METHOD TO THE MADNESS:
WHY ASSESSMENT TECHNIQUE MATTERS WHEN INSPECTING DENT STRAIN

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Abstract

This case study compares dent strain assessments between ILI and laser scanning methods, showing agreement in overall trends but revealing meaningful variations in measured values. While both techniques produced consistent patterns in strain distribution, the observed differences between methods underscore how inspection approaches can influence results.

The research particularly explores scenarios where ASME B31.8 Appendix R shows limitations: with dents approaching 6% restriction, in skewed geometries causing uneven circumferential strain distribution, and in cases where combined high restriction and irregular shape may artificially inflate calculated strains. These findings demonstrate that while the standard provides a valuable baseline assessment, its assumptions become less reliable for complex dent profiles.

The study concludes that supplementary evaluation methods should be considered when dealing with non-uniform dents or those near the code's application boundaries, ensuring more accurate strain characterization for integrity management decisions.

Background

Dent strain analysis is an essential component of modern pipeline integrity management, offering a far more nuanced assessment of mechanical damage than traditional depth-based measurements alone. While simple depth measurements can indicate a dent's magnitude, strain analysis provides a comprehensive understanding of the localized stress and complex deformation experienced by the pipe wall. This granular detail is crucial for accurately predicting the potential for critical failure mechanisms such as cracking, fatigue, and rupture, thereby ensuring safe operational margins.

As a leading provider of in-line inspection (ILI) services, Entegra is committed to delivering precise and actionable dent strain reports. Our methodology integrates data from high-resolution caliper tools with proprietary algorithms, which have been rigorously developed in accordance with foundational industry standards, including ASME B31.8 and API 1183. This advanced service empowers our clients to make effective and efficient integrity management decisions. By providing a clear, quantitative assessment of dent severity, we enable operators to confidently prioritize repairs, optimize maintenance schedules, and justify the acceptance of less severe anomalies, ultimately enhancing both operational safety and resource allocation.

Since 2019, Entegra has successfully delivered dent strain analyses for a diverse range of operators across various global regions, demonstrating the robustness and reliability of our approach. In this presentation, we will share key insights gained from this extensive field experience, including a discussion of notable highlights and a detailed examination of a unique case study that showcases the diagnostic power of our technology.

Discussion

Originally, dent strain was needed to determine severity or sharpness of a plain dent for features below 6% of the outside diameter (OD). The sharper the dent, the more potential there is that stress concentrators will be present at the dent location. With time, dent strain has evolved into one data point for the Operator to consider when assessing the threat of a dent. Plain dents are still a concern, however interaction of coincidental features with a dent, — such as interacting with a girth weld, another dent, or metal loss — does pose a critical threat to the accuracy of the calculation. There are more detailed developed practices such as Engineering Critical Assessments (ECA) of dents and found in other Industry-led groups and recommended practices. The intent is not to discuss the merits of the performing an ECA, but the input of the parameter of dent strain, even before an ECA is considered.

Dent strain calculations are influenced by the complexity of the dent, and what makes a dent more complex is the interaction of the dent profile with its alignment on the pipeline or other features found in the pipeline. These scenarios may include such things as:

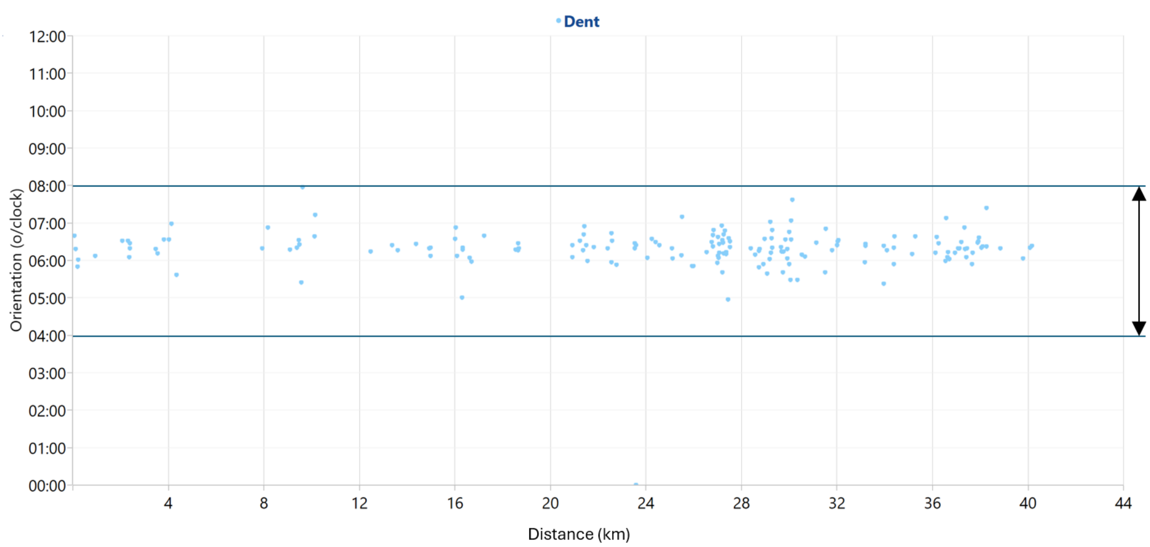
- Interaction with a girth weld/seam weld
- Interaction with another dent (multi-apex dent)
- Interaction with a bend
- Re-rounding of the pipe and reporting parameters
- Skewed or off-axis dents

