An Identity Crisis, the Impact of Manufactured Bends in Bending Strain Assessments

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Abstract

Assessments based on inertial measurement unit technology are an important component of many operator's geohazard integrity management programs. Bending strain assessments are commonly used by operators to identify areas of the pipeline that have been impacted by geohazards, and strain change assessments can be used to determine the stability of those suspected areas. Performing a bending strain assessment requires a vendor to successfully identify and classify bending strain features above a reporting threshold as either reportable bending strain features or as manufactured bends. Features identified as manufactured bends are excluded when reporting a bending strain feature or identifying peak strain locations. While the identification of manufactured bends is a critical step in performing a bending strain assessment, there have not been any publications to date examining vendor performance in correctly identifying manufactured bends. This is partly because original documentation does not exist for most pipelines conclusively identifying the location of cold bends or providing a description of their angle and orientation. However, this does not change the fact that subjectivity exists in bending strain assessments that has not been critically reviewed by the industry. This paper presents a first of its kind case study examining a bending strain assessment performed on a recently built pipeline with detailed records of manufactured cold bends from construction. The paper compares the bends recorded from construction with the bends identified by the vendor. Additionally, the study also examines the interaction of bending strain features and tie-in welds, as these welds have long been suspected as a source of construction induced bending strain. This paper will help operators using bending strain assessments to understand both the subjectivity in these assessments and the expected real-world performance in identifying manufactured bends.

Introduction

Over the last decade, bending strain features have become a mainstay for many operators in the management of geohazards. Previous studies performed by the authors have demonstrated the repeatability of bending strain assessments when assessing previously identified features or managing strain change features (1). Despite the reliability associated with calculating strain on previously identified features, issues have been raised by the same authors regarding variability in bending strain assessments when performed by different vendors (2; 3). Some of this variability could be attributed to the differences in the inspection conditions, the influence of gage length, or the reporting threshold used by the vendors. Unfortunately, the authors found most of the variation was due to inconsistencies between vendors in identifying bending strain features even when the combined bending strain was above the reporting threshold. Additionally, the authors have observed inconsistencies between vendors, and sometimes even within the vendors themselves, in the identification of manufactured bends.

Problem Statement

The identification of manufactured bends is the subject of this investigation. Unfortunately, there is little public information available on how bending strain analysts identify anomalous bending strain patterns while excluding intentional strains from manufactured bends. Most of the knowledge resides

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with the vendors who perform these bending strain analyses in the form of training material or presentations for clients. The authors are aware of one prior publication (4) that provided some guidance on how bending strain features are identified and discriminated.

While experienced analysts can readily discriminate an isolated bending strain pattern associated with a manufactured bend from anomalous bending strain patterns, these same analysts will admit that the discrimination can become more challenging in areas that are congested with manufactured bends or in vintage pipelines where the bending strain practices may have been less controlled. Unfortunately, these two scenarios are often commonly associated with the geohazard threat. Many geohazards occur in older pipelines located in areas of continuous elevation change where manufactured bends were necessary to construct the pipeline. Additionally, small diameter pipelines such as NPS4 or NPS6 can present challenges given the inherent flexibility of these diameters.

The authors of this paper have significant experience in analysing and interpreting bending strain patterns and are familiar with the challenges in identifying manufactured bends. Therefore, a study was conducted to investigate the ability of IMU bending strain analysis to identify known manufactured bends. To their knowledge, no published studies exist examining this critical question.

Case Study Data

Identifying a suitable segment for a case study examining manufactured bends is a challenging endeavour. Very few pipelines exist with records identifying the location of manufactured bends. Even newer pipelines are unlikely to have records of manufactured bend locations. Using bends identified through prior ILI assessments is self-defeating as these bends are typically identified using IMU-based technologies or caliper-based technologies, the latter of which are more subjective than IMU.

TC Energy identified a 36-inch diameter pipeline constructed in Louisiana in 2023 for the case study. The pipeline is 42.4 miles long and has detailed construction records of the manufactured bends used in the construction. An example of the construction records is shown in Figure 1. The hand-written record provides a unique identifier, orientation, angle, and quality control information for each bend. This information was available in the form of scanned documents. Fortunately, this information had previously been transferred into a digital Excel format that could be easily utilized by the authors for the purpose of this study.

The case study pipeline contained 498 manufactured bends in the digitized construction records for a rate of 11.7 bends per mile. The distribution of bends by orientation is shown in Figure 2. This distribution of bends is typical with over bends and sag bends having approximately equal distributions while turns (right or left) make up only 18% of the total. The distribution of the bends by angle and type is shown in

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Figure 3. Small bends with an angle between 0 and 2° make up 21% of the bends in this case study. This is significant as these smaller bends typically represent the more challenging bends to identify in a bending strain analysis. It is also noteworthy, but not surprising, that the largest manufactured bends by angle are typically turns.

