GAINS WITH ADVANCED DATA ASSESSMENT IN ILI:

LEVERAGING PIPELINE DATA WITH EXPERTISE TO ELIMINATE RISK, PRIORITIZE AND SCHEDULE NECESSARY REPAIRS

For traditional in-line inspection (ILI) vendors, considering 21.4 miles of a piggable 4" diesel pipeline is typically not a big deal and significant threats of 3rd party damage and external corrosion seem to come with the territory. However, at times, the assumption of standard piggability can be diminished when considering additional variables. For one Gulf of Mexico pipeline operator who previously had a pig stuck in the line, the fear of another pig run in a subsea environment was worrisome. Potentially blocking the flow of fuel critical to operations was simply not an option.

Quest Integrity Group's InVista™ technology was selected to perform the inspection based on these specialized conditions, along with preference for collecting comprehensive data in one pass. As a result, one flawless, uneventful integrity survey was achieved providing complete deformation and metal-loss data. Accordingly, the line's integrity goals were met, but what else could be leveraged?

The ultrasonic in-line inspection identified a total of 45 geometry anomalies (dents and ovalities). Data indicated that 16 of these were larger than the common depth based criteria threshold of 6% of OD which is used to develop a conservative dig repair program. However, an assessment based on depth alone does not identify the factors that can quantify their severity, because the amount of stress concentration caused by the dent and the amount of pressure cycling the dent experiences can vary.

The life cycle assessment of each geometry is started by engineering finite element analysis (FEA) models using the ultrasonic ILI data and then applying pressure cycling results to stress concentration factors. These advanced engineering calculations allow for a remaining life based upon the time for a crack to initiate and grow to failure to be considered. The results of the advanced assessment showed that only 3 dents had a calculated remaining life less than 50 years. The assessment reduced the number of anomalies not meeting criteria by over 80% - from 16 to 3. Furthermore, the remaining 3 locations were able to be prioritized based on risk profile for scheduled attention from the operator's preferred timeline.

BACKGROUND

In today's pipeline integrity environment, pressure for both documented regulatory compliance and threat based mitigation is a necessity. In-line inspection (ILI) has historically provided a great service in identifying pipeline features and anomalies in this regard. Understanding that pipeline failure or operational disruption is to be avoided is readily comprehended.

Similarly, designing or preparing a line for ILI seems pretty clear. Even before 1964, when the first commercial smart pig was run, pipeline pigging has been predicated on consideration of pipe diameter, access, flow and pressure along with distance. The thinking was that if a tool (smart pig or otherwise) could be matched to accommodate known line specifications and parameters, then the pipeline would be deemed "piggable".

However, with regards to pipeline integrity, simply having a piggable line is only one piece of the puzzle:

Important ILI Success Factors

1. "Piggability" - allows a tool to navigate a line

2. Tool Performance - running within tool navigational limitations and data measurement specifications consistently and completely

3. Usefulness of Data - applies to selecting the right technology, recording 100% of the required data and being accurate/repeatable

For many ILI projects, especially those populating the difficult and unpiggable space, planned success can be unnecessarily complicated with incorrect assumptions from any of the above three categories. Project success hinges on fleshing out the details. So knowledge and proficiency expertise improves pigging performance… that much is predictable, but what about the data?

Just getting a pig through a line with captured data no longer necessitates a stopping point from the integrity assessment standpoint. Leveraging the most out of collected pipeline data is the next logical step in pipeline integrity gains. Current Advanced Engineering approaches allow for higher level understanding of readily available or previously obtained data. Maximizing the latent data possibilities for pipeline operators can be of enormous value.

Understanding Value

During the fall of 2013, an operator teamed with Quest Integrity to inspect a 33 year old "piggable" line that had at one point held a gauge pig for more than 5 months before trapping to an offshore receiver. Something was askew.

Complicating matters, this line ran buried in the swamps of Louisiana, zig-zagging a subsea course to the client's marine terminal. There were tidal effects, erosion and boat activity to consider that made dents and external corrosion very likely. Absolutely no disruption to standard operations was acceptable.

For these reasons, the operator's system integrity assessment indicated a high risk potential for this pipeline. Despite not being mandated for any prescriptive ILI interval, the perceived risk indicated a need for data and this operator took action.

The planning and partnership with the specialized "unpiggable" pigging provider paid off – complete, combined deformation and wall-thickness data was achieved without complications or deviation from expectations. Best described as "anti-climatic", the tool run was a celebrated success on first attempt.

Fast-forward to the day the final reporting was issued and many geometry anomalies were revealed. For this operator, even one immediate repair condition was a notable event considering the minimum excavation cost of $200,000 each. While historically depth-based consideration would be applied, the operator questioned traditional efforts – was there benefit from more comprehensive analysis?

