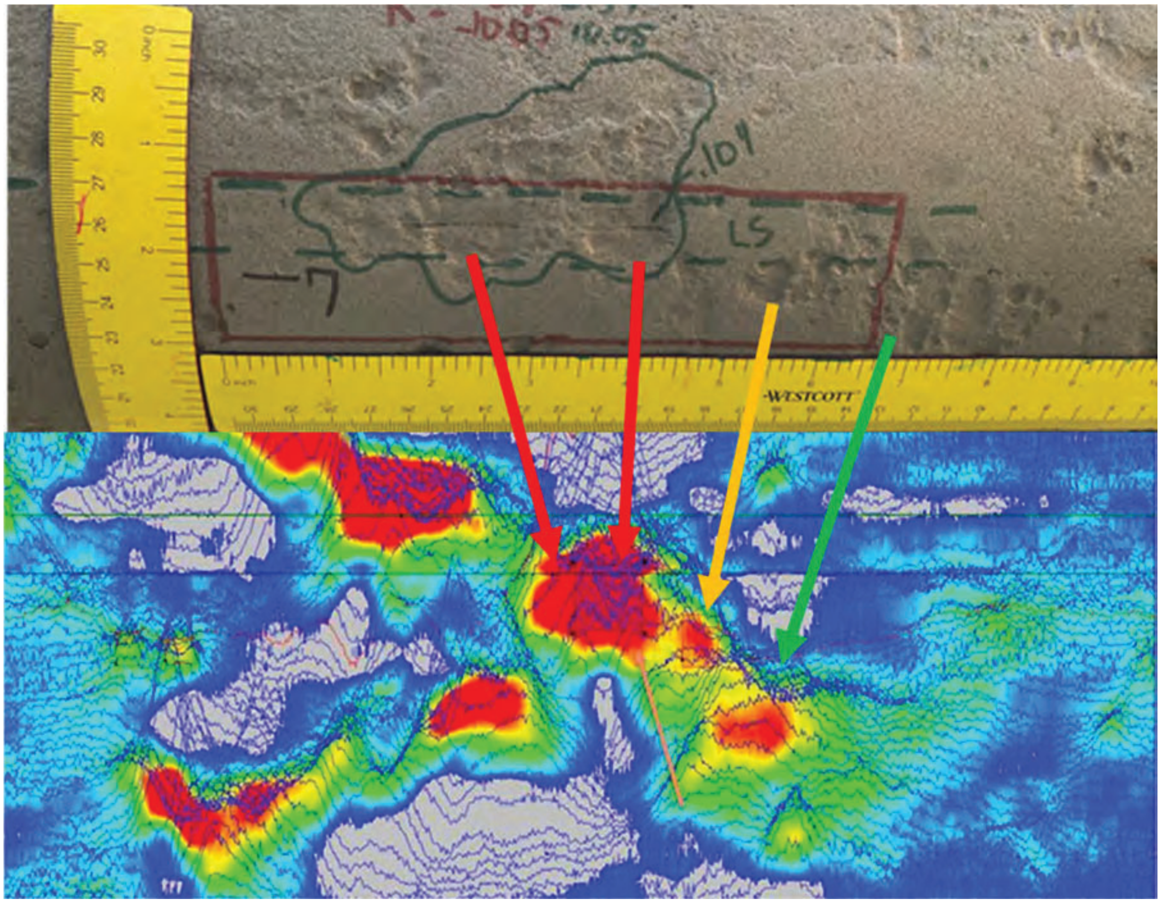

Figure 9: Two (2) 'Likely' SSWC anomalies confirmed as SSWC (Red Arrows) and 'Possible' SSWC (Orange Arrow)/'Unlikely' SSWC (Green Arrow) confirmed as general corrosion

Evidence of SSWC was also observed at three (3) of the 'Possible' SSWC classifications. An example of 'Possible' SSWC anomalies found to be SSWC can be seen in **Figure 10**, alongside the corresponding MFL-C Ultra signal response.

