Pipeline Bending Strain Assessment using ILI Tools: Case Studies

Ian Murray CEng IMechE, Jane Dawson, Lautaro Ganim (PII Pipeline Solutions, UK)
Daniel Bieger (EGO, Switzerland)) Daniel Vallejo, GVM Switzerland)

Abstract

Mapping the position of a pipeline using pipeline location coordinates (x, y, z) collected from an in-line inspection (ILI) survey has become routine practice for many pipeline operators over recent years. When an IMU (Inertial Mapping Unit) tool is included as part of an ILI survey it provides a synchronized stream of x, y, z mapping information which aligned with the ILI data provides the means to accurately and easily locate pipeline anomalies, features and fittings. Indeed, regulations in some regions require that the precise location of pipeline assets are documented as part of managing the integrity of a pipeline and certainly this is considered to be good practice.

The x, y, z mapping information collected by an IMU tool has an additional use which is less widely understood. The mapping data can be used in the determination of sections of a pipeline indicating potential deviation from the pipelines' original position. Specialized assessment of the IMU data can be performed to calculate curvature and to derive the consequential bending strain levels throughout the pipeline. The use of data from repeat runs can identify where even small changes to pipeline shape changes are occurring. However, the use of the IMU mapping data is less known for this purpose and has not yet been widely adopted across the industry. There is no requirement in pipeline regulations to conduct this type of study and furthermore little guidance in industry codes on what level of movement or bending strain should be considered actionable.

This paper presents case studies describing the rupture failure of a 10 inch natural gas pipeline caused by a spontaneous and localised landslide event. The metallurgical failure investigations carried out on the pipe material taken from the failure site did not find any evidence of sub-standard pipe material or of any pre-existing pipeline defects, this was further confirmed from ILI and IMU data collected from the failed pipe several months prior to the event. Hence, it can be concluded that the rupture was caused solely by the catastrophic external loading on the pipeline resulting from the sudden landslide.

The paper goes on to discuss the specialized assessment of IMU mapping data to derive the magnitude of sub-critical bending strains present on the pipeline prior to the landslide event and whether such assessment could be used to indicate the pipeline segments in unstable ground conditions and potentially at risk from environmental outside force events. Taking experience from these case studies and from other known pipeline events, the level of bending strain that may be considered actionable is also discussed.

1. Introduction

The x, y, z mapping information collected by an IMU (Inertial Measurement Unit) has a further use which is less widely realised. The mapping data can be used in the determination of the location of sections of a pipeline indicating potential deviation from the pipelines' original position.

Specialized assessment of the IMU data can be performed to calculate curvature and to derive the consequential bending strain levels throughout the pipeline. The use of data from repeat runs can identify where even small changes to pipeline shape changes are occurring.

However, the use of the IMU mapping data is less known for this purpose and has not yet been widely adopted across the industry. There is no requirement in pipeline regulations to conduct this type of study and furthermore little guidance in industry codes on what level of movement or bending strain should be considered actionable.

This paper presents 2 case studies detailing the uses of this type of investigation in order to mitigate against the pipeline integrity threats caused by land movement.

2. Case Study 1: Pipeline Rupture

On Sunday, March 30, 2014, a Gasverbund Mittelland AG (GVM) natural gas pipeline ruptured. The gas line runs through a mountainous region in Europe, from Arlesheim to Oberbuchsiten and was constructed in the mid-1960s.

An incident investigation was initiated immediately, focusing on prior in-line inspection data, the failure site and pipe material investigations.

The failure site was investigated and it was found the rupture had resulted in a large crater exposing the previously buried pipeline. Photographs of the failure area are presented in Figure 1.

Figure 1 – Rupture Site Photographs

2.1. In-Field investigations

2.1.1. Material Investigation

A comprehensive material analysis by the Institute of Materials Technology (IWT) in Wallisellen did not identify any pre-existing defects, material weakness, wall thickness loss, aging or material damage. In addition the rupture site was located in the pipe body and was not located at a weld. Material testing confirmed the pipe steel was in excellent condition and in full compliance with required material specifications.

2.1.2. Geotechnical Investigation

Geological and geodetic studies were performed in order to analyse the geological substratum behaviours in the failure location.

The investigations considered the soil types and layers, slope movements and the directions of movement. In addition, data from existing slope monitoring measurements were considered.

Historical data indicated the slope had been moving over time, with more recent records indicating an increase in these movements from 2013. It was concluded that this increase in movement lead to high shear forces which ultimately caused the failure.

2.2. In-Line Inspection Investigation

Following the pipeline rupture GVM requested PII to further examine the data collected via an in-line inspection (ILI) performed in 2013; 6 months prior to the rupture.

The tool used in this inspection was a combination ILI vehicle comprising of MFL (magnetic-flux leakage) and calliper technology, capable of identifying significant threats to pipeline integrity. In addition the vehicle also contained an inertial measurement unit (IMU) used to map the position of the pipeline. The rupture area was reviewed in the ILI data sets and it was found there was no evidence of stress raisers in the area.