It would appear obvious that the interacting feature would have an identifiable trait that can be detected by the geometry tool sensors. Now let's explore examples of these various scenarios and observe how the outcome may not be as expected.

Dent Case Study I

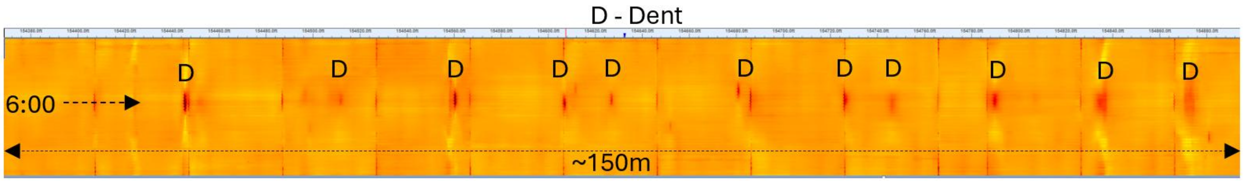
This case study will show how a dent located on the bottom of the pipe impacts performing dent strain calculation. When the pipe shows a dent that is situated over a hard surface, such as a rock, the pipe tends to re-round upon excavation, presenting a unique situation. If the pipeline is constructed in a rocky terrain, a high density of bottom-side dents may be reported as seen in Figure 1.

Figure 1: Orientation of Dents in a 30in Pipeline with Bottom-side Location Defined



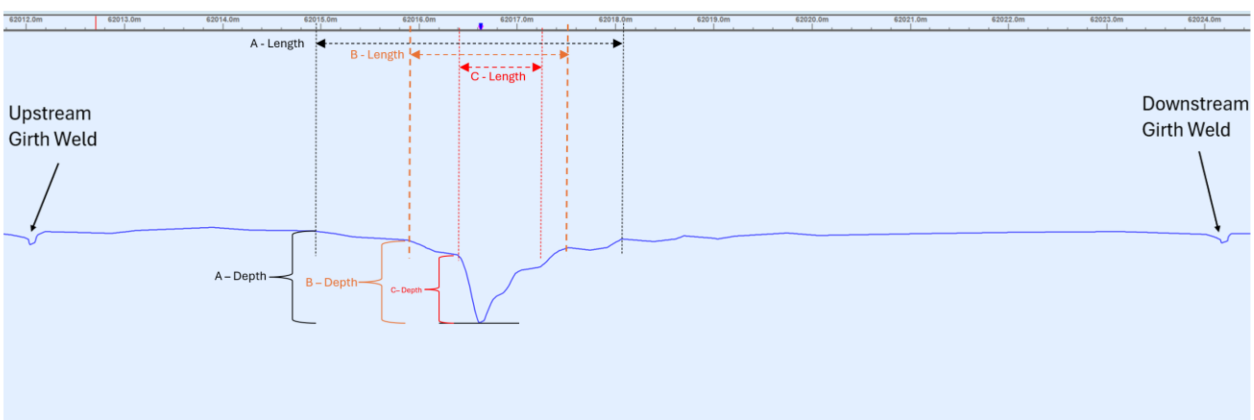
Typically, bottom-side dents are classified this way when the dent apex is located between the 4:00 and 8:00 clock positions. An example relevant to this discussion can be seen in an image derived from caliper data across approximately a 150-meter stretch of pipeline, which reveals several bottom-side dents in Figure 2.