> There are things known and there are things unknown, and in between are the doors of perception.
>
> Aldous Huxley

What Was Found: Inspection Results

A risk assessment can identify what damage types are anticipated on a pipeline, a key element in selecting the correct inspection technology, but the actual type and severity of the damage is unknown until the inspection is performed. Quest Integrity's InVista™ ultrasonic platform gathers high resolution data for both deformation and metal loss in one pass. For this subsea pipeline inspection, the InVista data would be available to perform assessments for both damage types based on what was identified in the survey.

Metal loss is identified and measured using the wall thickness data. The thickness measured is a direct measurement and provides the detail required to perform a level 2 or 3 assessment to determine the severity of the wall loss.

Deformation is identified using the standoff, the distance between the ultrasonic sensor and the pipe inner wall. A centering algorithm is applied to the standoff reading to create an engineering measurement of the inner radius of the pipe. The inner radius profile data can be used to generate models of deformation damage that are used as part of level 3 assessments.

The inspection identified over one hundred metal features and 45 deformations (dents and ovalities). The data quality was high throughout the run and the anomalies that were identified matched the expected damage types based upon the risk assessment. However, the assessment of the two damage types revealed much different results.

A level 2 assessment was performed on the metal loss and it showed that the minimum safe operating pressure of the metal flaws was greater than the maximum rated pressure for the line. Based upon the inspection results and the assessment, metal loss was not an immediate concern to the operation of the pipeline.

Conversely, sixteen of the deformations that were identified had a depth greater than 6% of OD, the common dent depth acceptance criteria. The deepest deformation was an ovality with a measured depth of 26.6%. Screenshots of the ILI data from the deepest ovality and dent are shown in figures 1 and 2. An anomaly investigation program can be based upon the 6% depth criteria and that would have placed all sixteen of these anomalies on the dig list.

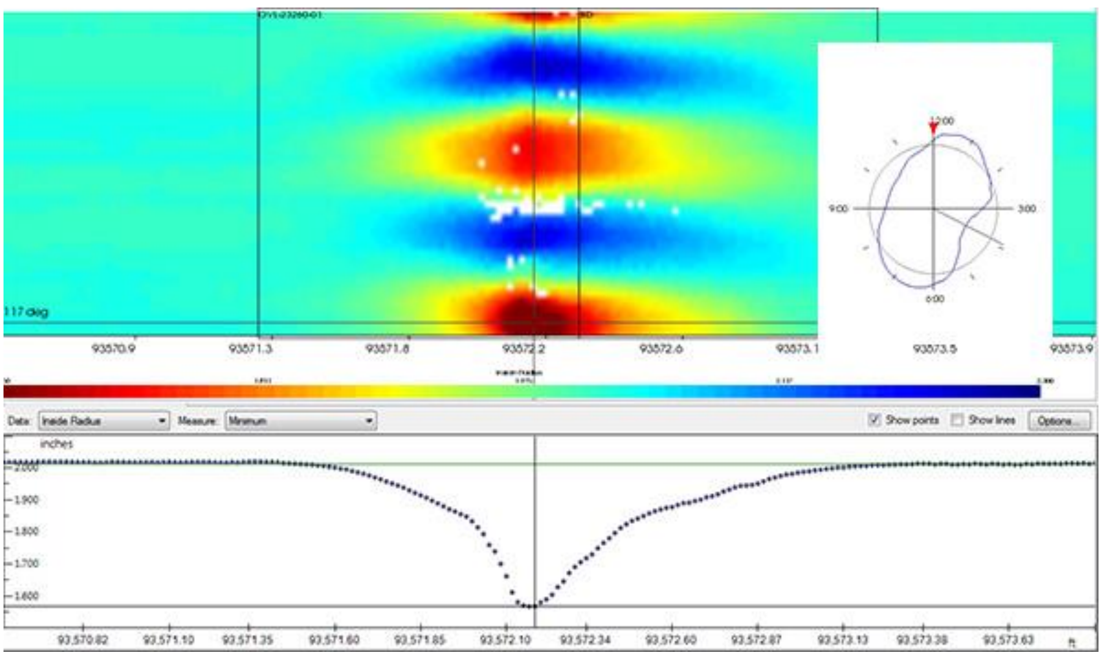

Figure 1. ILI data showing 2D, axial, and cross-section views of 26.6% deep ovality.

