To Dig or Not to Dig - Determining Which Dents Are Suitable for Engineering Critical Assessment per 192.712 (c)

Shanshan Wu[1], Jing Wang[2], Joseph Bratton[1], David Kemp[1], Luyao Xu[1], Greg Quickel[1]

[1]DNV, [2]TC Energy

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Abstract

The Pipeline and Hazardous Materials Safety Administration (PHMSA) issued RIN2 of the Final Rule (frequently referred to as the "Mega Rule") on August 4, 2022, which will impact the pipeline industry's approach to the assessment of dents and other mechanical damage. The Mega Rule provides detailed requirements in the Code of Federal Regulations (CFR) Title 49 Part §192.712(c) regarding how to perform a dent engineering critical assessment (ECA). With the Mega Rule taking effect in 2024, it is expected that more dents will be considered for ECA to determine the response plan and timeline.

This paper will share guidance on selection criteria for dent ECA through four case studies. The case studies include Ductile Failure Damage Indicator (DFDI), Strain Limit Damage (SLD), and dent fatigue analysis using finite element analysis (FEA). Additionally, findings from field investigations, laboratory results, and other pertinent information associated with the respective dents will be presented. Guidance regarding best practices to assist operators in selecting suitable locations for dent ECA versus excavation will be provided from the case studies.

The primary objective of this paper is to share experiences to the industry ahead of the upcoming dent ECA requirements outlined in Part §192.712 (c). This paper will share lessons learned for things to consider when evaluating the suitability of performing an ECA and to help avoid sole reliance on ECA results when other factors demonstrate that the results may not be reliable.

Introduction

Due to the issued RIN2 and subsequent allowance for dent ECA following the requirements in §192.712(c), it is expected that operators will perform assessments of dents and/or request support for assessments of dents with an increased frequency. This may be done in lieu of previously prescriptive excavation and repair requirements. While §192.712(c) provides a thorough framework for required analysis steps to determine whether a dent is fit for service or requires repair, it is imperative that practical engineering practices are followed throughout the process to ensure that the results are reliable and conservative. ECA could be performed on any dent under any condition; however, there are cases where engineering discretions from experience identify concerns that may warrant a pause in the analysis and consideration of alternative solutions. Not every dent is a good candidate for ECA. The background review requirements in §192.712(c) help identify cases where an ECA may not be the most reliable solution to determine the severity of a dent subject to certain conditions.

This paper provides case studies that demonstrate how practical engineering principles support decision making processes that help determine if ECA can provide a reliable and conservative solution or in cases where the results may not be as reliable and excavation and repair should be recommended.

Case 1 – Is this a dent?

The Case 1 Dent is reported to be within a casing under a train track. Refer to Figure 1 for the location of the Case 1 Dent. The most recent 2020 MFL/caliper inspection reported this feature as

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"Dent Depth of 1.20% OD with reported strain of 12%, at 5:51 o'clock, commented as associated with debris". Due to the high strain, this dent was selected for an ECA.

Remove the text demoting where this is. Change color of Case 1 to be more noticeable.

Figure 1. Case 1 Dent Location

The first step of this dent ECA was to verify the high dent strain reported by the ILI vendor by reviewing the caliper measurements. The caliper measurements from the 2020 inspection of the reported dent did not seem to demonstrate typical characteristics of a dent. Therefore, the caliper measurements from the 2013 ILI were used to compare the shape of this dent between the two inspections. The 2013 inspection did not report this dent and commented the caliper sensor change at this location is likely due to the presence of debris. Figure 2 shows the side by side comparison of the caliper measurements at this feature location from the 2013 (left) and 2020 (right) inspections. As shown in Figure 2, there is no discernible dent shape that can be identified from the 2013 caliper measurements.