Figure 2: Dents Detected along the Bottom-side of the Pipe



An assessment of one of these dents is examined in greater detail to highlight variability in dent reporting, both from the perspectives of dent restriction and dent strain. This case study involves a 30-inch pipeline with a standard wall thickness of 9.53 mm. One important factor to consider is the ratio of the outside diameter to the wall thickness (D/t). Typically, when the D/t ratio exceeds 35, there is potential for re-rounding of the pipe in the case of bottom-side dents. In this example, the ratio is notably high—approximately 80. Dent strain calculations will be presented, including variations in the reported length and depth of the dent. For a clearer understanding of where these variables are derived, refer to Figure 3.

Figure 3: Axial View of Target Dent with Variable Stated Lengths and Depths on a Caliper Channel



In the image above, the variables presented illustrate the effect of modifying the length and/or depth of the dent. The parameters associated with the feature labeled 'A' represent a dent region that accounts for the entire length of the deformity, including both the dent and the ovality components. Feature 'B' defines a dent region that excludes most of the ovality, beginning at the first notable change in slope of the dent. Feature 'C' isolates the dent component of the deformity, removing all ovality from both the length and depth reporting perspectives. A summary of these three variable definitions is provided in Table 1.

Table 1: Variable Dent Length and Depth Parameters with Calculated Strain

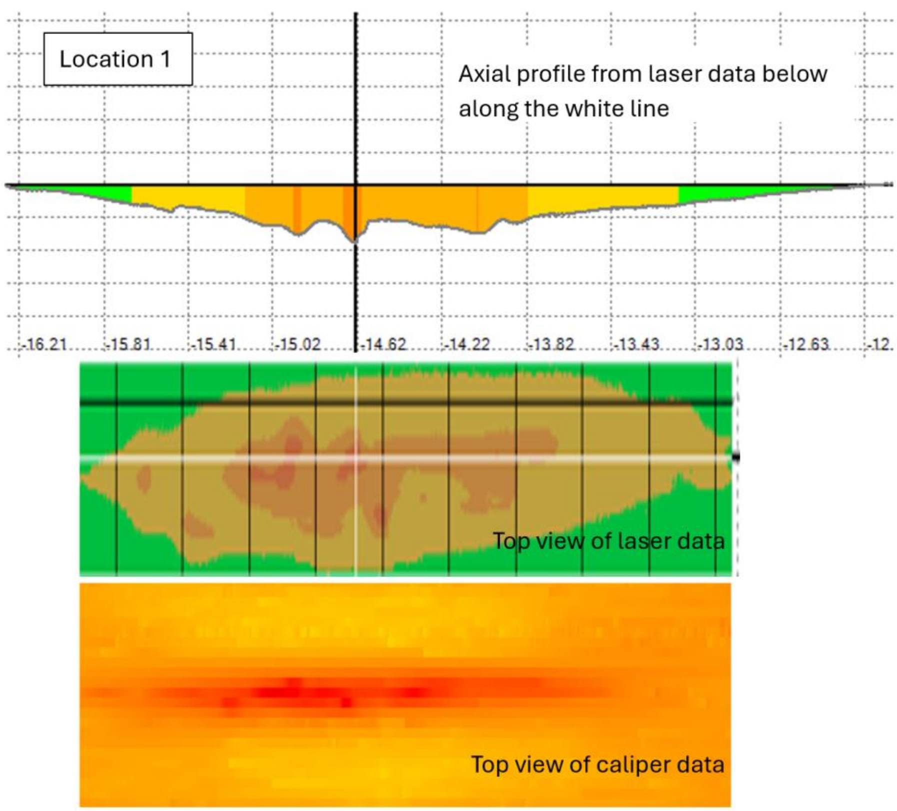
30in Pipe - 9.53mm WT				
Dent Classification	Dent Depth (%)	Dent Depth (mm)	Dent Length (mm)	Dent Strain
A	3.36	25.6	3115	7.4%
B	2.17	16.5	1606	4.2%
C	1.81	13.8	827	3.4%

Dent depth is the variable that has a greater impact on the above values. If the dent depth is kept constant and the length is longer or shorter than what is stated in the table, the dent strain calculation will remain at 7.4%, which does exceed 6% strain. The important aspect of this dent feature is that Dent A has the maximum reported restriction which includes the ovality component of the dent. When the dent was excavated the dent depth was 1.4% (10.7mm deep) with a length of 526mm, which would have computed to a strain value of 2.6%. These notable changes in the input parameters will have an effect on the calculated strain and need to be taken into consideration when the output is evaluated further.(1)

Dent Case Study II

This case study examines a dent with multiple restrictions to determine its impact on strain calculations. A dent with multiple restrictions is defined as one having several measurable reductions in internal diameter (ID) without regaining the nominal ID within that region.