Methodology

The methodology for identifying manufactured bends and bending strain features is described in (1) and (4). A brief description is also included in this paper. An example of an easily identifiable manufactured bend is shown in

Figure 4. The image provides a typical bending strain plot. The top panel provides the horizontal out-of-straightness (OOS) in black and the corresponding horizontal bending strain in red. The second panel provides the vertical OOS in black and the corresponding vertical bending strain in blue. The third panel provides the combined bending strain. The bottom pane provides the heading angles with pitch shown in blue and azimuth in red. The girth welds are shown as vertical lines in each of the panels with a corresponding numerical identifier beside them. All data is plotted against the odometer in the bottom of each panel.

The manufactured bend is shaded in pink in

Figure 4, and the identifying characteristics are annotated in the image. First, the combined bending strain in the third panel is greater than the chosen reporting threshold of 0.125%, indicating the feature should be evaluated. However, the first observation is that the pattern is sharp and isolated in the first and third panels. Next, the orientation of the strain is reviewed. The bending strain is almost exclusively in the horizontal direction, as noted by the horizontal bending strain in the top plot and the azimuth change in the bottom plot. However, the horizontal strain pattern shows only a positive signal, and there are no adjacent negative horizontal strains on either side of the positive signal pattern. This is another indication that the pattern is related to a manufacturing process rather than an external load. Finally, the change in the azimuth is isolated between girth welds 2940 and 2950 with no change across either girth weld. This is consistent with the formation process used for manufactured field bends, which typically avoid bending across girth welds. This feature should be confidently identified as a manufactured bend.

In contrast, the bending strain feature shown in Figure 5 has nearly opposite characteristics. First, the combined strain exceeds the reporting threshold of 0.125% in the third panel. The strain signal is longer than 60-ft extending across two joints (three girth welds). Second, the pattern has a clear oscillating response in the vertical direction with oscillating positive and negative strain values. Finally, the heading angle clearly changes across girth welds, indicating that the bending occurs over the girth weld. This feature should be confidently identified as a bending strain feature. The general

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principles described in this section were used to identify and classify all the signals in the case study segment.

Results

The analysis of the baseline IMU data identified 497 of the 498 (99.8%) manufactured bends from the digitized construction documents. Only one feature that was identified to be a bend in the construction documents was not identified during the analysis. This feature is shown in Figure 6 as the darker red stripe. The three features shaded in pink to the left are all positively identified manufactured bends. The feature on the right in dark red notes a location where a 1.5° sag bend should exist based on the digitized construction records. However, the IMU data shows no reportable signals at this location. While it is possible that this is an example of a false negative, it is more likely that the feature is an error in the digitized construction records. When the authors attempted to locate the feature in the original hand-written construction records, the bend identifier could not be located.

Two additional bend features were identified during the IMU analysis that were not present in the digitized construction records. These features are reproduced in Figure 7 and Figure 8 and noted with the dark red shading. Both features clearly show evidence of being manufactured bends. The feature in Figure 7 appears as a 1.5° overbend. The feature is nearly identical in appearance to the three signals to the right in the image, which were all positively identified manufactured bends. The second additional bend feature in Figure 8 appears as a 2.25° overbend. Like the previous example, the characteristics of this signal are nearly identical to the other 4 signals in the image, which were all positively identified as manufactured bends. It is the opinion of the authors that both signals are likely construction bends that were not captured in the documentation rather than false positives.

Attributing the only three "false" hit rates to documentation errors would appear convenient to any astute reader and to the authors. Therefore, the authors performed a discrepancy analysis between the digitized construction bend listing and the IMU data to see if other translation errors might exist. First, the authors compared the construction bend angle from the digitized records to the calculated bend angle based on the IMU data. The results of the comparison are shown in Figure 9. The angles compare reasonably well with over 90% of the features having bend angles that agree within 1 degree (the dashed red lines represent a 1-degree margin). However, several outliers can be seen in the image. The six bends with the largest overall angle discrepancy were reviewed by locating the bends in the original hand-written records and comparing the bend angles with the values in the digitized records. The results are shown in Table 1. The authors were able to identify that five of the bends had errors in the reported angles when the results were translated into a digital format. If the angles were corrected to match the original hand-written construction records, the digitized record would more closely matched the IMU data. One of the six bends could not be found in the hand-written records based on the bend ID.

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A similar review was also performed using the information for the reported bend orientation. Of the 498 bends, only six had orientations that differed between the IMU data and the digitized construction records. Those six bends are summarized in Table 2. Like the comparison on bend angle, only one of the bend features could not be found in the hand-written construction records based on the bend ID. For the remaining five bends, the original hand-written construction records confirmed that the orientation from the IMU analysis was correct and that the digitized records were incorrect. While the examples shown here are not conclusive evidence that the three "false" features are likely a function of incorrectly translated digitized records, they do strongly suggest this is the likely cause.

Examination of Tie-In Welds

The case study data provided the opportunity to examine another question related to bending strain assessments. It is known that many of the features identified in bending strain assessments are likely a result of construction, as they show no correlation with actual geohazards (5). This suspicion appears justified as many bending strain features are often located near challenging construction areas, such as cased road crossings or trenched water crossings. Tie-in welds would represent similar construction challenges. Unfortunately, records of actual tie-in welds are not available for most pipelines to review their interaction with bending strain features, but they were available for the case study data. The 42.4 mile case study pipeline contained 3,900 welds. Of these 3,900 welds, 454 were identified as tie-in welds, occurring approximately every 500-ft.

