Office of Pipeline and Hazardous Materials Safety Administration (PHMSA)

Gas Integrity Management (49 CFR Part 192)

192.18 Notification

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Notification Statement:

Pursuant to 192.712(e)(2)(i)(E) Williams is submitting this notification to use other appropriate and conservative default Charpy V-Notch (CVN) and/or fracture toughness values (K_c) for use in analyzing crack-related conditions applicable to 192.712(d). These CVN and/or K_c values are demonstrated to be appropriate and conservative through an exhaustive statistical analysis performed with Structural Integrity Associates, Inc.

Similar to the study that was performed by INGAA [1], Williams used data from two of their Gas Transmission pipeline systems to evaluate CVN/K_c values for three different seam types: 1) Low Frequency Electric Resistance Welded (LF-ERW), 2) Electric Flash Welded (EFW), and 3) Double Submerged Arc-Welded (DSAW). The results of these analyses are presented below.

Acronyms and Abbreviations

CFR	*Code of Federal Regulations*
CMFL	circumferential magnetic flux leakage
CVN	Charpy V-Notch
CW	cold weld
DSAW	double submerged arc welding
EFW	electric flash-welded
EMAT	electromagnetic acoustic transducer
FAD	failure assessment diagram
FEC	fatigue enlarged crack
FFS	fitness-for-service
HAZ	heat affected zone
HC	hook crack
INGAA	*Interstate Natural Gas Association of America*
ILI	Inline Inspection
LF-ERW	low frequency electric resistance welded
PFP	predicted failure pressure
SMYS	specified minimum yield strength
SSWC	selective seam weld corrosion

Notification Executive Summary

The Williams pipeline system(s) have line pipe manufactured using a variety of longitudinal seam weld processes. The weld quality (including number and types of defects present) and resultant material properties are influenced by several factors including the manufacturing process, vintage, and steel quality. Latent defects that may reside in the pipeline seam weld may be susceptible to failure. Certain types of seam welds have been identified to be more prone to failure and exhibit other material issues such as low toughness. This notification package provides a similar statistical analysis of material toughness to the one prepared for INGAA [1] which was the basis for some of the current guidance in 49 CFR 192.712(e)(2)(i)(C). The key difference(s) between the work performed previously [1] and the reason(s) for completing the work presented in this notification are as follows:

1) To use Williams pipeline specific data to evaluate fracture toughness for various seam weld types.
2) To focus on differentiating the fracture toughness values from DSAW vs EFW/LF-ERW seam types. Current guidance in 49 CFR 192.712(e)(2)(i)(C) does not allow for this differentiating when applying default values of 4 ft-lbs for long seam crack/crack-like defects.
3) To differentiate fracture toughness values applied to LF-ERW/EFW long seam defects (i.e., selective seam weld corrosion (SSWC) vs all other seam defects)

The objective of this report is to: 1) Provide a background on the types of seam welds and associated seam weld anomalies (SWAs) that may make a segment more susceptible to failure and 2) Notify PHMSA of Williams' intention to use other default Charpy V-Notch (CVN) and/or fracture toughness values (K_c) for different seam types (See Table 1) specific to Williams pipeline system(s). This update in CVN and/or K_c values will be used in the analyses of predicted failure pressures (49 CFR 192.712) and remediation of anomalies identified.

Table 1: Williams default $\mathbf{K_c}$ and CVN values by weld type and anomaly type

Weld Type	**Seam Anomaly Type Examples**	**K_c ksi√in**	**CVN ft-lbs**
LF-ERW & EFW	SSWC	9.5	1
LF-ERW & EFW	All except SSWC	43.8	7.1
DSAW	All	98.2	17.3

The following comprise the core components of this Notification:

1. Williams gas transmission system overview and historical seam weld failures by seam type.
2. A material property analysis of different seam types using industry and Williams data;
3. Summary of Results and Notification to PHMSA.