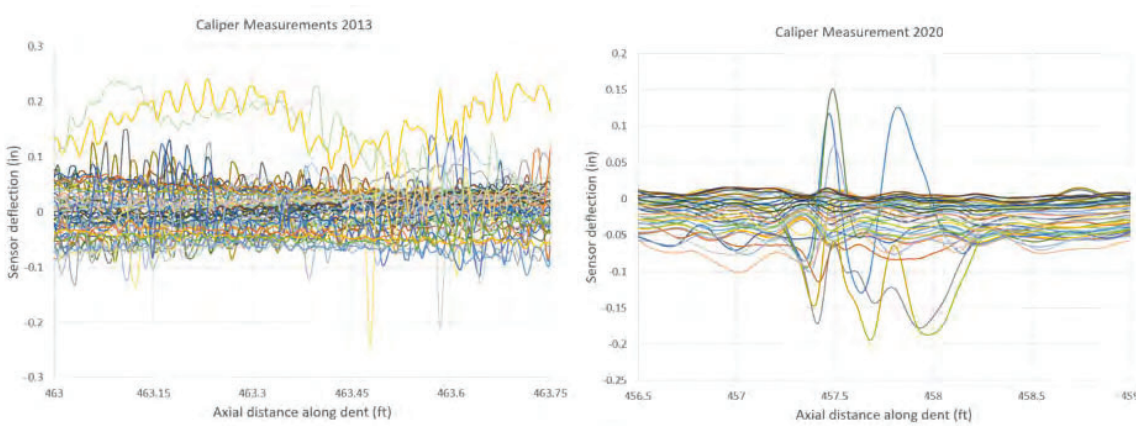

Figure 2. 2013 (left) and 2020 (right) Caliper Measurements Comparison

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In addition, the caliper signal data from both inspections was reviewed to further confirm whether this feature is a dent with debris or just debris. As a result of the review, similar findings were observed from the signal data comparison that no signal pattern in response to a typical dent could be identified. Therefore, it was believed this feature was debris which is consistent with the determination from the 2013 ILI vendor.

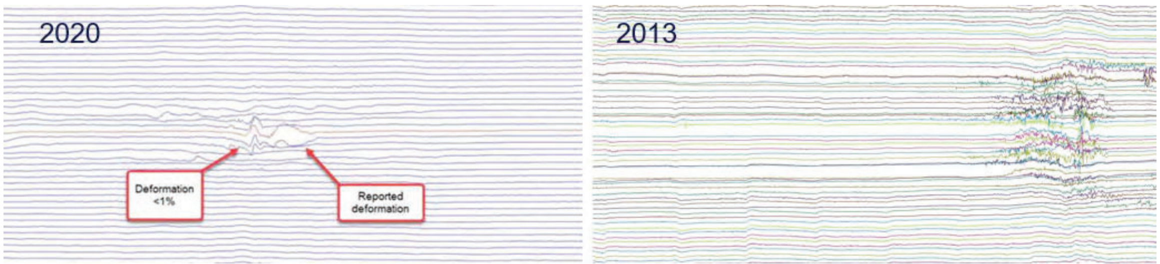

Figure 3. 2020 and 2013 Caliper Signal Data Comparison

After communicating the results of the review to the 2020 ILI vendor, the ILI vendor performed a detailed review and confirmed the signal is more representative of debris and revised the ILI listing. Due to this review, the feature was reclassified and an ECA is not required.

Case 2 – Is this a good candidate for dent ECA?

The Case 2 Dent is a topside dent with metal loss (ML), with the location shown below in Figure 4. The most recent 2021 MFL/caliper inspection reported this feature as "1.61%OD (0.35IN) – 0.72%OD (0.16IN) (ML – 23%), at 11:15 o'clock with a dent strain of 9.9%. Since this dent was reported as a topside dent with metal loss with high strain, it was selected for a dent ECA.

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Figure 4. Case 2 Dent Location

The concern of a topside dent with metal loss is that the associated metal loss could be a result of potential gouging/third party damage with a higher likelihood of crack initiation within the gouge. Per this particular ILI vendor, various criteria were used to determine whether to report the associated wall loss feature as metal loss or possible mechanical damage (i.e., gouge) and this feature did satisfy the minimum screening criteria to be called as possible mechanical damage.

In order to rule out the possibility of a dent with gouging, the following data was reviewed as the first step:

- Previous ILI data – determine whether this is a new dent
- Location of the dent – determine the likelihood of possible third-party damage
- Signal data – determine the relative location of the metal loss to the dent and dent shape

As a result of the review, the dent was visible in the 2014 signal data as shown in Figure 5 below. This finding proved the existence of the dent previously and thus the feature is not a new dent. Further investigation into the location of the dent by reviewing satellite imagery, it was found that this dent is located in an area with considerable ground disturbance, running through/adjacent to a plant providing ready-mixed concrete and related construction supplies. In addition, by comparing the relative metal loss location to the dent location based on the 2021 signal data, the metal loss is contained within the dent, as shown in Figure 6.

