IPG 2023
INTERNATIONAL PIPELINE GEOTECHNICAL CONFERENCE
November 23rd - 24th. Bogotá D.C. - Colombia
Under the auspices of:
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ASOCIACIÓN DE EMPRESAS DE PETRÓLEO, GAS Y ENERGÍA RENOVABLE DE AMÉRICA LATINA Y EL CARIBE
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6TH INTERNATIONAL PIPELINE GEOTECHNICAL CONFERENCE IPG 2023

IPG2023-####

OPTIMIZING DATA AND TECHNOLOGY TO DRIVE DOWN GEOHAZARD RELATED PIPELINE FAILURES

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ABSTRACT

The pipeline industry is continuing to develop methods and technologies to combat the increasing threat posed to pipelines by geohazards. Whilst impressive progress has been made in this area, it is necessary to ensure that the data gathered by surveys and inspections is used to its fullest extent and that multiple individual strategies are combined in such a way to complement each other.

Most geotechnical related pipeline failures can be prevented by developing effective and targeted monitoring programs, but in order to eliminate failures, monitoring must be combined with predictive modelling to identify movement that can occur over short periods of time and result in failure before the threat can be identified by existing inspection / monitoring methods.

Keywords: In-line inspection, LiDAR, High resolution caliper, predictive modelling

NOMENCLATURE

ILI	In-Line Inspection
IMU	Inertial Mapping Unit
LiDAR	Light Detection and Ranging

1. INTRODUCTION

Ongoing technology developments, data analysis improvements and advanced survey techniques have led to a wealth of information that can be used to manage the geohazard threats that pipelines are exposed to. But in order to drive down the number of failures that continue to occur from ground movement events, improvements are required with regards to optimizing the available data, combining methods and selecting the best management strategy for the particular threat.

The most effective approaches may focus more on the stability of the soil in the pipeline right of way or on the predicted response of the pipeline subject to external loads. The former includes routine patrols of the right-of-way, periodic aerial surveillance and geotechnical instrumentation to detect any indication of ground movement. The latter makes use of in-line inspection equipped with inertial measurement unit (IMU) for the detection of flexural deformation along the entire length of the pipeline, caliper data to detect localized deformation (e.g. ovality, wrinkles) and on information relating to the ability of the pipeline to withstand axial strains. Selecting the correct approach requires a thorough understanding of the prevailing threats, noting that this may not be the same along the full length of the pipeline.

Once external loads affecting the pipeline have been identified, it is necessary to evaluate, in detail, the level of threat and define mitigation actions to avoid an increase in loading and prevent failure. This process requires regular monitoring of the strain levels and pipeline movement over time to have a clear picture of the evolution of the loading mechanism and to monitor the effectiveness of any mitigation methods used, such as drainage controls and ground reinforcement works.

In this paper a methodology for the evaluation of geohazard loading based on bending strain and pipeline movement data is presented. The importance of understanding the effects of coincident threats in terms of a potential reduction in strain capacity is discussed with a particular focus on how combined evaluation of pipeline curvature data and high resolution caliper data can provide an improved understanding of the probability of failure. The methodology is applied to two case studies to demonstrate how multiple data sets can be combined and used to prioritize locations for preventative action. Due to the presence of dense vegetation in one of the areas considered, this included the use of LiDAR (Light Detection and Ranging) survey data to relate the findings from the ILI with the terrain condition.

Finally, this paper discusses the remaining likelihood of failure even when a thorough monitoring and inspection program has been completed and options that exist – including predictive modelling – to further reduce this.

2. ASSESSMENT APPROACH

The identification and evaluation of geohazards in operating pipelines should integrate the information related with the terrain condition and the effect of those potential instabilities on the pipeline. Firstly, the focus is made on the detection of bending strains possibly linked to external loading. Once these locations have been identified and isolated from apparent strain relating to fabricated bending, it is necessary to evaluate the tensile and compressive strain capacity of the pipe. The presence of other anomalies within the bending strain areas can dramatically reduce strain capacity and so must also be considered in the evaluation of the threat to the structural integrity. The available geotechnical surveys are then considered to define the cause of the flexural deformation and to prioritize those locations of highest concern. In the following sections, a brief description of the steps from the identification of locations of concern to the prioritization and definition of mitigation activities is presented.

2.1 IMU Data, Bending Strain and Pipeline Movement

When onshore pipelines are subject to external loading possibly related with ground movement (e.g. landslide, subsidence, water course exposure), their trajectory can deviate from their original position, potentially resulting in non-desired deformations in the pipeline in terms of global bending.

The modification of the curvature from the design condition is the key indication used by In-line Inspections equipped with Inertial Mapping Units (IMU) to detect perturbations in the flexural deformation along the pipeline route. In turn, this curvature is then translated into vertical and horizontal bending strain profiles.