1.0 Williams Gas Transmission System Overview

A careful review of available gas transmission records was completed of Williams' pipeline network consisting of two main pipeline systems: 1) Northwest Pipeline (NWP) and 2) Eastern Interstates Transcontinental Pipeline System (Transco). Addressing approximately 14,000 miles of pipeline systems, data was compiled to provide a detailed overview of seam types by diameter. Additionally, failures (leaks/ruptures) were also reviewed by seam type and diameter. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

1.1 Seam Weld Inventory

To understand a relationship between the seam weld failures that have occurred in the past and the type of seam welds, an inventory of pipelines by diameter and seam type were collected for Transco and NWP. For Transco, the majority of pipeline segments consist of 16", 20", 24", 30", 36", and 42" OD pipe [redacted] with DSAW, LF-ERW, and EFW being the primary seam types. For the NWP system, there is a similar dataset to the Transco system relative to seam leaks and/or ruptures. The majority of the pipeline segments within the NWP system span from 6.625" to 30" OD [redacted]. The two most common seam types are LF-ERW and DSAW, where LF-ERW is typically limited to smaller diameters (ranging from 6.625" to 16") and DSAW is more prevalent on larger diameter pipeline segments (20" and greater).

[redacted]

[redacted]

1.2 Seam Weld Failures

The most readily available data collected on seam weld failures was documented on both NWP and Transco pipeline systems dating back to the 1950s. The information presented from these data does not reflect the nature of the failure by specific anomaly type (e.g., hook crack, toe crack, cold weld, etc.), but only the specific seam weld type which failed. The information in Figure 3, is a high-level summary of failures by diameter on Transco and NWP. Failures attributed to the long seam on Transco are predominantly on the larger diameter DSAW pipe. This pipe was installed in the mid-1950s. The majority of the failures on NWP were attributed to the smaller diameter LF-ERW pipe, however, there was still a considerable amount of larger diameter DSAW failures observed on NWP as well.

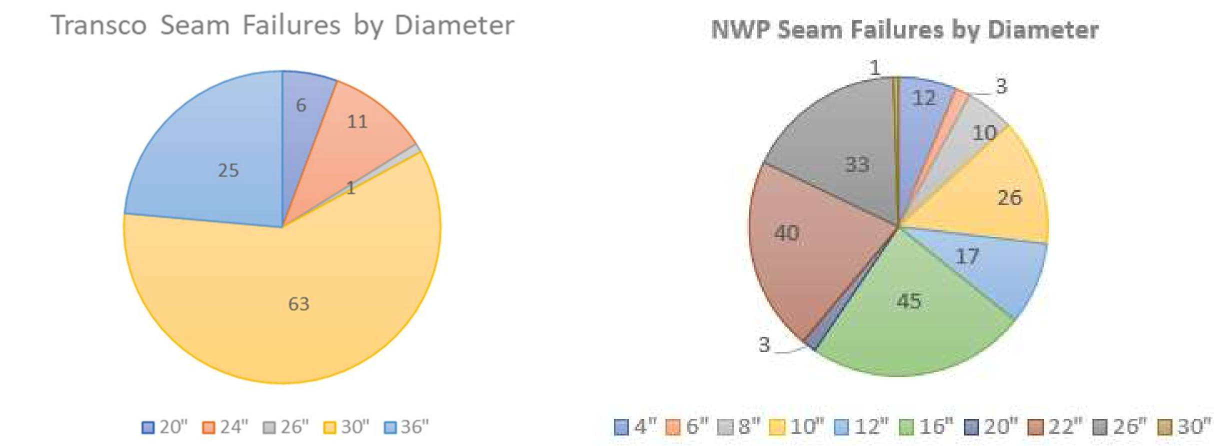

Figure 3: Failures by Diameter on Transco and NWP

Failure modes for NWP and Transco were subdivided into two categories: 1) Leaks and 2) Ruptures. A plot of all failures, including in-service and during hydrostatic testing, on NWP and Transco for three different seam weld types (LF-ERW, DSAW, and EFW) are shown below (see Figure 4) as a function of failure pressure normalized by the specified minimum yield strength (SMYS). As expected, DSAW seam welds show a higher failure pressure/SMYS, followed by EFW, and then LF-ERW. This is supported by other industry research and other Williams data which shows a tendency for higher toughness values observed for DSAW pipe vs EFW/LF-ERW.