Figure 2 – Strain Data for Failure Area

A further review was conducted utilising the IMU data to investigate the line shape in the rupture area. From the pipeline curvature it is possible to determine the extent of bending strain at the failure location.

It was determined that at the time of the 2013 ILI there was significant bending at the failure site; the equivalent bending strain was found to be >0.5% (see Figure 2 for the peak in strain evident at the failure location).

2.3. Conclusions

The findings of both the in-field and in line inspection review are detailed below:

- The metallurgical failure investigations carried out on the pipe material taken from the failure site did not find any evidence of sub-standard pipe material or of any pre-existing pipeline defects
- The geotechnical investigation confirmed there was additional loading on the pipeline due to ground movement in the area.
- The in-line inspection data confirmed there were no stress raisers evident at the failure location
- Detailed review of the ILI mapping data identified significant bending strains were evident at the failure site

Therefore it can be concluded that the rupture was caused solely by the catastrophic external loading on the pipeline resulting from the sudden landslide. Using an IMU unit to identify areas susceptible to ground instability can aid in mitigation of these catastrophic events.

3. Case Study 2: Coincident Features

In 2014 Erdgas Ostschweiz EGO commissioned an ILI inspection of a 10 inch pipeline running through a hilly landscape. The tool used in this inspection was a combination ILI vehicle comprising of MFL (magnetic-flux leakage), calliper and IMU technology, capable of identifying significant threats to pipeline integrity.

In addition EGO commissioned an investigation of the bending strain utilising the IMU data for the pipeline. This investigation identified an area of significant bending strain >0.5%; the findings are detailed below.

3.1. Equivalent Bending Strain Investigation Findings

The investigation identified an area of high strain, coincident with a number of bends as well as a number of strain peaks. Several of these peaks showed some characteristics of bends however they were not typical of the signals seen on the rest of the line therefore in order to be conservative these peaks were included in the reported strain magnitude.

The data collected for this area is presented in Figure 3 below. This data shows the horizontal and vertical strain profiles. The strain peaks are highlighted in red, with the identified intentional bends highlighted in blue.

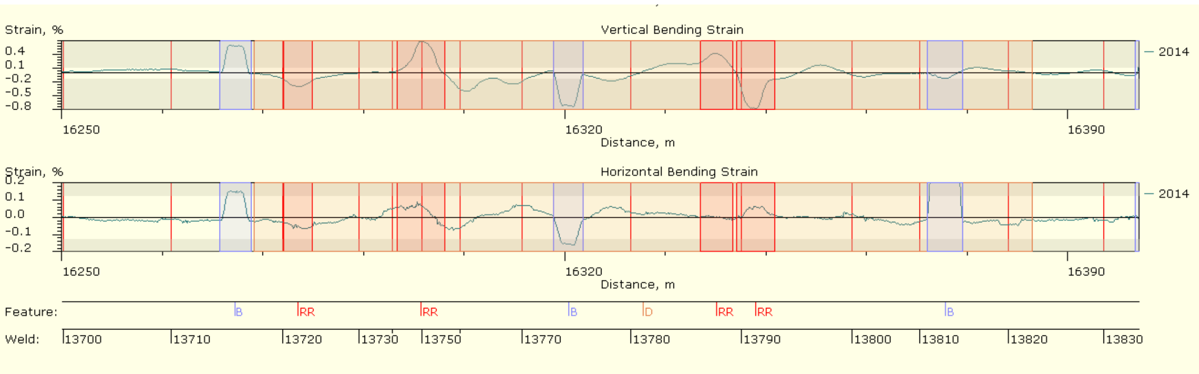

Figure 3 - Equivalent Bending Strain Investigation Findings

3.2. MFL Data Review

The bends and strain peaks were reviewed in the magnetics data. It was determined that the identified bends showed evidence of intentional construction bending; however the review of the areas was not conclusive in determining their origin.

3.3. Coincident Features Review

As part of the investigation the coincident features reported from the MFL tool were reviewed. It was determined that, coincident with one of the strain peaks, a metal loss feature had been reported. This was identified as a 39% wall thickness in depth external metal loss feature, which was axially short and circumferentially wide (the ILI signal data for this feature is shown in Figure 4 below).