The identification of the so-called areas of bending strains is the initial step in determining potential locations of concern from a geohazard perspective. However, not all bending strain areas are associated with external loading and a comprehensive analysis of the available information is required to further refine the locations of interest. The bending strain analysis requires only one IMU inspection and so cannot be used to determine when any movement first initiated.

In Figure 1 an example of the horizontal (top plot) and vertical (bottom plot) strain profile at an area of bending strain is presented. The red lines represent the strain and the black line refers to the deviation of the trajectory from a straight line. Green shadowed areas highlight field bends, red shading indicates a bending strain area and vertical dashed lines show the location of girth welds.

In the example in Figure 1, it is presented an area subject to ground movement that has resulted in horizontal strain and a noticeable out-of-straightness to the right. Vertical sag field bends are present at this location which prevents to clearly visualize bending strain in the vertical direction. It is important to note that the horizontal bending strain has affected a girth weld.

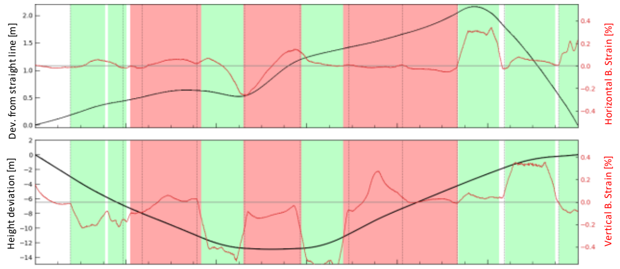

FIGURE 1: BENDING STRAIN PROFILES EXAMPLE

In case two or more IMU inspections are available, comparison between the bending strain profiles and pipeline trajectories recorded over time can be performed, enabling areas of active movement to be identified. This is the Pipeline Movement Assessment and is used as the main indication of progression of the bending strain.

Figure 2 shows an example of a pipeline movement area detected using two different inertial inspections that performed 4 years apart. The top plot illustrates the top view and the bottom plot shows the lateral view. The red line represents the trajectory of the pipeline recorded during the first inspection while the blue line indicates the recorded trajectory 4 years later. The green line indicates the difference between both trajectories.

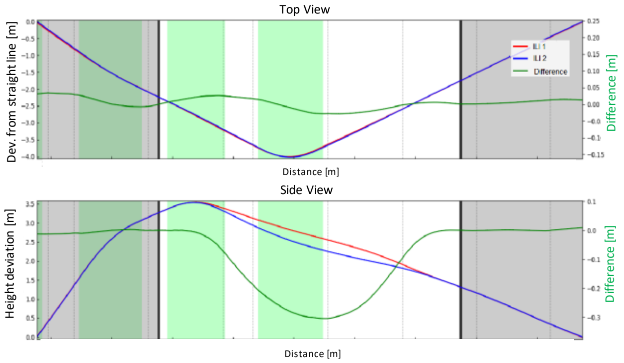

FIGURE 2: PIPELINE MOVEMENT EXAMPLE

In the practice, the identification process requires the estimated strain levels, strain difference and pipeline displacement to exceed the reporting criteria. Usual strain threshold for bending strain areas is 0.125%. For pipeline movement to be reported the strain difference should typically be greater than 0.04% and the pipe displacement more than 0.2 m. These thresholds might vary from different ILI providers according to tool specification and the evaluator criteria.

2.2 Strain Limits for Bending Strain Areas

Pipelines subject to bending strains are affected by compressive strain at the intrados of the bend and tensile strains at the extrados (see Figure 3). Limit states for each strain direction must be established: the Compressive Strain Capacity (CSC) is typically characterized by the onset of local buckling; and the Tensile Strain Capacity (TSC) is limited by the fracture resistance of the pipe, usually occurring at a girth weld where the prevalence of stress concentrations, material inhomogeneities and weld anomalies can result in fracture at lower levels of strain compared to the pipe body. Several methodologies have been presented in the industry for the calculation of the CSC and TSC in areas of bending strain. Commonly used methods include local buckling capacity models based on work performed by Gresnigt [1] and the strain-based girth weld assessment criteria developed as part of a European Pipeline Research Group (EPRG) project [2][3].