A bending strain analysis was completed using the case study data, and 78 bending strain features were identified. Based on the authors combined experience, the number of features for this length of line and location is above average; however, this may be explained in part by the X70 high-strength steel used in most of the construction. Higher grade steels permit higher longitudinal stresses and larger permissible curvatures during construction. The bending strain reporting threshold of 0.125% represents only 53% of the yield strength for a Grade X70 material. Based on a review of the strain magnitude, orientation, and signal characteristics, all the bending strain features represent a low priority and are not likely to be associated with geohazards. All but one of the features (77 out of 78 or 95%) were oriented in the vertical direction. This one feature had a combined orientation and was located near a road crossing with two back-to-back turns where the horizontal strains are likely associated with construction.

After completing the analysis, 66 of the 78 features (84%) were found to interact with tie-in welds. Nearly half (29) of these 66 features interacted with 2 or more tie-in welds. At first glance, the numbers appear to confirm that tie-in welds are a large contributing factor to bending strains. Therefore, a more detailed review of the features was conducted. Some of the interacting features were consistent with external loads applied to the tie-in weld as shown in Figure 10. The location of

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the tie-in weld is annotated in the image. The bending strains are near the reporting threshold and show an oscillating pattern centered on the tie-in weld. In contrast, the bending strain feature in Figure 11 has a tie-in weld interaction, but the location of the weld and the signal patterns do not clearly indicate that the tie-in weld is the likely cause of the bending strain feature. The tie-in weld is located near the edge of the bending strain feature, while the bending strain pattern appears to be more centered around the foreign line crossing identified by the three vertical bends in the center of the image.

After further review, half of the interacting features (33) showed signs that the bending strains could be attributed to the tie-in weld. Twenty-three of the interacting features did not show signs of the tie-in weld being a contributing factor, and ten bending strain features were unclear. While these results are only from a single study (and to the author's knowledge, the only study), they do support the notion that tie-in welds are a contributing factor to construction-induced bending strain features. The authors believe future investigations should continue to review this contribution. Additionally, where possible, it is recommended that operators try to integrate the location of tie-in welds with their bending strain features.

Conclusions

The case study described in this paper presented a first of its kind investigation into the ability of IMU bending strain assessments to accurately identify manufactured bends from construction records. The results confirmed that bending strain analyses can effectively identify manufactured bends and properly discriminate them from actual bending strain features induced by external loads. Additionally, the bending strain analysis showed an excellent ability to identify both the orientation and magnitude of the manufactured bends. However, it is important to note that this paper examined a newly constructed pipeline that was built in an area with relatively minor elevation changes. In addition to reviewing the identification of manufactured bends, the study also investigated the interaction of bending strain features with tie-in welds from construction. The study found that over 40% of the bending strain features were associated with a tie-in weld where the tie-in weld could be suspected of contributing to or causing the external loads. Although limited in scope, these results confirm the suspicion that tie-in welds are a contributing factor to bending strains. Moving forward, the authors believe that future studies should be conducted on smaller diameter segments and older pipelines if possible.

Recognition

The authors wish to recognize TC Energy for their organization's support of this publication and their continued research into improving the use of IMU-based bending strain assessments. Additionally, specific appreciation is offered to Justin Healy and Cassie Ruminski for their help in performing the bending strain evaluation.

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Pipe Diameter-36" xxx

Date	Bend No.	Pipe No.	Chainage (m)	Bend ID				Degree of Bend	Wall Thickness (in)			Number of Pulls	Length of bend increments (in)	Bending Shoes Properly Placed		Out of Roundness (Ovality) Max OD - Min OD After Bending		% Ovality
				RT	LT	OB	SAG		0.465	0.572				YES	NO			
08-24-23	#13	D11022628	18				√	6°		√		12	12	√		36	36	0%
08-24-23	#14	D11022628	56			√		6		√		12	12	√		36	36	0%
08-24-23	#15	D11024226	58			√		3½		√		7	12	√		36	36	0%
08-24-23	#16	D11024076	25			√		2½		√		5	12	√		36	36	0%
08-24-23	#17	D11021293	53				√	6¾		√		13	12	√		36	36	0%
08-24-23	#18	A11083653	41				√	8°	√			16	12	√		36	36	0%
08-24-23	#19	A10040633				√		3¼	√			7	12	√		36	36	0%