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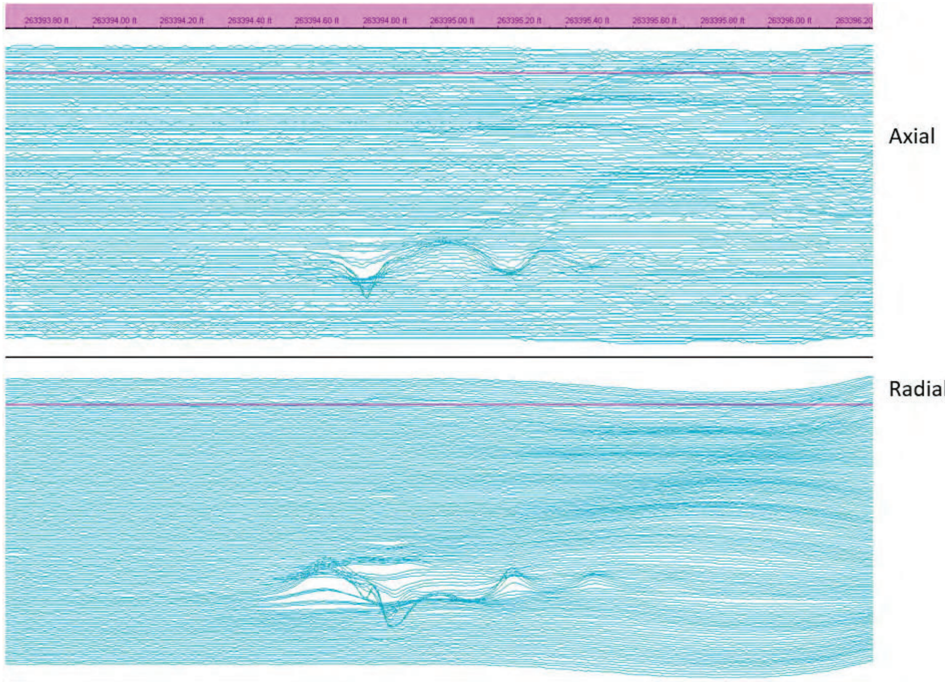

Figure 5. 2014 Signal Data

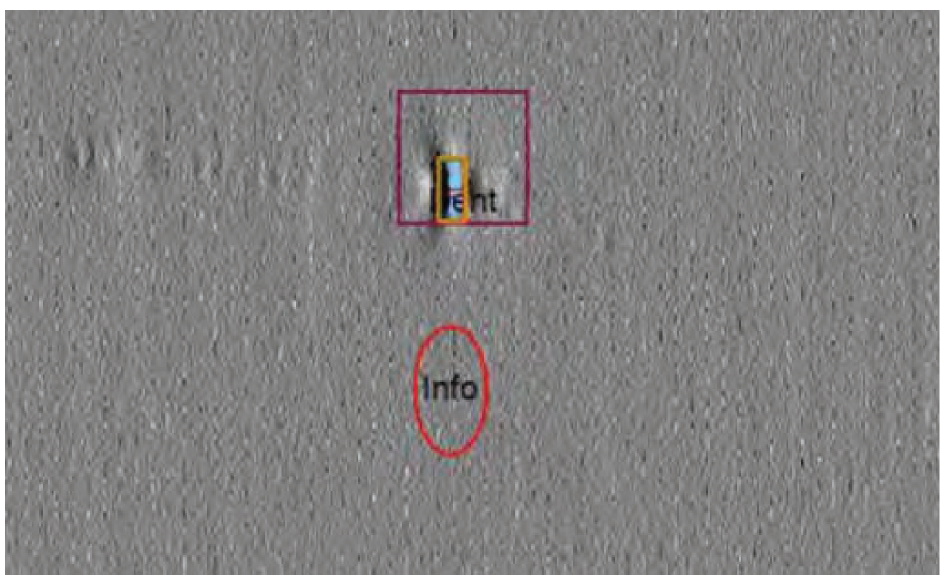

Figure 6. 2021 Signal Data

Based on the findings of the review, it was most probable that this feature was a dent with a gouge, which had likely been present in the pipeline for some time. Because it was decided that this dent would not be a good candidate for ECA, it was recommended for excavation. The dent was examined in the field and was found to be a dent with gouge with linear indications beneath the gouge, shown below in Figure 7.

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Figure 7. Case 2 Dent Field Findings

Case 3 – What could have been missed in a dent ECA?

The Case 3 Dent is a bottomside dent interacting with metal loss. The most recent 2021 MFL/caliper inspection reported this feature as "Dent Depth: 8.37% OD with metal loss - 26% (manually sized) additional interactions" with a second dent peak depth of 5.25% of the OD, at 5:47 o'clock with a dent strain of 5.54%. This dent was selected for a dent ECA due to the total deformation depth and the associated metal loss.

Since this dent with metal loss is at the bottomside of the pipe, it is unlikely to be a dent with gouge. In order to further rule out the possibility of a dent with gouge, a 3D profile was created using the caliper measurements and the relative location of the associated metal loss. As shown in **Figure 8**, the associated ML is located at the upstream edge of the dent which suggested a lower likelihood for this feature to be a dent with gouge.