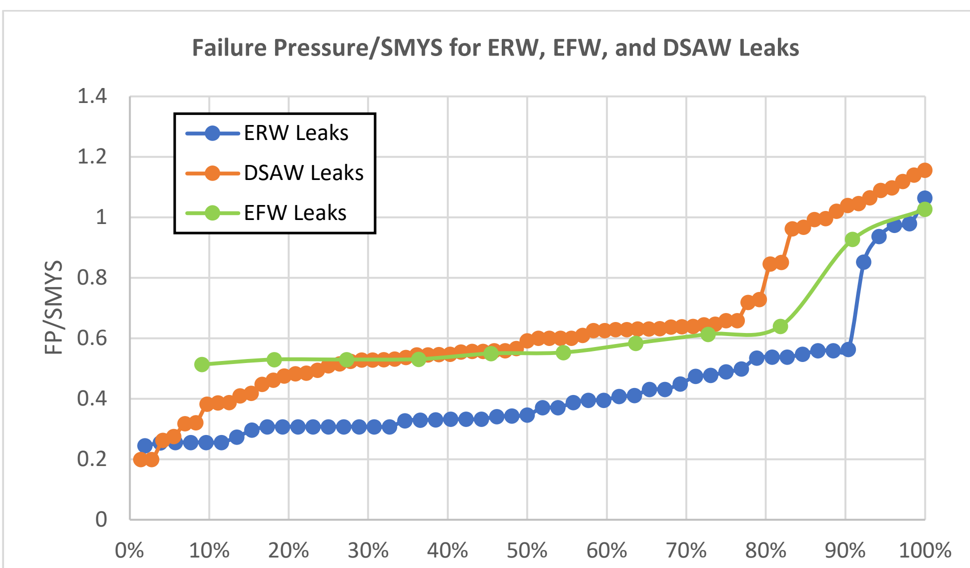

Figure 4: Seam Leaks Relative to Operating Stress

Similar to what was observed from the Transco and NWP leak data for seam weld types, the rupture data (see Figure 5) also shows a higher failure pressure/SMYS for DSAW vs LF-ERW seam weld ruptures. Considering a normal distribution of seam weld anomalies that caused these ruptures, a higher toughness in DSAW vs LF-ERW can be inferred. Note that there was minimal EFW seam weld rupture data available from Williams, therefore it was not considered in this plot. However, the industry data, which was also used in this analysis, incorporated both LF-

ERW and EFW and grouped those together; for that reason, Williams also grouped these two seam types together. Final observations from this data in Figures 4 and 5 are that all but 7 ruptures occurred as a result of hydrotests, and the vast majority of the in-service failures were found to be leaks and not ruptures.

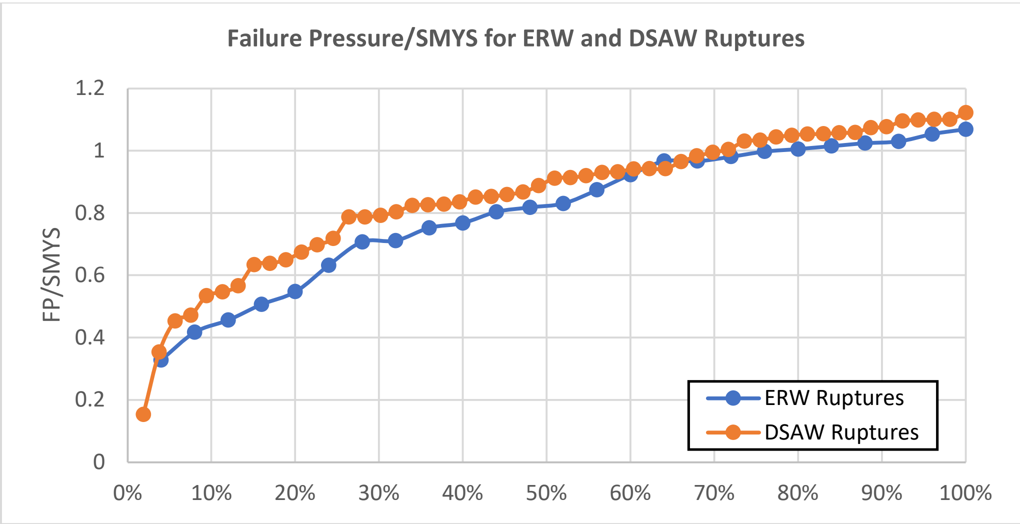

Figure 5: Seam Ruptures Relative to Operating Stress

[redacted]

[redacted]

2.0 Williams Seam Weld Material Properties Overview

The fitness for service and remaining life of a seam weld defect are highly dependent upon material fracture toughness at the specific location of the defect (e.g., bond-line or Heat Affected Zone-HAZ). To determine the appropriate analysis technique and response criteria for a given seam type and defect, a more detailed review and statistical analysis of material toughness properties was performed and is summarized in the following sections.

