Assessing Landslide Risk to Pipelines Installed by Horizontal Directional Drilling Using Inertial Measurement Unit Data

Joel Van Hove, Owen Bunce, Pete Barlow, Casey Dowling
BGC Engineering Inc.

PPIM 2025
PIPELINE PIGGING & INTEGRITY MANAGEMENT
JANUARY 27-31 • HOUSTON

Organized by
CLARION TECHNICAL CONFERENCES

https://doi.org/10.52202/078572-0026

https://doi.org/10.52202/078572-0026

Abstract

Horizontal directional drilling (HDD) is a widely used trenchless technology for pipeline installations, especially in areas where conventional open trench construction poses significant construction challenges, such as river or landslide crossings – areas which also present geohazard risks. HDD installations can be highly effective at avoiding and nearly eliminating geohazard risk, but the failure records from industry reveal that many HDDs fail to effectively avoid landslides and some significantly increase geohazard risk. A recent study of North American pipeline systems estimated that HDD installations have been used at approximately 14% of landslide crossings, and at 16% of those crossings, the pipeline is drilled through, rather than below the landslide. The same study reviewed an extensive history of geohazard related pipeline failures and found a 15-times greater failure rate for pipelines intersected by active moving landslides where the installation method was HDD versus conventional trenching. This observation means that pipelines installed by HDD, which do not effectively avoid landslides, are at a much higher risk of failure and represent the category of geohazards most likely to cause pipeline failure.

Considering the elevated risk ineffective HDD crossings of landslides represent, assessing the effectiveness of each crossing is critical to successful geohazard risk management. Existing methods of landslide assessment such as visual inspections from landslide experts, survey monitoring, and lidar change detection often fall short in evaluating the depth and activity of a landslide, which is crucial for understanding the risk to HDDs. While installing deep instrumentation like slope inclinometers can provide the necessary data, it is costly, time-consuming and prohibitive for wide scale application.

Inertial Measurement Unit (IMU) bending strain analysis has become a critical tool for HDD effectiveness assessment because the data is widely available, precise, and provides the opportunity to directly observe landslide impact to a pipeline by transforming the pipeline itself into an instrument to detect bending strain, much like a slope inclinometer. This paper compiles findings from bending strain analysis of around two thousand HDDs, detailing characteristic strain patterns and cataloguing examples where landslide impact was identified and confirmed. The distinct bending strain patterns caused by landslide movements can be detected at low strain levels, often below typical reportable limits for bending strain analysis, due to the unique and low strain magnitude signatures typical of HDD installation.

Recognizing these strain signatures and interpreting them in the context of potential landslide loads allows early identification of landslide impact and provides operators the opportunity to proactively manage risk and avoid ruptures and service outages. Since ineffective HDDs represent a disproportionate amount of geohazard risk, assessing HDDs for landslide impact is one of the highest value actions operators can take to manage geohazard risk. IMU bending strain analysis proves to be an effective tool for this purpose, offering a practical method for detecting and assessing landslide impacts on HDD pipelines.

https://doi.org/10.52202/078572-0026

What is the problem with HDD crossings of landslides?

HDD has become the dominant trenchless technology for pipeline installations and has been in use since the 1970s, providing an effective means of avoiding areas where conventional open trench construction poses significant construction challenges at surface. HDD is often preferred for river and landslide crossings because these areas often have steep unstable terrain, flowing water and environmental restrictions. HDD offers the additional benefit of avoiding the geohazards posed by rivers and landslides through deep installation, which is often not possible with conventional trenching. A recent study (Van Hove et al., 2022) of North American pipeline systems estimated that HDD has been used at approximately 14% of landslide crossings. Unfortunately landslide avoidance is not consistently considered during HDD design, resulting in HDD installation through rather than below the landslide. Over a ten-year period more than one third of all geohazard related pipeline failures were on HDDs that were impacted by actively moving landslides. When an HDD does not avoid a landslide, the risk of failure is significantly increased, and the pipeline is in a much more vulnerable position, relative to crossing a landslide by conventional trenched installation. This increased risk is a result of the higher vulnerability of HDD installations caused primarily by the increased ground loads on the pipeline at greater burial depths. The increased loads lead to more acute bending and higher strain at smaller amounts of movement than conventionally installed pipelines. The increase in vulnerability of HDD installations engaged by landslide movement has been estimated from failure statistics to be 15-times higher than a conventionally trenched pipeline.

Pipeline damage or failure on a section installed by HDD typically has much higher consequence because mitigation options are limited. Due to the installation depth, an HDD generally cannot be dug, stress relieved or repaired, meaning the only option is to abandon the impacted section and plan for a replacement HDD or reroute. Loss of service of an HDD section could shut down an entire system for months or more as alternatives are arranged, creating significant service interruption costs. HDDs are also frequently located near watercourses, which increases the consequences of a product release into a sensitive environment. Clean up can be extremely challenging due to the depth of product release.

HDD crossings of landslides therefore generally fall into two categories of geohazard risk. Most (84%) are deep and long enough to spatially avoid landslides and landslide risk to the pipeline is negligible, but the minority (16%), which are installed through a landslide, are at significantly elevated risk because of the 15-times reduced tolerance of pipelines to ground movement at depth. In the case of a failure or need for pipeline shut-in, HDDs are often impossible to access and repair, leading to costly service interruption and environmental damage and cleanup. This underscores the importance of evaluating the effectiveness of all existing HDDs and highlights the risk reduction benefits to operators to prioritize HDD assessment as one of the highest impact actions of an entire geohazard management program.

https://doi.org/10.52202/078572-0026

Why evaluating HDDs for landslide impact is a challenge

If the risk posed by HDDs which intersect landslides is clear, the solution is conceptually simple: find all the landslides crossed by a pipeline, identify HDDs which intersect landslides, and determine which of those landslides are active. While inventories of all landslides crossed by a pipeline system have become commonplace in North American geohazard management programs, evaluating the depth and activity of those landslides has proven to be a more significant challenge.

