Pipe Expansions and Bulges: Consideration of Their Impact on Short-Term and Long-Term Pipeline Integrity

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Presentation # 64, Pipe expansions and bulges: Consideration of their impact on short-term and long-term pipeline integrity

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Contents

- Introduction / background
- Data evaluation of bulges and pipe expansions
- Integrity assessment
- Case study
- Conclusions

Introduction – Pipe Expansion

A Pipe Expansion is a localized increase in the diameter of a pipeline.

API 579 definition:
An outward deviation of a cross-section of a shell member from an ideal geometry characterized by local radii and angular extent. The local bulge geometry may be spherical or cylindrical.

Causes:

- Mechanical expansion during manufacturing
- Overstress during hydrostatic testing, caused by low yield strength or reduced wall thickness
- Additional loading from construction or ground movement combined with high hoop stress

Introduction - Bulge

ROSEN definition: A bulge is a localized outward deformation of the pipe, with an appearance similar to a ‘reversed’ dent.

No API 579 (or other) definition

Differs from pipe expansions

Poss. Causes:

- Bulging of a lamination caused by accumulation of hydrogen gas (bulging not consistent across the pipe WT)
- Local reduction in wall thickness combined with high pressure
- Localized mechanical force
- Excessive bending stresses leading to buckling (typically combined with inward bulging)

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Why could those indications pose a threat?

Localized deformation resulting in high curvature strains

Localized bulges with high strains could result in cracking.

Geometric stress concentrations can lead to reduced fatigue life

Stress concentrations shorten the time required to initiate and grow fatigue cracking.

Lower-than-specified material strength or wall thickness leads to high operating stresses

If pipe expansion was caused by a hoop stress above yield, operating stresses may exceed allowable pressure. Higher stress makes the pipe less resistant to damage (ex. corrosion) and increases the susceptibility to stress corrosion cracking.

Additional cold working can have a detrimental effect on the rate of hydrogen absorption

Pipes exposed to sour environments are more susceptible to hydrogen related cracking.

Additional cold working (ex. from expansion) could increase the absorption rate of hydrogen.

Regulatory Guidance and Requirements

§ 192.632 (c) mandates using ILI tools that can detect pipe expansion for the ECA analysis
No Response criteria for bulges and pipe expansions provided in CFR.
No established industry standard exists for integrity assessment.
INGAA provided a white paper guideline for evaluation and mitigation of expanded pipes in 2010.

PHMSA advisory notice ADB–09–01: pipe expansions can pose a credible threat to the integrity of a pipeline.

- Issued following discovery of a number of expansions caused by yield strengths lower than specified minimum requirements
- Significance of reliably detecting and sizing bulges and expansions

Fundamental questions:

- How can pipe expansions and bulges get identified?
- What assessments can be used to evaluate fitness for service?

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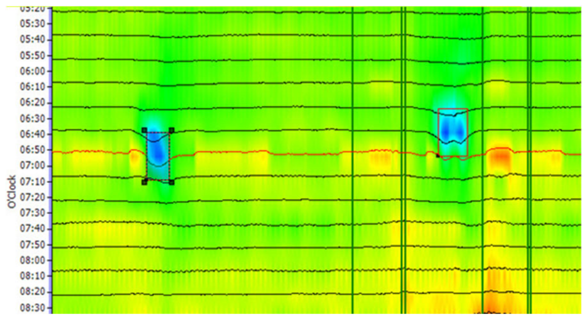
Bulges - data appearance

Bulges appear in the Geometry ILI data as a localized ID increase (indicated by the blue color in the data screenshots)



Calculated 'height': -1.0%
Dig Verified 'height': n/a

Calculated 'height': -0.8%
Dig Verified 'height': -1.02%
with 5% wall thinning
already sleeved

Field measurement [%]	ILI measurement [%]
1.3	1.2
1.0	0.8
0.4	0.5
0.3	0.5
1.1	1
1.1	0.6