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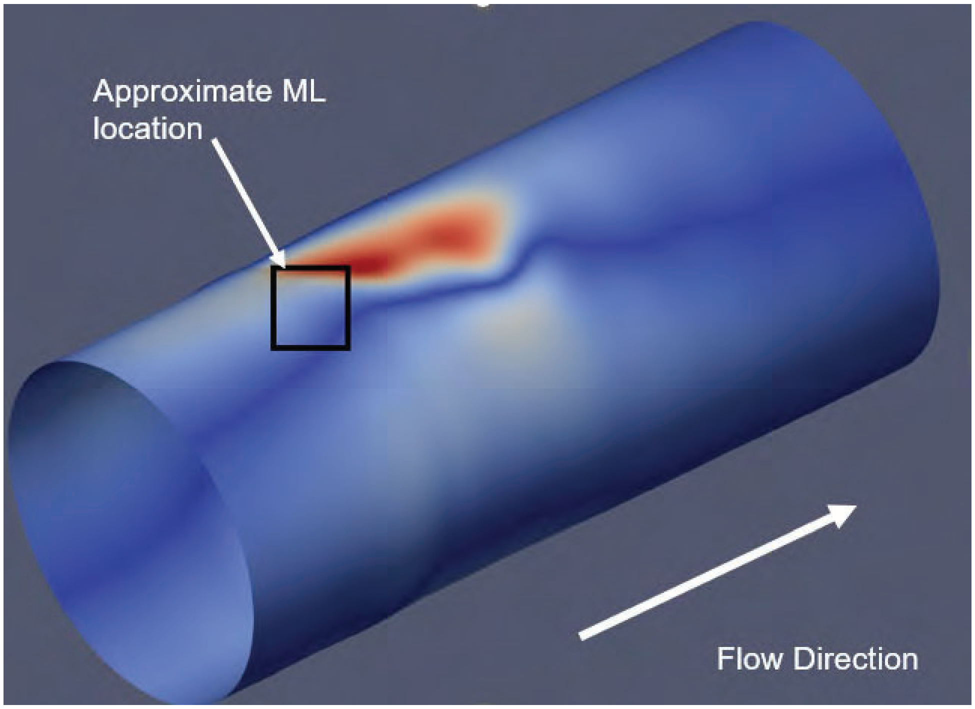

Figure 8. Case 3 Dent 3D Profile and the Relative ML Location

A signal review comparison was also performed using the 2021 ILI signal data and the previous ILI signal data from 2014. Based upon the comparison shown in Figure 9, the associated metal loss seemed to be a new metal loss feature in the 2021 MFL signal data. Therefore, the FEA model should conservatively account for the potential metal loss growth between the 2014 and the 2021 inspections. This step could have been very easily missed if the signal data comparison was not performed.

Based upon the findings that the associated metal loss is a new metal loss feature, this dent was scheduled to be excavated in March 2024. Therefore, no field data is available at this time.

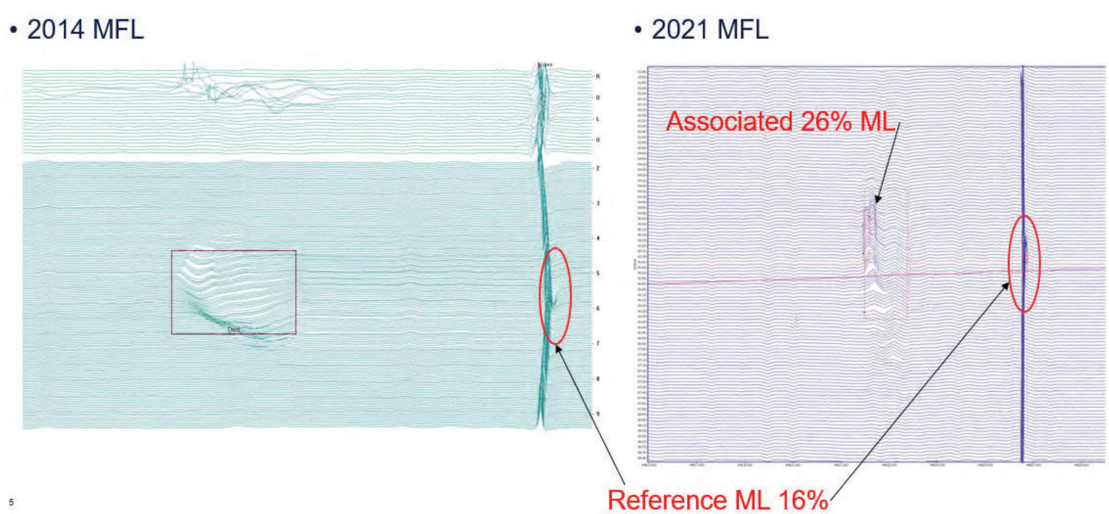

Figure 9. Case 3 Dent with Metal loss Comparison between 2014 and 2021 Signal Data

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Case 4 – What is the basis for a dig decision?