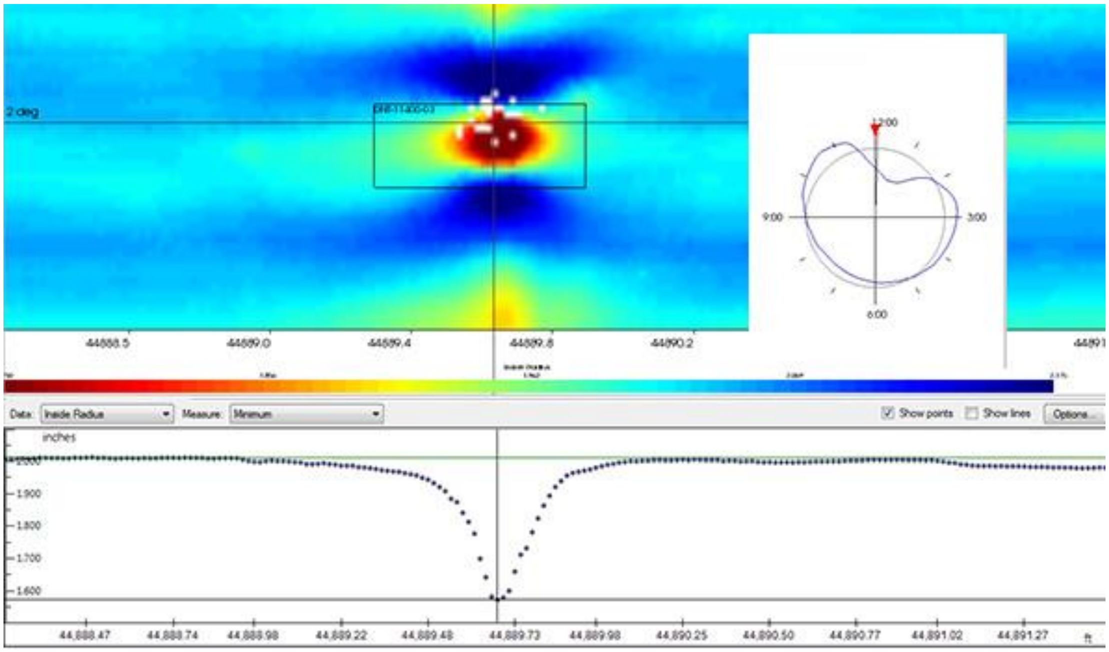

Figure 2. ILI data showing 2D, axial, and cross-section views of 9.8% deep dent.

However, simply using a depth criterion for deformation anomalies ignores two factors that contribute to the severity of the dent: the sharpness of the anomaly and the amount of pressure cycling to which it is subjected. Because these anomalies appeared smooth and the pressure cycling was low on these lines, a level 3 assessment was identified as a good method for providing a better understanding of the risk associated with each anomaly and to see if the 6% depth criterion was overly conservative when profile and operating conditions were considered.

DEFORMATION ANOMALY LIFE ASSESSMENT

Unlike metal loss, a dent does not simply fail based upon its ability to contain pressure or leak due to through-wall corrosion. An unconstrained dent can develop cracking over time as the damage from dent formation (and subsequent re-rounding) and the damage from operational pressure cycling accumulates, exhausting the steel's fatigue life. Once a crack is formed in a dent it will typically grow to critical size quickly due to the stress concentration caused by the deformation. Advanced assessments of dents are performed quite differently than those for metal loss as it considers the life cycle of the dent.

The driving force for fatigue crack formation is the pressure loading to which the pipeline is subjected. To perform the life assessment, operational pressure data is required to determine pressure cycling. Typically, pressure data from transmitters upstream and downstream of the anomaly are used to determine pressure at each anomaly location. Pressure data is then converted into number and magnitude of pressure cycles through a process called rainflow counting.

For this pipeline, pressure data was not available electronically through a SCADA historian. However, pressure trends showing typical pipeline operation were available and provided the information required to understand the cycling regime. The trends were reviewed for both pump and terminal locations to create pressure cycling histograms. A typical pressure trend showing a weekly delivery cycle that was used in the analysis is shown in figure 3. The amount of cycling at each anomaly was determined based on the relative distance to the pump station and the delivery terminal.