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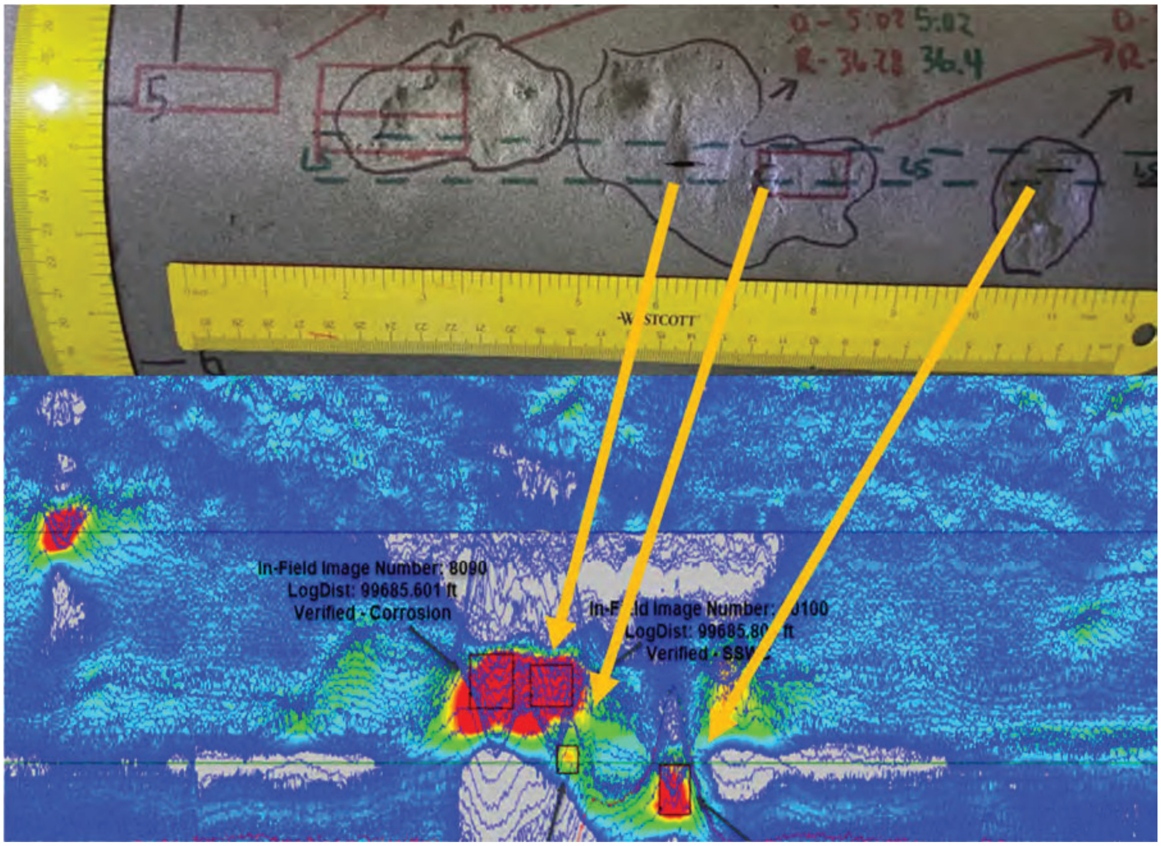

Figure 10: Three (3) 'Possible' SSWC anomalies confirmed as SSWC (Orange Arrows)

Two (2) 'Likely' SSWC anomalies reported in a single joint were not found to be SSWC . The classification of these anomalies correspond to the initial characterization of a peak amplitude directly coinciding with the longitudinal weld. Following infield investigation, these 'Likely' SSWC anomalies were found to be deep general/pitting corrosion directly on the longitudinal seam, as shown in **Figure 11**.