Van Hove et al. (2024) discusses the challenges with evaluating the activity of slow-moving landslides and the many tools which can provide insight into landslide activity. The source of the challenge is that most landslides move at velocities which are extremely slow to very slow (less than two inches per year) and are below levels of detection of many tools. Movement may be active without evidence of fresh scarps, cracks or other visible evidence of movement. Despite these slow rates of movement, cumulative movement over multi-year to multi-decade timeframes is enough to result in pipeline failure. This is particularly true of large, deep-seated landslides which tend to move extremely slowly but may have engaged a long length of pipeline at a great depth, resulting in greater stresses on the pipe.

Geotechnical instrumentation (slope inclinometers, shape-accel arrays), visual ground inspections by landslide specialists, survey monitoring, lidar change detection and interferometric synthetic aperture radar (InSAR) are some of the more common tools for evaluating landslide activity. One of the key limitations of these tools is that they only measure ground movement from the point of initial data gathering, which can be missing decades of historical ground movement. Often measurements will also only be made at ground surface and not provide insight into whether or not the pipeline is engaged or is safely below the movements. Landslide depth is rarely known and requires expert level skill to estimate. Determining the depth of a landslide often requires installing subsurface geotechnical instruments, which is cost prohibitive for broad adoption.

Why IMU is well suited to checking HDDs for landslide impact

Van Hove et al. (2024) outlines reasons why IMU bending strain assessment addresses the key challenges of the existing tools for evaluating landslide impact to pipelines. IMU data is widely available, economical, continuous, precise, it measures the pipeline directly and provides insight into pipeline strains and pipeline condition, and it preserves bending impact from ground movement over the entire life of the pipeline.

For evaluating landslide impact to HDDs, the value of IMU is further increased because one of the key uncertainties is the depth of the landslide relative to the pipeline. A landslide may be clearly active on surface, but the HDD may be safely removed from the landslide. Alternatively, IMU may be able to detect impact to an HDD from a landslide with otherwise unknown depth and activity. Furthermore, the pattern of bending from landslide impact is often distinctly different than the

https://doi.org/10.52202/078572-0026

normal bend pattern induced by the HDD installation process, increasing the likelihood of detection and reducing the need for run-to-run bending strain change assessment.

An accurate HDD as-built can also be developed by combining the location and elevation of the pipeline from IMU data with a ground elevation from lidar or survey. Typical positional accuracy is 1/2,000th of the distance to the nearest tie-point (Hart et al., 2019), which means the drift over a 1000 ft HDD would be about 0.5 ft. The quality of data can be evaluated by comparing the drift at two known pipeline locations on either end of the HDD. Older pipelines missing installation as-builts are a common problem and preclude assessment of the potential for landslide interaction.

How IMU is used for checking HDDs for landslide impact

Hart et al. (2019) describe the characteristics of IMU bending strain signatures which indicate ground movement impact and contrasts them to intentional bend signatures from construction. Dowling et al. (2024) builds on this work by emphasizing the importance of evaluating the bending signatures within the context of the mechanics of the landslide being assessed. Assessing HDDs for landslide impact is an extension of this previous work and requires the integration of knowledge and experience from HDD installation practices, assessment of landslide mechanisms and soil-pipeline interaction, and processing and interpreting IMU data. The key difference between evaluating conventional trenched installations and HDDs is needing to understand how HDDs are installed and the typical bending strain signatures that are observed by IMU, and to understand how soil-pipeline interaction changes at typical HDD installation depths due to the increase in soil stiffness.

The authors' combined personal experience includes analysing more than 2000 HDDs to check for evidence of landslide impact using IMU. A large majority of HDD landslide crossings have no evidence of landslide impact because they are deep enough to avoid the landslide, or they intersect the landslide, but the landslide is either inactive or has not yet moved in a manner that generated abnormal bends (e.g., extremely low movement magnitudes). For this paper, IMU bending strain data for 30 HDD installations impacted by active landslides was compiled. While the library is modest, the guidelines provided are based on key characteristics that distinguish this small subset of landslide affected installations from a much larger dataset of installations that are not impacted by active landslides. The authors have personal experience assessing a greater number of HDDs with landslide impact, but they were not included in the library due to a lack of tabular IMU data or pending data publication requests at the time of publication.