Figure 1. Example hand-written bend record from construction

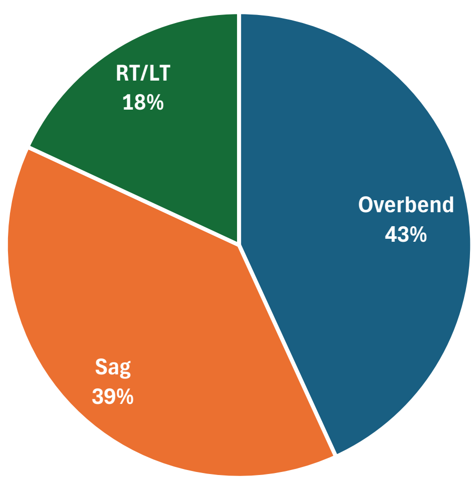

Figure 2: Bend Distribution by Type

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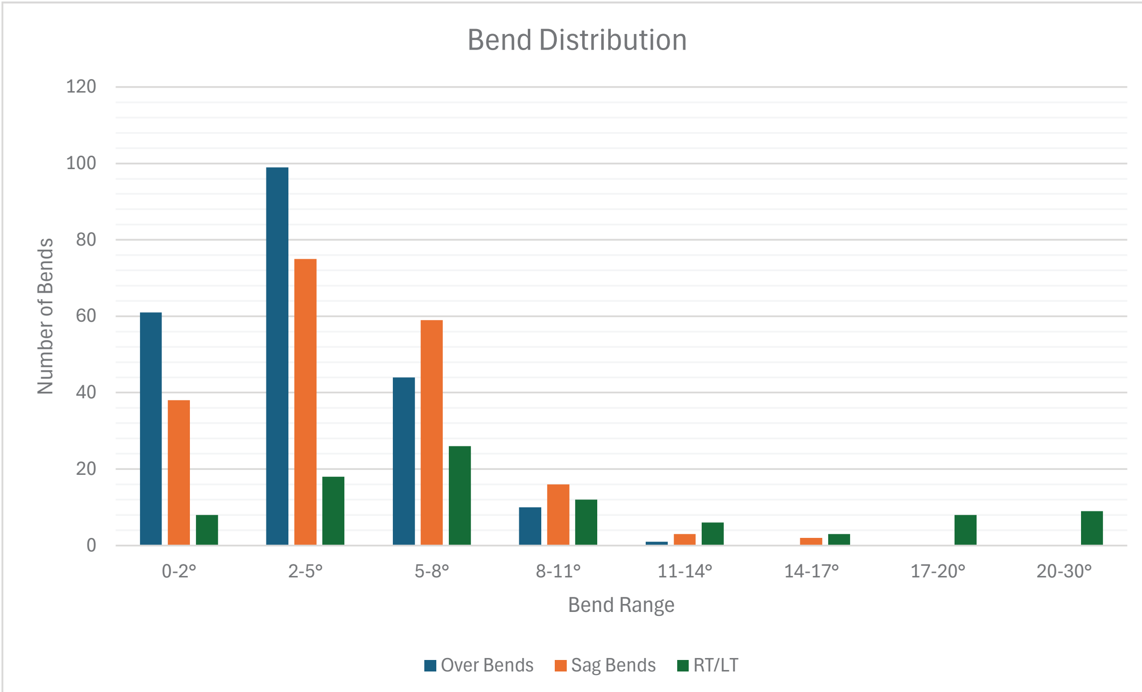