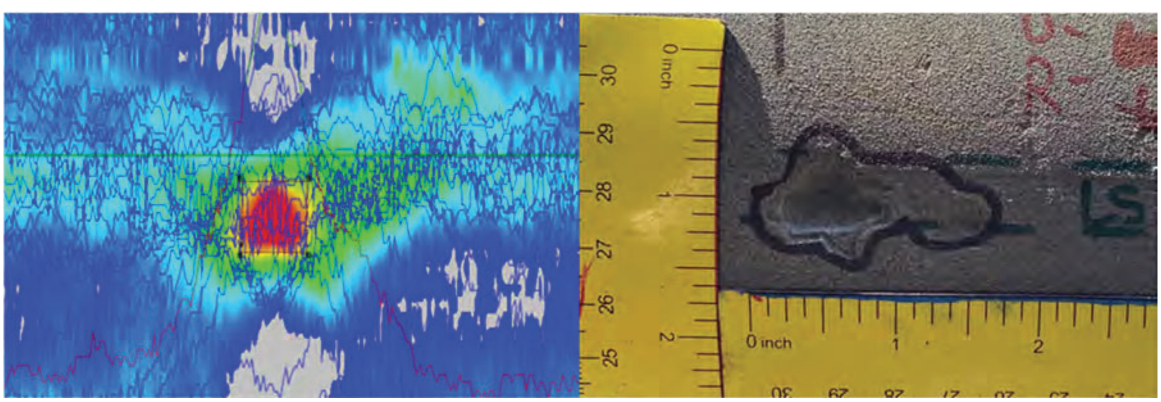

Figure 11: 'Likely' SSWC classification confirmed as deep general/pitting corrosion directly on long seam

Although considered a false positive in terms of classification, information gathered from this verification dig is useful when incorporating the findings back into the evaluation process to help refine the remaining anomaly classifications. Whilst SSWC was not found at two (2) of the reported 'Likely' SSWC Classification, SSWC was observed and correctly identified by the evaluation process in the same joint of pipe as shown in **Figure 12**.

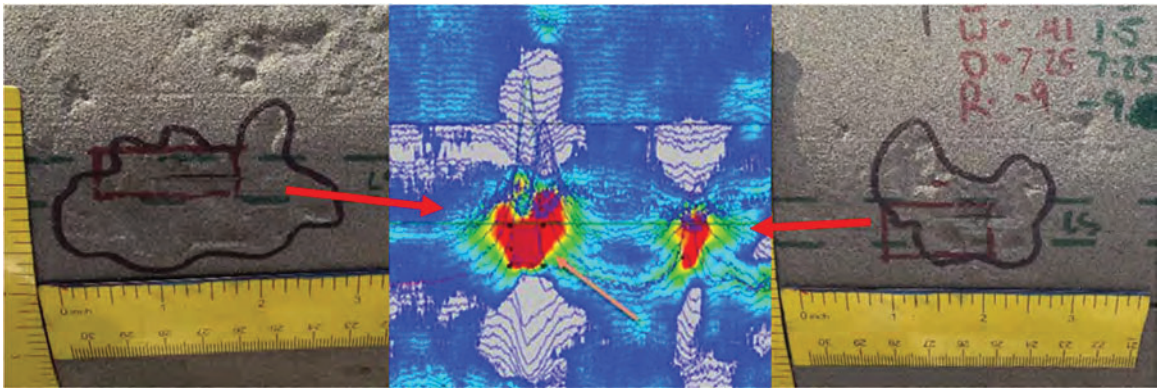

Figure 12: 'Likely' SSWC classification confirmed as SSWC in same joint as false positive

An example of an 'Unlikely' SSWC anomaly found to be general corrosion crossing the weld i.e. not SSWC, is provided in **Figure 13**, alongside the MFL-C Ultra signal response.

