ASSESSMENT AND ANALYSIS OF PIPELINE BUCKLES

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Aberdeen, November, 14th 2007

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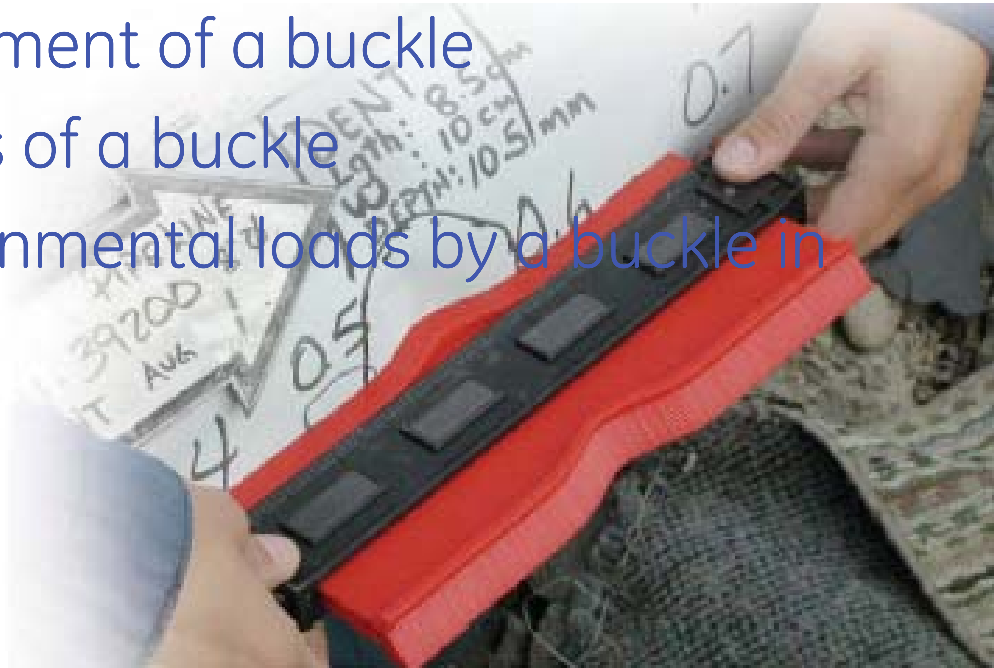
Assessment And Analysis Of Pipeline Buckles

- Introduction
- Dent and buckle differentiation
- Dent and buckle assessment
- Post inspection dent assessment methods
- Practical strain assessment of a buckle
- Finite element analysis of a buckle
- Amplification of environmental loads by a buckle in the pipeline



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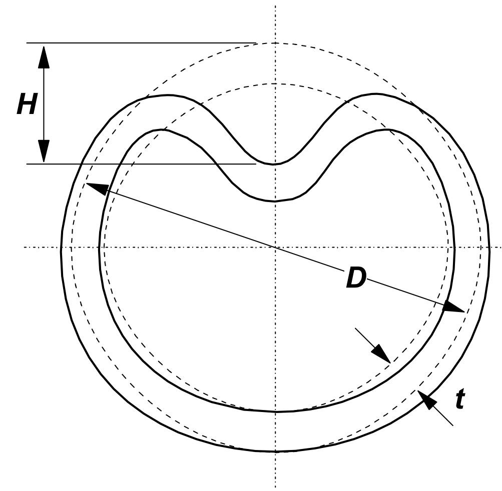
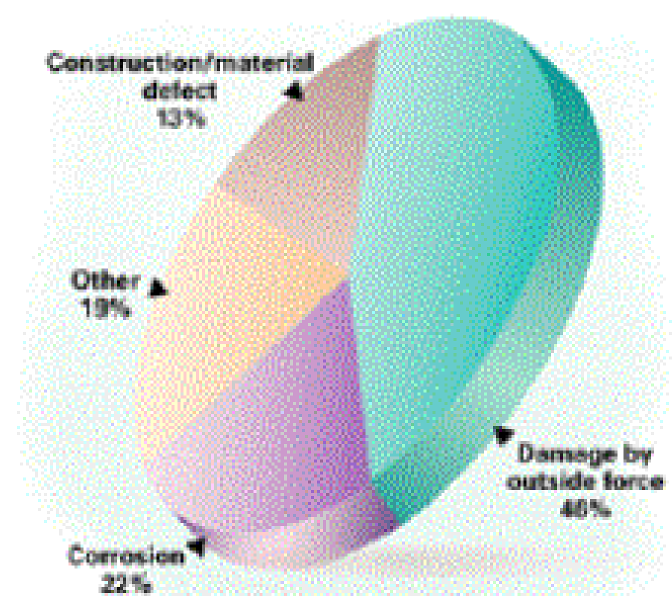
Dents in Pipelines