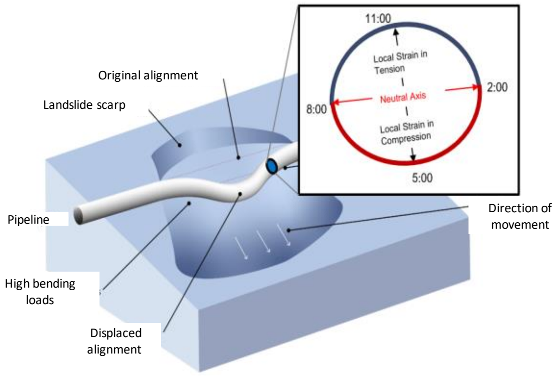

FIGURE 3: ILLUSTRATION OF REGION IN TENSION AND COMPRESSION

These strain limits provide an indication about which areas could be subject to excessive external loading leading to failure. In cases where the loading mechanism is continuously progressing, the applied bending strain can increase from values below the reporting threshold to critical levels over time. This highlights the importance of using repeat IMU inspections to identify areas of active movement, regardless of the magnitude of bending strain. Early identification of these areas allows the operator to define and implement a suitable mitigation strategy in time for that area. It is important to note that predicting the rate of change in applied bending strain over time is challenging because it will be impacted by changes in environmental conditions (e.g. rainfall) and the local topography and soil types.

Figure 4 presents an example of a location of bending strain where pipeline movement has been recorded and the maximum strain evolution is captured with four different inspections using IMU. Additionally, the reporting threshold and the strain limits are included.

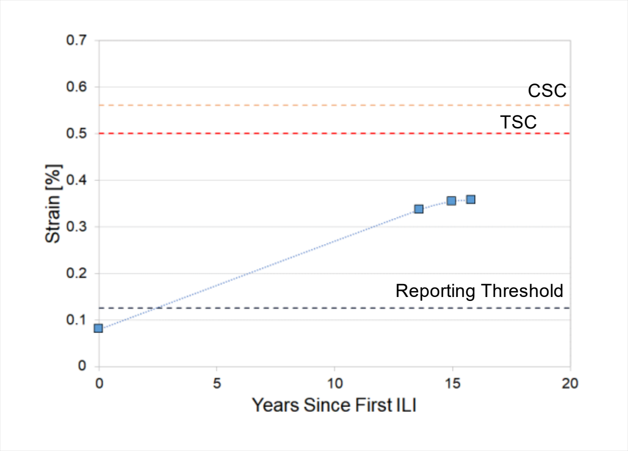

FIGURE 4: STRAIN EVOLUTION OVER TIME – EXAMPLE

From Figure 4 it is evident that in the first inspection the maximum strain was below the reporting threshold, therefore it is likely that the bending strain area would not have been identified. The second inspection was performed after ~ 13 years from the first inspection and the maximum strain was recorded at ~0.35 %. At this moment the bending strain area is identified. In following inspections the strain has continued to increase in a non-linear behavior. The latest inspection reported a maximum strain still below the TSC.

At this point, the projection of behavior after 16 years is uncertain as the response of the pipeline in terms of flexural deformation depends on several factors as: instability feature progression affecting the pipeline, soil properties, the structural resistance of the pipe and the position of the pipeline with respect to the direction of the external loading.

It is important to highlight that the selection of the location of the maximum strain has a strong impact on the interpretation of the evolution of the strain i.e. non-linear increases may be related to changes in the location of the maximum strain.

2.3 Assessment of Coincident Threats

The presence of additional anomalies in areas of bending strain can drastically reduce either the compressive or tensile strain capacity and can also introduce an additional factor that can deteriorate with time (e.g. growth of coincident corrosion anomalies). Furthermore, the additional loading associated with the bending strain can reduce the safe working pressure of a pipeline containing other anomalies such as corrosion. This situation represents an interaction of several threats which might increase the overall likelihood of failure of the pipeline. Depending of the type of anomaly, there are different approaches for addressing this issue. However, this assessment requires the availability of other ILI (i.e. metal loss, caliper, linear anomalies) which provides data of additional anomalies and / or indications of excessive loadings.

2.3.1 Metal Loss Anomalies

Metal loss anomalies (corrosion and manufacturing) can reduce the TSC and CSC of a pipeline making it more susceptible to geohazard related failures.

According to the research performed by the US Department of Transport, the greatest effect is expected on the compressive strain capacity [4]. In this regard, an initial screening can be made by estimating the modified CSC using the Gresnigt approach, but providing a reduced wall thickness associated with the metal loss in the compression region.

Besides, the PRCI project SBD-1-4 has developed a tensile strain capacity model to check the potential effect of metal loss anomalies on the tensile strain capacity [5]. This method requires the anomaly dimensions, pipe properties and assessment pressure to calculate a modified TSC but is only applicable to pipe and anomaly dimensions that were considered during the validation stage.