Figure 3: Bend distribution by angle

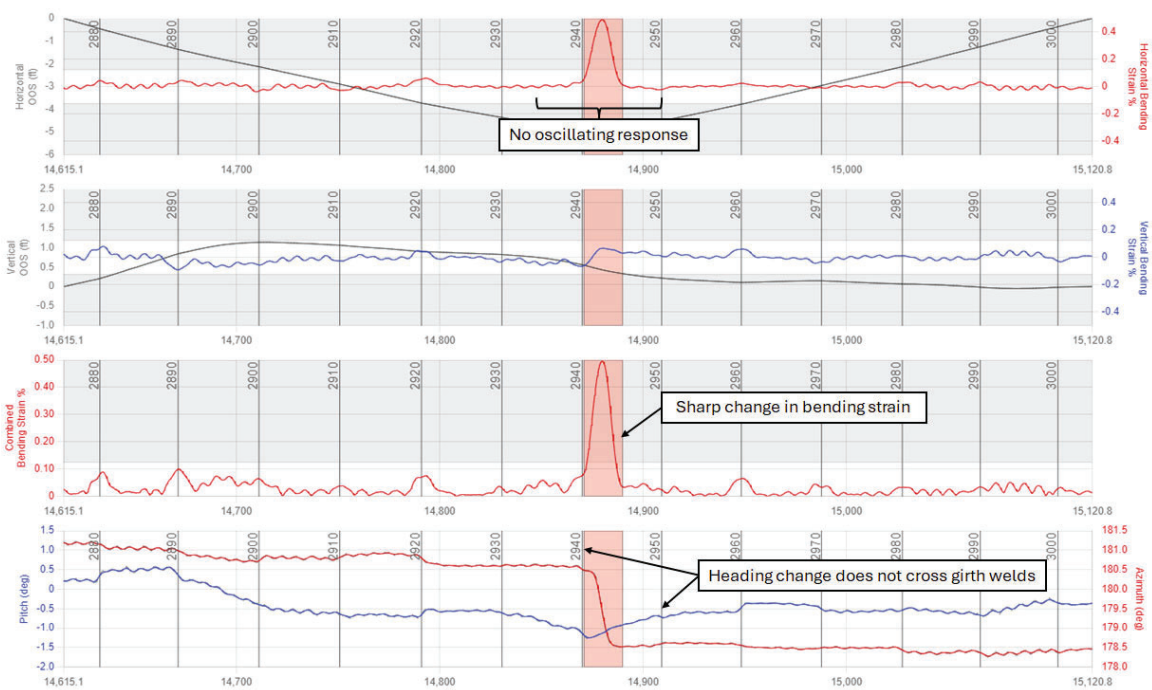

Figure 4: Manufactured bend characteristics

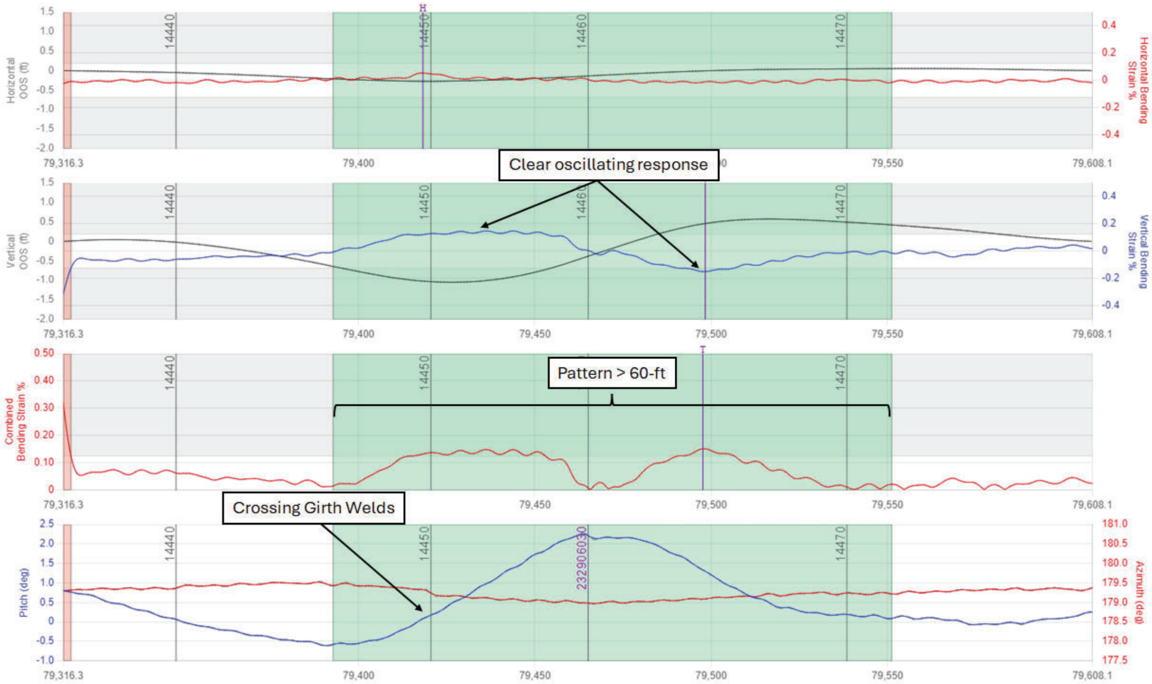

Figure 5: Example bending strain pattern

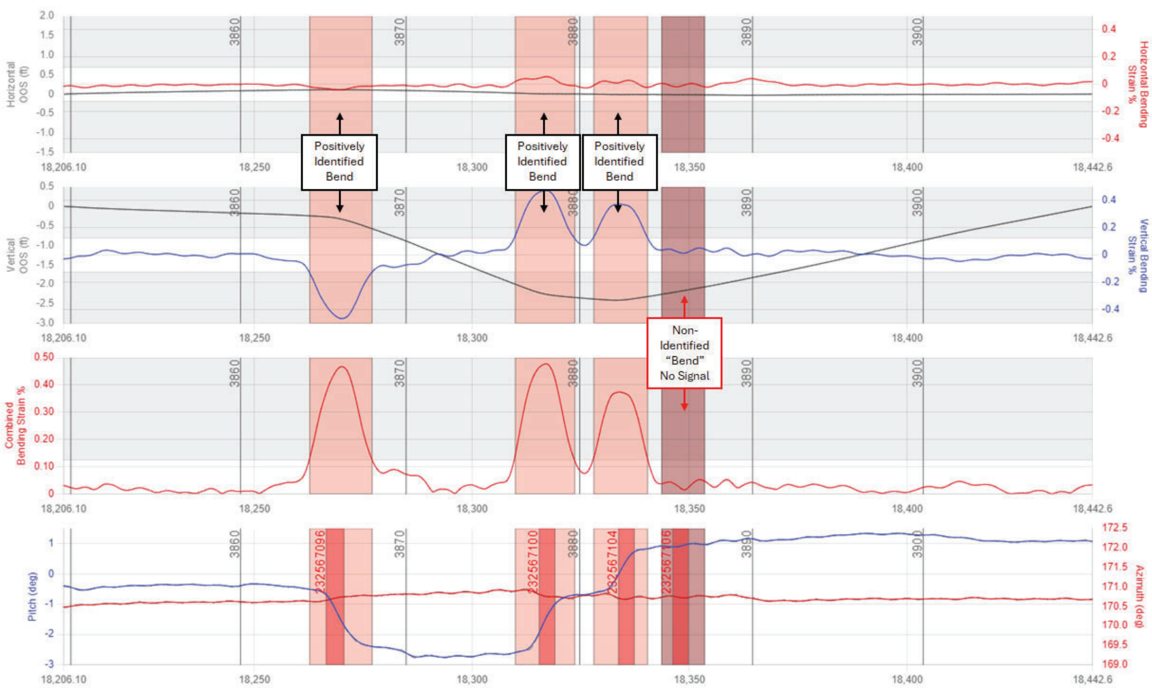

Figure 6: Non-identified "bend" from digitized construction documents

