ENTERPRISE PRODUCTS PARTNERS L.P.

INTEGRITY ASSESSMENT OF LF ERW SEAM VIA HYDROSTATIC TEST

83 mile segment of an HVL pipeline

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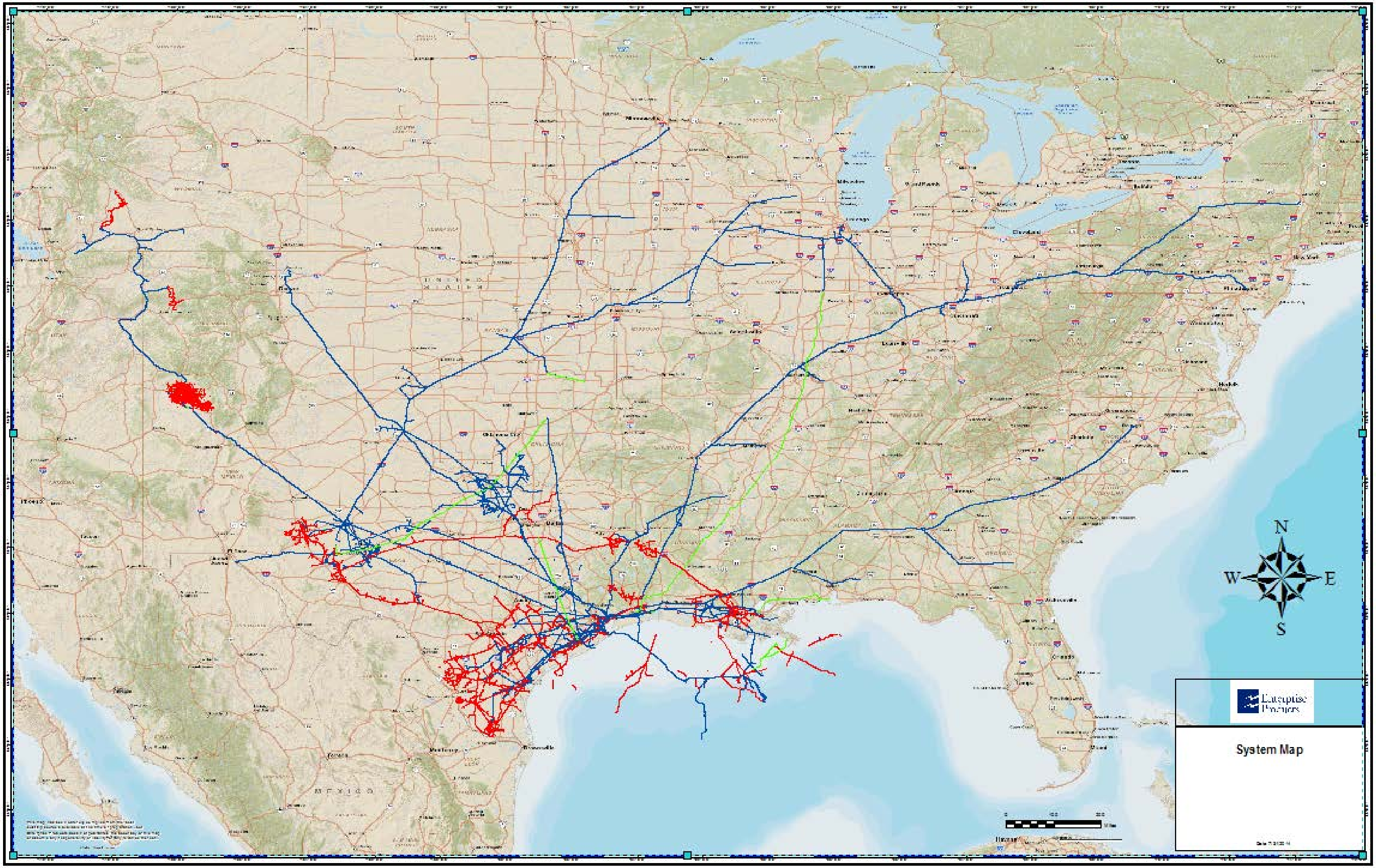
EPD LISTED NYSE

MAP OF ENTERPRISE PRODUCTS SYSTEM



SUMMARY OF HYDROSTATIC TESTING

Summary:

- This 12-inch Pipeline System has been managing the risk of failure from pressure-cycle-induced fatigue of LF ERW seams by performing seam–integrity assessments via hydrostatic testing. SCC not identified in this segment
- This presentation focuses on the results of 3 integrity assessments via hydrostatic testing on a single 83 mile segment between 2 pump stations
- Hydrostatic testing was performed in 2004, 2009 & 2013.
- The results indicate that current operating pressure spectrum does not present a threat of cycle fatigue to the longitudinal seams of this line segment and that current failure prediction methods are excessively conservative.
  - no in-service fatigue failures have occurred in this segment over 53 yrs of operation
  - of the seam hydrotest failures that occurred (All failed at >90% SMYS), none showed any evidence that the defects had been enlarged by fatigue while in service.

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PIPELINE SEGMENT DETAILS

Pipeline Attributes:

- 12.75” OD x 0.250 wt Grade X52 pipe, 85% SMYS API Min Hydro (1,733 psig)
- Pipe Manufacture Lone Star Steel in 1961
- Low Frequency Electric-Resistance Welded pipe seam
- Pipe was full body normalized to 1,650 F
- Coal Tar Enamel / Felt
- Pipeline Installed in 1961 (53 yrs old as of 2014)
- Pressure testing to a minimum of 1,600 psig (78.5% SMYS)

Operating Parameters:

- Nominal Maximum Operating Pressure (MOP) = 1,440 psig (70.6% SMYS)
- Propane Service

Leak History:

- No in-service ruptures of the LF ERW seam have been identified on this line segment

PAST HYDROSTATIC TESTING RESULTS

Observations of 2004 Pressure Test Failures

- No test failures occurred
- Maximum test pressure was limited to 1,837 psig (90% SMYS)
- Actual test range was 85% to 90% SMYS

Observations of 2009 Pressure Test Failures

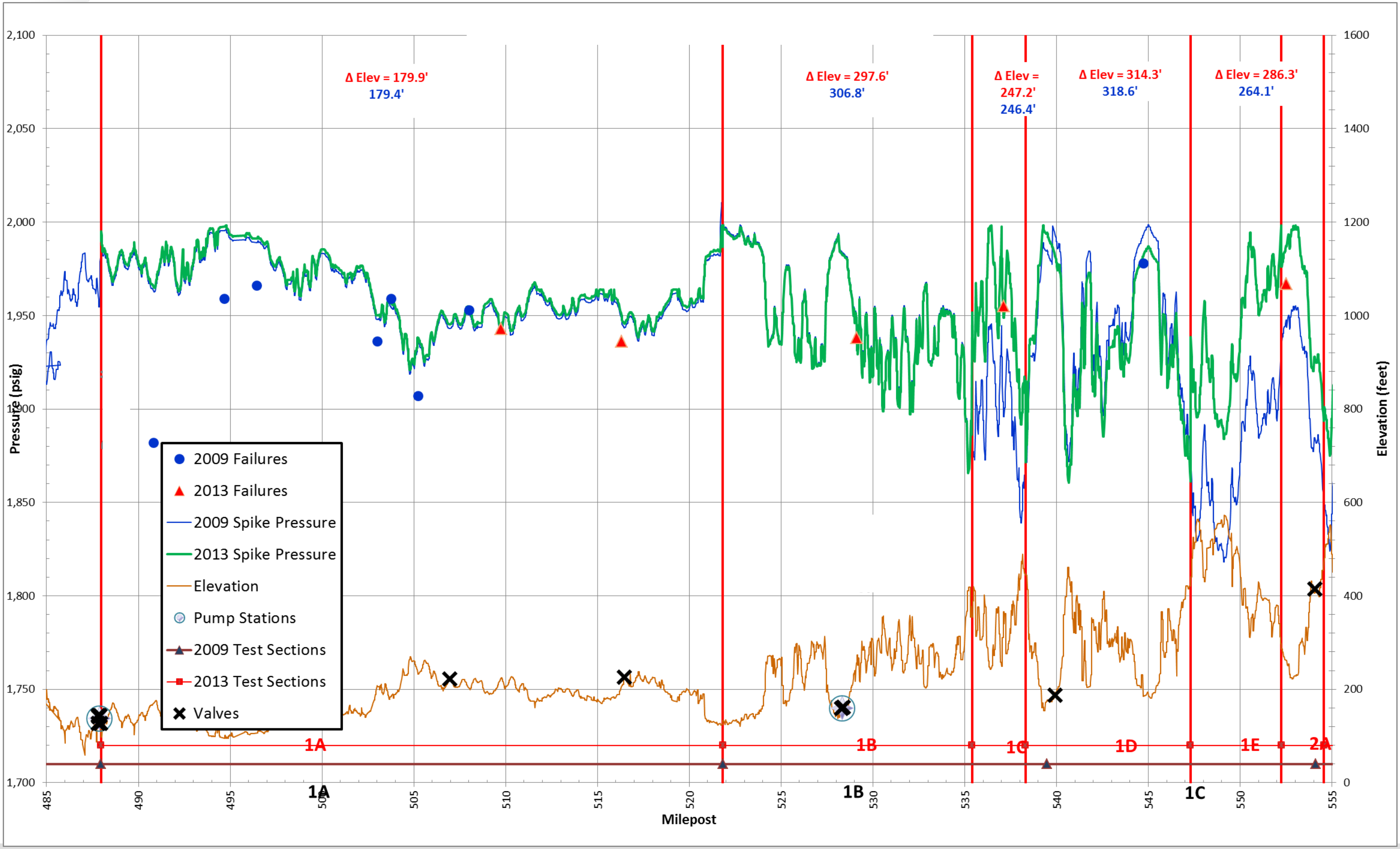
- 12 test failures occurred in LF ERW seams (all > 90% SMYS)
- 6 hook cracks
- 3 Stitched welds with low ductility in bondline region
- 2 low ductility in bondline
- 1 cold weld or lack-of-fusion.
- None of the failures exhibited evidence that the defects had enlarged in service
- All failed at or above the pressure achieved in the 2004 hydrostatic test
- One failed as a leak of a short, nearly through wall lack of fusion defect