The compressive bending strain can also reduce the burst pressure at the location of a metal loss anomaly. In case of corrosion anomalies, this represents an increase in the susceptibility of failure of internal / external corrosion threat. The extent to which the bending load impacts the failure pressure is dependent on the how that load is applied. Under load-controlled scenarios, the bending load should be assessed using a stress-based approach such as that provided within DNVGL-RP-F101 [6] whereas most ground movement related bending loads can be assessed using strain-based methods. The research performed by the US Department of Transport developed a correlation between the reduction of burst pressure of a corrosion anomaly and the applied bending strain [4]. This showed that the impact of the bending strain is more pronounced when assessing deeper, axially orientated anomalies. However, for general corrosion up to 40% of the wall thickness in depth, the reduction in burst pressure is less than 5% when the applied strain is below 2%. Consequently, for the majority of cases, the impact of applied bending strains on the burst pressure of a corroded pipeline is small.

2.3.2 Linear Anomalies

The effect of the coincidence of bending strain with linear anomalies is highly dependent on the orientation of the anomalies. Circumferential linear anomalies, such as circumferential stress corrosion cracking (CSCC), can significantly reduce the TSC. Furthermore, the applied tensile strain can also increase the susceptibility of pipelines to CSCC and therefore the coincidence of these threats is of particular concern.

Depending on the dominant failure mechanism (i.e. fracture or plastic collapse), longitudinal linear anomalies can reduce the compressive strain capacity and therefore this combination of loading and anomaly location should be considered. Limited guidance exists to assess the impact of longitudinal linear anomalies in regions of compressive bending strain. Ensuring that a conservative assessment of the linear anomalies has been conducted, considering internal pressure loading only, and reviewing the stability of both the cracking and the loading is typically sufficient to identify locations that present a credible failure threat.

2.3.3 Geometric Anomalies

Geometric anomalies can reduce the compressive strain capacity by acting as initiation sites for local buckling. The presence of a deformation at a peak bending strain location may also indicate that the CSC has been exceeded and local buckling has initiated. Research has indicated that geometric anomalies do not significantly reduce the tensile strain capacity [4].

It is important to mention that the presence of geometric anomalies could be associated with several threat (i.e. geohazards and third party damage) or could be introduced during the construction. Defining if the anomaly is generated due to excessive compressive loading associated with geohazards is key for evaluating the threat. The most common indication of such association is the coincidence of geometric anomalies with the maximum strain considered to arise from external loading. Defining this relationship requires expertise on correctly interpreting the source of strain profiles and the direction of expected progression in agreement with the presence of geometric anomalies.

At locations of an active geohazard that is affecting a pipeline, the early indication of excessive compressive loading is the presence of ovalities. These anomalies could eventually become a ripple/wrinkle and finally form a buckle in the compressive region of the pipe. Wrinkles and buckles introduce high strains within the pipe material and can result in cracking.

Pipe deformation caused by bending loads will initially result in an anomaly well below normal reporting thresholds for high resolution caliper tools. Therefore, the available geometric data need to be interrogated in detail in the areas of highest strain. If repeat caliper inspections are available, it is also possible to evaluate the change in radii profiles and link the cross-sectional deformation with the progression of the external loading.

2.4 Diagnosing the Cause of Pipeline Movement and Developing Mitigation Strategies

Up to now, this paper has focused on the response of the pipeline to external loading and the effects of coincident pipeline anomalies. In order to develop appropriate mitigation strategies, knowledge of the cause of the loading and how it may progress is required. This can be gained through direct or indirect geotechnical surveys.

Direct geotechnical surveys are those performed on site as geomorphological mapping of the location, instrumentation for ground monitoring, topographic measurement using monuments, etc. These activities are usually defined following the requirement of a geotechnical monitoring plan at specific sites where a credible geohazard threat has already been identified. This can also include geotechnical exploration for further analysis of the soil properties.

On the other hand, indirect surveys are those activities that aim to identify possible instabilities in the terrain without explicitly going into the field. The most common approach is using aerial imagery as it is an easily accessible source of information for the environment in the proximity of the already detected bending strain / pipeline movement areas. With updated and high-resolution imagery it is possible to identify if the land surface is affected by geomorphological or anthropic processes. Additionally, with the use of Digital Elevation Models (DEM) the topography can be added to the discussion for generating 3D models of the landforms close to the pipeline right-of-way.

It is important to clarify that the proper identification of potential hazards in the proximity of a pipeline requires aerial imagery of good quality. This might be challenging in remote areas or location with dense vegetation and cloud cover as the case of tropical regions. Therefore, the use of Light Detection and Ranging (LiDAR) is progressively becoming of great importance for the onshore pipeline transport industry [7]. This penetrates through the surface vegetation and allows a high-resolution DEM to be defined for the ground surface. Processes are also being developed to facilitate the review and comparison of repeat LiDAR surveys in order to identify changes that may indicate a threat to the pipeline.