Figure 4: Multiple Dents Across the Axial Length of Pipe – Two Locations.



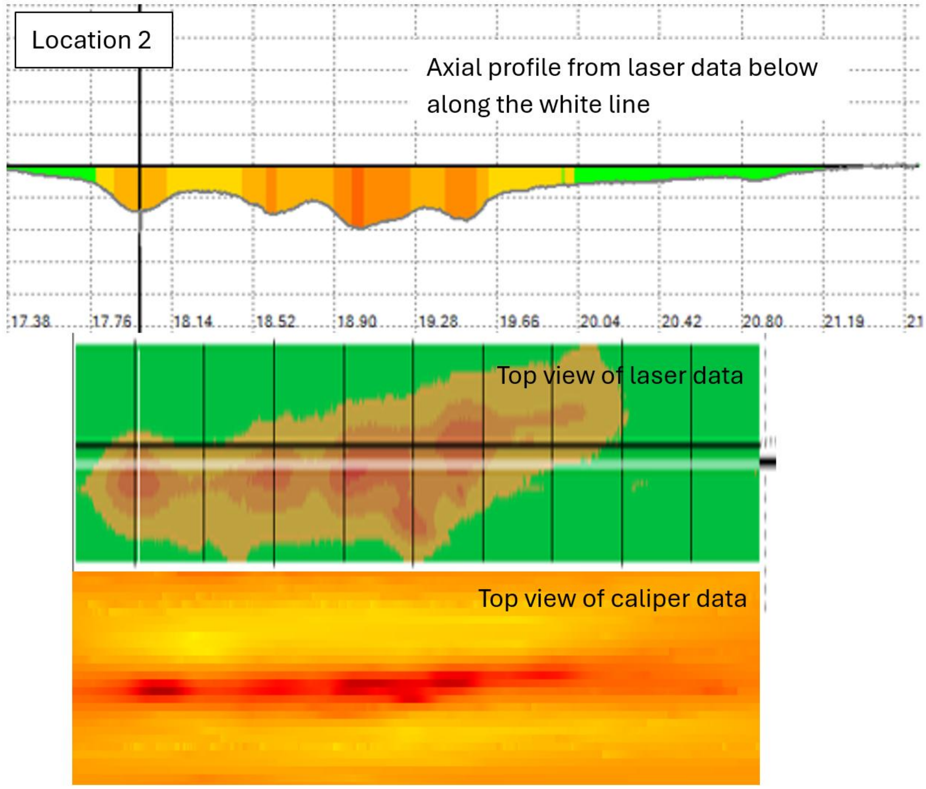


Figure 4 provides the axial profile of two such locations, based on laser scanning data from a 6-inch pipeline with a 4.78 mm nominal wall thickness. In this figure, the vertical black line indicates the point of maximum strain, whereas the color variation illustrates the change in restriction. In both examples, the multiple ID restrictions span a length of up to 4 feet (1219 mm). In location 1, the maximum strain occurs at the dent's apex. In location 2, however, the maximum strain is found not at the deepest point, but at a less restrictive dent.

To accurately calculate dent strains, the slopes of the upstream/downstream axial components and the clockwise/counterclockwise circumferential components are mapped. Generally, a sharper slope corresponds to a greater dent strain. In these situations, the adjacent restriction prevents the slope from being mapped from its peak point back to the nominal ID.

This methodology artificially reduces the calculated dent strain, and manual intervention may be required to determine the true maximum strain. To ensure accuracy, each dent must be isolated to properly map its measurement components; otherwise, the calculation will be inaccurate.

Dent Case Study III

In this last case study, a look at an off-axis dent will be discussed to witness another variable that can alter the output calculation (see Figure 4). While processing a large volume of dent strain analysis data, an unusually high dent strain value of 63% was identified on an 8-inch natural gas pipeline. According to ASME

B31.8R, a dent strain ≤6% restriction is considered a conservative acceptance criterion for plain dents. In the U.S., any dent with a restriction ≥6% is classified as a critical defect requiring immediate attention. A slightly lower threshold of 4% may be acceptable in specific cases, such as when different materials are involved or when dents affect ductile welds.(2)

However, a strain of 63.6% is an order of magnitude higher than what is typically deemed safe. As shown in Table 2, the dent has a depth of 16.9 mm, corresponding to 7.7% of the pipe diameter. This relatively low depth indicates a sharp dent, especially when compared to the hundreds of other dents found on the same pipeline.