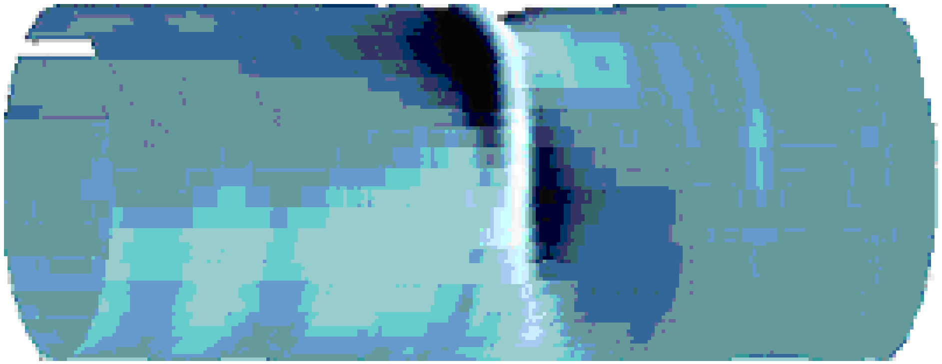
- *A* ***dent*** *is as a depression which causes a* ***gross disturbance in the curvature*** *of the pipe wall (ASME B31.8)*
- Mechanical damage failures
  - **>80% immediate failures**
  - **<20% from latent damage**
- *Latent mechanical damage is defined as a* ***dent and/or gouge w/ or w/o cracking or corrosion***

INCIDENT CAUSES FOR US GAS PIPELINES, 1986-2001



Buckles in Pipelines

- ***Buckle***: *A buckle is a local geometric instability causing ovalisation and flattening of the pipe, and possibly abrupt changes in the local curvature, which may or may not result in a loss of containment.*
- ***Global buckle***: *Buckling of the pipe in a manner analogous to a bar in compression. A global buckle will typically involve several pipe lengths. The pipe may buckle downwards (as in free span), laterally (snaking on the sea bed), or vertically (as in upheaval bucking).*
- ***Local buckle***: *A buckling mode causing gross deformation of the pipe cross-section, also known as pipe wall buckling. Collapse, localized wall wrinkling and kinking are examples of local buckling.*



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Classification of Geometric Anomalies According to the Codes

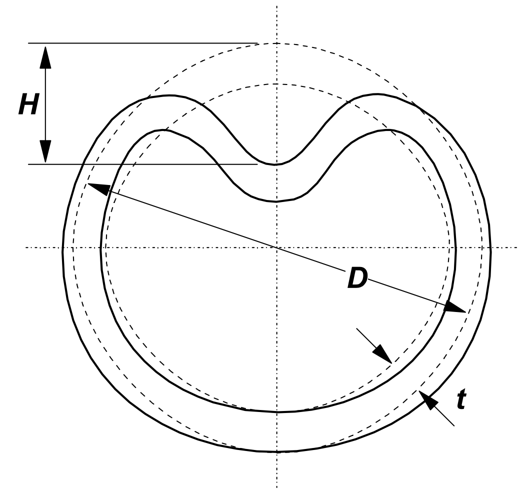
	Dents	Buckles
OS-F101 Submarine Pipeline Systems, 2000	A dent is defined as a depression which produces a gross disturbance in the curvature of the pipe wall, and which results in a diameter variation of more than 2% of the nominal diameter	Local buckling implies gross deformation of the cross section, confined to a short length of the pipeline, under following conditions: system collapse (under external pressure) or combined loading, i.e interaction between external or internal pressure, axial force and bending moment ; localised wall wrinkling and kinking are examples thereof.
ASME B31.8-2003, Gas Transmission and Distribution Systems	Dents are indentations of the pipe or distortions of the pipe's circular cross section caused by external forces	Buckling is the form of wrinkling of the pipe wall or lateral instability
PD 8010-2:2004, Code of Practice for Pipelines Part 2: Subsea pipelines		Local buckling of the pipe wall may be due to external pressure, axial tension or compression, bending and torsion or a combination of these loads