Calculated 'height': -1.2%
Dig Verified 'height': -1.34%
already sleeved

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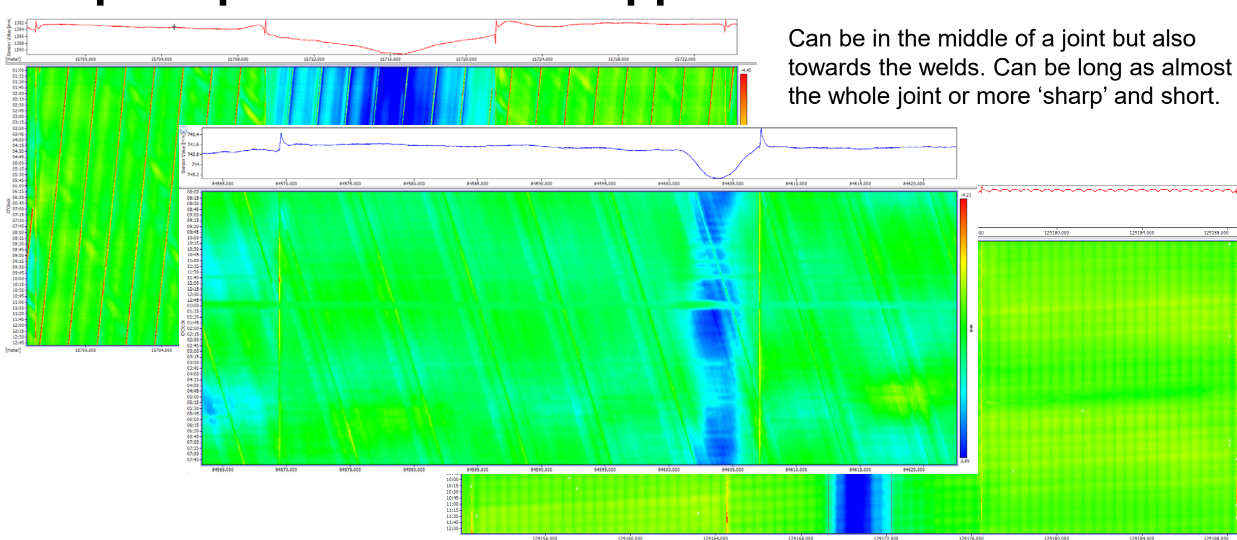
Pipe expansions – Data appearance



Can be in the middle of a joint but also towards the welds. Can be long as almost the whole joint or more 'sharp' and short.

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Sizing of pipe expansions

Circumferential pipe expansions are sized using the following formula

$$PIPEEXP = \frac{\max(MAXID_{in}) - \text{median}(DID_{out})}{\text{median}(DID_{out})} * 100\%$$

Max ID = maximum ID at the position of the expansion
DIDout = average ID from nearby section of non-deformed pipe

INGAA formula:

$$\% \text{ Expansion} = \frac{\text{Max ID Avg}_{\text{subject joint}} - \text{Max ID Avg}_{\text{adjacent joints}}}{\text{Max ID Avg}_{\text{adjacent joints}}} \times 100$$

Difference in formulas in average only 0.1 % apart

Field measurement [%]	ILI measurement [%]
2.8	2.7
2.3	2.8
2	2.2
2.2	2.0
1.6	1.9
1.7	1.5
2.4	2.3
1.4	1.5
1.9	2.0