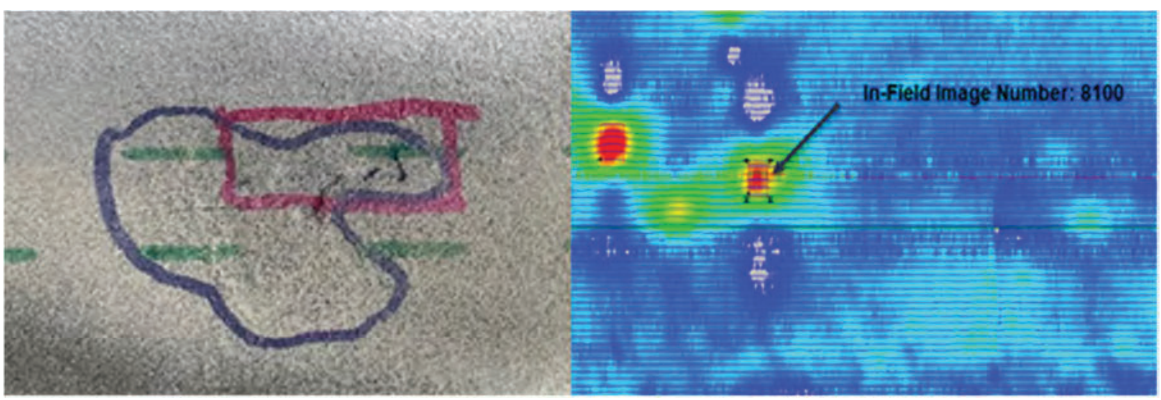

Figure 13: 'Unlikely' SSWC classification confirmed as corrosion crossing the seam weld not SSWC

On-going activities and mitigation

Following the 2022 dig campaign, a total of 65 individual corrosion anomalies associated with the longitudinal weld remain in the line. The results of the latest dig campaign were used to further refine and reclassify the assigned SSWC likelihoods for the remaining 65 anomalies associated with the longitudinal weld. The evaluation process was revisited and a refined likelihood classification was established, identifying and prioritizing a total of 33 SSWC anomalies:

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- 10 'Likely' SSWC anomalies
- 23 'Possible' SSWC anomalies

All 32 remaining anomalies associated with the longitudinal weld were considered to be 'Unlikely' SSWC. As a result, a further six (6) locations have been prioritized covering a total of 27 individual corrosion anomalies associated with the weld (10 'Likely', 10 'Possible' and 7 'Unlikely'). These anomalies are located in a total of 8 joints and include all 'Likely' SSWC likelihoods remaining in the line as shown in **Figure 14**.