Typical HDD construction bending strain signatures

Following the process outlined by Hart et al. (2019) and Dowling et al. (2024), the first step in evaluating an IMU bending strain signature for landslide impact is to understand the bending strain signatures typical of construction. Understanding how HDDs are constructed is therefore fundamental to assessing HDDs for landslide impact.

https://doi.org/10.52202/078572-0026

While there are many variations on the construction technique, broadly speaking an HDD will involve drilling a directional pilot borehole along a pre-planned bore path by a steerable head from a planned entry to exit point. Once the pilot bore is established, additional passes may be completed to ream the borehole to a diameter which is larger than the pipeline. A string of pipeline is welded together on surface and is dragged back through the borehole. Once the dragged section is in place, it is tied-in to conventionally trenched pipeline on either side. This construction tends to generate the bending strain signature characteristics described below:

- **Bend orientation:** HDDs tend to follow a straight path horizontally (i.e., in plan view) but vertical bends are required to follow the designed profile to depth, and back to surface. On rare occasions broad horizontal bends are designed to stay within right-of-way boundaries or avoid other borepath restrictions (e.g., adjacent pipelines). In general, vertical bends are required for installation and are observed by IMU. Horizontal bending is often less pronounced as many HDDs do not require horizontal bends.
- **Peak bend magnitude:** Peak bending strain measured by IMU tends to be lower than typical roping strain for conventional sections. Bending strains are induced as the pipeline is pulled through a curved borepath. The bore path will have a planned radius of curvature which is generally reported relative to the pipeline diameter (D). An industry rule of thumb is 100 ft radius of curvature per inch of pipeline diameter (da Silva et al., 2009), which relates to a radius of curvature of 1200D, which according to bending strain formulas (Czyz and Adams, 1994) equates to a bending strain of around 0.04%. For larger diameter pipes, it is common to adopt a radius of 1000D – 2000D. Smaller diameter pipes are sometimes installed with smaller radius of curvature because the pipes are more flexible and require less pullback force through tighter curves. In general, peak bending strains tend to be around the industry rule of thumb 0.04%, but may be as high as 0.2%, particularly for small diameter pipelines and jetting installations, where the bore depth may be much shallower due to lower fluid pressures and manual locating of the drill head from the ground surface.
- **Bend length:** The bend length tends to be long because the bends are formed by the pipeline conforming to the curvature of the borepath. Since the borepath curvature is low, long bends are required to achieve a change in direction and bends often span multiple pipeline joints.
- **Bend form:** The combination of low bending strain magnitudes and long bend lengths tends to result in broad, smooth bends lacking abrupt pitch or heading changes.
- **Number of bending strain lobes:** HDD installation bends tend to appear as "single-lobed" bends in IMU bending strain plots. This means that the pipeline is straight, bends in one directional change, and returns to straight. This pattern is expected as the pipeline reaches the target depth and then is steered upward towards the exit point. The most common

https://doi.org/10.52202/078572-0026

pattern is one or more broad sag bends, though broad overbends are sometimes drilled, either as corrections or due to the crossing geometry.

- **Formed bends:** HDD sections are absent formed bends, which are typically manufactured by an on-site bending machine or as factory induction bends. Formed bends are common at the HDD entry and exit points where the drag section is tied-in to trenched pipeline but would not occur in the drag section. Roping bends are also common at the tie-in points because aligning the conventionally trenched pipeline with the relatively fixed location of the drag section is rarely perfect.
- **Steering bends or HDD path variation from geology:** While bends tend to be smooth and avoid abrupt changes in direction, steering corrections or encountering stronger geology may cause the cutting head to change direction more abruptly. Although these changes are more abrupt, they tend to be in a single direction (i.e., single lobed).

These typical observations are helpful for developing a baseline expectation for IMU bending strain signatures for HDD construction, but exceptions to these guidelines are common. There are many reasons for atypical signatures including different HDD installation techniques, designs, geological conditions and drillers.

Typical HDD landslide impact bending strain signatures

IMU signatures from landslide impact will overprint the signature of HDD construction and can be differentiated by assessing bending strain patterns in the context of a correct understanding of the mechanics of the landslide with an appreciation of soil-pipeline interaction at depth. Landslide impact tends to generate the bending strain signature characteristics outlined below:

- **Bend orientation:** If the landslide mechanism has a component of movement which is oblique or horizontally transverse to the pipeline, horizontal bend patterns are frequently observed and often correspond to vertical bend patterns. When ground movement is dominantly aligned with the pipeline axis, bending tends to be most pronounced vertically, resulting from the component of ground movement which is vertically transverse to the pipeline.
- **Peak bend magnitude:** Peak bend magnitude resulting from landslide impact may be much higher than 0.1 – 0.2%. Bends resulting from landslide impact can range from magnitudes which are indistinguishable from construction related strains to greater than 0.5%. As a general guideline, the greater the bend magnitude the higher the probability the bend is a result of landslide impact.
- **Bend length:** Bends formed by landslide impact along an HDD bore path tend to be shorter and often having bend lengths of less than a joint length. These bends are most often formed at locations where the pipeline is accommodating differential ground movement, such as at a landslide scarp or toe. One reason for shorter bend length is that the stiffness

https://doi.org/10.52202/078572-0026

of the ground relative to the pipeline is higher at HDD depths than typical trench burial depths. This results in ground movements being accommodated over a shorter length of pipeline because the pipeline is not stiff enough to resist the ground movement. Another reason is that landslide slip surfaces at depth may be confined to a narrower shear zone compared to more distributed shearing near surface. This would also have the effect of forcing the pipeline to accommodate ground movement over a shorter length of pipe. These mechanics tend to generate bend signatures which could be confused with formed construction bends (i.e., short abrupt bends) and are in contrast to the longer broad bends typical of landslide impact to shallower pipeline described by Hart et al. (2019).