The case 4 dent is a bottomside dent with an ILI-reported depth of 2.5% OD, at 6:01 o'clock orientation with a dent strain of 5%. This dent is determined to interact with an external metal loss with a depth of 44% wall thickness. The case 4 dent 3D calliper profile is shown below in **Figure 10**.

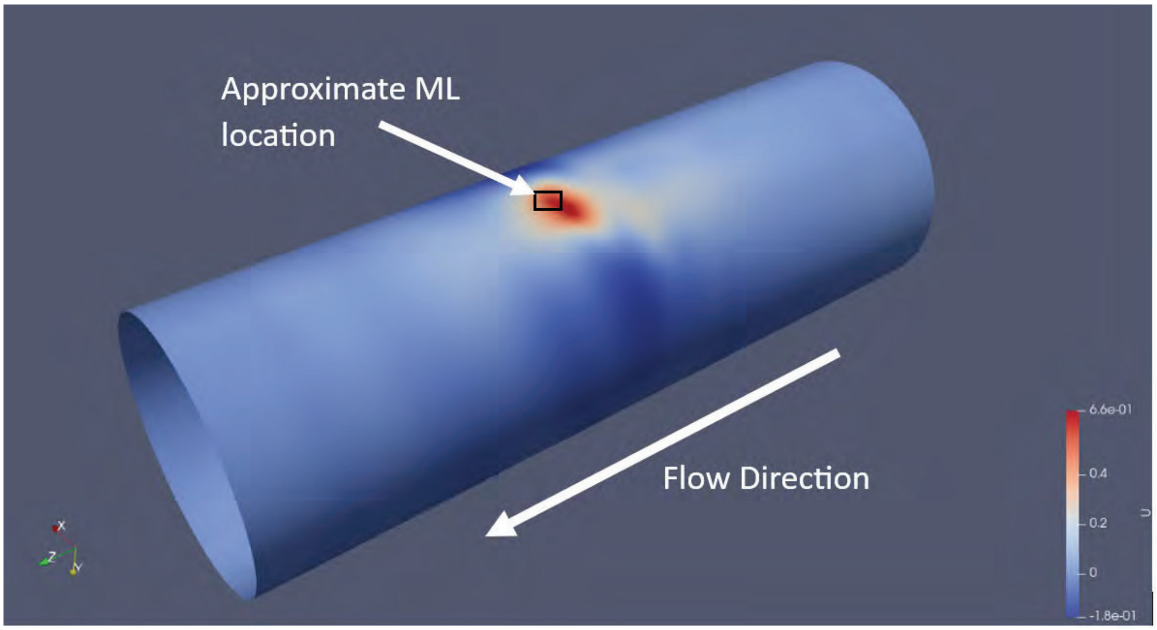

Figure 10. Case 4 3D Caliper Profile

This dent with metal loss is a bottomside dent with relatively low dent strain. However, the fact that the associated metal loss is 44% of the wall thickness (significantly deep) and the metal loss is adjacent to the dent apex, practical engineering judgement raised a red flag that an ECA may not be reliable or conservative with the potential severity of the defect. The decision to excavate this dent with metal loss was decided rather than an ECA due to the background review.

However, what if an operator elected to perform a Level 3 FEA assessment to analyze the dent from the stress and strain perspective? Below is an example of the Level 3 FEA process and results.

In the FEA modeling process, the dent was assumed as a constrained dent according to the o'clock orientation and a rigid indenter surface based on ILI caliper data was created for the dent feature to impart the deformation profile into the pipe. The rigid indenter was displaced into the pipe surface in the FEA model using surface-surface contact with hard contact behavior in the normal direction. To simulate the denting process, the feature dent was placed at the 12 o'clock position and rigid shell supports were added at the bottom and sides of the pipe, opposing the force of the indenter into the pipe, in order to simulate potential ovality deformation and best match the axial and circumferential profiles of the FEA results with those reported from the caliper data. **Figure 11** shows the longitudinal and circumferential profiles of the ILI and FEA modeling. It is seen that there is good profile agreement between the ILI and FEA model results, indicating that the FEA modeling accurately reproduced the dent formation process.

