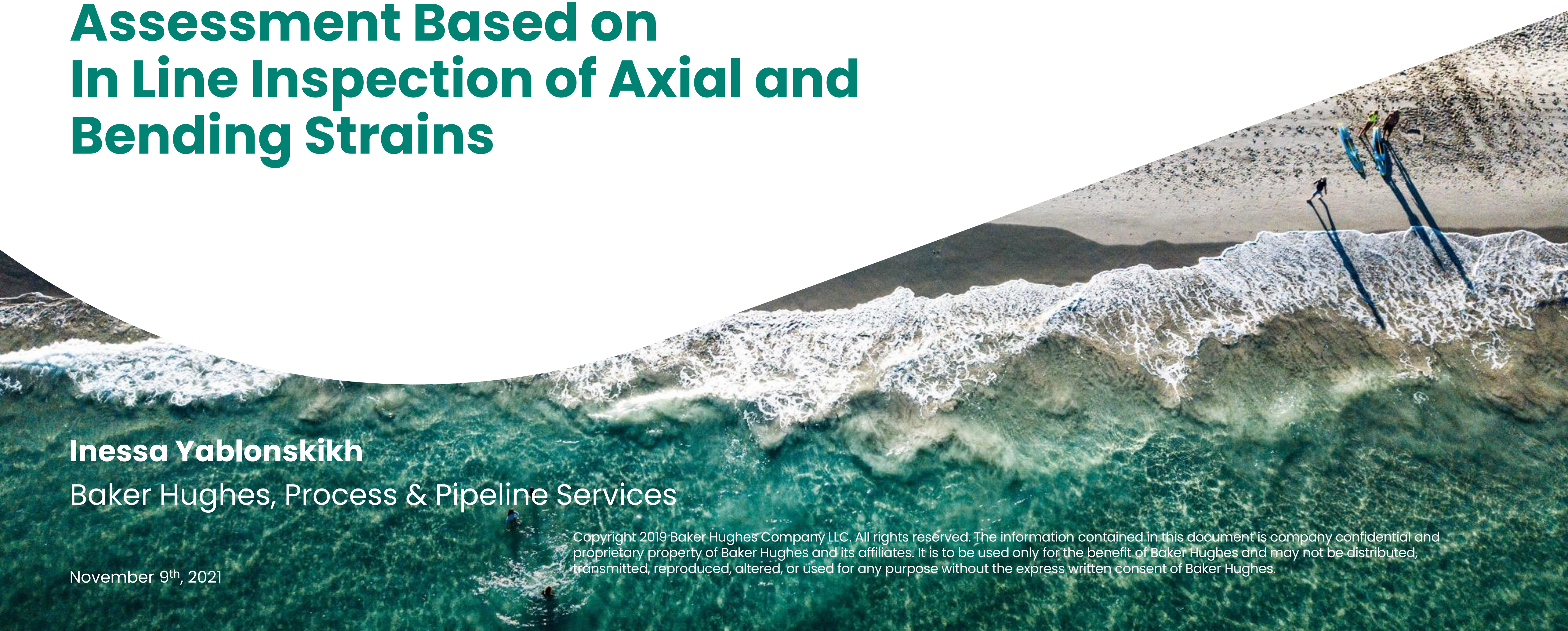
Strain Demand and Capacity Assessment Based on In Line Inspection of Axial and Bending Strains



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Overview

- Introduction
- Integrity Concerns in Pipeline Segments Affected by Longitudinal Strain
- Measuring strain with IMU & AXISS
  - IMU Bending Strain Measurement
  - Axial Strain Measurement
- Evaluating Strain Demand
- Evaluating Strain Capacity
- Case Studies

Integrity Concerns
… in Pipeline Segments Affected by Longitudinal Strain

- Under tensile longitudinal strain, the main integrity concern is a leak or rupture at an affected girth weld or other weakened location e.g., wide area of corrosion
- Compressive longitudinal strain may cause wrinkles or buckles
- The presence of girth weld anomalies, metal loss defects and dents can also affect capability of the pipe to sustain longitudinal loading.