- **Bend form:** Bends formed by landslide impact tend to have more abrupt pitch and heading ramps and often have a similar form to construction bends. This is caused by the above-mentioned mechanisms of ground stiffness and narrower shear zones which force the pipeline to accommodate ground movement over a short length of pipe.
- **Number of bending strain lobes:** Landslide impact tends to generate "multi-lobed" bending strain patterns which are a result of the pipeline bending in two opposing directions to accommodate differential ground movement. These patterns are also referred to as bend-reactionary bend pairs (Dowling et al. 2024), sinusoid-bends, S-bends or W-bends (Hart et al. 2019). The bends are often adjacent and symmetrical, centred around the plane of movement. If there is a component of landslide movement horizontally transverse to the pipeline, a corresponding horizontal S- or W-bend will often share a centre point with the vertical bending strain pattern because the movement is centred around the same plane of movement.
- **Location:** The location of landslide bending strain signatures tends to be where there is differential movement transverse (vertically, horizontally, or both) to the pipeline axis. To assess IMU for landslide impact, information must be available to characterize the presence, dimensions, and mechanism of the landslide. Points of differential movement tend to correspond to prominent scarps or toes, basal shear planes or internal landslide block boundaries.
- **Directionality:** Directionality refers to the direction of ground movement implied by the direction of bending. A pattern of a bend-reactionary bend pair consisting of an overbend-sagbend (from upslope-downslope) is common with cross cutting movement at landslide scarps and toes. Opposite (sagbend-overbend) bend signatures may exist at features where relative movement of landslide blocks is reversed, such as at anti-slope (upslope facing) scarps common at graben-horst boundaries in deep-seated translational slides.
- **Run-to-run change:** Run-to-run change which follows a pattern of growth consistent with the landslide mechanism is a strong indicator of landslide impact. Often run-to-run analysis is not required to make a confident assessment of landslide impact because of how distinct the signature of landslide impact is relative to typical HDD installation signatures. Run-to-run change consistent with growth of a landslide impact signature provides an

 https://doi.org/10.52202/078572-0026

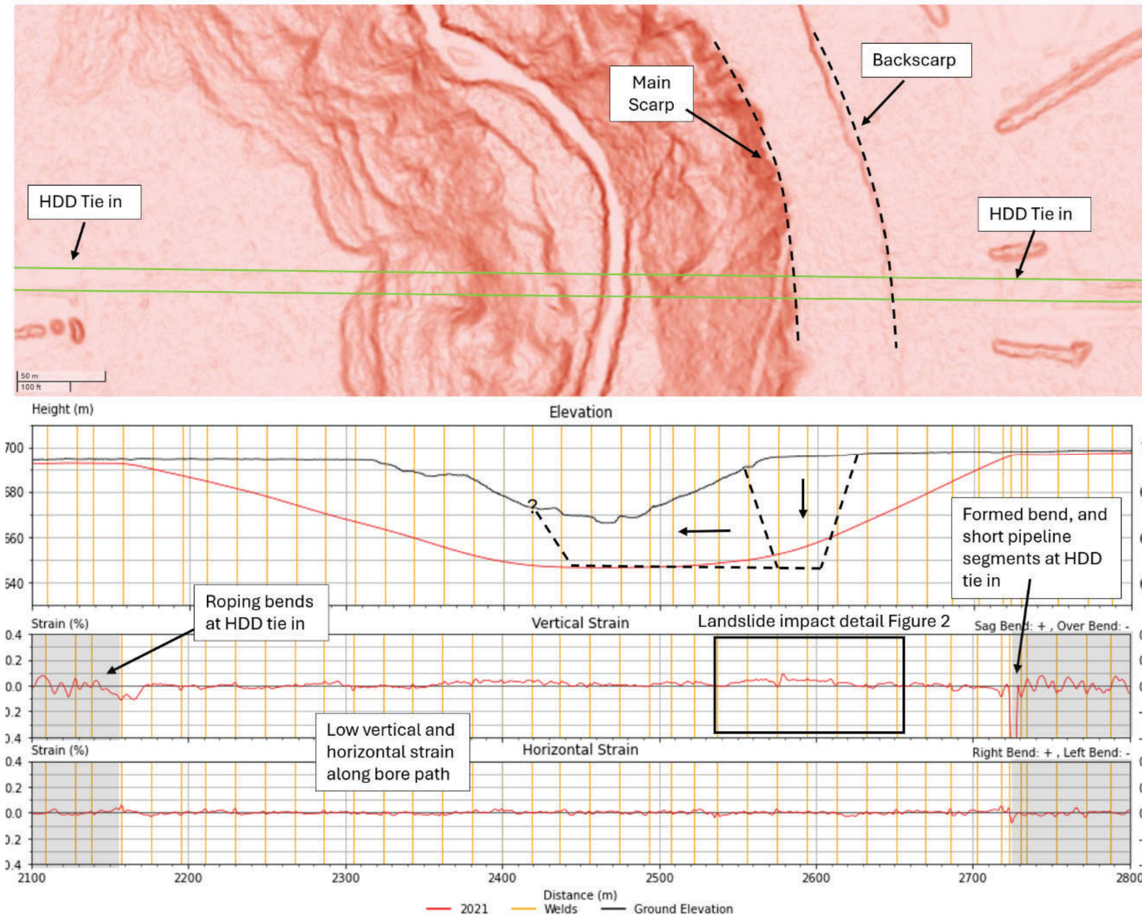
indication of the landslide activity during the period between runs. A lack of change run-to-run does not mean that the signature is unrelated to ground movement but could imply a lack of movement during the period between runs.

It is rare that landslide impact would only generate one characteristic, which is why the pattern of bending is considered a signature, or combination of the characteristics which jointly strengthen the probability the source of the bending is landslide impact. If only one characteristic is observed, there is greater uncertainty and greater potential for another explanation for the atypical signature.