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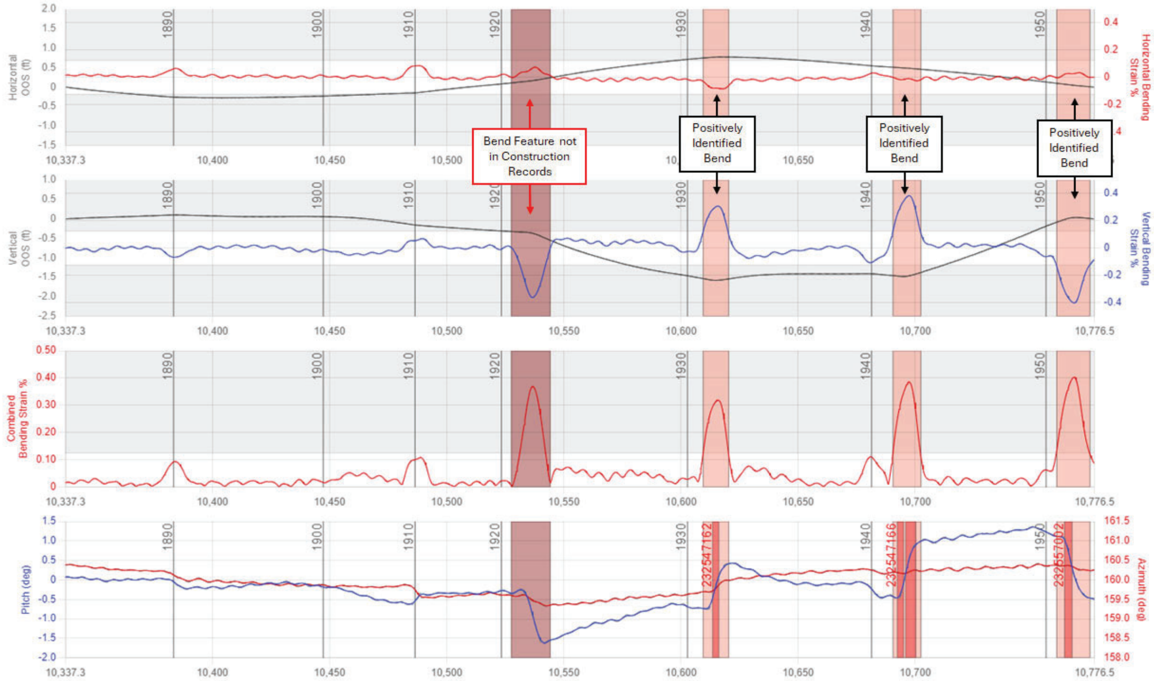

Figure 7: First manufactured bend feature not in digitized construction documents

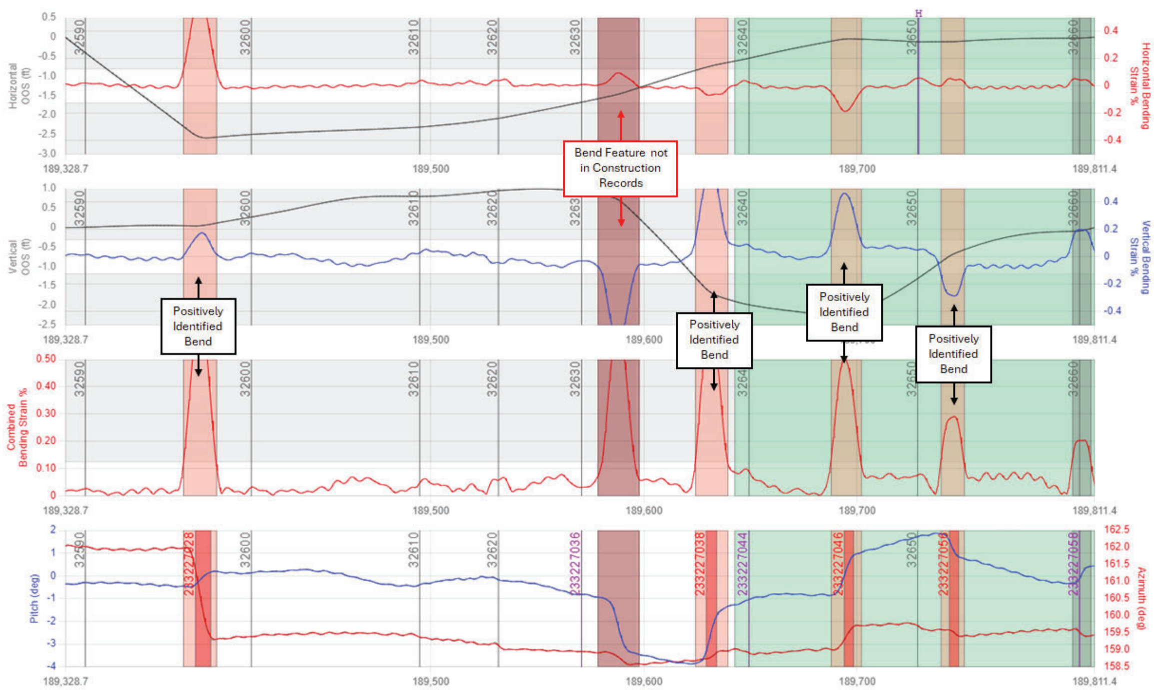

Figure 8: Second manufactured bend feature not in digitized construction documents