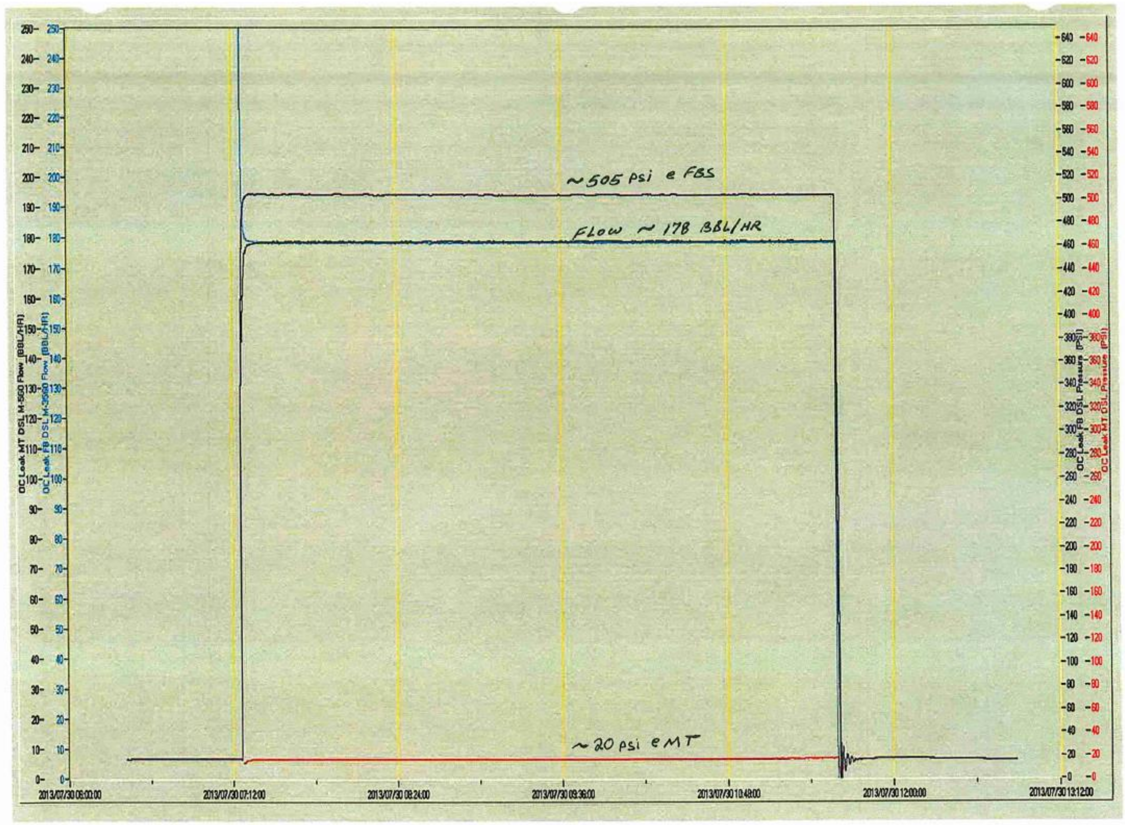

Figure 3. Typical Pipeline Delivery Pressure Trend

Deformations have the effect of concentrating the amount of stress at the anomaly due to the change in shape from a cylindrical shell. The typical pipeline is not subjected to sufficient cycles in its lifetime to reach its fatigue limit without a stress concentrator (typically a crack, sharp metal loss defect or a deformation). The amount of stress concentration is calculated by comparing the relative increase in stress due to the deformation in what is called the stress concentration factor (SCF).

In a deformation anomaly the amount of stress intensification is related to the sharpness, not the depth, of the defect profile. There are two methods used to calculate the SCF using ILI data.

1. Create Finite Element Analysis (FEA) models of each defect and subject them to a load to measure their effect to the level of stress seen at the anomaly.

2. Use the anomaly profile data and then numerically model each defect and use the profile to determine the strain due to the defect. A correlation between strain and stress is then developed by creating FEA models for a representative sample of defects.

Because of the large depth and some unusual deformation geometries it was decided that FEA models would be generated for all of the defects.

- Profile data from the InVista tool was used to generate a mesh for the FEA model.
- As part of the mesh generation, minimal data smoothing was performed as the FEA is sensitive to the noise that is typical of ILI geometry data.
- Outliers were removed using a median filter. Smoothing of the data was performed using a moving weighted average.
- To improve FEA results mesh refinement was performed. This increased the number of nodes in the FEA model beyond the resolution of the ILI tool.
- Refinement was performed using a spline fit of the geometry data.

The FEA analysis was performed using the Abaqus finite element solver by means of quadratic shell elements. Linear-elastic finite element analysis was performed. Both an axial thrust load and internal pressure load were added to the model in separate load steps. An example using a dent is shown in figure 4. The peak hoop and axial stress for each load (axial thrust and internal pressure) is used to determine the SCF for each anomaly.