At this point two main different type of information are available: the inertial data gathered using the IMU, and the direct or indirect geotechnical survey data. As discussed, the former quantifies the amount of additional bending loading affecting the pipeline but is not sufficient to establish its potential causes. The latter may identify movement of the soil surrounding the pipeline but does not indicate the extent to which that movement has affected the pipeline. Therefore, the use of ILI data must be analyzed in conjunction with the geotechnical survey data in order to fully understand the relationship between terrain features and pipeline deformation.

This combined analysis leads to the prioritization of the locations based on the level of threat for the pipeline structural integrity. At this stage, all the available data gathered from previous steps is also complemented with other published sources of data covering region geology, topography, hydrogeology, geomorphology and geohazards. The information of excavations, maintenance activities and records of events is also of great benefit when defining the level of threat. The primary goal is to establish if the strain in the pipeline is associated with an active loading.

Finally, the bending strain / pipeline movement areas which are more likely to be associated with geohazards are classified in three levels of priority:

- Priority 1 (High): The strain profile is linked to ground movement and represents an immediate threat to the pipeline.
- Priority 2 (Medium): There is insufficient evidence to rule out the presence of geohazard or the loading process is not interpreted as an immediate theat.
- Priority 3 (Low): The bending strain / pipeline movement is not associated with ground displacement loads during the service life of the pipeline or could be related with pipeline construction activities.

The approach proposed in this paper make use of the indirect geotechnical surveys at the bending strain / pipeline movement areas which are more likely to be associated with geohazards. Then, the need of direct activities can be focus on for Priority 1 and 2 locations depending on the nature of the loading source. This approach allows the available resources and budget to be targeted in the most efficient manner towards the locations that most require attention.

2.5 The Requirement for Predictive Modelling

Combining data relating to the pipeline trajectory and geotechnical monitoring of the ground surrounding the pipeline allows locations that are impacted by a geohazard threat to be identified, monitored and prioritized for mitigation actions. However, unless the frequency of the in-line inspections and additional surveys are sufficiently high, ground movement can initiate and progress to a critical level between inspections. One way of minimizing the likelihood of failure from the short-term development of critical levels of bending strain is to ensure that the inspection frequency is sufficiently high, and this strategy is commonly used on pipelines that are routed through known geohazard locations. To supplement this management strategy, predictive modelling should be considered.

In terms of geohazard management, predictive modelling relies upon identifying the key factors that lead to the development of additional loading on pipelines and implementing appropriate measures in areas that are identified as most susceptible. To capture threats that develop over a short time period, it may be necessary to collect data along the pipeline route at a high frequency, potentially in real-time. An example that is highly relevant for pipelines in the Andean region of South America is rainfall. Whilst rainfall data is available, it is not always feasible to obtain this at sufficient intervals along the pipeline routes at the necessary frequency. Therefore, the value in capturing such data must first be demonstrated in order to justify the expense of developing the infrastructure needed for data collection.

Initiatives are underway to develop predictive models for geohazards and to use the vast volumes of data from IMU inspections to validate those models so they can be used in combination with existing approaches to further reduce geohazard related pipeline failures.

3 APPLICATION

3.1 Case Study 1: Strategy for Managing a Stable Bending Strain Location

A localized bending strain area was reported following an IMU inspection of a small diameter pipeline in Australasia. The strain was confined to the vertical direction and coincided with a stream crossing. A caliper inspection had reported a small dent that was coincident with the peak of the bending strain and warranted further investigation to determine whether local buckling of the pipeline was an imminent threat at this location.

The peak vertical strain was estimated at 0.4% (Figure 5), which was within the compressive strain capacity for defect-free pipe. However, the presence of the dent would reduce the CSC of the pipe at this location and therefore the stability of the area from a geotechnical perspective as well as the significance of the dent had to be reviewed.

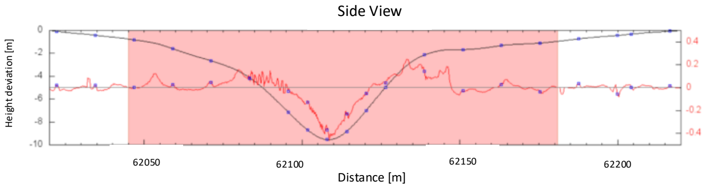

FIGURE 5: VERTICAL STRAIN PROFILE COINCIDENT WITH DENT

Initially, a desk-based review of the geohazard threat in this area was performed. This confirmed that pipeline trajectory had most likely remained unchanged from the time it was constructed and identified no evidence of active movement in the area. Focus was therefore placed on understanding the impact of the existing dent on the integrity of the pipeline, from both a static and fatigue perspective. Detailed analysis of the dent profile (Figure 6) identified evidence of the onset of local buckling in the form of minor wrinkles / ripples associated with the indentation. An assessment was performed to determine the curvature strain associated with the anomaly to understand the likelihood of associated cracking. This concluded that the strain was well within acceptance limits and so cracking was unlikely. Finite element analysis was also performed to estimate the stress concentration factor associated with the dent and that was used to determine its remaining fatigue life. Due to the low level of pressure cycling on the line, the predicted remaining fatigue life was over 100 years.