Where … Strain demand limit > Strain demand → Acceptable

Strain Demand - magnitude of strain acting on affected pipeline segment
Strain Capacity - measure of pipeline segment's capability to resist failure
Strain Demand Limit - permitted value of strain demand (strain capacity x safety factor)

Measuring Strain Using ILI …

- **IMU** – measures pipe curvature, which is converted to bending strain … used to find potential geohazards

Bending strain is produced when a transverse load to the pipeline causes bending moment & pipeline curvature (deformation) to occur.

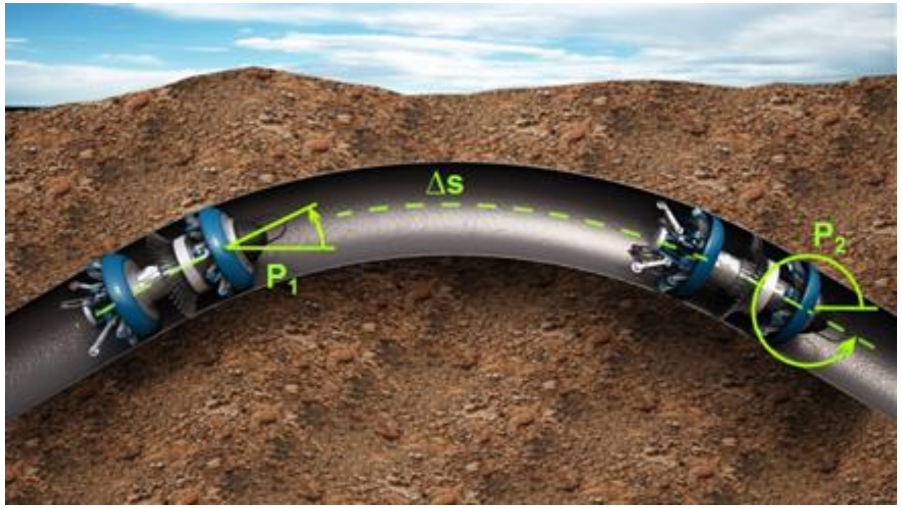
IMU measures the pipe curvature … from which we derive the bending strain

- **AXISS** – measures pipe material magnetic properties, which are converted to axial strain … used to find potential geohazards

Axial strain is caused by an axial load acting in the same direction as the pipeline axis.

AXISS provides the axial strain (it can be a tensile or compressive strain).

IMU Bending Strain Measurement



Bending strain is calculated from the precise changes in direction made by the tool – measured by the IMU

Δs = Distance between samples
P_1 = Pitch at 1st sample
P_2 = Pitch at 2nd sample
A_1 = Azimuth at 1st sample
A_2 = Azimuth 2nd sample
ΔP = Corrected change in Pitch
ΔA = Corrected change in Azimuth
k_h = Vertical radius of curvature
k_v = Horizontal radius of curvature

$$\kappa_v = \frac{\Delta P}{\Delta s} \qquad \kappa_h = -\frac{\Delta A}{\Delta s}\cos(P)$$

$$\varepsilon_v = \frac{D}{2}\kappa_v \qquad \varepsilon_h = \frac{D}{2}\kappa_h$$