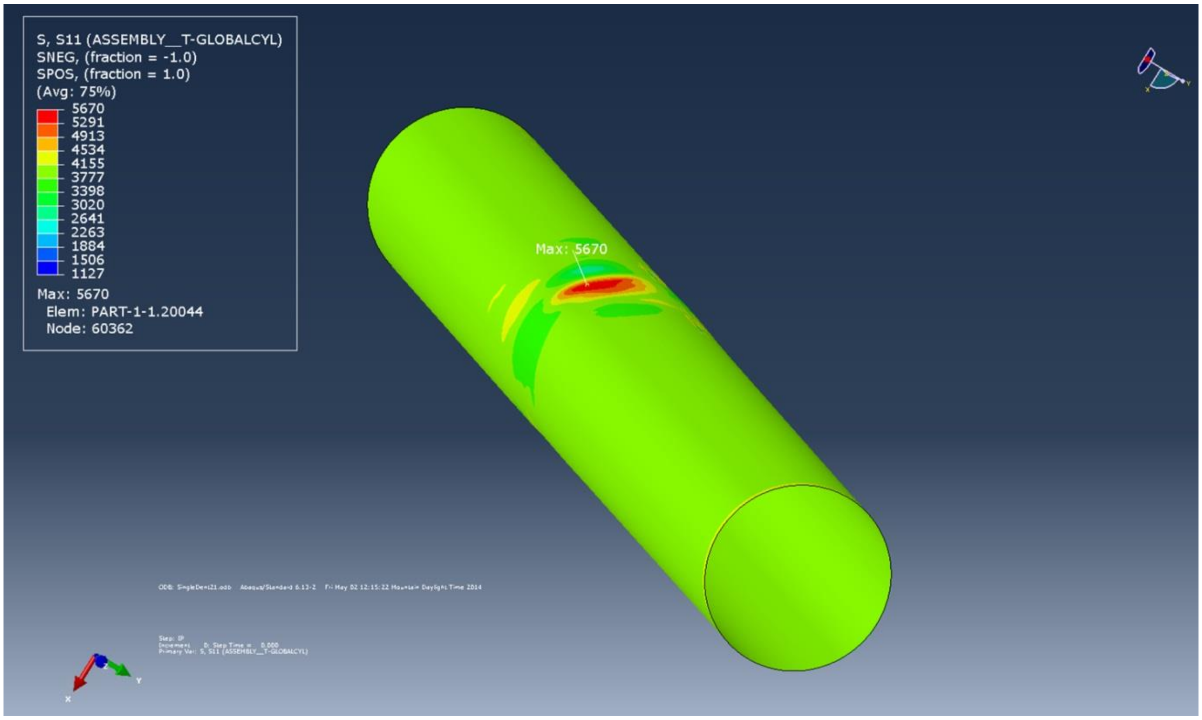

Figure 4. FEA model of dent showing axial stress due to pressure thrust load

The amount of fatigue life consumed through cyclic loading is estimated using an S-N curve which defines the number of allowable cycles at different stress levels for a material. The stress loading is determined by multiplying the pressure histogram by the SCF and comparing. That stress value is then compared with the allowable number of cycles for that stress level to determine the allowable number of remaining cycles before the fatigue life is consumed.

For this assessment it was assumed that half of the pipeline life was used up during the dent formation and subsequent re-rounding. This process is also called ‘shakedown’. This value is based upon the maximum value that has been seen from elastic plastic modeling of dent formation and shakedown. Two different fatigue curves, API 579 and API X, were used and the remaining life based upon the minimum of the two. Therefore, the remaining life of the dent is based upon when pressure cycling caused 50% of the allowable damage.

The pipeline had been in service for 33 years and the remaining life assessment assumes that the dents have been present from commissioning. Finally, a remaining life safety factor of 2 was applied to account for uncertainties in the data and assessment.

GAINS WITH ADVANCED DATA ASSESSMENT

Based upon the advanced assessment only 3 deformation anomalies had a calculated remaining life of less than 50 years. For the purposes of discussion 50 years is being used as the criteria for determining if a deformation will need to be addressed as it is a common pipeline design life.

The results of the assessment are shown in Figure 5 and only anomalies to the left of the vertical red line showing the 50 year criteria would not satisfy the remaining life criteria. All of the deformation anomalies not meeting the criteria had a depth of 10% OD or greater. Yet that was not a consistent finding as 3 anomalies with a depth greater than 10% OD, including a 26.6% ovality, had calculated remaining lives greater than 50 years.