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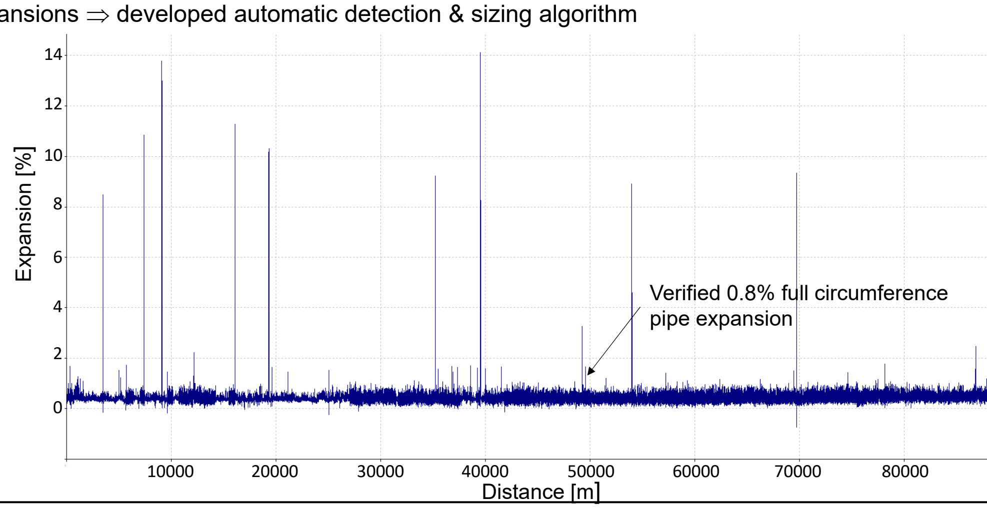
Automatic detection & sizing of expansions in ILI data

First try was a check graph but turned out to not be very effective due to relatively small ID change of the expansions ⇒ developed automatic detection & sizing algorithm



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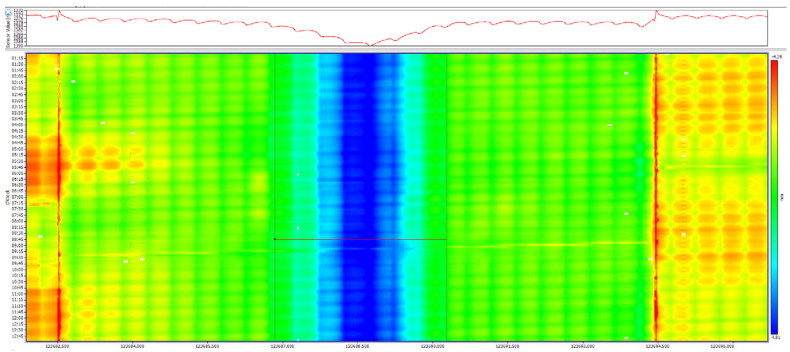
Automatic detection & sizing of expansions in ILI data



Search on mechanical (less susceptible for noise) or combined mechatronic sensors.

Only pre-processing step is a large floating median removal to remove poss. sensor offsets.

The algorithm delivers a feature box with full circumference and the sizing of the expansion.

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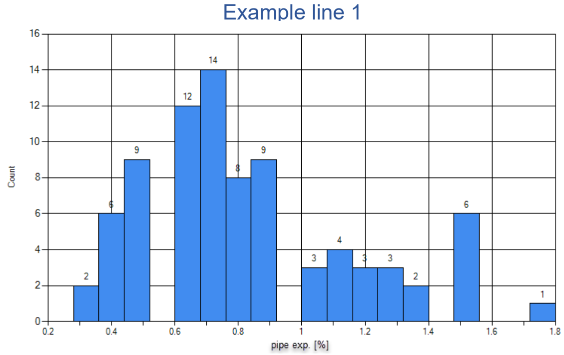
Statistics on pipe expansions

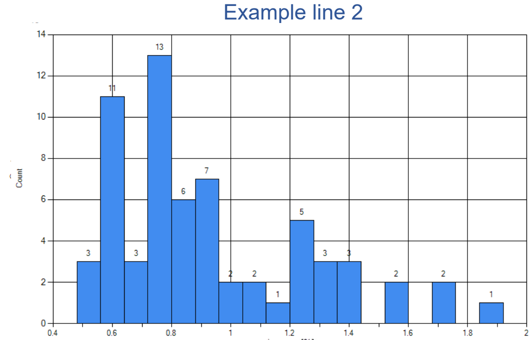
Usually only 1-2 expansions are found in a run but we also found lines with more than 80 of them
⇒ most likely manufacturer related (needs to be confirmed)