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The FEA model results for the dent deflection are shown below in **Figure 12** with the associated metal loss feature adjacent to the apex. The equivalent plastic strain distribution is shown in **Figure 13**, where it can be seen that the plastic strain area is concentrated at the dent apex region with a maximum value of 5.53%, which is close to the ILI reported curvature strain of 5%. Furthermore, there is no significant plastic deformation observed in the interacting metal loss region. The maximum hoop stresses as a function of internal pressure at the dent and the metal loss area were extracted and are shown below in **Figure 14**. The hoop stress for an un-dented pipe is also plotted in the figure as a comparison, where it can be seen that the presence of the dent and metal loss features generate a significant stress concentration. Further, the highest stress in the dented region is not located within the metal loss area.

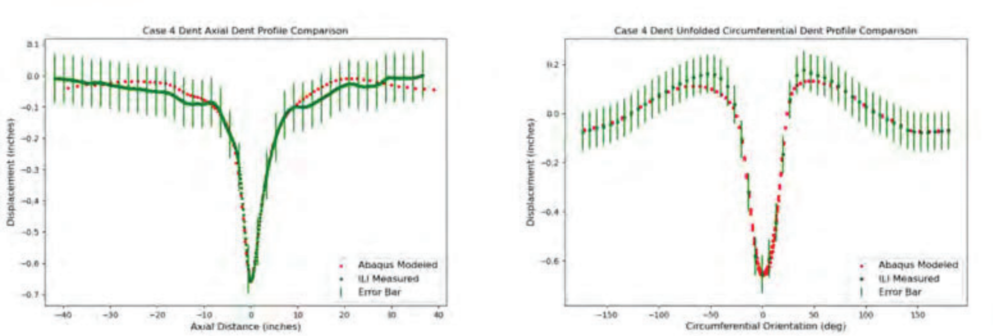

Figure 11. Case 4 Longitudinal and circumferential profiles comparison between ILI and FEA

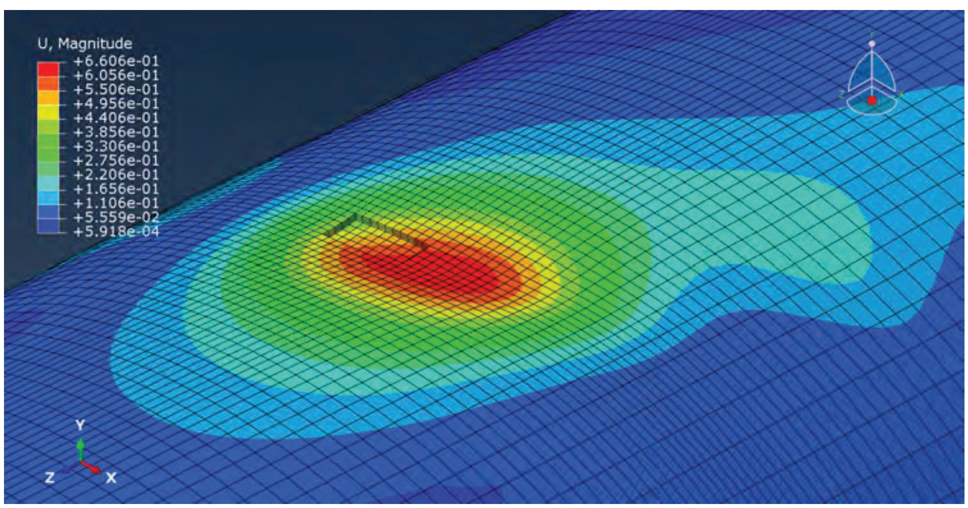

Figure 12. FEA Deformation of Case 4 Dent

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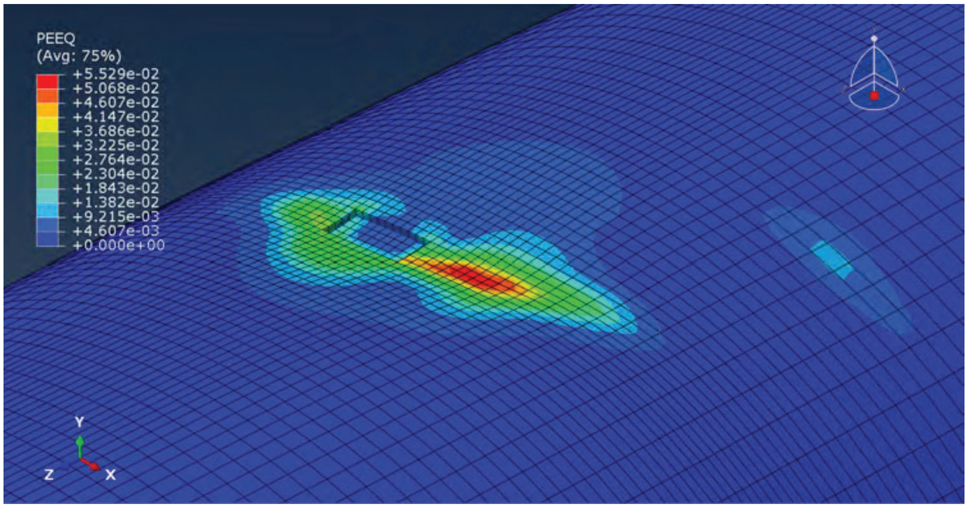