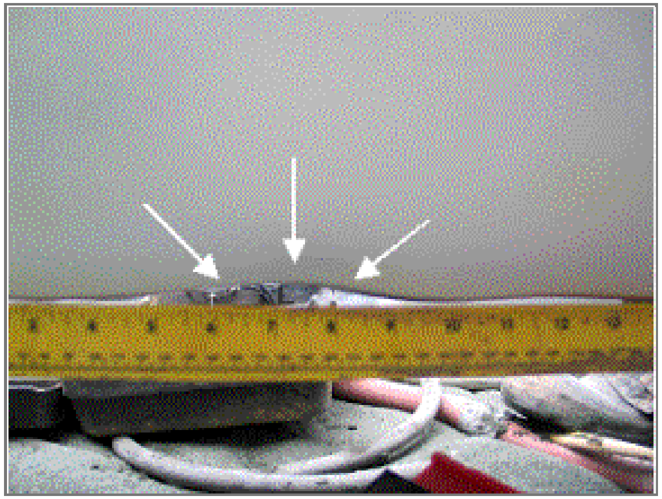
Acceptability Criteria for Geometric Anomalies on Welds

Code	Dents	Buckles
OS-F101 Submarine Pipeline Systems, 2000	A dent affecting the longitudinal or circumferential weld can result in cracks, and removal of the damaged portion of the pipe should be considered.	Design criteria included in the code to prevent local buckling caused by external or internal pressure or bending moment. The code distinguishes between load – controlled global buckling and displacement-controlled global buckling. Load – controlled buckling involves total failure, and is not allowed. Displacement-controlled global buckling may be allowed, provided that it does not result in other failure modes.
ASME B31.8-2003, Gas Transmission and Distribution Systems	Dents that affect ductile girth or seam weld are injurious, if they exceed a depth of 2% of the nominal pipe diameter, except those evaluated and determined to be safe by an engineering analysis, that considers weld quality, non-destructive examinations and operation of the pipeline are acceptable, provided strain level associated with the deformation do not exceed 4%. It is operator's responsibility to establish the quality level of the weld.	Buckling in the form of wrinkling of the pipe wall or lateral instability should be prevented by keeping the maximum allowable net compressive stress lower than 2/3 of the critical buckling stress, estimated using a suitable stability criterion.
PD 8010-2:2004, Code of Practice for Pipelines Part 2: Subsea pipelines		Local buckling of the pipe can be avoided if the various loads to which the pipe is subjected are less than characteristic values in Annex G

Industry Guidance on Dents

- Majority of code guidance is **dent depth-based**
- Local **strain in dent a better indicator of severity**/imminent failure (static behavior)
- Need to **assess threat from fatigue failure** on lines that are pressure cycled (dynamic behavior)