2.1 Fracture Toughness Properties.

Historically, fracture toughness of pipeline steels was collected using CVN testing. This was an approximate method used to measure the impact energy required to break a small, standard specimen from which material toughness can be inferred. Figure 6 presents a plot of CVN results for a collection of pipeline steels, showing data for base metal, LF-ERW weld HAZ material, and LF-ERW bondline material as a function of test temperature. It is seen from the trendlines in this figure that, in the typical pipeline operating temperature range (50°F to 70°F), the CVN impact energy in the bondline is roughly one-fourth of that in the pipe body, while in the upset/HAZ of the weld, it is roughly one-half of that of the pipe body.

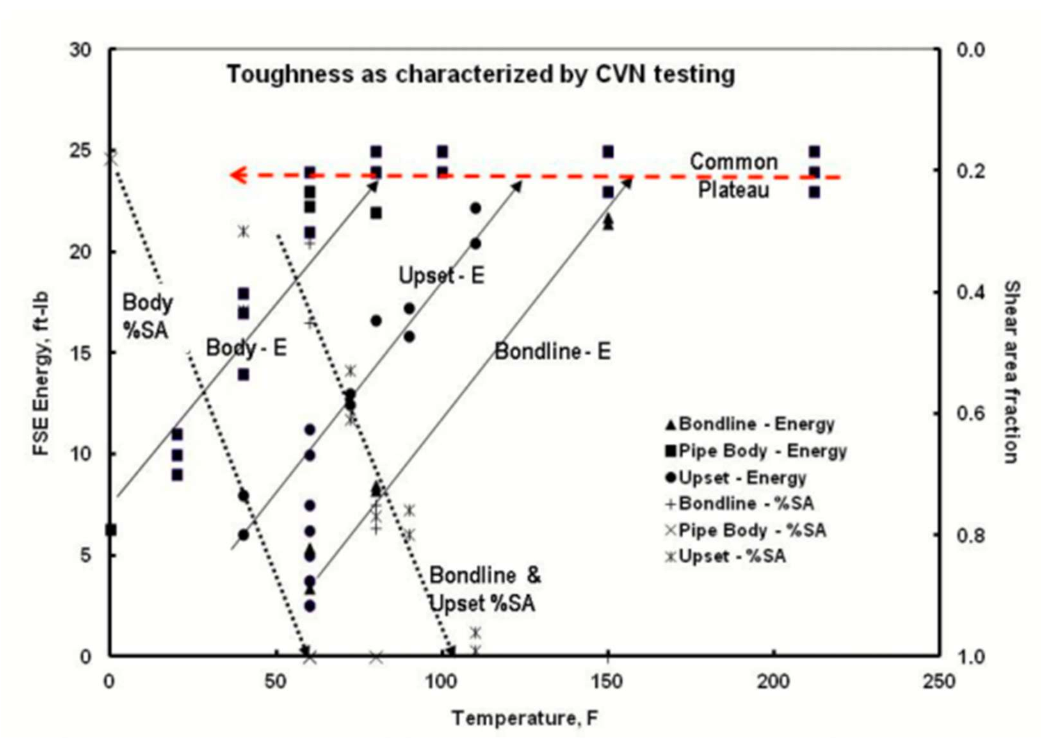

Figure 6: CVN Data for LF-ERW Seam Weld Material (depending on the location in the seam), [4]

Reference [5] states that: "The data in this study . . . do not support the notion that CVN tests of the bond line can be used in integrity assessments of bond line defects." It instead recommends that hydrostatic tests of segments of a pipeline, or of cut-outs containing bond line defects, can be performed to establish the range of bond line Charpy energies by the following steps:

1. Perform a series of hydrostatic pressure tests.
2. Measure the pipe geometry and initiating flaw dimensions (length and depth).

3. Measure the tensile properties of the pipe steel.
4. Use an appropriate fracture mechanics model to back-calculate the Charpy energy to cause failure.

A similar methodology to the above approach was used in the subsequent sections to estimate fracture toughness for Williams LF-ERW/EFW and DSAW seams in this project. First, a generic distribution of toughness was developed using an industry-wide, historical database of seam weld failures reported in Reference [6]. This follows the general approach originally presented in Reference [2] but makes use of either API-579 or MAT-8 fracture mechanics models in SI's APTITUDE software. Similar analyses are also performed for a group of hydrotest, burst test, and operational seam weld failures reported in Williams pipelines for which metallurgical failure analyses were completed. The resulting fracture toughness distribution is compared to that reported in Reference [2] to demonstrate consistency of the two fracture mechanics models.