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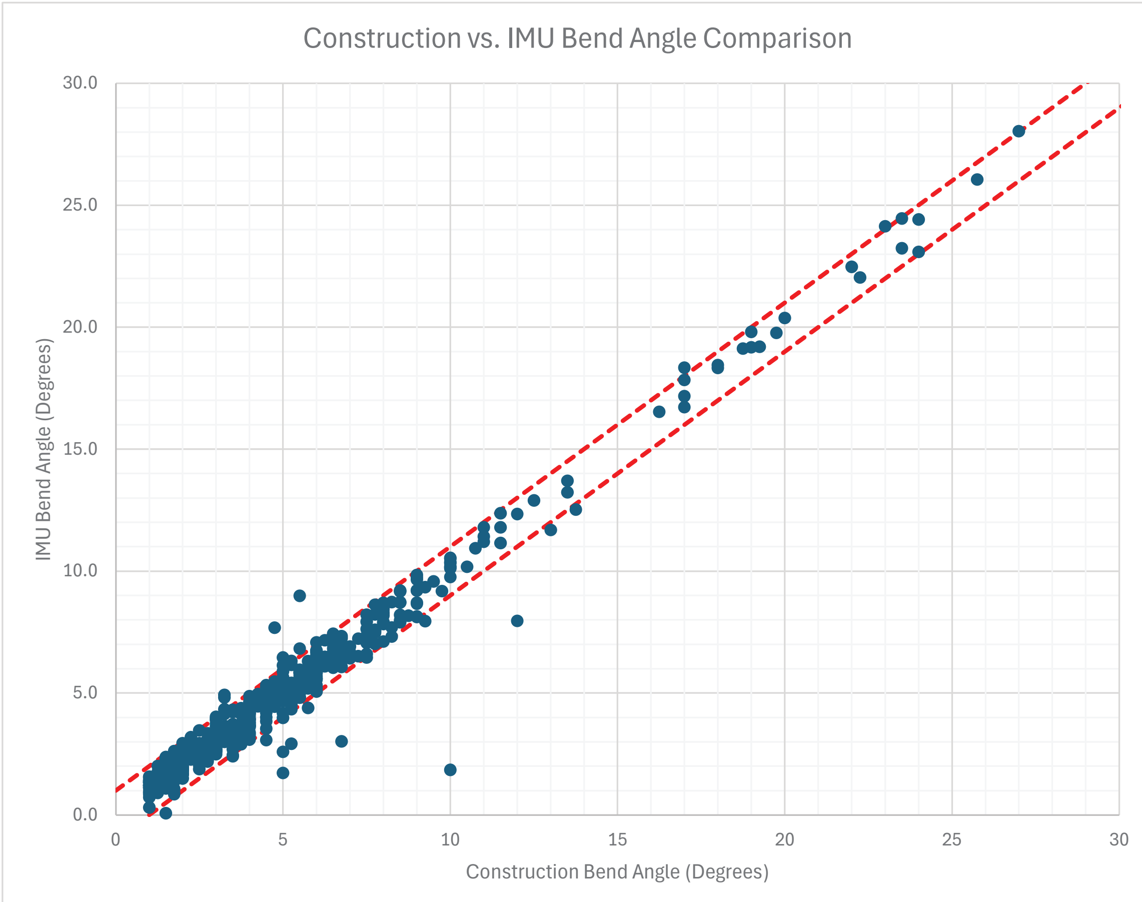