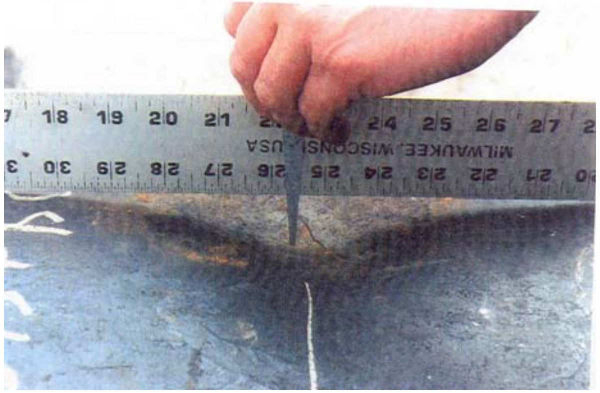


Enhanced Assessment of Dents

- Data from reportable incidents (Kiefner 2006) indicates that:
  > 83% of releases in liquid lines immediate (90% in gas lines)

  > Up to 17% of releases delayed (latent dents)

  > Majority (>80%) of delayed failures due to development of ancillary problems e.g., corrosion, SCC, pressure-cycle induced fatigue or punctures due to continued settlement



- Current industry thinking & research supports use of more advanced assessment techniques beyond depth based criteria
  > Baker (2004)

  > Rosenfeld (2001)

  > ASME B31.8 (2003)

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Post Inspection Dent Assessment (PIDA)

Static Assessment (PIDA^{Strain})

- ASME B31.8 (2003) methodology to estimate the total strain due to dent geometry
- Allowable **strain limits of 6% (plain dent) and 4% (dent on a sound weld)**
- Use to identify **'sharp'** dents susceptible to cracking
- Strain estimation **requires multi-channel calipper data**
- PIDA^{Strain} will:
  - > **Rank** dents in terms of severity
  - > **Assess compliance to strain criterion** in ASME B31.8 (2003)
- For **constrained dents** & dents with no pressure cycling

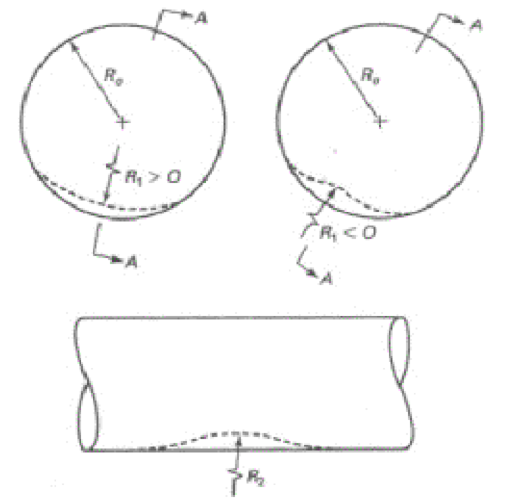


Fig. R1 Method for Estimating Strain In Dents

Inside surface

$$\varepsilon_i = \left[\varepsilon_1^2 - \varepsilon_1(\varepsilon_2 + \varepsilon_3) + (\varepsilon_2 + \varepsilon_3)^2\right]^{\frac{1}{2}}$$

Outside surface

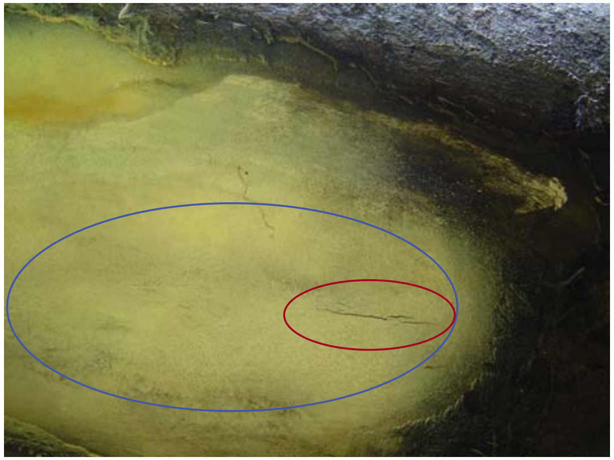
$$\varepsilon_o = \left[\varepsilon_1^2 - \varepsilon_1(-\varepsilon_2 + \varepsilon_3) + (-\varepsilon_2 + \varepsilon_3)^2\right]^{\frac{1}{2}}$$