In Sections 2.1.2 and 2.1.3, the resulting toughness data from the analysis of Williams tests are superimposed on the generic industry distribution to demonstrate that they belong to similar populations. The result is a set of toughness distributions for different seam weld anomaly types that can be used in Williams Seam Weld Integrity Management Program. Note that the toughness data in these sections are reported in terms of the actual fracture mechanics toughness parameter (K_c or K_{Jc}) rather than CVN, which eliminates the conversion step that interjects additional scatter and uncertainty into integrity analyses.

2.1.1 Industry LF-ERW and EFW Toughness Evaluation

Analyses of over 100 LF-ERW and/or EFW seam failures were performed, using the APTITUDE software. The data below leveraged an industry database which was initially presented as part of a DOT research project on seam failures [6] and then later used for a statistical evaluation of ERW/EFW toughness [1]. For each failure, a summary of the defect type, dimensions (defect length and depth), material and pipe properties (strength properties, outer diameter, and wall thickness), and failure pressure were given. The defects were analyzed using the API-579, Level II Failure Assessment Diagram (FAD) model in APTITUDE, calculating an apparent toughness for each seam weld defect that would result in a Predicted Failure Pressure (PFP) equal to the observed failure pressures in the aforementioned data. The resulting toughness distribution is shown in Figure 7 with the individual datapoints identified by flaw-type that caused them to fail, as designated in [6]:

- SSWC - Selective Seam Weld Corrosion
- CW - Cold Weld
- HC - Hook Crack
- FEC - Fatigue-Enlarged

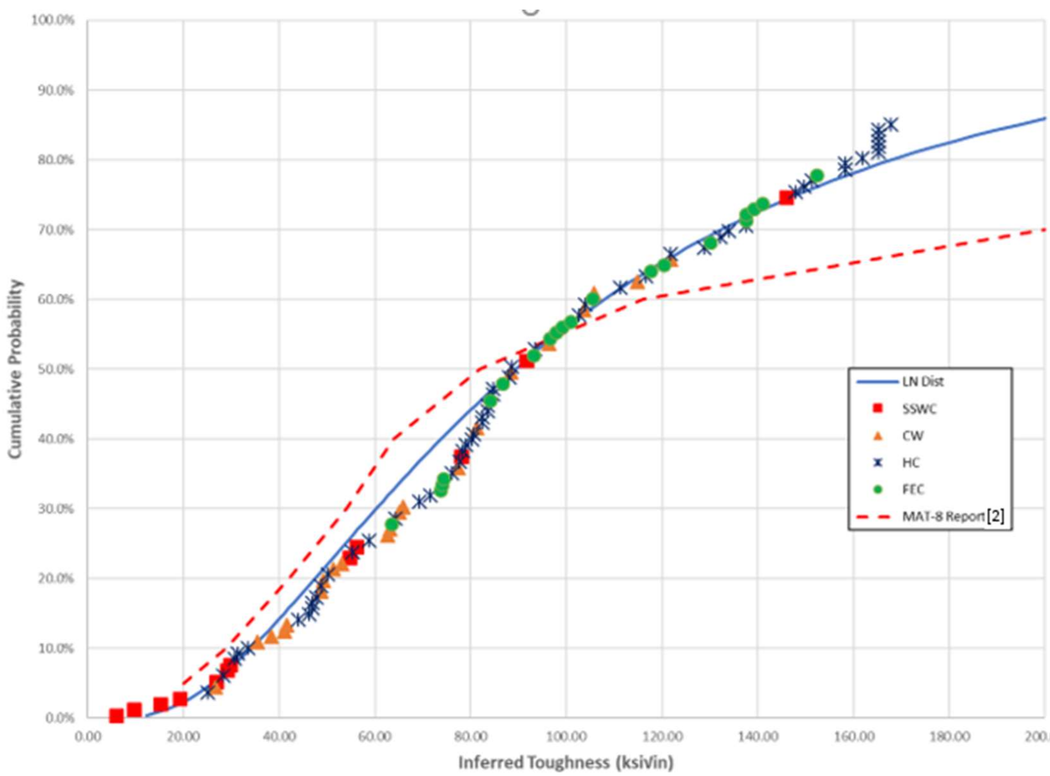

Figure 7: Inferred Fracture Toughness from Database on Pipeline Seam Weld Failures, Sorted by Defect Type [6]. Mat-8 Curve from [2] Also Plotted for Comparison

Two key observations from Figure 7:

- The low end of the distribution is dominated by failures attributed to SSWC (red squares)
- There is reasonable agreement with the MAT-8 results reported in [2] (red dashed curve). The 10 %-tile values are 29 versus 33 ksi√in for MAT-8 and API-579, respectively, and the median (50 %-tile) values are 82 versus 88 ksi√in.