Example line 1



82 expansions in total
Length range 756 mm – 10654 mm
Size 0.3 – 1.8 %

Example line 2



64 expansions in total
Length range 692 mm – 8250 mm
Size 0.5 – 1.9 %

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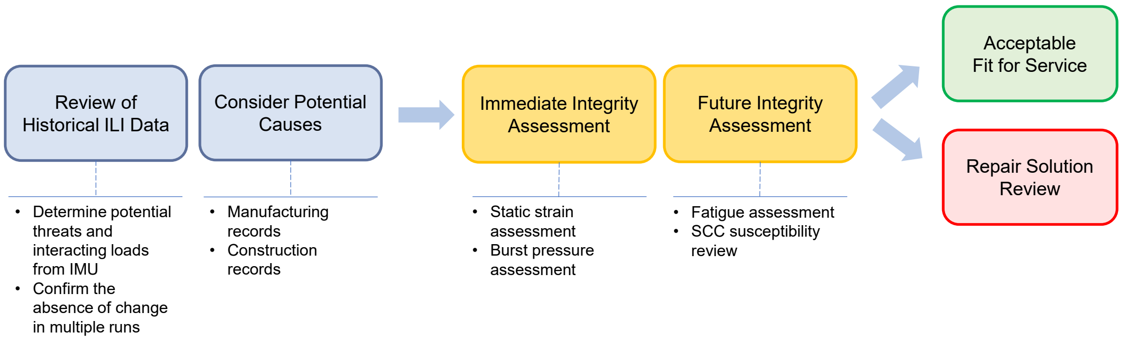
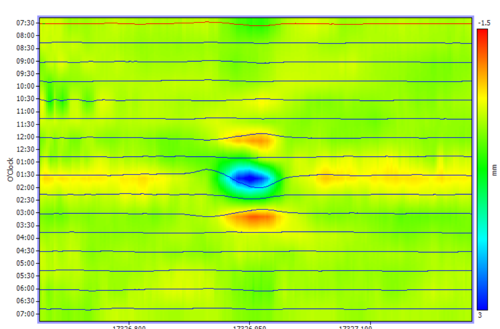
Integrity Assessment

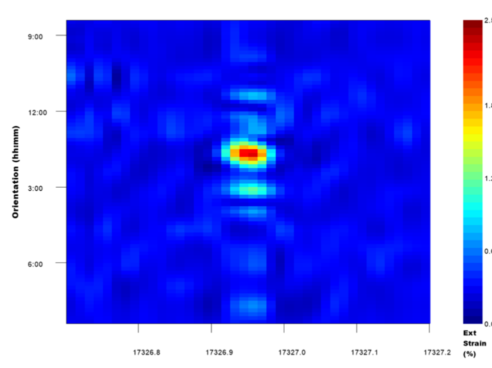
Proposed assessments for evaluation of Bulges and Pipe Expansions:



Bulge – Strain Calculation example

This bulge was reported with 2.1% depth, 72 mm length, 33 mm width.
The strain was calculated with a max. of 2.5 %, so not negligible but also not reaching the allowable limits.





The operator decided to repair the indication.