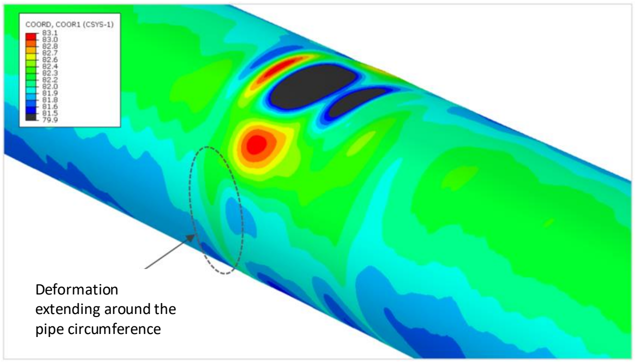

FIGURE 6: PROFILE OF REPORTED DENT INDICATING POSSIBLE EVIDENCE OF LOCAL BUCKLING / WRINKLING

This case study demonstrates the importance of understanding the long term impact of coincident threats, even in cases where the geohazard threat has been shown to be stable. The following case study shows that managing this threat can be significantly more challenging when the geohazard remains active.

3.2 Case Study 1: Combining Data to Manage an Active Geohazard

Following an IMU inspection of a gas pipeline in the Andes mountain range, a bending strain identification assessment was performed. As result, several areas of bending strain were reported and special attention was given to a location with very high strain levels, including a significant horizonal component. The bending strains of this area are shown in Figure 7. The top plot shows the horizontal bending strains and out-of-straightness, the middle plot is the vertical bending strain and elevation and the bottom plot shows total strain.

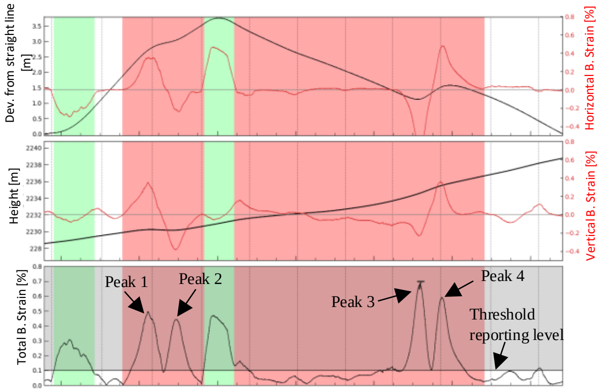

FIGURE 7: BS IMAGE CASE 1

The area was approximately 90 m long and covered eight pipe joints. High horizontal and vertical bending strains of 0.674% (at peak 3) had developed in two joints at the downstream end of the area. The horizontal strains present two noticeable adjacent peaks (peaks 3 and 4) of opposite directions and coincident with a distinct out-of-straightness to the right. Peak 4 coincides with the location of a girth weld. A similar behavior is observed in the two joints at the upstream end of the bending strain area (peaks 1 and 2).

The total peak strain had already exceeded the conservative CSC and TSC by the time of the inspection. Therefore, this area represents a high concern for the structural integrity of the pipeline.

Three previous inspections equipped with IMU had been conducted in this pipeline. Therefore, a pipeline movement assessment was performed to investigate the evolution of the possible external loading and define if the area was active. The inspections overed a period of time of 16.5 years and the latest two inspections were performed 6 months apart. Figure 8 shows the comparison of all available datasets in terms of displacement and strain. Top two plots are the top and lateral views respectively. Bottom plots are the horizontal and vertical bending strain profiles respectively. The blue line represents the pipe displacement between the two latest inspections in a 6-month period.