Regarding the second point above, the fact that API-579 results are below and to the right of the MAT-8 results indicates that the API-579 PFP model is slightly more conservative, similar to the observation in Table 2 below.

Table 2: Comparison of Fracture Methods and Actual Burst Pressure Results

Method	**Leak or Rupture**	**Predicted Failure Pressure (psi)**	**Actual Burst Pressure (psi)**
Mod Log-Secant	Leak	939	1360
	Rupture	1806	
API-579 FAD	Rupture	1309	1360
MAT-8 FAD		1358	
Limit Load		1947	
Pipe Details: 16-inch OD pipe, NWT = 0.25 in., Flaw Depth = 0.235 in., Flaw Length = 1.25 in, CVN = 21 ft-lbs			

To address the first observation, the results were separated into two distributions, one for SSWC failures (Figure 8) and a second for all other flaw types (Figure 9). For deterministic analysis Williams recommends using the 10th percentile CVN cumulative probability values similar to those values that were produced in a similar INGAA report [1]. For this analysis, the K_c values for LF-ERW and EFW would be 9.5 ksi√in for SSWC and 43.8 ksi√in for all other LF-ERW and EFW seam weld defects.

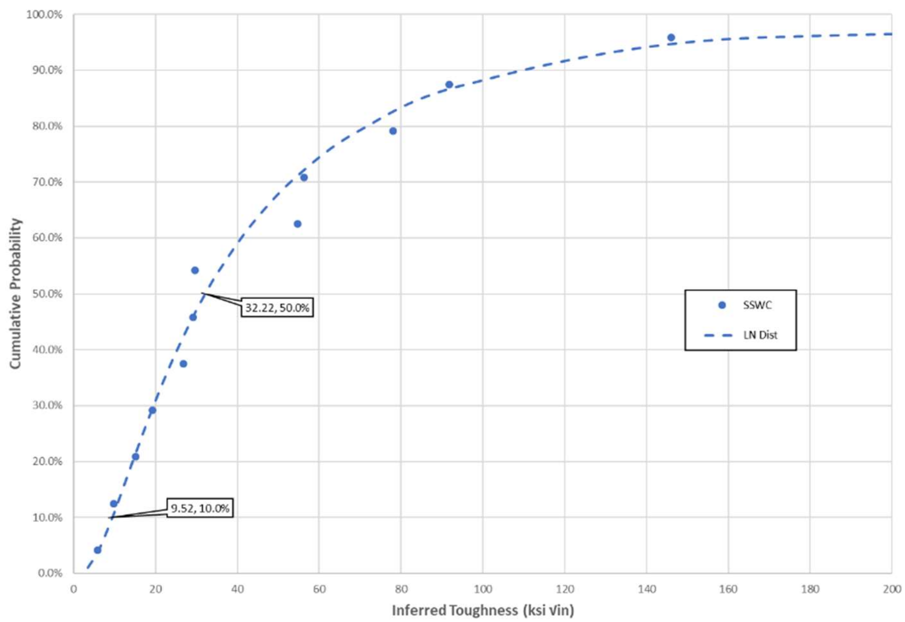

Figure 8: Inferred Fracture Toughness from Database of SSWC Seam Weld Failures

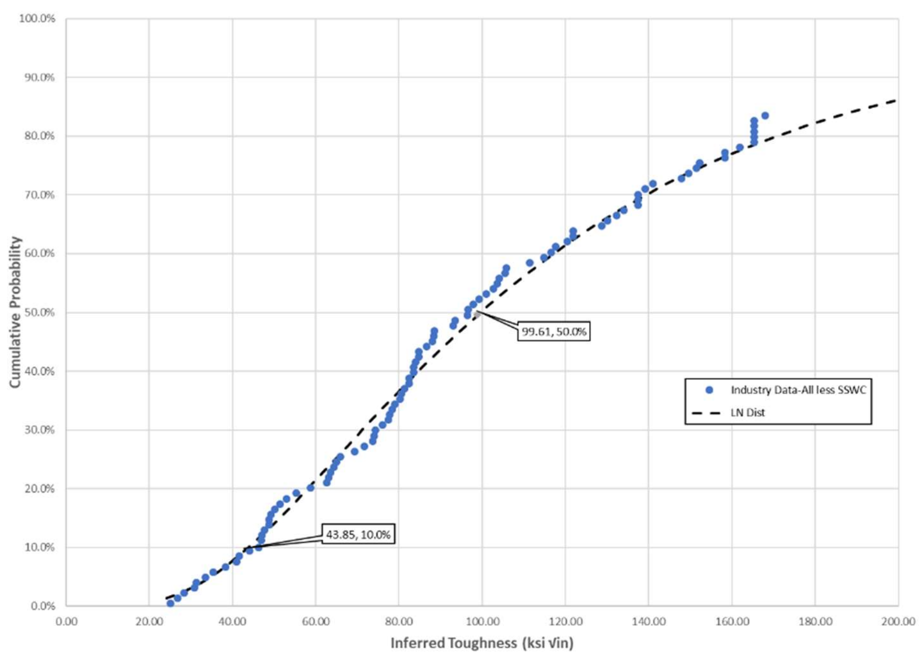

Figure 9: Inferred Fracture Toughness from Database Seam Weld Failures (All Except SSWC)

With the understanding that ILI technology has the capability of reliably identifying cases SSWC vs CW/HC/FEC, it is the intention of Williams Seam Weld Integrity Management Program to use these ln-normal distributions for fitness for service evaluations of the applicable defect types.