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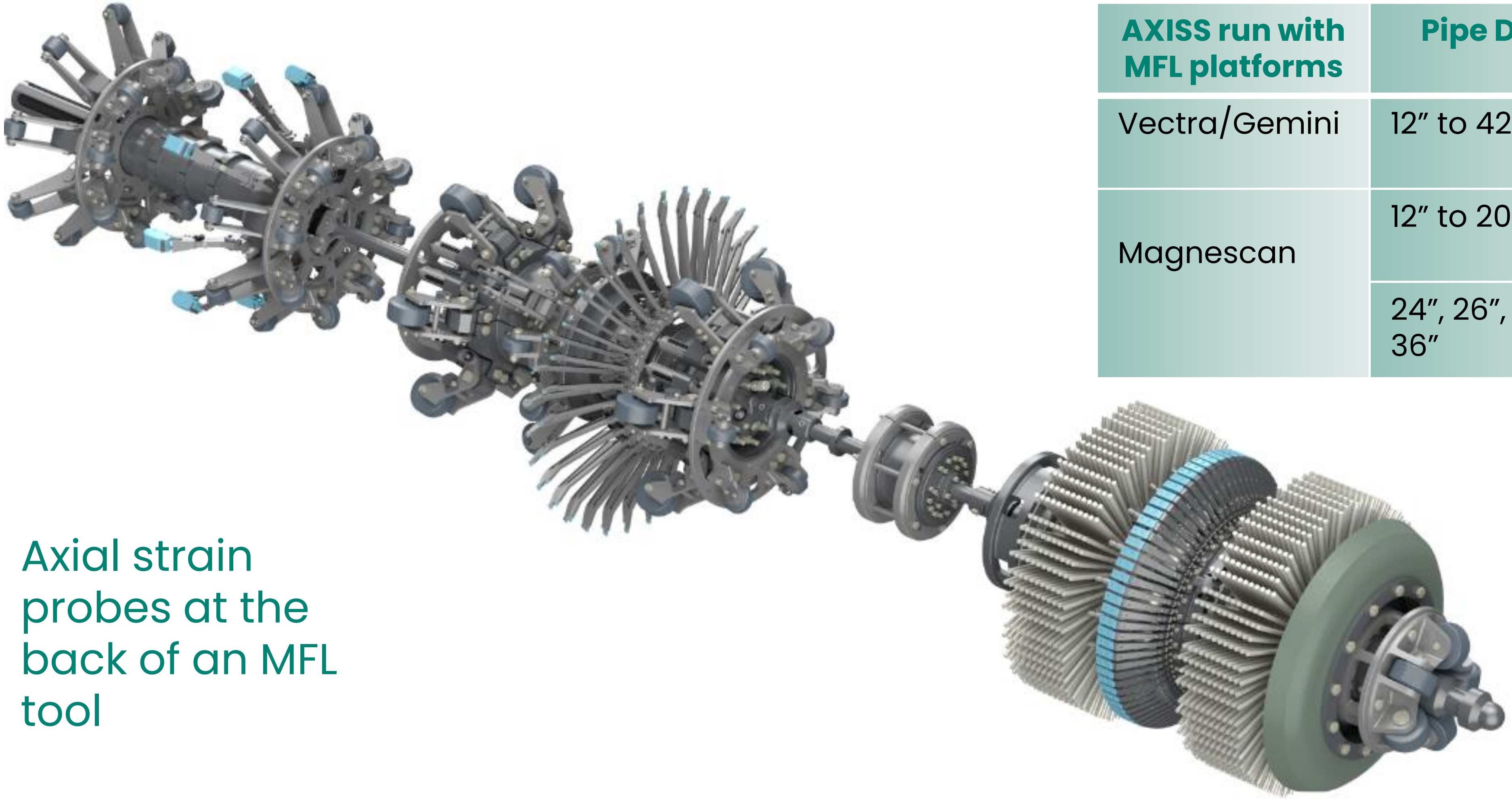
Axial Strain Measurement