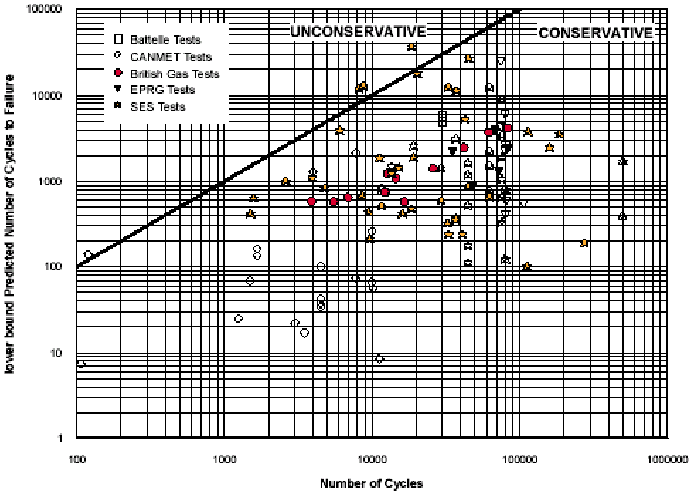
$$\varepsilon_{\max} = \mathrm{Max}\left\{\varepsilon_i, \varepsilon_o\right\}$$

Post Inspection Dent Assessment (PIDA)

Fatigue Assessment

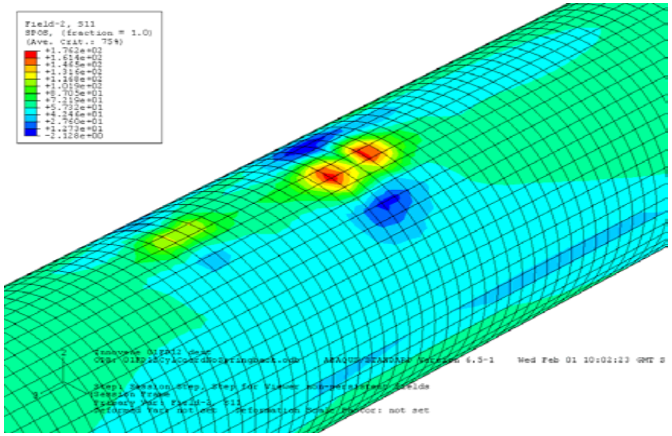
- Unconstrained dents in lines subjected to pressure-cycling
- Dent fatigue life **decreases** with increasing:
  - > pressure cycle range
  - > initial dent depth
  - > initial local strain
  - > dent volume
  - > D/t ratio
  - > SMYS
- Dent **fatigue models very conservative** (e.g., EPRG model – lower bound fit to test data)
- Majority requires **more accurate solution - FEA** to determine the stress range & hence the allowable fatigue cycles

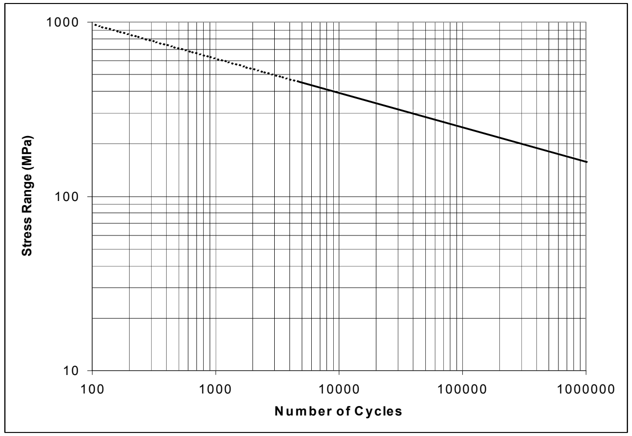




Post Inspection Dent Assessment (PIDA)