MOST RECENT HYDROSTATIC TESTING RESULTS

Observations of 2013 Pressure Test Failures

- 6 test failures occurred in LF ERW seams (all > 94% SMYS)
- 2 interacting ID & OD hook cracks
- 1 OD hook crack
- 2 ID hook cracks and stitched weld
- 1 OD hook crack and stitched weld
- None of the failures exhibited evidence the defects had enlarged in service
- All failed at or above the pressure test performed in 2004

TESTING AND FAILURE PRESSURES



2013 HYDROSTATIC TEST FAILURE DETAILS

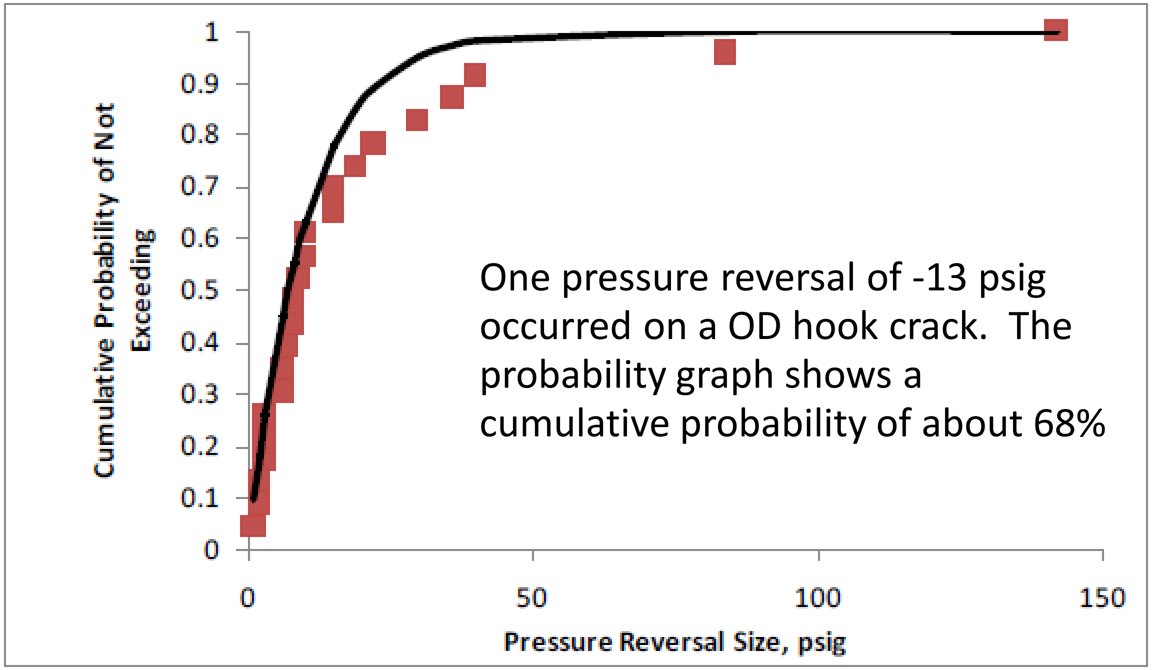
Observations of 2013 Pressure Test Failures