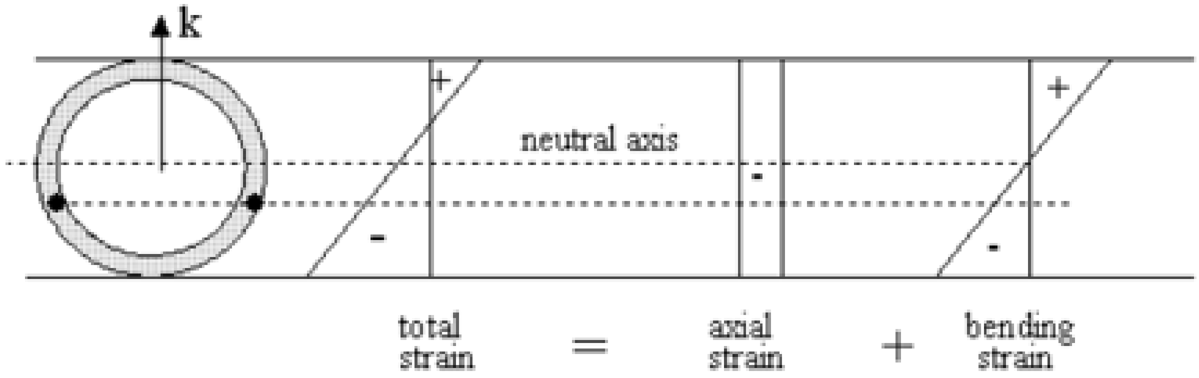


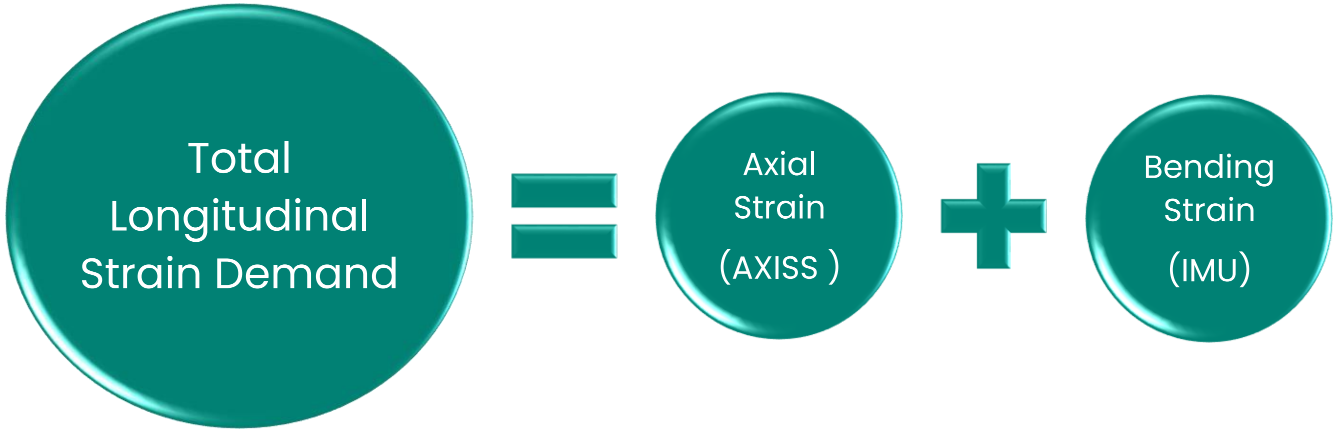
AXISS run with MFL platforms	Pipe Diameter	Deployment Date
Vectra/Gemini	12″ to 42″	Available now
Magnescan	12″ to 20″	Available now
	24″, 26″, 30″ and 36″	2021

Axial strain probes at the back of an MFL tool

Evaluating Strain Demand

- Both IMU & AXISS provide data to identify strain due to geotechnical events and complement each other
- Maximum benefit comes from using & combining information from both to provide an understanding of total strain at any point along the pipeline
- This supports the discrimination of strain induced by geological instabilities vs (inactive) strain due to construction





What is an Acceptable Level of Strain?

Tensile & compressive strain capacities depend on many parameters & have to be evaluated on a case-by-case basis.

Girth weld <u>tensile</u> strain capacity (TSC) can vary from 0.2% to >2% … in general …

- Vintage pipelines or modern high-strength pipelines → can be as low as 0.2% TSC

  Pipeline constructed before 1970, or without 100% GW QC, or under-matched welds, or HAZ softening.

- Modern pipelines with good quality welds → should have at least 0.4% TSC

  Pipeline constructed post circa. 1970, 100% GW QC during construction, GW strength equal to or better than base metal. No evidence of GW cracks or GW anomalies present.