2.1.2 Williams LF-ERW Toughness Validation

[redacted]

[redacted]

[redacted]

2.1.3 Williams DSAW CVN Data

A substantial number of seam welds in Williams' pipelines were fabricated using DSAW. There is not an industry-wide database of DSAW failures similar to the LF-ERW and EFW failure database discussed above. However, the configuration of a DSAW seam is such that CVN data can provide meaningful estimates of fracture toughness, since there is not a low toughness bondline in which the V-notch must be precisely located in order to measure minimum toughness of the weldment. Furthermore, the current guidance in 49 *CFR* 192.712(e)(2)(i)(C) appear to be a result of the work that was completed by INGAA [1] which only considered vintage LF-ERW and EFW pipe and utilized the 10th percentile CVN cumulative probability values. DSAW has been shown to exhibit much higher toughness values and therefore, this guidance seems less appropriate toward the application of DSAW CVN default values.

Williams performed extensive CVN testing of DSAW weldments, addressing both weld metal and weld HAZ material. [redacted] The CVN to Toughness conversion was performed using the Roberts-Newton Lower Bound correlation, along with a non-Plane Strain correction factor [3]. This conversion is illustrated and compared to the Wallin mean conversion [2] in Figure 12. [redacted] Similar to LF-ERW and EFW evaluations, the 10th percentile value is recommended for DSAW fracture toughness values, for both weld metal and HAZ flaw locations.

[redacted]