Milepost	Failure Pressure (psig)	Failure Pressure (%SMYS)	Pressure Reversal?	Cause	Failure Mode	2004 TP @ location		2009 TP @ location		2013-2009
509.75	1,943	95.28%	No	ID Hook Crack and Stitched Weld	Rupture	1,793	87.9%	1,942	95.2%	1 psig
516.32	1,936	94.94%	Yes	OD Hook Crack	Rupture	1,799	88.2%	1,949	95.6%	-13 psig
529.12	1,938	95.04%	No	Interacting OD and ID Hook Cracks	Rupture	1,834	89.9%	1,935	94.9%	3 psig
537.12	1,955	95.87%	No	Interacting OD and ID Hook Cracks	Rupture	1,795	88.0%	1,896	93.0%	59 psig
552.52	1,967	96.46%	No	ID Hook Crack and Stitched Weld	Rupture	1,844	90.0%	1,965	96.4%	2 psig
557.83	1,968	96.51%	No	OD Hook Crack and Stitched Weld	Rupture	1,798	88.2%	1,917	94.0%	51 psig

Notes:

- The average failure pressure was on the order of 95.7%
- On average the pressure test from 2013 was 141 psi higher than 2004 at the same location (higher test pressures deliberately introduced)
- Several of the test sections in 2013 had a 50-60 psig increase in pressure over 2009 None of the failures exhibited evidence the defects had enlarged in service
- Target test pressures were increased to extend fatigue life and to gain more information about any crack growth mechanisms

PRESSURE REVERSALS



One pressure reversal of -13 psig occurred on a OD hook crack. The probability graph shows a cumulative probability of about 68%

<u>Likelihood of Pressure Reversal</u>

Kiefner developed a frequency distribution for this pipeline based on 23 pressure reversals observed on the pipeline over several years of pressure testing. The results indicate:

- 26% cumulative probability that no pressure reversal will exceed 3 psig.
- 80% cumulative probability that no pressure reversal will exceed 16 psig.
- 99% cumulative probability that no pressure reversal will exceed 46 psig.
- 99.99% cumulative probability that no pressure reversal will exceed 92 psig.

2013 HYDROSTATIC TEST FAILURE DETAILS

Review of the OD Hook Crack

Test Failure Designation	Milepost	Failure Pressure (psig)	Failure Pressure (%SMYS)	Pressure Reversal?	Cause	Length	Depth
1A-2	516.32	1,936	94.94%	Yes (-13)	OD Hook Crack	4.0''	0.10''