Figure 13. FEA Equivalent Plastic Strain Value of Case 4 Dent

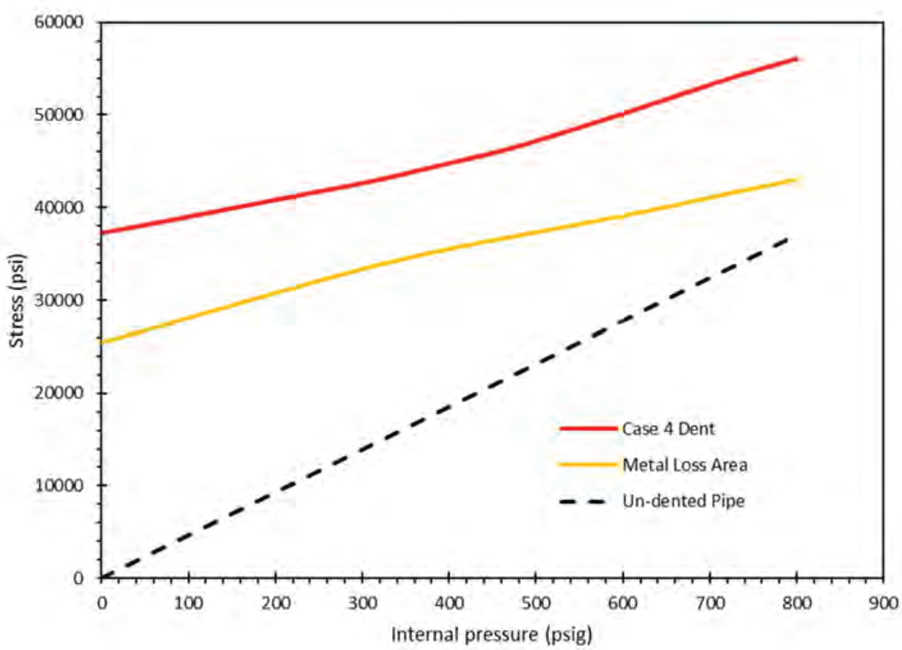

Figure 14. Maximum Hoop Stresses as a Function of Internal Pressure at the Case 4 Dent and Metal Loss Area

The FEA modelled maximum equivalent plastic strain, lower/upper bound Ductile Failure Damage Indicator (DFDI) and Strain Limit Damage (SLD) values, and the calculated fatigue life of the case 4 dent are listed in **Table 1**. The FEA modeling results show that this dent is acceptable for future service as there is low risk for crack initiation due to low DFDI and SLD values and the fatigue life is greater than 100 years.

Table 1: FEA Modelling Results for Case 4 Dent

Feature	Eq. Plastic Strain	DFDI Lower Bound	DFDI Upper Bound	SLD Lower Bound	SLD Upper Bound	Fatigue Life (Years)
Case 4 Dent	5.53%	0.087	0.173	0.128	0.246	>100

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Now, we have two different sets of data to support a dig or no dig decision. How about comparing it to the excavation results?

Based on the excavation examination findings and metallurgical analysis, a crack was found to be associated with the case 4 dent as shown in **Figure 15**. A portion of the pipe containing the dent was removed for a detailed metallurgical analysis and laboratory hydrostatic pressure testing. he results of the metallurgical analysis indicated that a crack was located at a bottomside dent and is associated with the ILI reported metal loss. The hydrostiatic pressure testing resulted in the crack failing at an internal pressure of 257 psig. **Figure *16*** shows an image of the pipe actively leaking during the laboratory hydrotest at 257 psig.