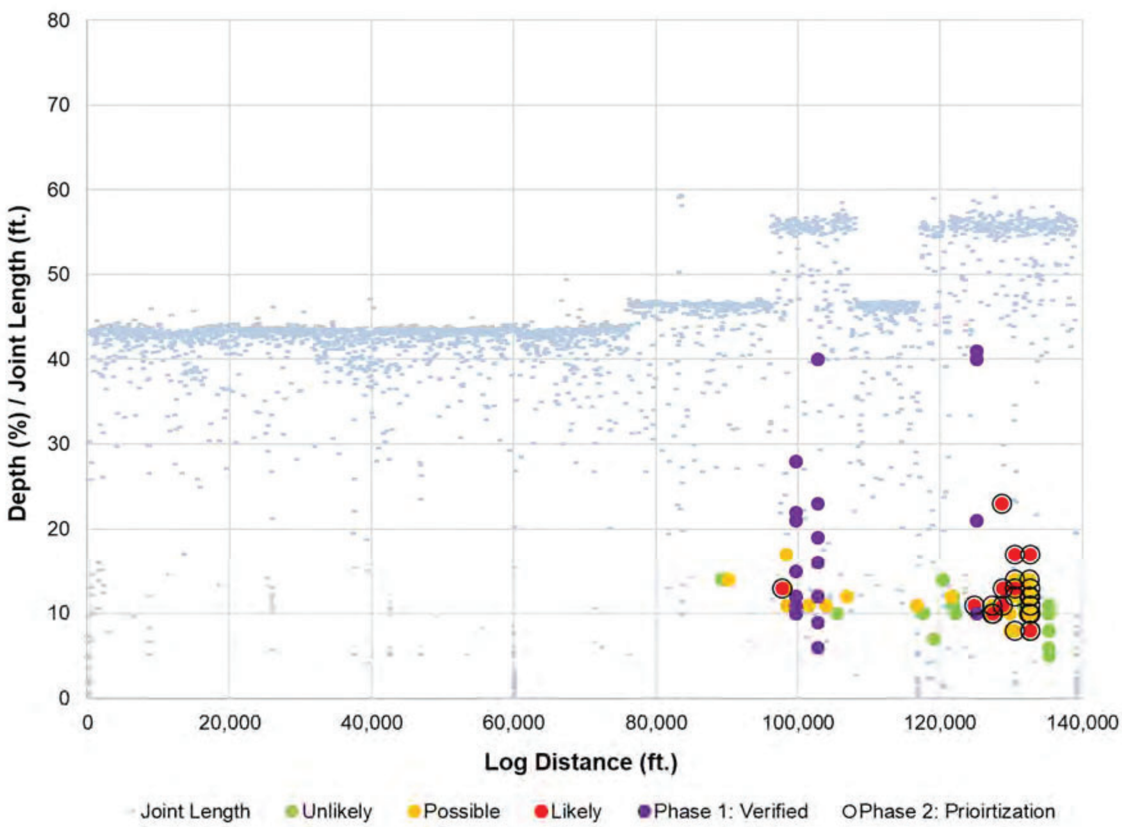

Figure 14: Pipeline DNA plot and Phase 2 classification and prioritization of corrosion associated with the seam weld reported by ILI

An extensive number of verification data points have been and will continue to be collected as the structured dig program progresses, based on the 2022 MFL-C Ultra ILI. If ILI is to be used as part of the future integrity management plan for SSWC, a definition of the ILI systems performance based on a thorough understanding of the ILI results compared with information received from verification digs will need to be performed. This robust understanding will help satisfy the required system validation in terms of Probability of Detection (POD), Probability of Identification (POI) and sizing.

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Nevertheless, using the aforementioned likelihood classification, SSWC has been successfully detected by ILI and validated in-situ, with anomalies classified as 'Unlikely' SSWC having been confirmed as 'general corrosion' and not SSWC. Verification of SSWC is challenging and it is understood that a sample of the confirmed SSWC anomalies are being subject to destructive testing in a laboratory to confirm their depth sizing.

Conclusions

An ILI of a 12-inch natural gas pipeline was performed, using ROSEN's MFL-C Ultra ILI system to explicitly discriminate between SSWC and 'general corrosion' in the area of the longitudinal weld, and assign likelihood classifications of 'Likely', 'Possible' and 'Unlikely' SSWC. When ILI identifies corrosion associated with the longitudinal weld the appropriate response can be challenging without sufficient classification as it leads to efficient integrity management.

Validation of the evaluation and classification was achieved through a structured dig program to actively remove and remediate the threat of SSWC i.e. 'Likely' and 'Possible' SSWC anomalies, and to confirm 'Unlikely' SSWC as true negatives i.e. not SSWC. An initial 3 excavations have been performed which targeted 24 reported corrosion anomalies associated with the long seam (13 'Likely', 5 'Possible' and 6 'Unlikely').

SSWC was confirmed for 11 of the 13 'Likely' SSWC classifications. Of the five (5) 'Possible' SSWC calls investigated, three (3) were confirmed to be SSWC. No evidence of SSWC was observed for the 'Unlikely' SSWC classification subject to infield investigation. The two (2) 'Likely' SSWC classifications whilst not found to be SSWC were confirmed to be deep isolated pits directly on the longitudinal seam weld with SSWC being identified on the same joint.

The results of these excavations were used to reclassify all remaining anomalies associated with the longitudinal weld and a refined likelihood classification and prioritization was established. Approaching the threat of SSWC in this way helps reduce the risk to pipeline integrity by focusing remediation on the most 'Likely' SSWC anomalies as a priority, whilst also iteratively incorporating the necessary information from infield investigations to ensure confidence in the likelihood classifications.

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