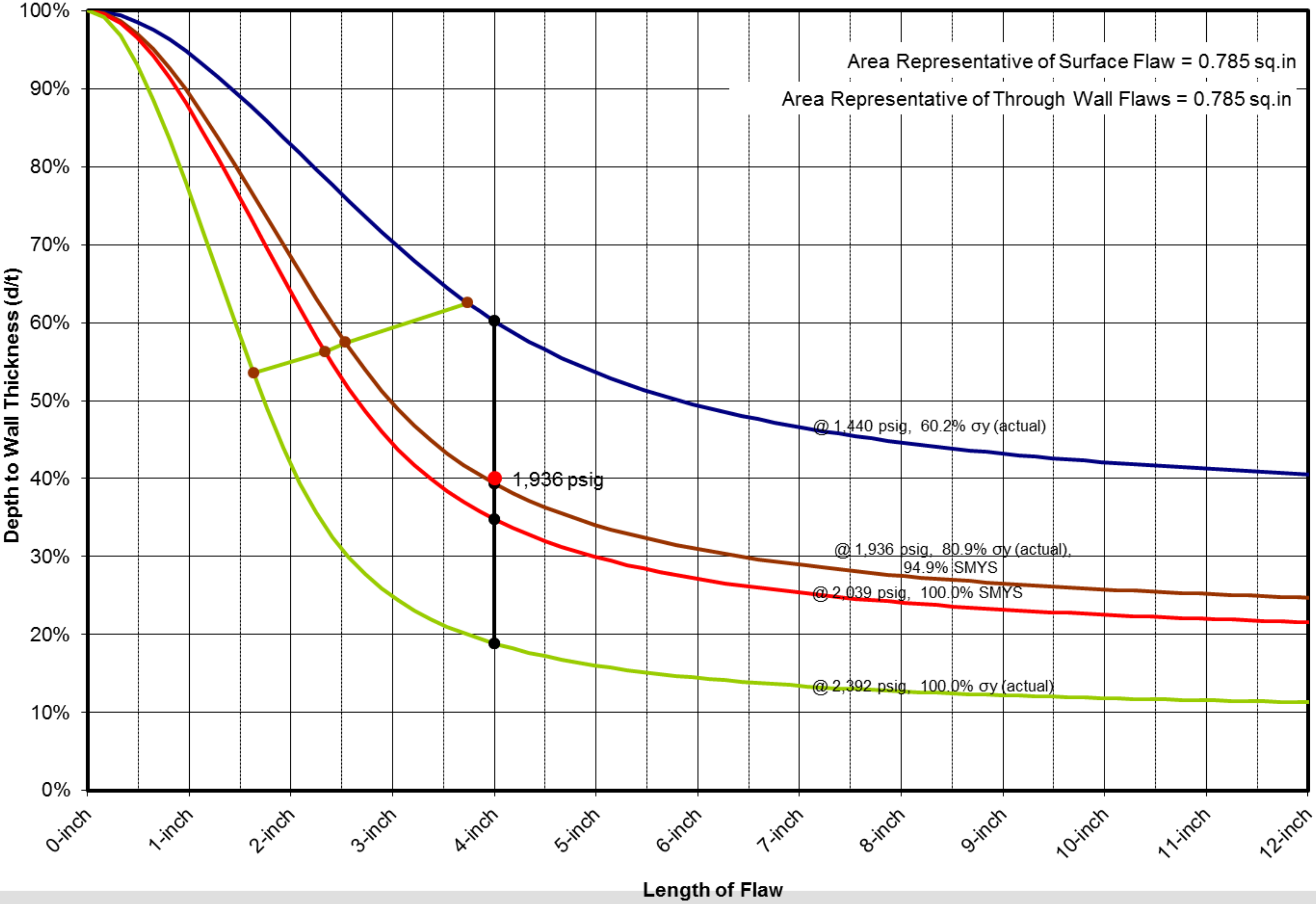
CVN Body (ft-lbs)	CVN Bondline (ft-lbs)
20	9

Yield Strength (psi)	Tensile Strength (psi)
61,000	84,000

- Industry experience with fatigue cracks in many pipelines of various sizes indicates that the most commonly recurring fatigue crack length is approximately $2x(Dt)^{1/2} = 3.6”$. The above hook crack conforms to these dimensions.
- No fatigue growth has observed on this failed Hook Crack.

Relationship Between Critical Crack Size and Failure Pressure (KAI Modified Ln-sec)

OD = 12.75", WT = 0.250", σy = 61,000 psi, Sflow = 72,500 psi, CVN = 9.0 ft-lb, CVN Area = 0.124 sq.in



2013 HYDROSTATIC TEST FAILURE DETAILS

Fatigue analysis of the OD hook crack that failed during hydrotest

Test Failure Designation	Milepost	Failure Pressure (psig)	Failure Pressure (%SMYS)	Pressure Reversal?	Cause	Length	Depth
1A-2	516.32	1,936	94.94%	Yes (-13)	OD Hook Crack	4.0''	0.10''

CVN Body (ft-lbs)	CVN Bondline (ft-lbs)
20	9

Yield Strength (psi)	Tensile Strength (psi)
61,000	84,000

A fatigue analysis was performed for this hook crack utilizing the actual pipe attribute, and 1 year of actual pressure information specific to the point of the hydrotest failure.
The results of the analysis are as follows:

- Calculated Time to Failure was 41.9 years at an operating pressure of 1,084 psig.
  Final Depth 0.182” (72.6%)
- Calculated Time to Failure at an MOP of 1,440 psig was 34 years . Final Depth 0.149” (59.4%)

Based on the fatigue analysis this defect should have failed by fatigue growth within the 52 years of in-service operation or during one of the several pressure test performed. It did not. Also, no other fatigue failures have occurred on this pipeline segment. This suggests that the various conservative parameters utilized in the fatigue model have a compounding effect. One would suspect some observance of fatigue growth.