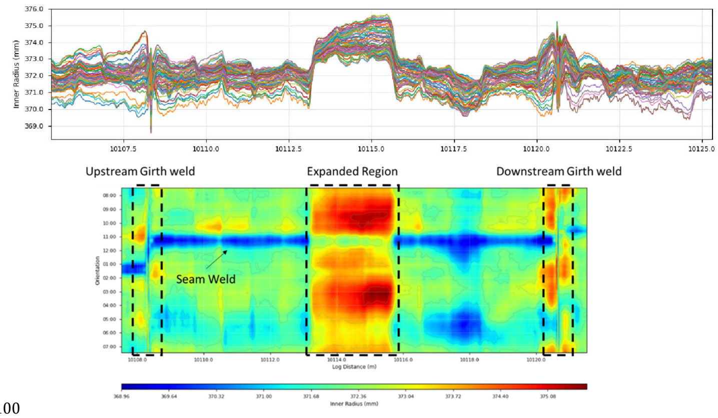
Case Study on a pipe expansion

Pipeline Characteristics

30 in. diameter pipe
WT 12.3 mm (0.484 in.)
API 5L X70, longitudinal weld
MOP and P_{design} 9,930 kPa (1440 psi)
53 mi. long, constructed in 2006, oil blend
ILI tools: MFL-A/XT

Pipe expansion calculated as 0.63%*
following INGAA guidelines:

$$\% \, Expansion = \frac{Max\ ID\ Ave_{Expansion} - Max\ ID\ Ave_{Adjacent\ Joints}}{Max\ ID\ Ave_{Adjacent\ Joints}} \times 100$$



Contour plot of the joint containing the Expansion

* Pipe expansions < 1% were not considered an integrity threat in 2010 INGAA White paper study

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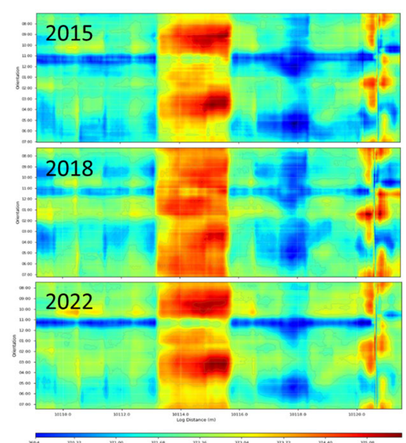
Case Study on a pipe expansion

Review of historical ILI data

Feature has remained stable since 2015

Potential causes of localized expansion

1. Tensile properties below specified minimums
2. Localized Compressive Axial Stresses
3. Localized Reduction in Wall Thickness
4. Over-pressurization or Mechanical Expansion



Caliper Data Associated with the Expansion in 2015, 2018 and 2022

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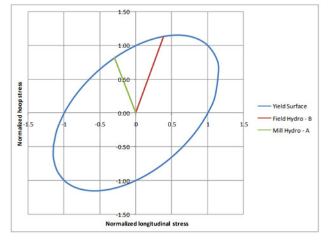
Case Study on a pipe expansion

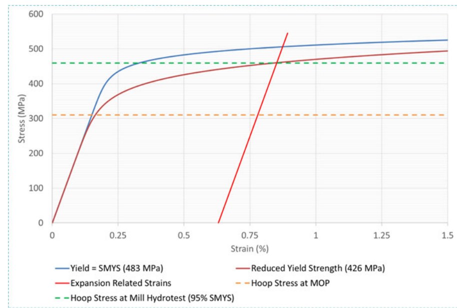
Check for Tensile properties below specification

To determine the point at which the pipe could yield during a hydrotest (mill and field), biaxial stress state is considered using von Mises equation.

A reduction of 12% SMYS would be required for the expansion to have been formed during the mill hydrotest.

Given the expansion is localized, it is unlikely that a reduction in yield strength alone caused the expansion.





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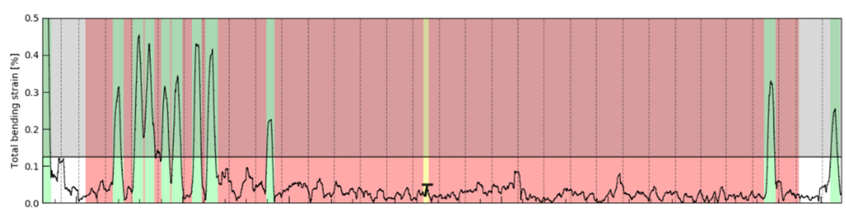
Case Study on a pipe expansion

Check for Localized Compressive Axial Stresses

IMU data were used to perform bending strain assessment

- No sharp changes in elevation was identified.
- No high bending strain or pipeline movement was reported at the expansion area (yellow shade in the center).