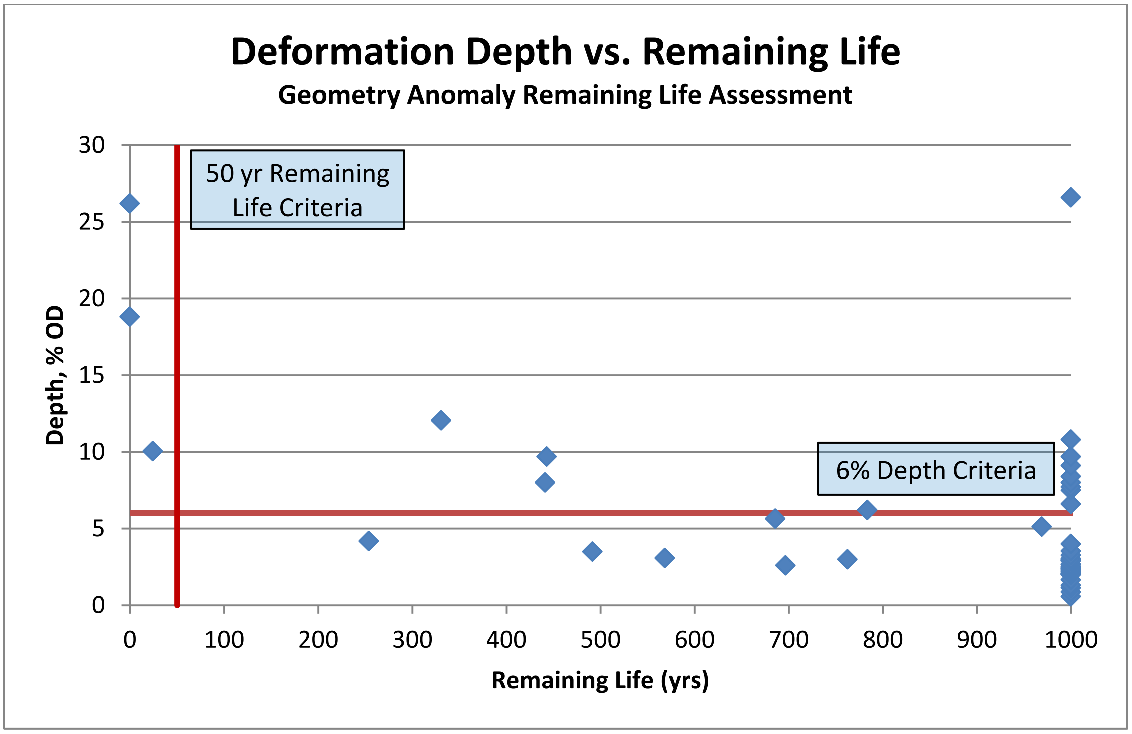

Figure 5. Results of the remaining life assessment: Depth vs. Remaining Life

A more in depth review of the results will make clear which factors are driving the remaining life assessment.

Figure 6 shows the number of cycles to failure plotted against the anomaly position. A correlation between the proximity of the deformation anomaly (regardless of depth) to the start of the line where the pressure cycling was highest, having fewer cycles to failure was apparent. Clearly, the magnitude of pressure cycling was having a large impact on the results.