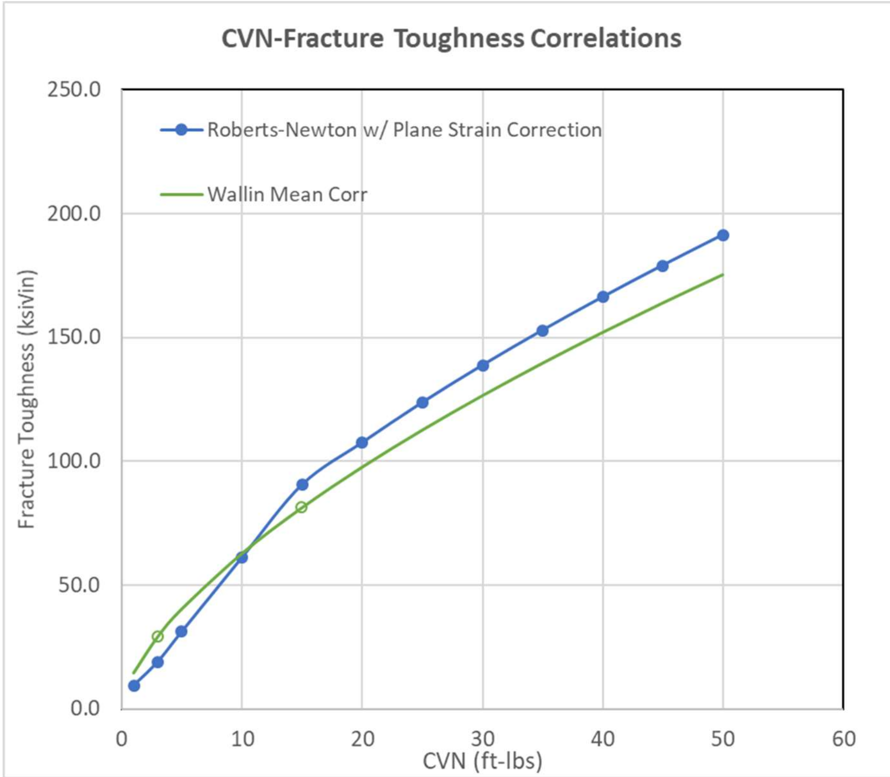

Figure 12: Comparison of CVN to Fracture Toughness Correlations

2.1.4 Williams DSAW Toughness Validation

The Williams-specific seam weld failures with metallurgical failure analyses also contained data for DSAW hydrotest failures. There were six failures identified, five on Transco and one on Northwest Pipeline. The APTITUDE API-579 FAD analysis approach was again used to back out apparent toughness for these failures at the applicable pressures and flaw sizes from the metallurgical failure analyses. The open data points in Figure 11 are based on data from these hydrotest ruptures. Note that only two of the six Williams DSAW rupture cases are shown, since the other 4 were in the high end of the distribution, above the 200 ksi√in cutoff on the plot.

3.0 Summary of Results and Notification to PHMSA

In summary, the following fracture toughness values below (see Table 3) resulted from the preceding analyses of industry-wide and Williams-specific data. Williams is notifying PHMSA that they intend to use these fracture toughness values as their default values in place of those provided in 192.712(e)(2)(i)(C). The results are presented in terms of both K_c (ksi√in) and CVN (ft-lbs) parameters, but Williams intends to use the K_c values in analysis of predicted failure pressure (192.712), as this removes one source of scatter and uncertainty in the conversion from CVN to K_c. For any deterministic analyses of crack/crack-like defects in the long seam, the 10th percentile value will be used; unless Williams has toughness values that satisfy 192.712(e)(2)(i)(A). Williams believes the 10th percentile is a sufficiently conservative lower bound that will yield conservative results when combined with other conservatisms typically incorporated in fitness-for-service (FFS) evaluations. Additionally, Williams believes the 10th percentile toughness values are consistent with the INGAA [1] analysis and are representative of the default CVN values currently utilized in 192.712(e)(2)(i)(C). For probabilistic analyses of crack/crack-like defects in the long seam, the ln-normal distributions upon which these values are based will be used by Williams.

Table 3: Summary of SWA Fracture Toughness Results

Weld Type	Seam Anomaly Type Examples	10th Percentile Toughness	
		K_c ksi√in	CVN ft-lbs
LF-ERW & EFW	SSWC	9.5	1
LF-ERW & EFW	All except SSWC	43.8	7.1
DSAW	All	98.2	17.3

References

[1] Structural Integrity Associates, Inc., "Statistical Evaluation of Charpy Toughness Levels for Gas Transmission Pipelines", Project No. 1600513, The INGAA Foundation, Inc, Washington, DC, 2016.

[2] T. L. Anderson, "Assessing Crack-Like Flaws in Longitudinal Seam Welds: A State-of-the-Art Review," Pipeline Research Council International, Inc., 2017.

[3] S. Riccardella, T. Manning, P. Riccardella, "APTITUDE User Guide Revision 0.3," Structural Integrity Associates, Denver, 2017.

[4] B. N. Leis, "Battelle's Experience in Predictions of Failure Pressure for ERW and Flash Weld Seams," Battelle Memorial Institute, Columbus, OH, 2012.

[5] B. N. Leis, B. A. Young, J. F. Kiefner, J. B. Nestleroth, J.A. Beavers, et al, "Final Summary Report and Recommendations for the Comprehensive Study to Understand Longitudinal ERW Seam Failures – Phase One," Battelle Memorial Institute, Columbus, OH, 2013.

[6] J. F. Kiefner. a. K. M. Kolovich, "Models for Predicting Failure Stress Levels for Defects Affecting ERW and Flash-Welded Seams (SubTask 2.4)," Kiefner & Associates, Inc., 2013.