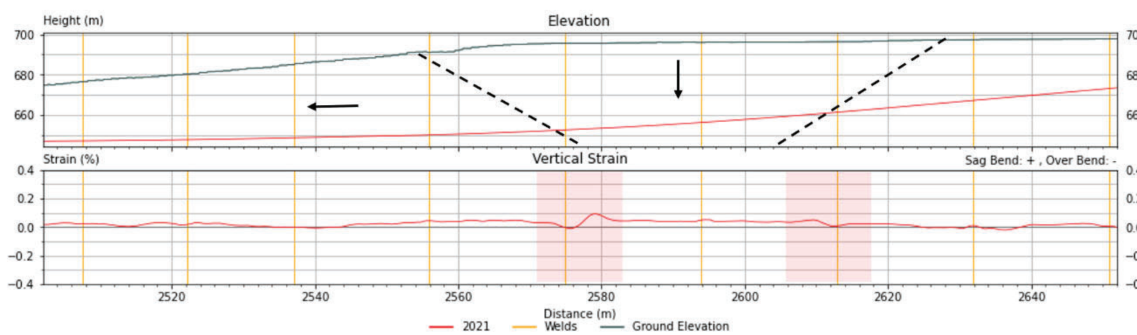
Examples

The following examples include IMU data from actual sites to illustrate the bending strain signatures of typical HDD installations and landslide impact to HDDs. The key characteristics of each signature are annotated to demonstrate how the signatures of landslide impact were identified.

https://doi.org/10.52202/078572-0026

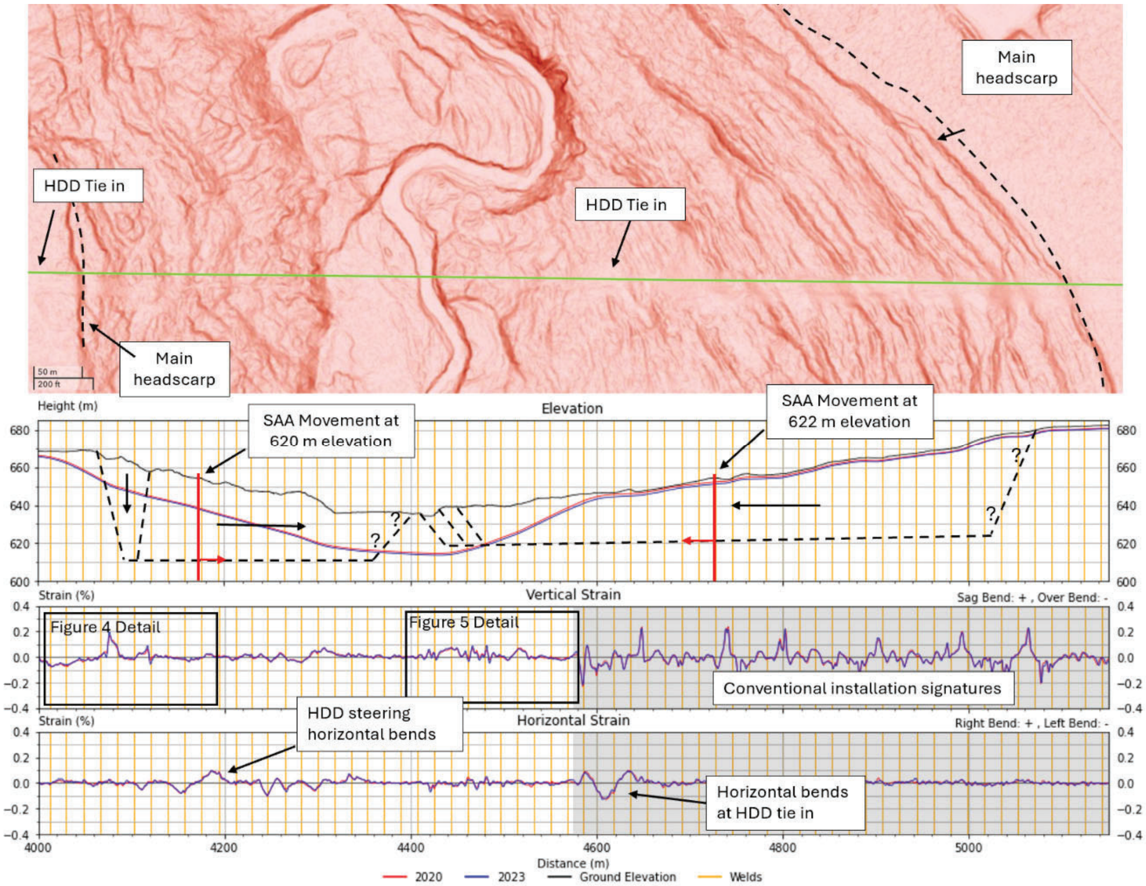


➢ **Figure 1.** Landslide impact observed due to deep seated ground movement in a small creek valley. IMU signatures in the pull section are low magnitude (< 0.04%), long wavelength and no horizontal bends or strains are observed. Large, formed bends and increased roping are observed at the HDD tie-ins on each side of the valley.