Figure 9: Comparison of digitized construction and IMU-calculated bend angles

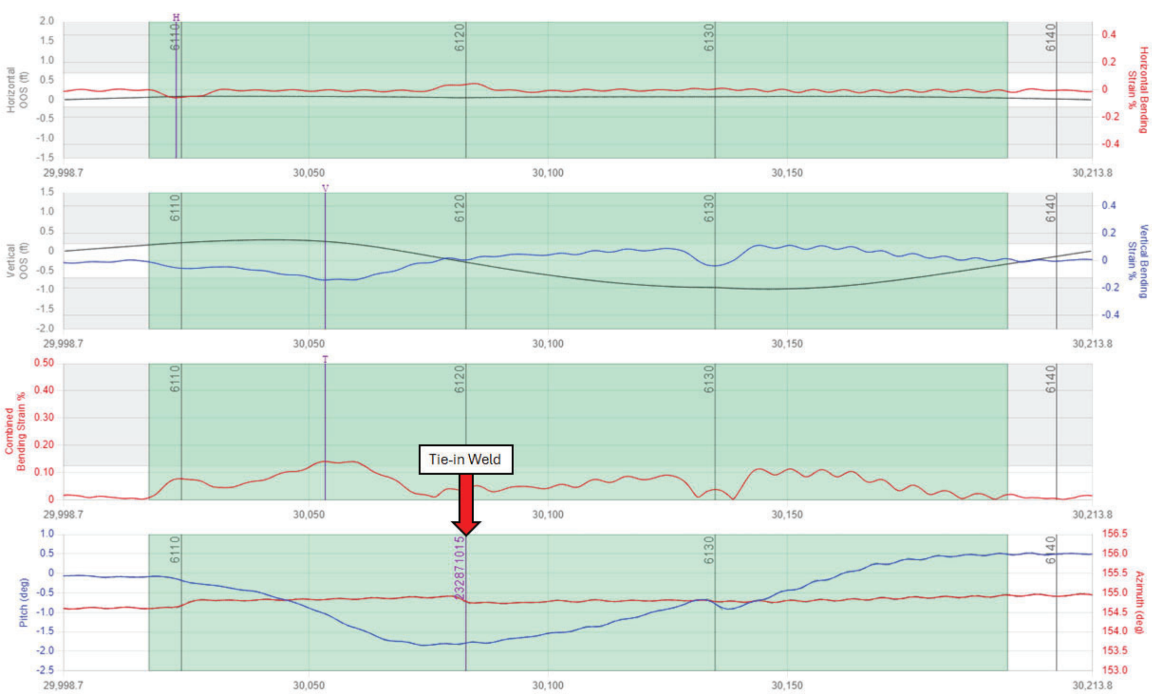

Figure 10: Tie-in weld Example #1

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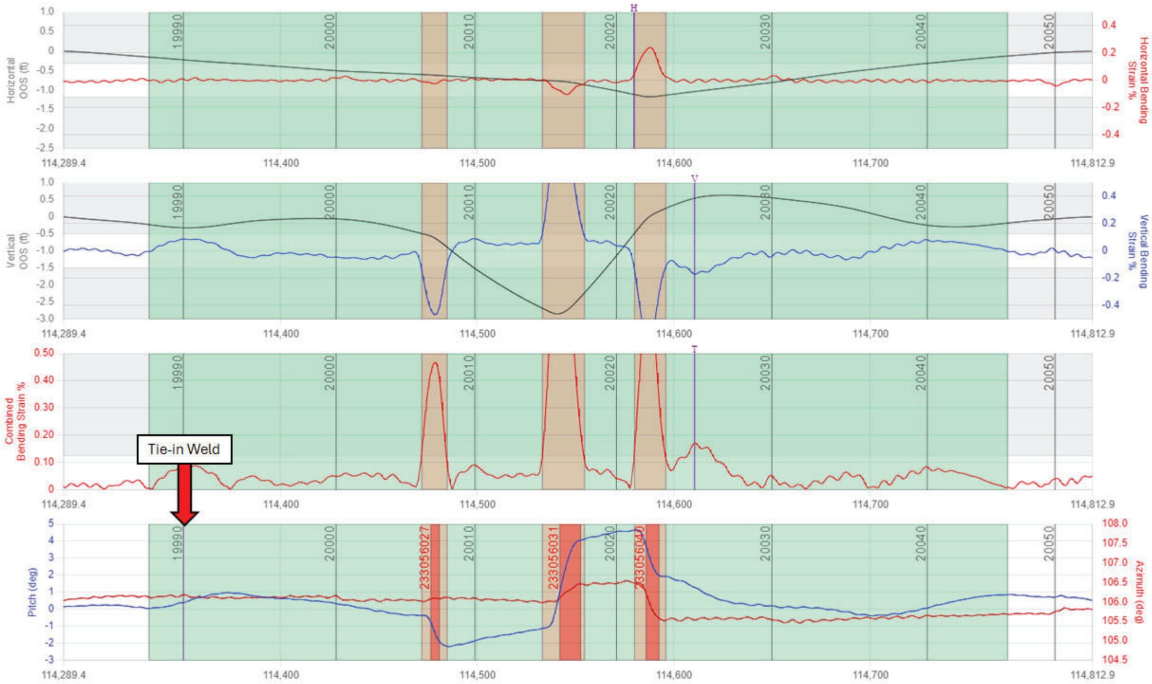

Figure 11: Tie-in weld Example #2

Table 1. Bend Angle Review

Bend ID	Digitized Construction Angle (Degrees)	IMU Angle (Degrees)	Hand-Written Construction Angle (Degrees)
233097014	10	1.9	1.0
233135069	12	8.0	8.5
232925016	6.75	3.0	3.25
233187005	5.5	9.0	9.5
232832030	5	1.7	N/A
233227019	4.75	7.7	9.75

Table 2. Bend Orientation Review

Bend ID	Digitized Construction Orientation	IMU Orientation	Hand-Written Orientation
233065014	Right Turn	Over Bend	Over Bend
232852019	Left Turn	Sag Bend	N/A
233065007	Sag Bend	Right Turn	Right Turn
232597030	Left Turn	Sag Bend	Sag Bend
232557002	Left Turn	Over Bend	Over Bend
232597088	Left Turn	Over Bend	Over end

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