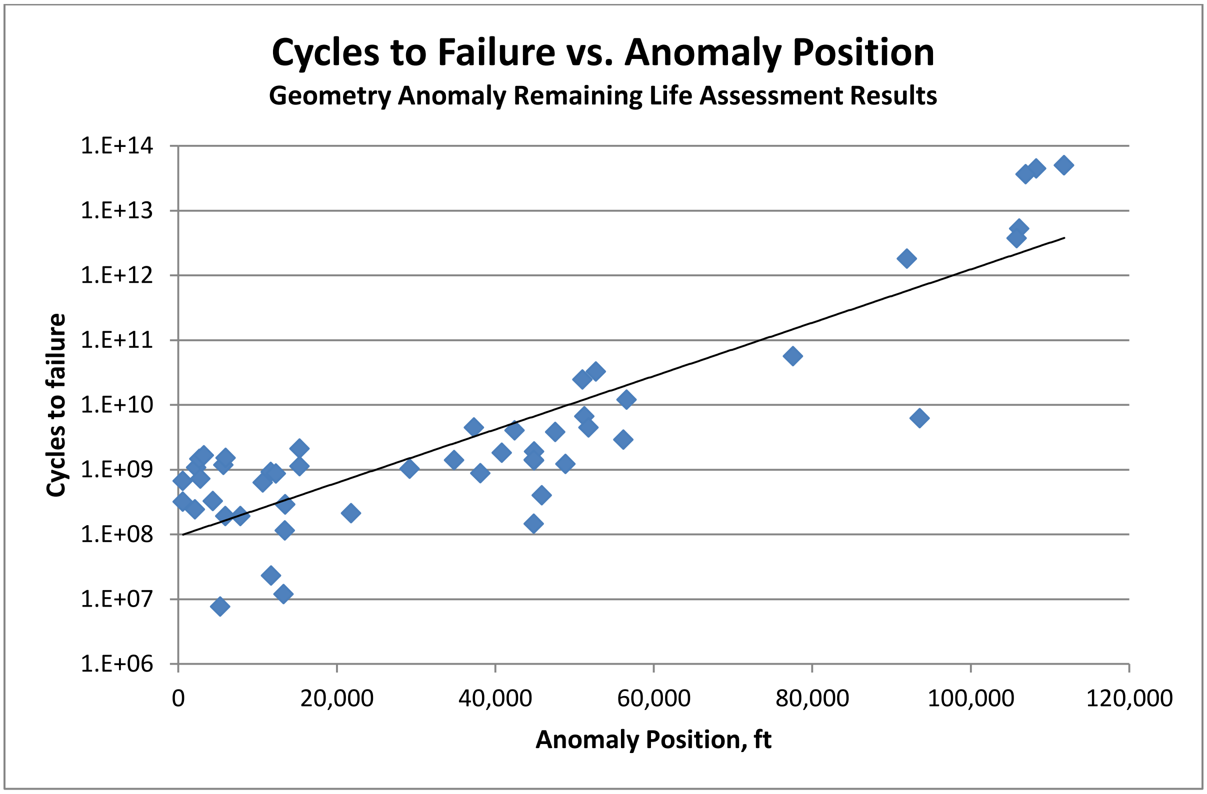

Figure 6. Results of the remaining life assessment: Cycles vs. Position

A similar plot showing the number of cycles to failure plotted against depth is shown in Figure 7. A review of these results shows a weak correlation between depth and the results of the remaining life assessment. **These two plots show us that for this pipeline the proximity to the pump station had a larger impact on the remaining life of the dent than the depth.**

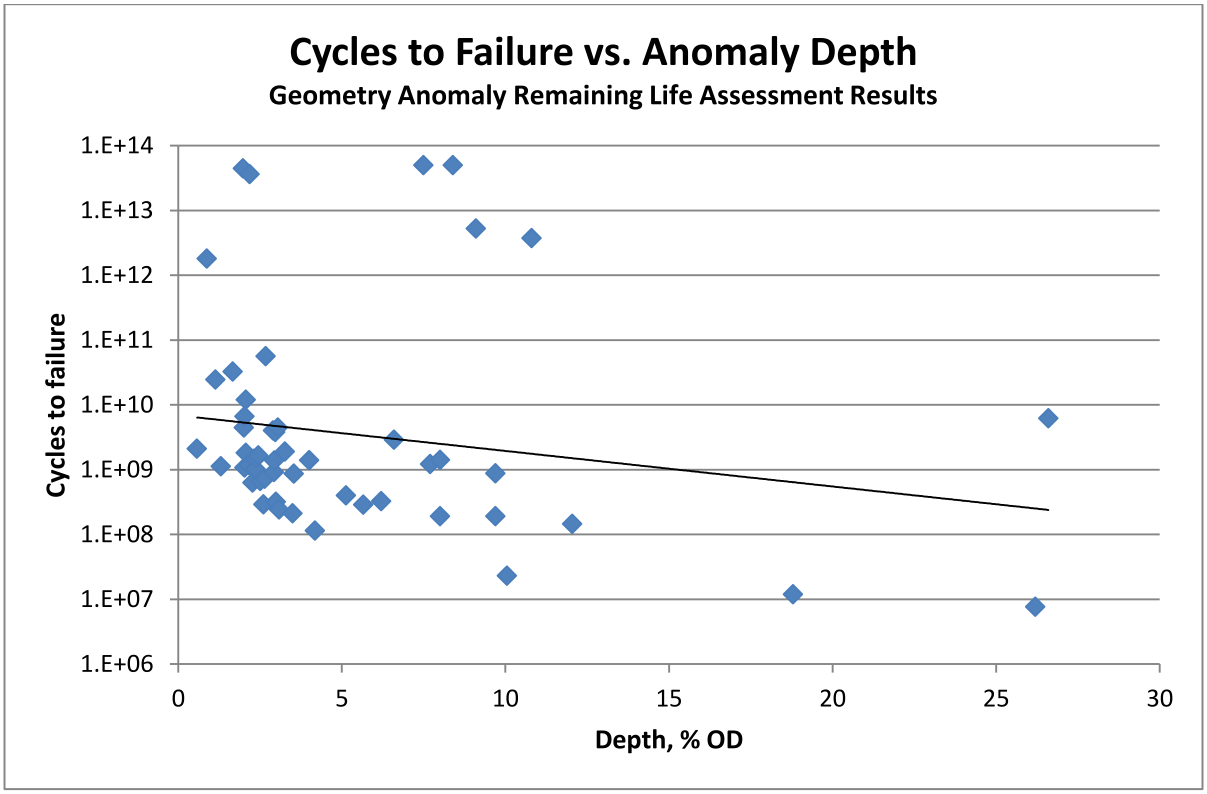

Figure 7. Results of the remaining life assessment: Cycles vs. Depth

Up to now we have only been looking at the remaining life. This is because the remaining life value includes a life cycle assessment of the deformation and provides the best overall criteria to understand the risk of failure attached to each dent. An SCF was calculated for each dent and was used in the remaining life assessment. SCF provides a measure of the severity of the dent but does not consider the life cycle. Figure 8 shows a plot of the SCF calculated from the FEA models against the depth of the deformations. A correlation, with outliers, is seen between SCF and deformation depth.