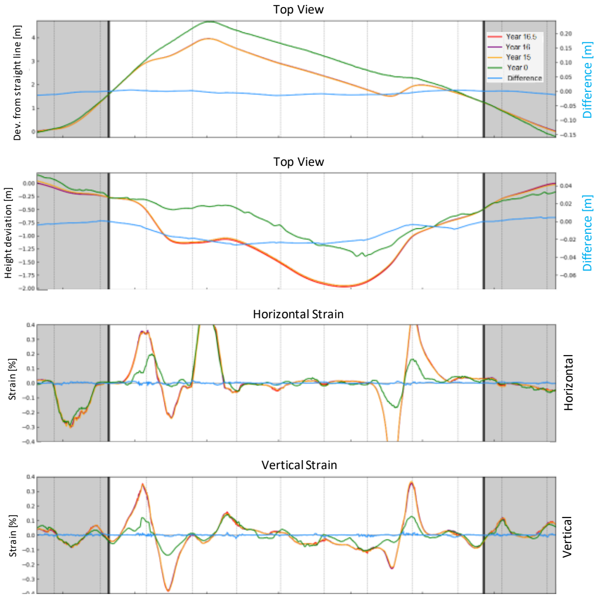

FIGURE 8: PIPELINE MOVEMENT IMAGE CASE 1

The recorded movement since the first inspection was 1.1 m, occurred within the middle of the area and consisted of both vertical and lateral movement. The peak strains occur at the upstream and downstream edges of the area, indicating the transition between stable and unstable soils. Comparison of the latest inspections showed that only small levels of movement had occurred. However, a review of the strain profiles and direction of movement concluded that the changes were indicative of a continuation of the movement noted between the first two inspections. This suggested that the geohazard threat remains active.

As well as IMU data, high resolution caliper data was also available from the last two inspections. Therefore, the geometric data was analyzed in detail at the location of the four strain peaks. At all of these locations indications of ovalization were detected which were below the reporting threshold of the caliper tool. Ovalities in Peak 2 (maximum strain) and Peak 3 did not present any indication of change in the radii data. In contrast, at Peak 1 and Peak 2 (see Figure 7) the comparison of the radii data showed an increase in the ovality size between the latest two inspections (see Figure 9).

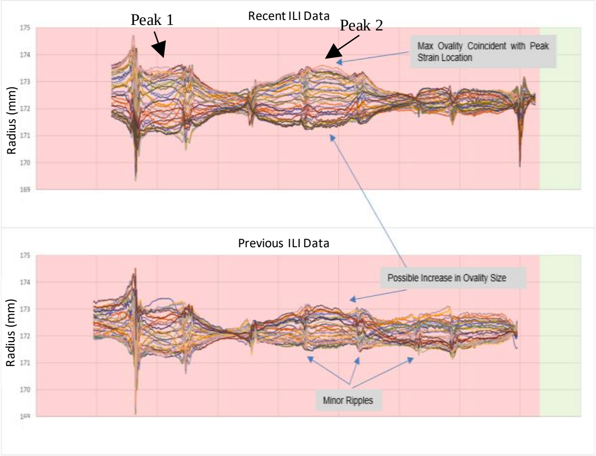

FIGURE 9: RADII DATA COMPARISON FROM TWO LATEST INSPECTIONS CASE 1

Minor ripples were also identified that were coincident with the ovality associated with Peak 2. Most likely these indicate that some degree of field bending had occurred within this region during pipeline construction. The combination of active bending strain, ovality and ripples indicate a significant threat from local buckling.

Aerial imagery for this location was also inspected and this is presented in Figure 10 (Image © 2023 CNES / Airbus). This shows that the bending strain / pipeline movement area is in the lower slope of a narrow river valley.

It is observed that at the location of the bending strain area, the vegetation has been removed in the downslope direction. This feature is observed upslope and downslope of the road and is likely linked with the instabilities in the slope. For this area there is also LiDAR imagery available (see Figure 11) and this indicates that the pipeline crosses a clearly defined mudslide feature (delimited in dashed blue line).

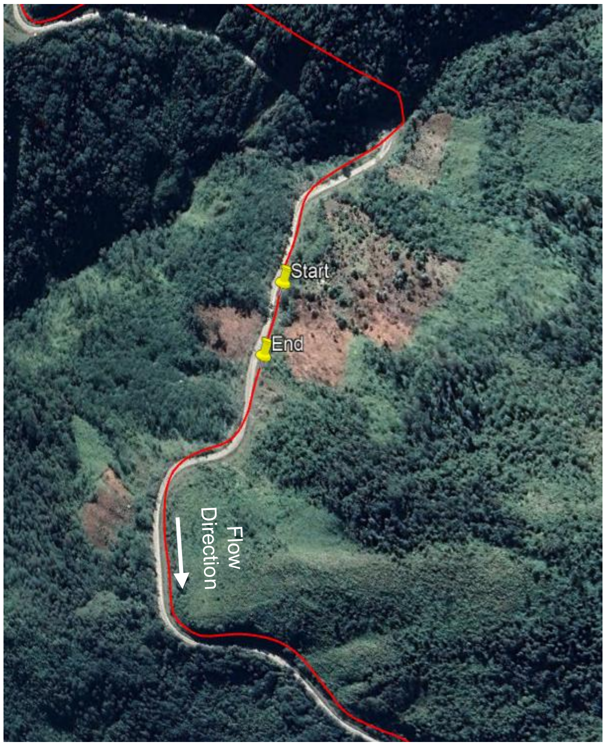

FIGURE 10: AERIAL IMAGERY CASE 1

Bringing all the information together, the IMU data detects high strains associated with pipeline movement since the first inspection. The aerial imagery allows to conclude that this movement is in the downslope direction and coincident with a mudslide feature clearly visible in the LiDAR imagery. Therefore, the external loading appears to be associated with the mudslide feature activity. The minor displacement between the latest inspections and the increase in the ovalization in the upstream end of the movement area indicates that the external loading is active and continues to deform the pipeline, further increasing the likelihood that local buckling will occur.