Bending Strain Profile in the Pipe Section Containing the Expansion

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Case Study on a pipe expansion

Localized Reduction in Wall Thickness

A localized, uniform WT reduction of 14% is needed to cause expansion during the mill hydrotest.

Over-pressurization or Mechanical Expansion

No record of significant over-pressure during hydrotest or normal operation was available.
The line pipe was cold formed, uncertainty on manufacturing, cold expansion was not ruled out.

The most plausible causes were found to be:

- Mechanical expansion caused during manufacturing related to cold expansion
- Localized reduction in WT / under-strength pipe / localized compressive axial stresses

Immediate Integrity Assessment

Failure Pressure

- For expansions related to under-strength pipe, INGAA recommend using stress-based Remaining Strength Factor (RSF approach in API 579).

Static Strain Assessment

- A maximum total strain of 1.25% was found.
- The strain was found to be acceptable when compared against ASME B31.8-2022 limits.

$$\varepsilon = \left(\frac{2}{\sqrt{3}}\right)\left[{\varepsilon_1}^2 + \varepsilon_1(\varepsilon_2 + \varepsilon_3) + (\varepsilon_2 + \varepsilon_3)^2\right]^{0.5}$$

ε is the total strain
ε_1 is the strain in the circumferential direction, taken to be the strain caused by the radial expansion calculated as 0.95%
ε_2 is the bending strain in the longitudinal direction (calculated to be 0.22% using ROSEN's in-house software)
ε_3 is the extensional strain in the longitudinal direction calculated as 0.01%

$$\%\ Elastic\ Expansion = \frac{P_{MOP}}{P_{SMYS}} \times 0.5$$

P_{MOP} is the maximum operating pressure
P_{SMYS} is the pressure that results in a hoop stress of 100% SMYS

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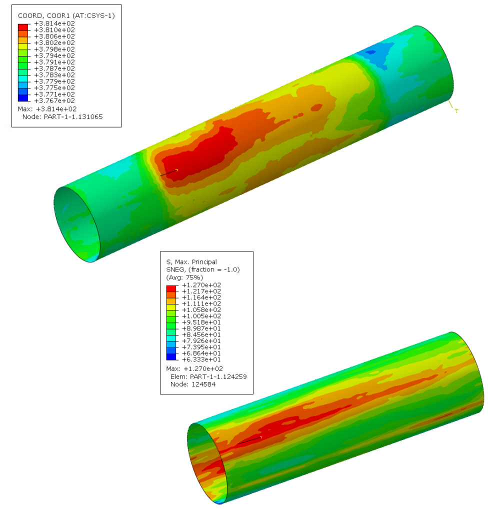
Future Integrity Assessment

Future Integrity Assessment

- The maximum stress concentration factor at expansion area was found to be small (< 1.3)
- Cyclic pressure data was used with a class C S-N curve
- A design fatigue reduction factor 3 has been applied.
- An S-N based fatigue assessment resulted in a remaining life of more than 100 years.
- Stress Corrosion Cracking (SCC) and hydrogen cracking were not found to be a threat for this area.

Given all the assessments, the expansion was found to be acceptable and fit for service.



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Conclusions

Pipe expansions and bulges can indicate concerns relating to the pipe manufacturing or construction processes and can threaten pipeline integrity.

Although ILI tools were not originally designed to detect such anomalies, ILI technology is capable of detecting and sizing pipe expansions and bulges accurately.

An integrity assessment approach is proposed to evaluate the fitness for service of bulges and pipe expansions.

Long term integrity implications should not be overlooked, for example the potential increase in cracking susceptibility.

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QUESTIONS

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Thank you for your time and attention