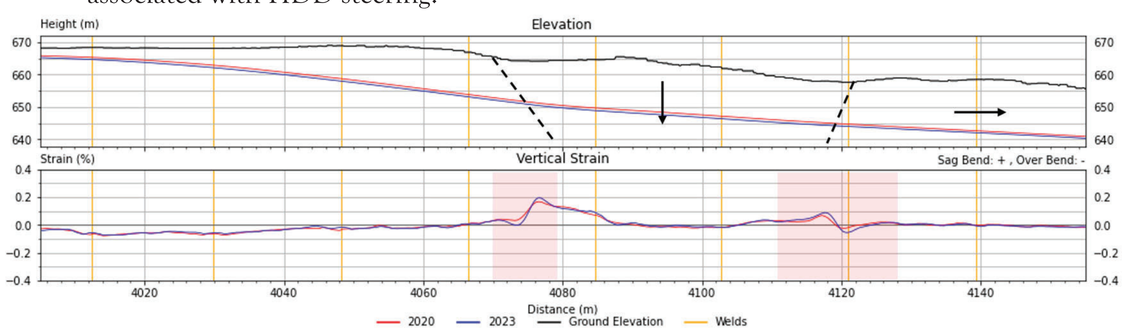


➢ **Figure 2.** Detail of the area of impact for Figure 1. Subtle low magnitude bending strain features are observed (shaded red) which are coincident with the location of the scarps observed in the lidar. The bend signatures are multi-lobed, symmetrical, short wavelength with abrupt change, and have a relative high bend magnitude in comparison to the rest of the drag section. The bend signature is consistent with downward movement (directionality) at the intersection of a graben block (location). Despite the low strain levels and lack of run-to-run data, the signature of landslide impact is apparent.

https://doi.org/10.52202/078572-0026

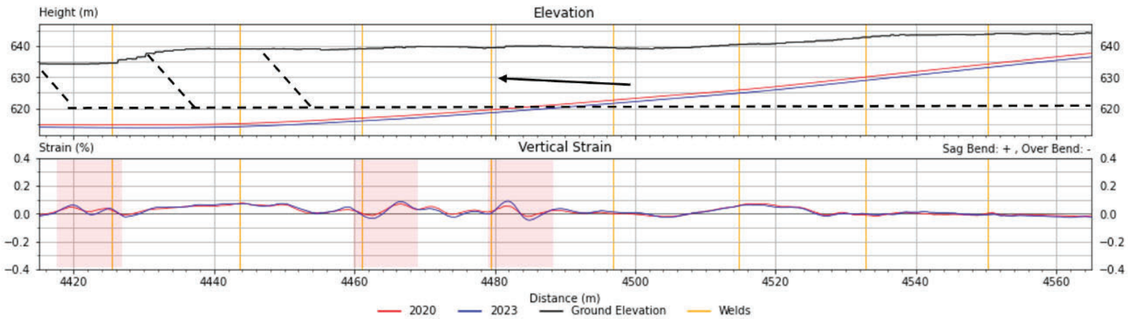


➢ **Figure 3.** Landslide impact observed in IMU data from two deep-seated landslides on either side of a valley. The HDD tie in is located in the lower mid slope on the right slope, which highlights the difference in signatures. IMU signatures in the drag section are low magnitude (< 0.1%) and have a long wavelength. Horizontal bends are observed on the left slope associated with HDD steering.