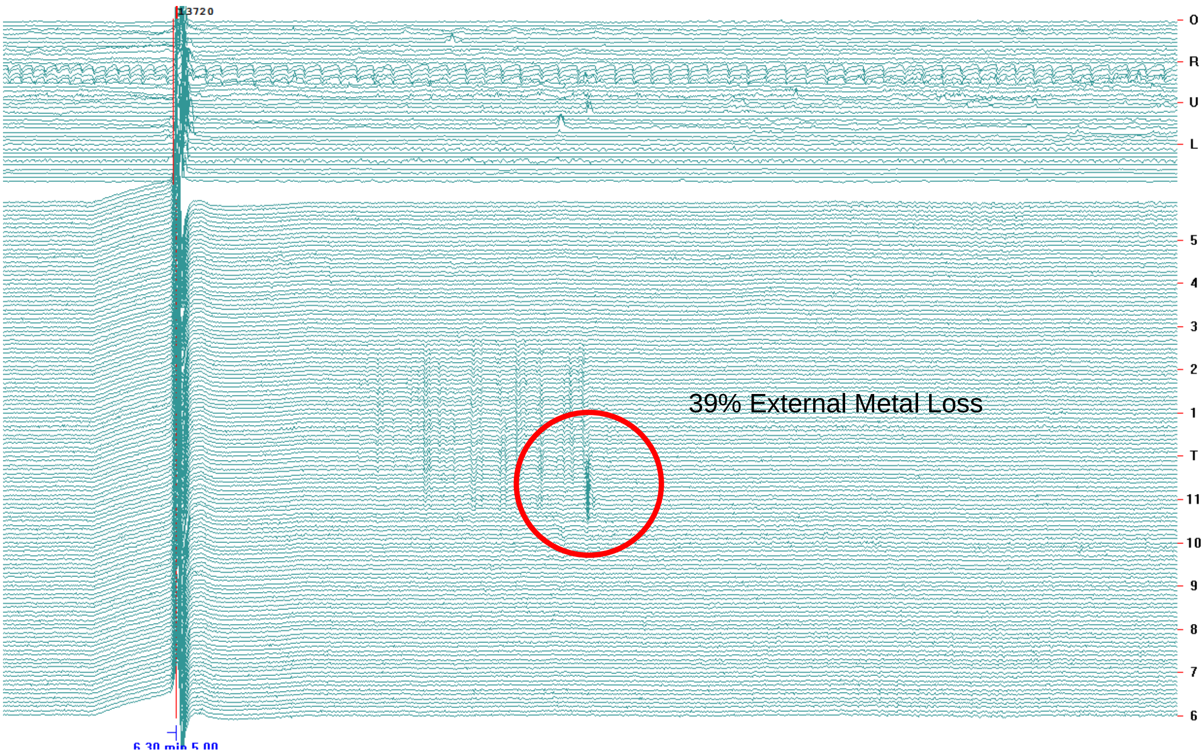

Figure 4 – Magnetic Flux Data showing Coincident Feature

It was determined through interrogation of the data that this feature was located in the tensile zone of a peak in bending strain.

3.4. In-Field Investigation

EGO carried out in-field investigations to excavate and further investigate the origin of the identified strain and bending (Figure 5). At the location identified as metal loss in the ILI report no external metal loss was found. Following localised grinding at the location it became evident that the reported metal loss feature was in-fact a circumferential crack (Figure 6). The crack was located at the top of the pipe in a tensile strain zone.

It was determined that the crack was 40% wall thickness in depth with comparable circumferential length as reported by the MFL ILI tool. This feature was repaired as part of this investigation. In addition the bending loads were relieved from the line.

Figure 5 - In-Field Feature Investigation

Figure 6 –Crack found from In-field investigation at location of reported External Metal Loss Feature

3.5. Conclusions

Through the combined review of the ILI data including magnetics and IMU data the threat of failure from ground movement causing a circumferential crack to form was mitigated.

PII have seen other examples of this type of circumferential cracking feature caused by land movement leading to pipeline failure.

4. Industry Guidance on Bending Strain Limits

The approach used in these studies to determine the level of equivalent bending strain is based on the measured pipeline shape. It is assumed the pipeline was laid straight and that curvature is the result of external loading (with the exception of intentional field bending). It is possible in some cases that a line will have some curvature when it is laid (outside of intentional bends). There are also limitations in determining the total strain loading on the line; if the line has additional axial stresses from for example temperature loading these will not be evident in the bending strain derivation.

Determining what is an acceptable limit for bending strain in a pipeline is not a straight forward exercise. From research into the various codified documents PII has found that there is no single strain limit that can be applied. Indeed, tensile strain capacities as low as 0.2% and as high as 2 to 4% have been obtained from experimental tests. From the research in the PDAM[1], CSA_Z662_11[2], PD 8010[3] and DNV-OS-F101[4] documents, PII has found various guidelines in which conservative strain acceptability limits can be derived.

There are different methods for deriving the strain acceptability limits. For defect free pipe the CSA_Z662_11 and PD 8010 documents have equations to calculate conservative compressive strain acceptability limits.. The Ramberg-Osgood stress-strain relationship equation assumes a tensile yield point of 0.5% strain and DNV-OS-F101 states a girth weld fracture (tensile strain) limit of 0.4% strain.

It is noted that the above considerations apply to defect-free pipe. In cases where coincident features are present a further in-depth study can be carried out to calculate and assess the pipeline integrity on a case by case basis.

5. References

1	Andrew Cosham & Phil Hopkins	The Pipeline Defect Assessment Manual (PDAM), A Report to the PDAM Joint Industry Project, June 2006
2	The Canadian Standards Association (CSA)	CAN/CSA-Z662-11, A National Standard of Canada, Oil and gas pipeline systems, (approved September 2012)
3	Technical Committee PSE/17 & Subcommittee PSE/17/2	PD 8010-1:2004, Code of practice for pipelines - Part 1: Steel pipelines on land, British Standards Institution, BSI 31 July 2004
4	Det Norske Veritas (DNV)	DNV-OS-F101, Offshore Standards, Submarine Pipeline Systems, August 2012