- **Fatigue Assessment (PIDA^{FEA})**
- Full finite element analysis of a dent
- Requires:
  - > Detailed **dent geometry** - from multi-channel calipper data
  - > **Pipe geometry** & **true stress-true strain**
  - > **Pressure range & frequency of cycles**
  - > **S-N fatigue curve** relevant to the pipe type & grade
- Use FEA to determine the **peak stress range**
- Estimate the **allowable number of cycles** from S-N fatigue curve
- Determine **remaining fatigue life** of the dent





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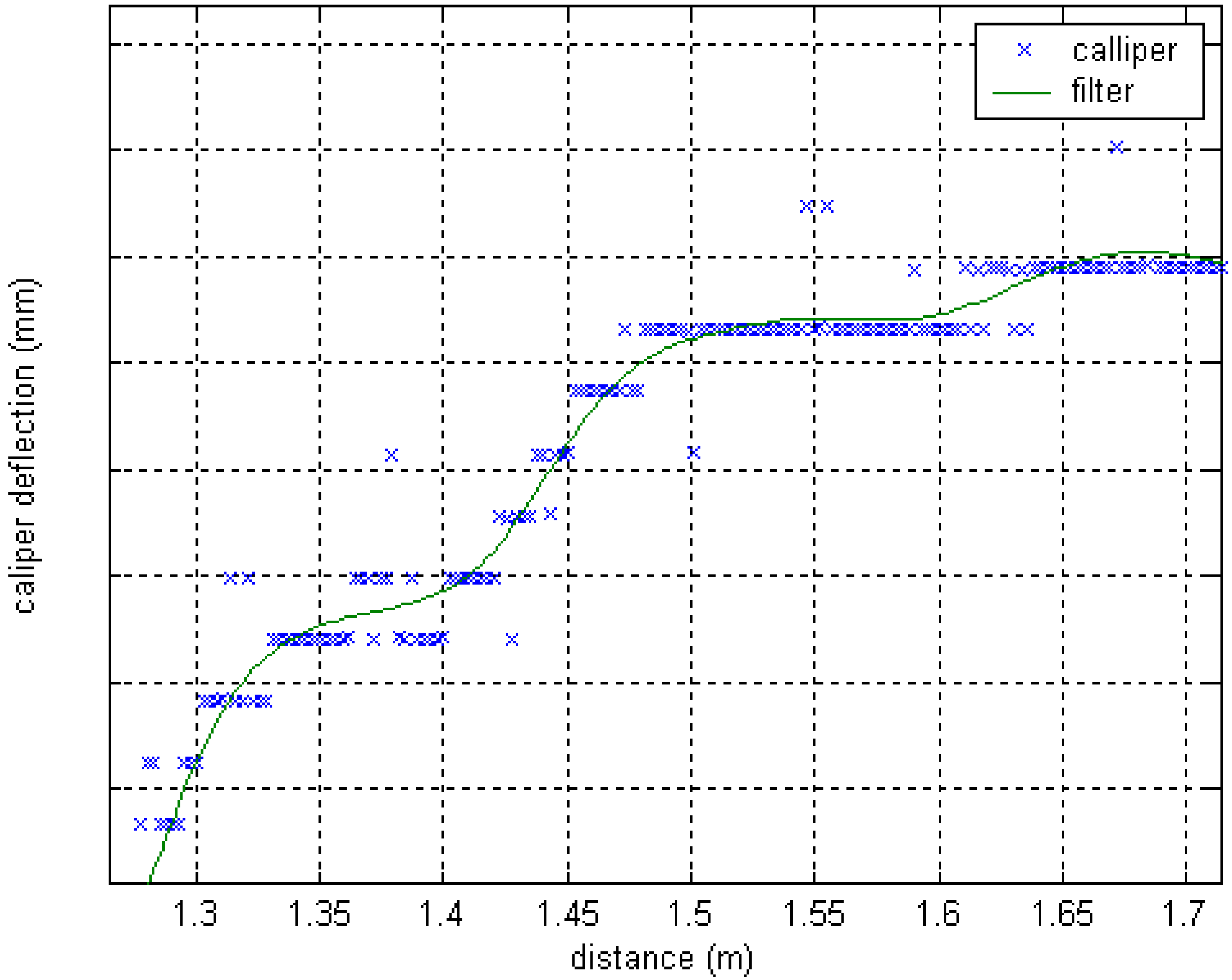
Example of a Caliper **buckle** measurement, demonstrating significant quantisation of signal and noise