CONSERVATISM OF FAILURE PREDICTION

A review of some of the fatigue life parameters that could contribute to conservative fatigue predictions.

Fatigue Life Parameters that Could Contribute to Conservative Predictions	Conservatism
The API 579 crack rate of C=8.61E-19 vs other published work such as C=3.6E-19	2.40 x
The Crack growth rates are based on $\mu \pm 2\sigma$ that provides that 97.5% confidence level that the fatigue life will be longer. One report suggest the difference from μ to $\mu \pm 2\sigma$ being a factor of greater than 2	2.28 x
Utilizing the lower bound crack length $\sqrt{(Dt)}$ vs $2\sqrt{(Dt)}$ (1.8" vs 3.6")	1.54 x
Utilizing pressure spectrum just downstream of pump station and applying to entire section	2.11 x

Total: **17.75 x**

Additional FOS: **2.00 x**

35.50 x

Note: Experience suggests that the lengths of fatigue cracks that have caused failures range from about $\sqrt{(Dt)}$ to $4\sqrt{(Dt)}$ The most common size associated with past ERW seam fatigue ruptures seems to be $>2\sqrt{(Dt)}$.

It is noted that the industry is funding research into fatigue crack growth in seam type material. It is believed this research will better define crack growth parameters to be utilized in crack growth models.

CONSERVATISM OF FAILURE PREDICTION

Life Predictions based Conservative Assumptions

- 12.75-inch-OD, 0.250 inch WT, Grade 52
- SMYS = 52,000 psi
- Charpy V-notch upper shelf energy (full size) 35 ft-lb
- Fatigue crack growth rate: $C = 8.61 \times 10^{-19}$, $N = 3$
- Pressure spectrum from pump station discharge (1 year of data)
- Length of crack chosen 1.8 and 3.6 inches equal to $\sqrt{(Dt)}$ and $2\sqrt{(Dt)}$.
- Actual achieved Hydrotest.

Results

- For 1.8" Length of crack $\sqrt{(Dt)}$, Depth = 0.150" = 19.42 years
- For 3.6" Length of crack $\sqrt{(Dt)}$, Depth = 0.094" = 30.98 years

CONCLUSIONS

Conclusions

- The results indicate that current operating pressure spectrum does not present a significant threat of cycle fatigue to the longitudinal seams.

This was confirmed as follows:

1. No fatigue failures have occurred on the pipeline section in over 53 years of service.
2. The 2nd (2009) and 3rd (2013) round of pressure testing did have failures, however those failures were during the spike pressure phase of the test.
3. Investigation of the failures did not show any evidence the seam defects had enlarged by fatigue while in service.
4. It is expected that the pressure reversal of the seam defect occurred as a function of the previous hydrostatic test and this explains why the failure occurred at a slightly lower test pressure.
5. Based on a fatigue analysis of the seam flaws that pre-existed in the pipeline since 1961, fatigue growth should have occurred – but didn't.
6. It was concluded that the various conservative factors of safety applied to the fatigue modeling is the reason for no observed growth. In some cases, it can be as high as 35 x more conservative.

CONCLUSIONS CONTINUED

Conclusions

- When comprehensive, highly-detailed information about seam defect behavior is known, consideration should be given to reducing the additive factors of safety (FOS) associated with failure life prediction.

- Excessive factors of safety do not improve integrity and limit an operator’s ability to best understand and manage cracking threats.

- Consideration should be giving to decreasing the frequency of hydrotesting since the threat of cyclic fatigue to the longitudinal seams is low. A testing frequency of 10 years is more appropriate. This will reduce the potential damage to seam flaws as a result of high pressure tests and subsequent pressure reversals that have occurred over the years.

CONCLUSIONS CONTINUED

Conclusions

- Consideration should be given to performing In-line inspection with an axial crack detection tool. Technology in the detection and sizing of crack-like defects is constantly evolving. The benefit of ILI is that smaller defects can be pinpointed and repaired without disrupting service or introducing damage.

- Alternating in-line inspection and hydrostatic testing for seam integrity assessments can be beneficial:
  - Operators need to determine on a case by case basis
  - Can improve operator's ability to find and remove seam defects
  - Allow opportunity to better understand and leverage improving ILI technology.

Questions