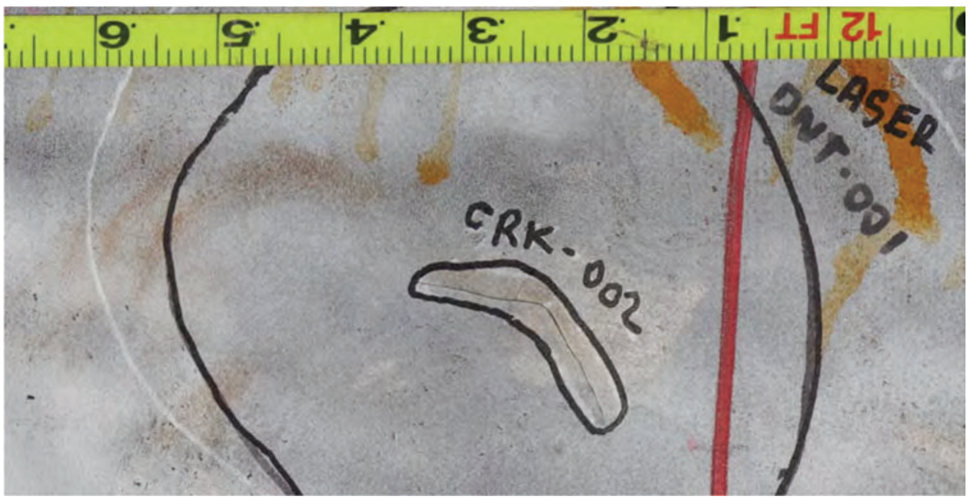

Figure 15. Close-up Photograph of the External Surface of the Pipe Section Containing the Case 4 Dent, Showing a Crack at a Bottomside Dent

Figure 16. Close-up Photograph of the External Surface of the Pipe Section Containing the Case 4 Dent during the Hydrostatic Pressure Test Showing the Leak Location

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The crack was slightly longer on the internal diameter (ID) surface (2.5 inches long) compared to the outside diameter (OD) surface (1.9 inches long), indicating crack initiation at the ID surface. Beach marks on the fracture surface also are consistent with crack initiation at the ID surface and propagation to the OD surface. The beach marks also indicate that the cracking initiated at/near where the dent was the deepest.

The ID surface of the pipe would be in tension from a restrained bottomside dent (likely a rock dent) and is consistent with ID crack initiation. The failure pressure value, presence of an OD surface breaking crack prior to the hydrostatic pressure test, ID crack initiation, and no clear evidence of ductile features on the fracture surface indicate the crack was through-wall prior to the hydrotest. The through-wall crack depth is not consistent with the in-the-ditch (ITD) crack depth of 0.097 inches (34.5% of nominal wall thickness). The detailed geometry information of the case 4 dent and the interacting crack feature is listed in Table 2.

The most likely mechanism for crack propagation is fatigue, based on the location of the crack at the apex of the dent, the propagation direction from ID to OD, and the presence of beach marks on the fracture surface. There was no evidence of fatigue striations; however, the fracture surfaces were corroded, obscuring any fatigue striations that may have been present.

Table 2: NDE Information of Case 4 Dent and the Interacted Crack Feature

NDE Feature Type	Distance from U/S GW [ft]	Depth (%)	Length (in)	Width (in)	O'clock Orientation
Dent	12.08	2.8% OD	6.865	6.176	6:05
Crack	12.20	34.5% WT	2.500	0.125	6:18

Comparing the two approaches and results in evaluating the case 4 dent, it can be shown that the presence of a metal loss feature interacting with a dent requires more considerations in the dent ECA, especially when adjacent to the dent apex, where the ML feature could be a crack-like feature, regardless of the o'clock position. Therefore, simply using the o'clock position to rule out the potential for a dent with gouge to support a no dig decision might not be sufficient.

Conclusion and Recommendation

Based on the four case studies presented in this paper, it is obvious that the background review prior to the Finite Element analysis step is critical for each dent ECA. Incorporating a comparison to previous ILI data, along with a detailed review of the signal data can yield significant insights into the ECA evaluation process as well as the overall conclusions and response decisions. It is not recommended to only rely on the most recent caliper inspection data to perform a dent ECA, as important details for the reported features can be missed, leading to misguided conclusions. The background review should consider all relevant information that is available, including but not limited to, the following components.

- Historical ILIs and signal data
- Records of any operational changes

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- Repair history of the pipelines
- Aerial images
- Damage prevention information
- Field engineer knowledge/expertise

Further, it is imperative to consider all information/conclusions gleaned from each step of the review and to not discount outliers without justifiable cause. If engineering judgment raise any potential red flags within the review, take note and consider within the context of the entire dataset in order to apply the most reliable and conservative assessment methods or recommendations to aid in appropriate integrity management decisions. The case studies presented in this paper demonstrate how a dent ECA could theoretically provide non conservative results when not performing a rigorous background review and applying practical engineering judgment practices.

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