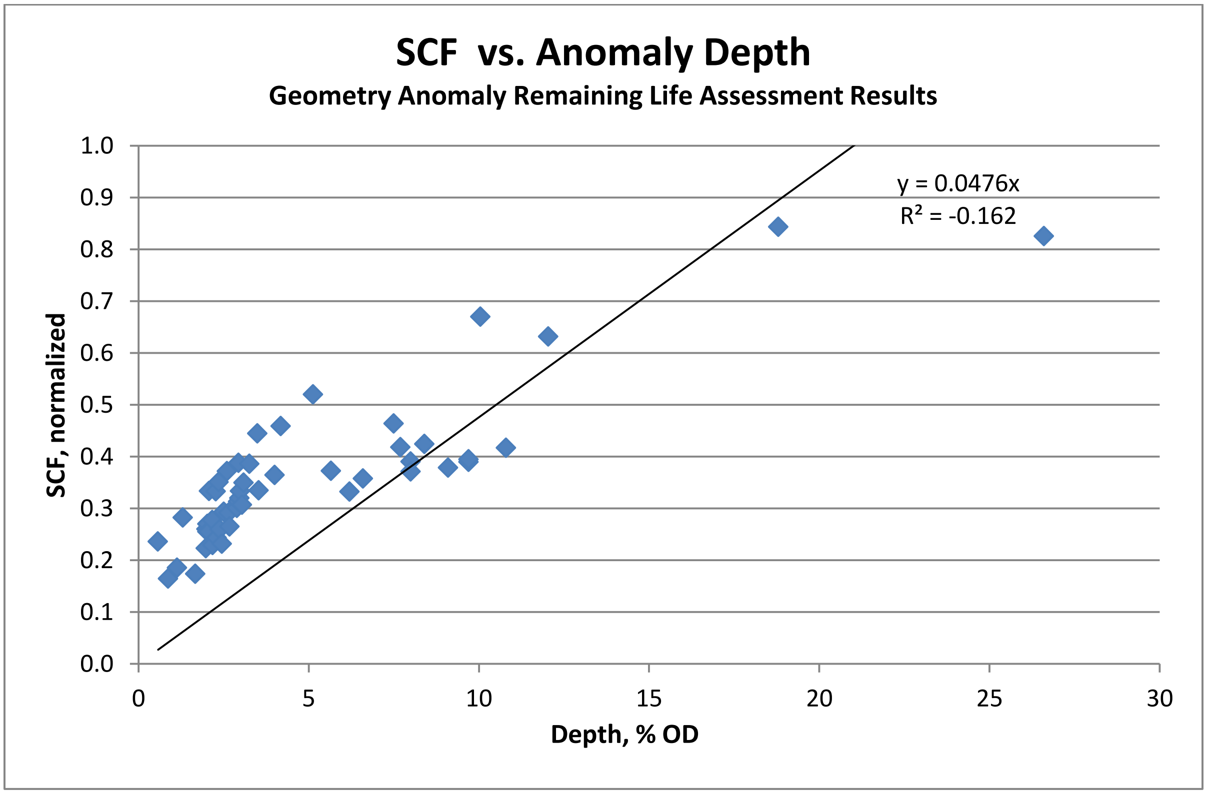

Figure 8. Results of the remaining life assessment: SCF vs. Depth

Many of the trends seen in the results of the assessment are known but have not yet been adopted as standard assessment methodology. For example, a strain-based dent assessments is recognized as an assessment methodology on gas pipelines but not liquid ones due to the impact of pressure cycling. **With the right expertise, tools are available to perform stronger assessments and often can be done using data that has already been collected.** The impact in this case was the avoidance of investigations on anomalies that could effectively be shown to be fit for continued service.

Making Known the Previously Unknown

With current combined inspection and advanced engineering capabilities, it can be advantageous and impactful to leverage latent data potential because standard ILI reporting evades consideration of variables outside of defect identification, sizing and level 1 or 2 metal loss assessment.

By rationalizing pipeline threat representation and including formerly isolated parameters, advanced engineering more precisely quantifies risk and provides for better pipeline utilization. Having improved perception, higher level data assessment supports superior operator decision-making in:

- Reflecting more accurate integrity condition assessment
- More accurate risk defining and more developed risk ranking
- Introducing a sequenced repair strategy vs. reactive anomaly mitigation
- Avoiding unnecessary activities, whether planning, gathering more information or even digs
- Providing a clearer understanding of specific pipeline integrity hazards and damage mechanisms

Take Away

Opportunities exist to leverage existing pipeline integrity data to become more effective and yield directed gains—honing time, resources and budgets while reducing risk:

1. Traditional mental paradigms are not always sufficient (may not reflect current, complete or best options)
2. Expertise delivers a force multiplier (maximize efficiencies, minimize complications and unnecessary work)
3. What you think is a threat may not actually be so (anomaly sizing is not the only determinant)

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