A specific strain-based integrity assessment is recommended to evaluate both tensile & compressive strain capacities for specific pipeline segments

Evaluating Strain Capacity

- Estimate strain capacity at girth welds and pipe anomalies
- Information required …
  - Expected weld quality (misalignment, acceptable flaw dimensions) … welding requirements & records, construction NDT records
  - Expected pipe tensile strength, weld tensile strength & fracture toughness (pipe MTRs, weld consumable certificates)
  - Location of manual welds (tie-in welds)

If Strain demand limit > Strain demand ➔ Acceptable

Appropriate factor of safety must be included in the calculation of strain demand limit

- Safety factor in tension ≥ 0.6
- Safety factor in compression ≥ 0.8

Strain Capacity Model (example)

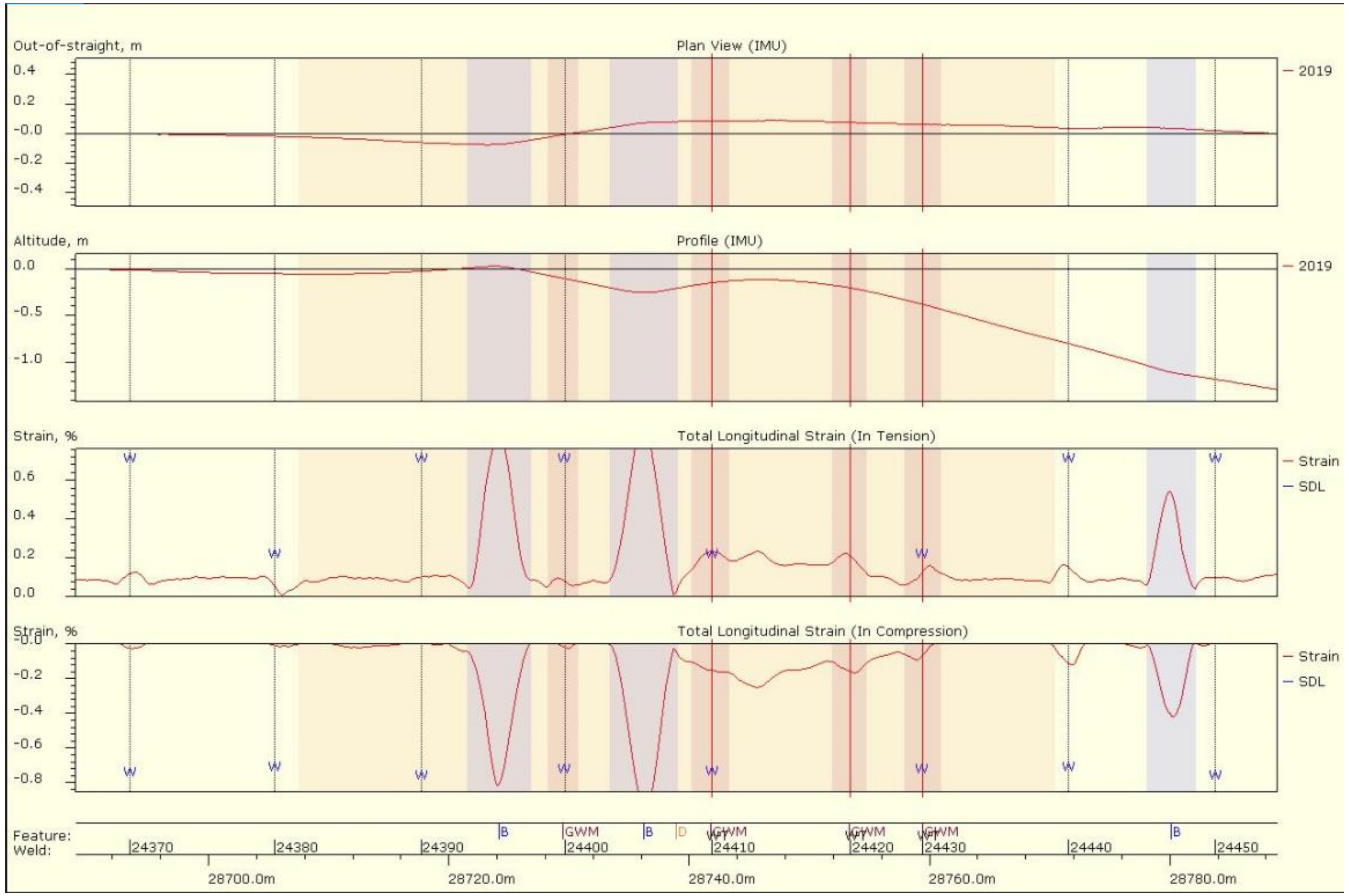
PHMSA Guidelines for Strain-Based Design and Assessment of Pipeline Segments are based on a set of strain capacity parametric equations that consider a wide range of influential attributes used to describe pipe strain hardening behaviour and including the:

- Type of the girth weld (manual (e.g., tie-in welds) vs mechanized/automatic)
- Girth weld strength mismatch (ratio of the weld metal tensile strength to the parent metal tensile strength)
- Pipe and weld fracture toughness
- Pipe and weld geometry and imperfections
- Anomaly dimensions.

This combination of attributes enables a rigorous assessment of the TSC and CSC limits.

Case Study 1 … Modern, Large Diameter Pipeline

- High strength pipe (X70)
- Identified axial & bending strain events
- Potential undermatching of properties in welds (particularly in manual welds)
- Unknown mechanical and fracture properties



Strain Demand vs Strain Demand Limit along the Pipeline

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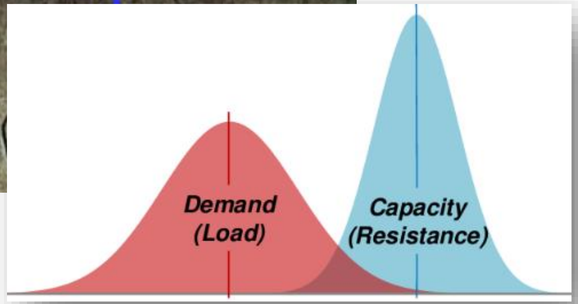
Case Study 1 … Immediate Integrity of Girth Welds

The tensile SDL varied between
- 0.2% for manual, tie-in welds in the lowest pipe wall thickness and
- 0.93% associated with the automatic welds in the thicker wall pipe.

The compressive SDL varied between
- 0.43% and 1.17% depending on the pipe wall thickness and the magnitude of the measured axial strain.

The maximum tensile strain demand
- 0.15% at a manual (tie-in) weld
- 0.46% at an automated weld.



Conclusion: Immediate integrity of the girth welds subjected to the tensile and compressive longitudinal strain was confirmed

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Case Study 1 … Future Integrity of Girth Welds

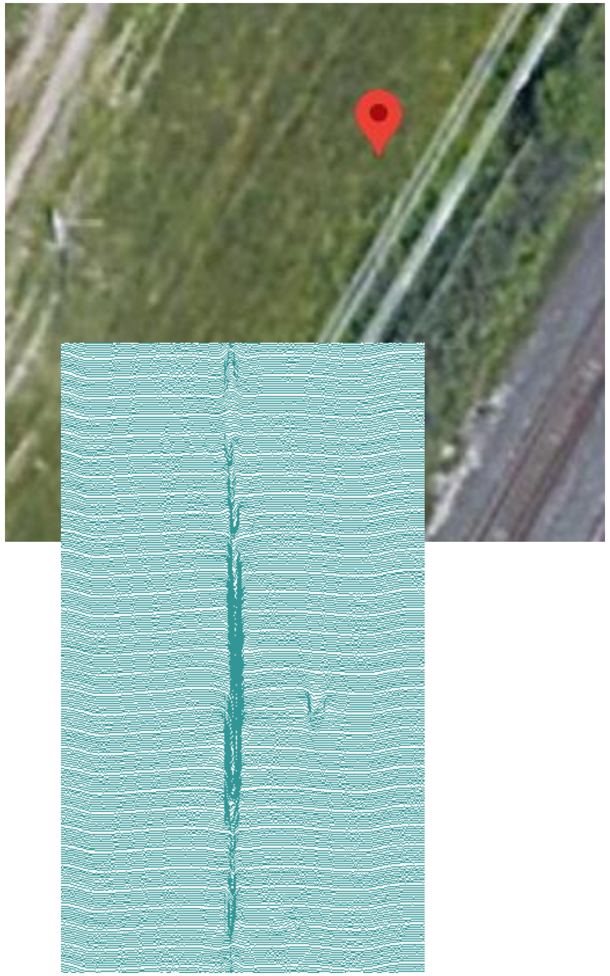
The indicators associated with the presence of a geo-hazard for example can include, but are not limited to:

- A significant horizontal component of bending strain.
- Presence of both bending strain and axial strain at the same location.
- Change in bending strain or axial strain identified from a subsequent ILI survey.
- Terrain susceptible to ground instabilities.

Conclusion … the reported strain demand was related to the pipeline construction and therefore not expected to progress with time

Case Study 2 … Small Diameter, 1950s Pipeline

- IMU strain and strain change reports have been delivered to the operator
- Operator required support with strain data interpretation, geotechnical threat evaluation, integrity evaluation & integrity response
  - Which strain and strain change features are of concern vs benign construction related strain or repair activities?
  - For the strain features of concern … what is the …
    - Longitudinal strain demand at girth welds
    - Longitudinal strain demand at reported defects (GWA, corrosion, dents)
    - Is the level of strain demand acceptable?
    - What action is required … Monitor / Field Investigate / Remediation?

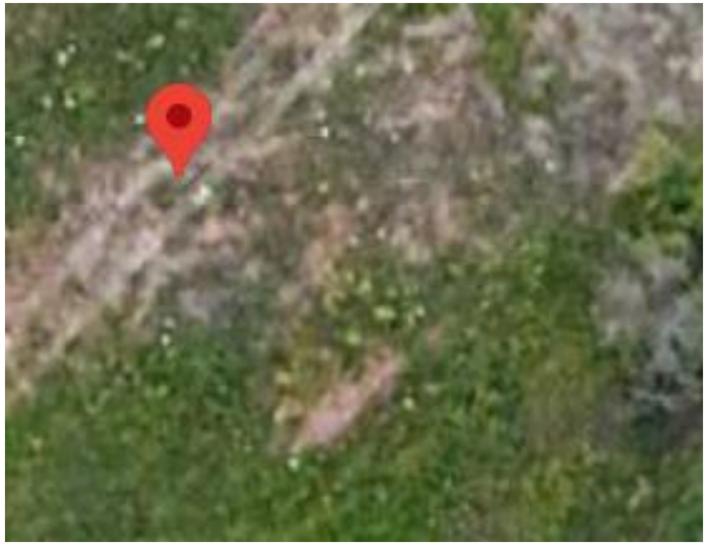


Case Study 2 … Small Diameter, 1950s Pipeline

Strain capacity assessment methodology applicable to vintage girth welds

- The tensile strain demand limit of 0.34%
- The maximum reported bending strain was 0.26%

Note: ILI survey did not include axial strain sensors. A conservative safety factor of 0.6 was used in SDL to account for the unknown axial strain component.



Conclusions …

1. The strain events were safe in terms of the immediate integrity of the pipeline.
2. Changes in bending strain associated with recent excavation and repair activities, therefore not a threat of progressive pipeline movement.

Conclusions

- IMU and AXISS ILI technologies provide the bending and axial strain information to determine total longitudinal strain demand at any position in a pipeline
- Where strain demand exceeds strain capacity remedial action is required
- Pipeline strain capacity is not an easy quantity to determine, it is influenced by many factors and there is no single set of strain limits that can be applied
- The strain capacity methodology to use must be carefully researched and selected
- The paper provides an effective and more comprehensive strain-based pipeline integrity solution to support geohazard risk management programs of pipeline operators.

Questions?