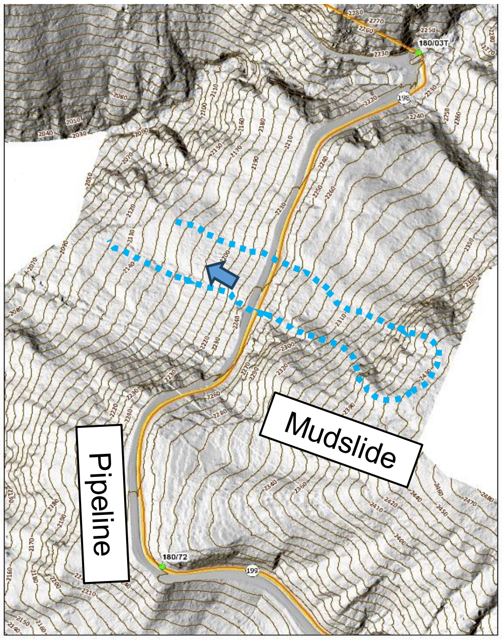

FIGURE 11: LIDAR IMAGERY CASE 1

Finally, this location was classified as priority 1 (high) and was considered to represent an immediate threat to the integrity of the pipeline. Therefore, a range of site specific actions were recommended to characterize the instability feature, its level of activity and relieve the strain levels recorded in the pipeline.

3.3 Discussion

The proposed methodology permits to identify, evaluate and prioritize the locations of concerns associated with ground movement by using a combined assessment with the IMU data and the aerial imagery. This allows to efficiently manage problematic locations and progressive ground movement loading in order to maintain within acceptable limits. However, it is not possible to address sudden ground movement triggered by specific unforeseen events (e.g. earthquakes). The only available strategy for such conditions is to perform frequent ILI inspection equipped with the IMU to collect strain and trajectory data in a timely manner. Routine inspection of the right-of-way can also be effective in identifying unforeseen events, however the logistic is complicate in remote locations and information on the effects on the pipeline is limited.

In addition, the importance of having pertinent information of other anomalies and geotechnical surveys is only overpass by using the data in an effective manner. However, the acquisition and evaluation of the data could be an impressive task that requires expertise in the different technologies.

4 CONCLUSION

This paper has provided an overview of an assessment approach that is designed to minimize the likelihood of pipeline failures due to geohazards. It is clear that an effective strategy must combine data from multiple sources / technologies and consider the integrity risk posed by coincident threats such as localized deformation, corrosion activity and bending strains. The importance of conducting assessments at a sufficiently high frequency has been discussed as well as the need for predictive modelling to further reduce the likelihood of pipeline failures from geohazards.

REFERENCES

[1] Gresnigt, AM. Plastic Design of Buried Steel Pipelines in Settlement Areas, *Heron Publications, Vol. 31, No. 4*, 1986.

[2] Knauf, G. Hopkins, P. The EPRG Guidelines on the Assessment of Defects in Transmission Pipeline Girth Welds, *3R International*, 1996.

[3] European Pipeline Research Group. *EPRG guidelines on the assessment of defects in transmission pipeline girth welds – Revision 2014*, 2015.

[4] Strain-Based Design and Assessment in Critical Areas of Pipeline Systems with Realistic Anomalies, Contract No. DTPH56-14-H-00003, Final Report, Prepared for US Department of Transportation, Pipeline and Hazardous Materials Safety Administration Office of Pipeline Safety, Prepared by Ming Liu, Honggang Zhou, Bo Wang, and Yong-Yi Wang, Jason Bergman, Brent Ayton, Mark Stephens, Timothy Weeks, Jim Gianetto, 2017.

[5] Characterization of Pipeline Wall Loss for Strain Capacity Evaluation of Damaged Pipelines Subjected to Ground Movement, PRCI Project SBD – 1 – 4, Honggang Zhou, Bo Wang and Yong-Yi Wang, December 21, 2018.

[6] DNV-RP-F101 Corroded pipelines, Recommended practice. Edition 2019-09 - Amended 2021-09

[7] Young, A. Gómez, O. Wilde, A. A Rigorous Geohazard Management Process for Operational Pipelines Combining Inline Inspection with LiDAR, *Rio Pipeline Conference & Exhibition*, 2023.