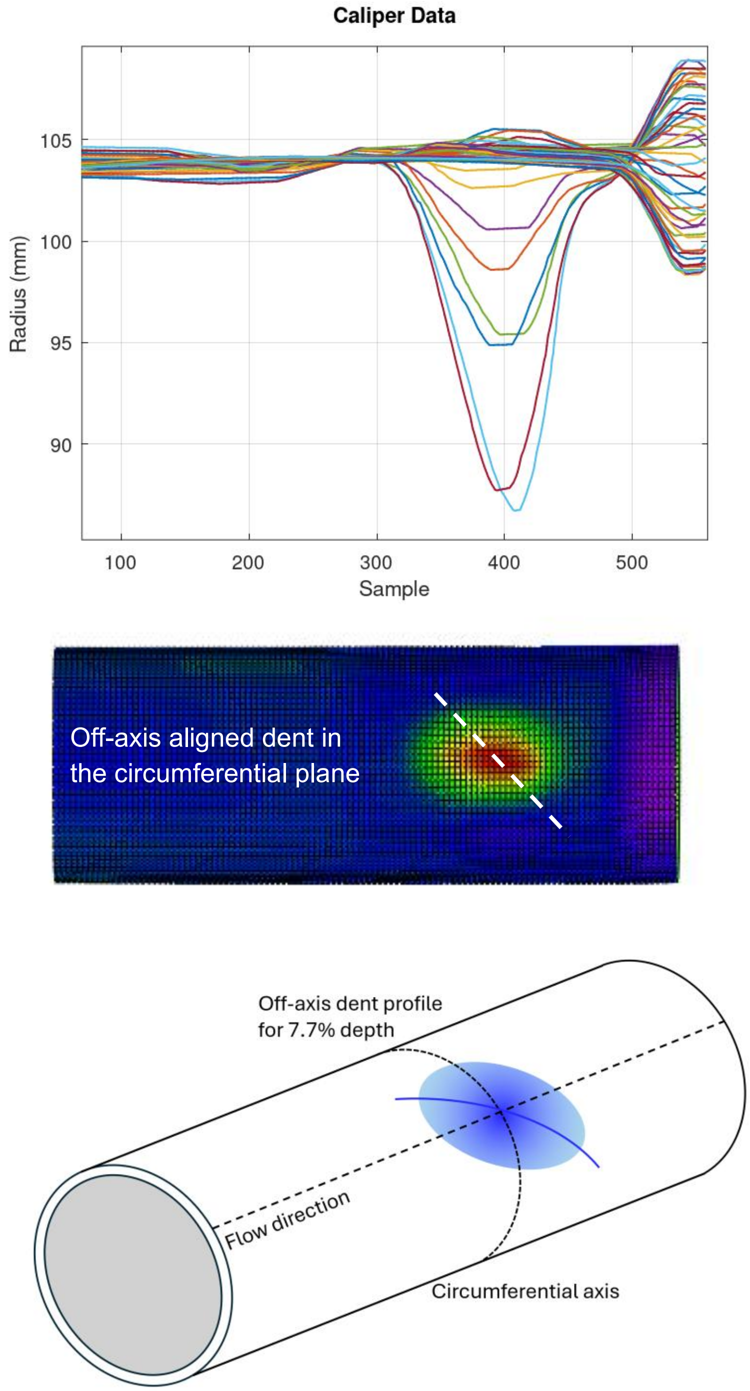
Table 2. Dent Dimension Summary

Measurement	Dimension
Length	160 mm
Width	93 mm
Depth	16.9 mm
Circ Radius	-5.62 mm
Axial Radius	-55.56 mm
Circ Bending Strain	52.1 %
Axial Bending Strain	5 %
Axial Membrane Strain	0.6 %
Inner Surface Strain	49.5 %
Outer Surface Strain	50 %
Max Strain	63.6 %

Given the sensor density of the caliper system on our 8-inch ILI tool, a resolution of 12 mm in the circumferential direction is expected. In contrast, the high sampling rate of caliper sensors allows for a finer resolution of 1 mm in the axial direction. However, the dent profile may appear abruptly distorted along the circumferential axis due to the lower resolution and off-axis alignment, increasing the calculation of curvature radius in the transverse plane and further affecting strain calculations. Because the estimation of curvature is highly sensitive to these data undulations, applying appropriate smoothing and filtering algorithms is a critical prerequisite for achieving accurate and reliable strain calculations. In situations where off-axis dents are present, smoothing and filtering cannot alter the alignment of a dent.