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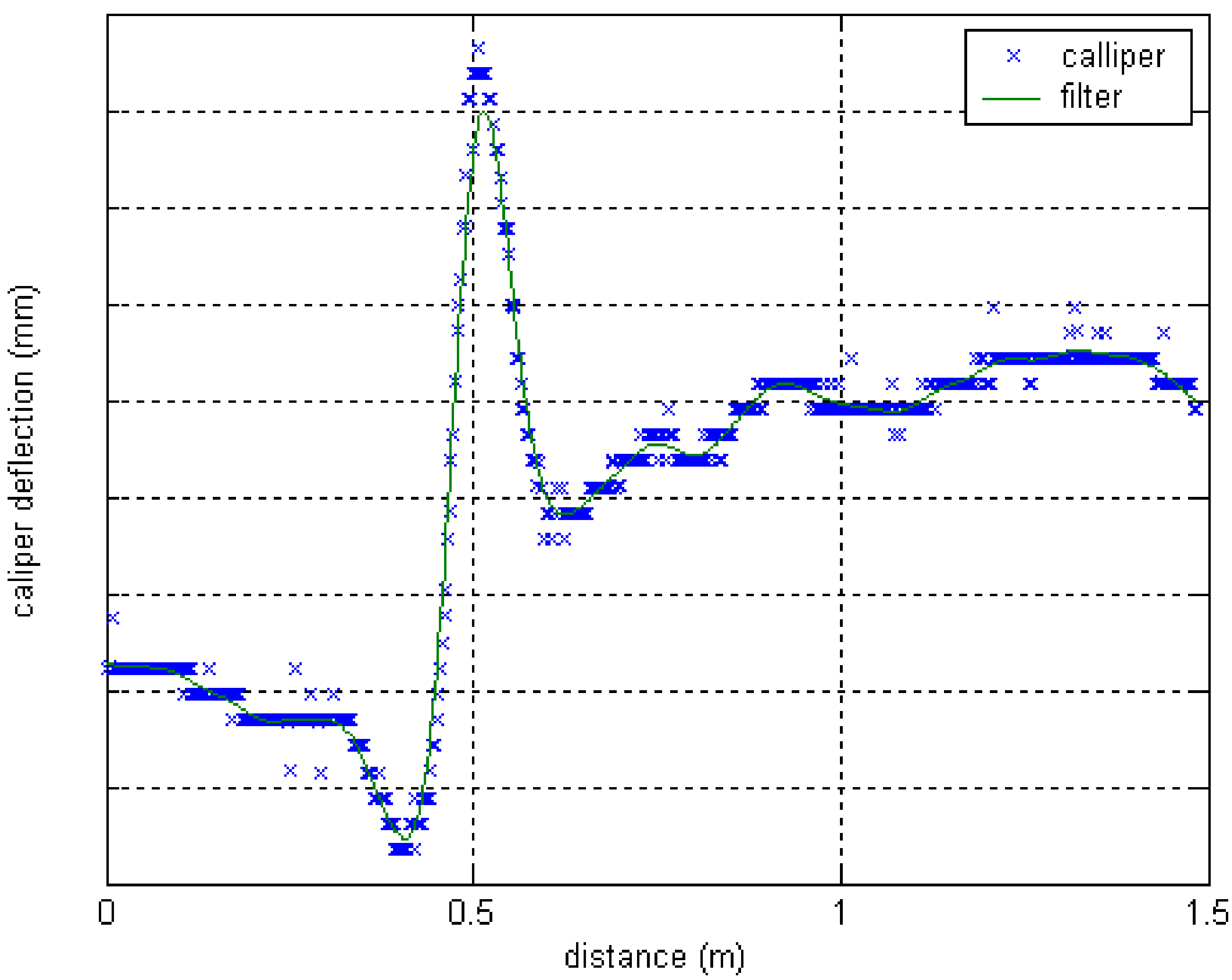
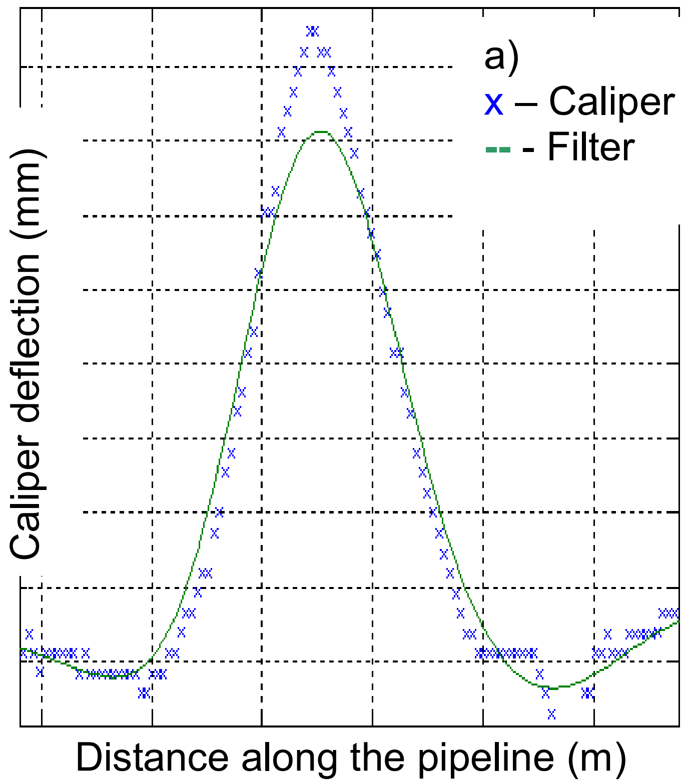
Example of a Caliper measurement, demonstrating filtered and fitted data