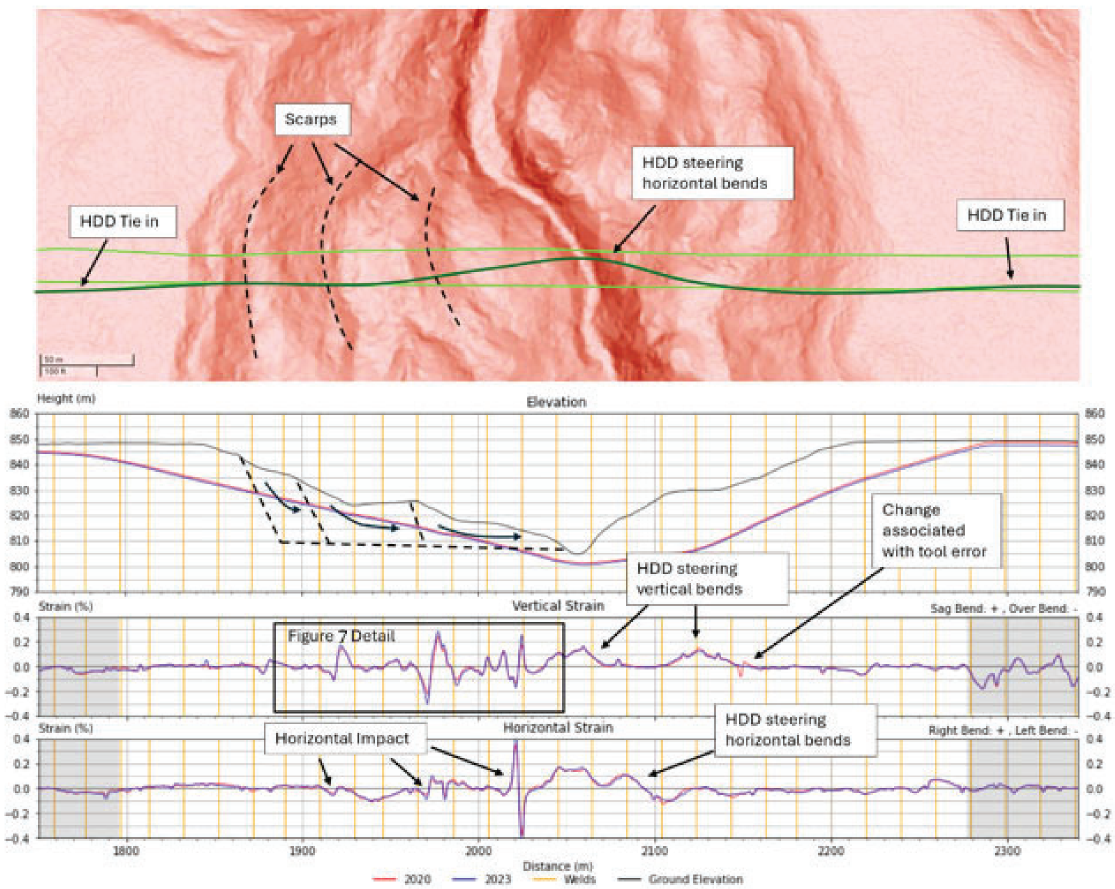


➢ **Figure 4.** Detail of the area of impact on the left slope from Figure 3. Bending strain features are observed (shaded red) which are coincident with the location of the scarps observed in the lidar. The bend signatures overprint broad sag bends and are multi-lobed, symmetrical, short wavelength and abrupt, and have a higher bend magnitude (up to 0.2%). Bending strain change is observed between 2020 and 2023, showing bend growth. The bend signatures are consistent with downward movement (directionality) at the intersection of a graben block (location).

https://doi.org/10.52202/078572-0026

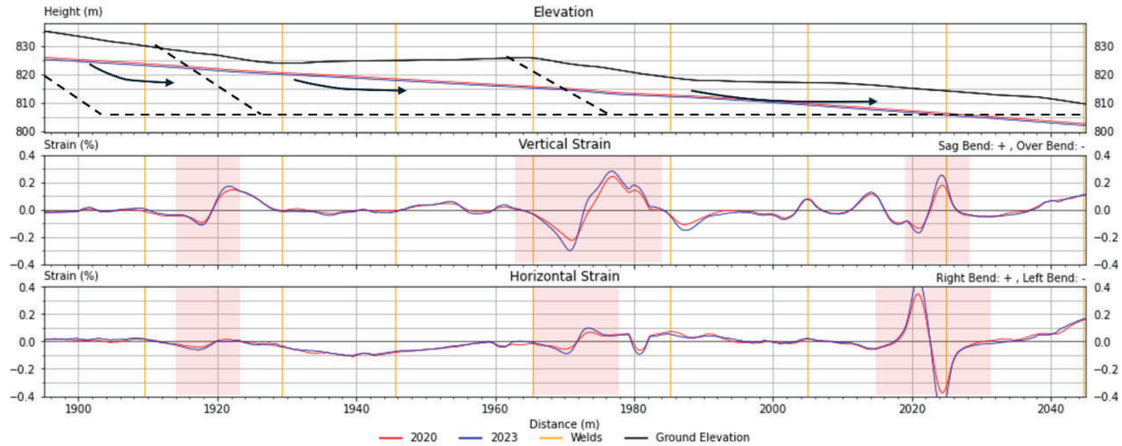


➢ **Figure 5.** Detail of the area of impact on the right slope from Figure 3. Several bending strain features area observed (shaded in red) which are consistent with the expected depth of movement observed in other on-site instrumentation (slope inclinometers). The strain features are short wavelength and multilobed. Bending strain change is observed between 2020 and 2023, showing bend growth at these locations.



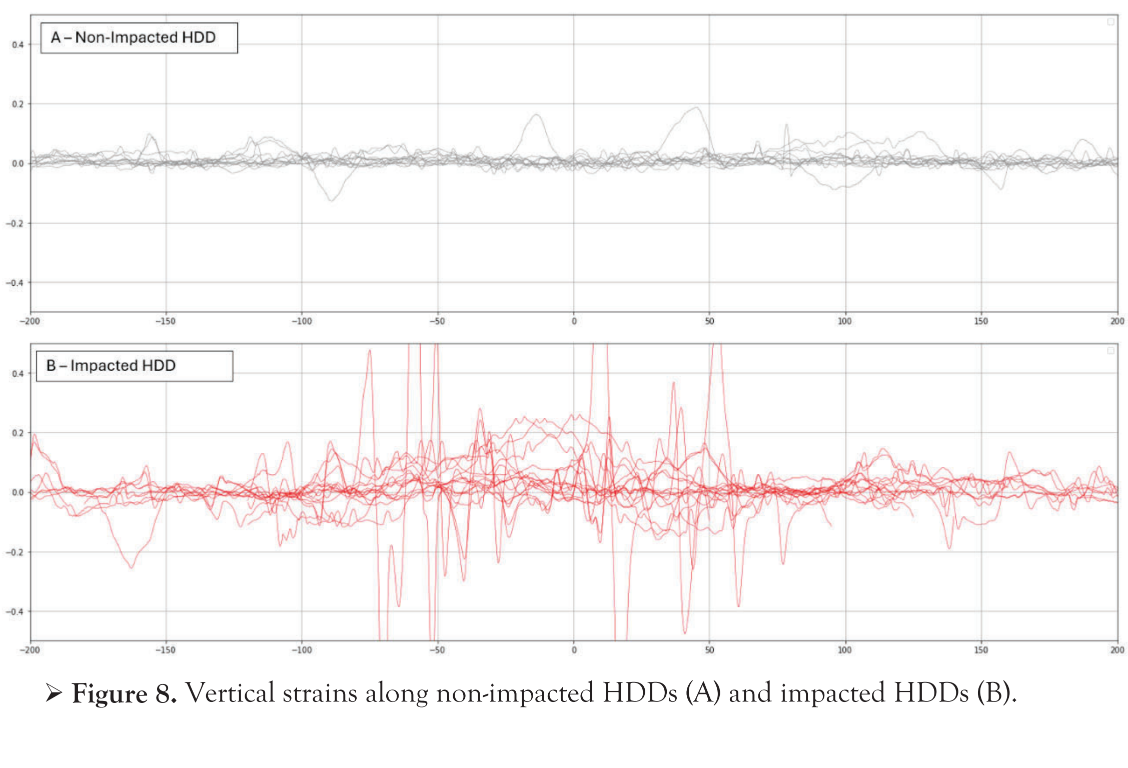
➢ **Figure 6.** Landslide impact observed in IMU data along a shallow HDD crossing a short valley slope. On the right slope the IMU signatures are low magnitude (< 0.15%) and have a long wavelength associated with horizontal and vertical HDD steering where expected at the bottom of the HDD bore path and following the pipeline alignment.