As a result, the circumferential bending strain for this dent was calculated to be 52.1%, while the axial bending strain was significantly lower at 5.0%. This suggests a smooth profile along the pipe axis but a sharp profile circumferentially. The axial profile of the dent, based on the sensor reading at the point of maximum restriction, is shown in Figure 5. It can be observed that the dent peak is not perfectly perpendicular to the flow direction; instead, it is diagonally aligned across the pipe axis.

Figure 5. Axial Profile of Caliper Data and 3D Geometry Demonstration



Due to the combination of high dent restriction, lower data density in the circumferential direction, and an irregular dent profile (off-axis alignment), the calculated dent strain value may be artificially inflated. These findings highlight that while the standard provides a valuable baseline for assessment, its assumptions may become less reliable for complex dent geometries.

It should be noted that when an off-axis dent is observed, it may indicate a potential red flag, such as mechanical damage caused by a third party. This is a critical finding, as dents—particularly those interacting with welds or containing stress concentrators like gouges—are considered potentially severe imperfections under standards such as CSA Z662 (2) and API RP 1183 (*Assessment of Dents in Pipelines*) (3). In the cases discussed above, the curvature-based equation provides a series of curve fits in two planes. This simplified approach is typically used as a preliminary step (Level 1 or Level 2 assessment) within a broader Engineering Critical Assessment (ECA) of the dent.

When these simplified models are insufficient, or the dent exceeds their prescribed limits, further screening is needed. This more rigorous (Level 3) ECA, following the methodologies outlined in API 1183 or CSA Z662, almost always involves a finite element model. This FEA is essential to accurately capture complex 3D geometry, local plastic strain concentration, and residual stresses. Such advanced analysis, often informed by foundational research from organizations like the Pipeline Research Council International (PRCI) (4), is required to provide a more precise, strain-based prediction of the dent's impact on pipeline integrity and fitness-for-service.

Conclusion

As an efficient method that integrates parameters such as depth, length, and width, the curvature-based strain equations in ASME B31.8 Appendix R offer valuable insights and effective preliminary screening for dent assessment. However, when complexities arise in real-world applications—such as dents within regions of ovality, dents with multiple restrictions, or off-axis dents (which are often red flags for third-party mechanical damage)—significant inaccuracies can occur in dent strain calculations.

In essence, while the ASME B31.8 equations are a critical Level 1 assessment tool, they are not a definitive solution for all scenarios. When these preliminary screening criteria are not met, or when complex geometries are present, a more rigorous Level 2 or 3 Engineering Critical Assessment (ECA) is mandated. This advanced analysis, following the tiered methodologies of industry standards like API RP 1183 (Assessment of Dents in Pipelines) and CSA Z662, necessitates the use of finite element analysis (FEA). Ultimately, FEA is the primary method capable of accurately modeling the complex 3D strain state and residual stresses, providing the reliable data needed for a final fitness-for-service determination, often drawing upon foundational research from bodies like the Pipeline Research Council International (PRCI).

Reference

[1] D. D. Mackintosh, “Pipeline Dent Strain Assessment Using ASME B31.8,”1. Mackintosh DD. Pipeline Dent Strain Assessment Using ASME B31.8 [Internet]. 2020.

[2] *CSA Z662:19 - Oil and Gas Pipeline Systems*. Toronto, Canada: CSA Group, 2019.

[3] “Assessment and Management of Dents in Pipelines,” Washington, D.C., USA, Nov. 2020.

[4] A. Rana and S. Tiku, “Guidance for Performing Engineering Critical Assessments for Dents on Natural Gas Pipelines,” USA, Nov. 2023. doi: 10.55274/R0000044.

2. CSA Z662:19 - Oil and Gas Pipeline Systems. Toronto, Canada: CSA Group; 2019.

3. Assessment and Management of Dents in Pipelines [Internet]. 1st ed. Washington, D.C., USA; 2020 Nov.

4. Rana A, Tiku S. Guidance for Performing Engineering Critical Assessments for Dents on Natural Gas Pipelines [Internet]. USA; 2023 Nov.