https://doi.org/10.52202/078572-0026



➢ **Figure 7.** Detail of the area of impact from Figure 6. Bending strain features along the shallow HDD profile observed (shaded in red) which are consistent the locations of scarps observed during ground inspections. Horizontal bending strains are observed at the slope where the ground movement is oblique to the pipeline resulting in large horizontal strain (total strain 0.5%). All the strain features are short wavelength and multilobed and bending strain change is observed between 2020 and 2023, showing bend growth at these locations.

To further illustrate the general patterns of impact from the 30 sites in the library compiled for this paper, a composite of typical HDD bending strain signatures is shown in Figure 8A, contrasted with sections where landslide impact is present in Figure 8B.



➢ **Figure 8.** Vertical strains along non-impacted HDDs (A) and impacted HDDs (B).

Discussion and conclusions

The purpose of this paper is to highlight the importance of checking for evidence of landslide impact to HDDs, recognizing that HDDs which intersect landslides are at a 15-times greater risk of failure compared to conventionally trenched pipelines in landslides. IMU is presented as a uniquely well-suited tool for evaluating HDD impact. Characteristics of the bending strain signatures of typical HDD installation and landslide impact to HDDs are presented with real world examples.

Effective interpretation of IMU bending strain signatures for HDD impact from landslides requires knowledge and experience of typical HDD installation practices, specialized knowledge of landslide assessment and knowledge of how to process and interpret IMU data. When this unique combination of skills is brought together IMU assessment is a highly effective tool for identifying landslide impact. Identifying landslide impact prior to becoming a critical pipeline integrity risk offers operators the opportunity to proactively plan risk mitigations such as replacement, rerouting, or advanced monitoring.

IMU has become the most valuable tool for assessing landslide risk to HDDs, but like any tool it has limitations. If no evidence of landslide impact is observed, it cannot be concluded that the landslide avoids the pipeline or is inactive. It is possible that the landslide is intersecting the pipeline but is dormant or is moving slowly enough that impact is not yet apparent. For this reason, ongoing screening for bending strain change or pipeline movement may be worth continuing, even if landslide impact is not initially identified.

Bending strain is also only one component of total strain demand from landslide impact and axial strain must also be considered. Because the pipeline bending is landslide displacement constrained, it cannot alleviate axial compression through bending the way a shallowly buried pipeline can. This can result in axial strain being significantly larger than the bending strain measured by IMU. In a pipeline stress analysis completed for the pipeline in Figures 3 – 5, the axial compression was estimated to be two times larger than bending strain, so the total longitudinal strain was three times the bending strain measured by IMU.

The guidelines provided in this paper are not iron-clad rules and many exceptions will be encountered. Depending on the angle of intersection of the slip plane to the pipeline and the nature of the slip planes, scarps and internal shearing within a landslide mass, reasonably complex and irregular bending strain signatures can emerge. Despite these limitations, the guidelines have proven highly effective and early identification of landslide impact to HDDs has reduced pipeline failure rates significantly. From the pipeline failure dataset published in Van Hove et al. (2022) 35% of the failures resulted from landslide impacted HDDs, averaging 1 failure per year. Over the past three years zero failures have occurred from the same group of pipelines, meanwhile several critical landslide impacts to HDDs have been identified annually using IMU.

https://doi.org/10.52202/078572-0026

References

Czyz, J., and Adams J. 1994. Computation of pipeline-bending strains based on geopig measurements. Pipeline Pigging and Integrity Management Conference. February 14 – 17, 1994.

Da Silva, D., Rodrigues, M., Venås, A., de Medeiros, A. 2009. Methodology for definition of bending radius and pullback force in HDD operations. Rio Pipeline Conference and Exhibition 2009.

Dowling. C., Barlow, P., Van Hove, J., Hanvi, T., Hart, J.D. 2024. Ground movement or Construction? How to identify clear ground movement signatures in inertial measurement unit data. Pipeline Pigging and Integrity Management Conference. February 12 – 16, 2024.

Hart, J.D., Czyz, J.A., Zulfiqar, N. 2019. Review of pipeline inertial surveying for ground movement-induced deformations. Proceedings of the Conference on Asset Integrity Management-Pipeline Integrity Management Under Geohazard Conditions AIM-PIMG2019. March 25 - 28, 2019, Houston, TX, USA.

Van Hove, J., Barlow, P., Duguay, M., Karimian, H. 2022. Vulnerability of pipelines installed by horizontal directional drilling to landslides and a proposed framework for developing preliminary no drill zones for landslide avoidance. 13th International Pipeline Conference. September 26 – 30, 2022. Calgary, Canada.

Van Hove, J., Barlow P., Dowling C. 2024. The use of inertial measurement unit data for managing slow-moving landslides. Pipeline Pigging and Integrity Management Conference. February 12 – 16, 2024.

https://doi.org/10.52202/078572-0026