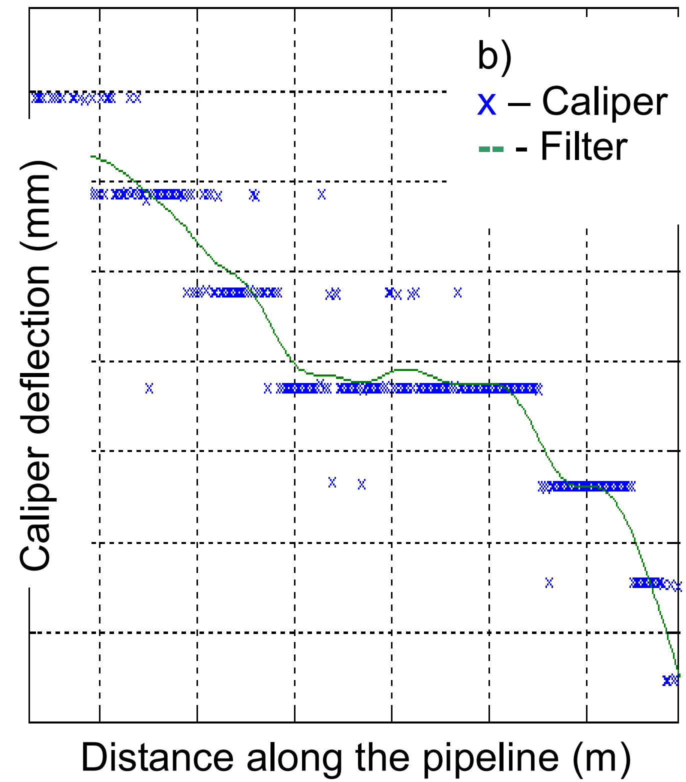


Geometric Data Filtering and Fitting, Using a Wide Window.

a) around the top of a buckle,

b) at a distance from the buckle top





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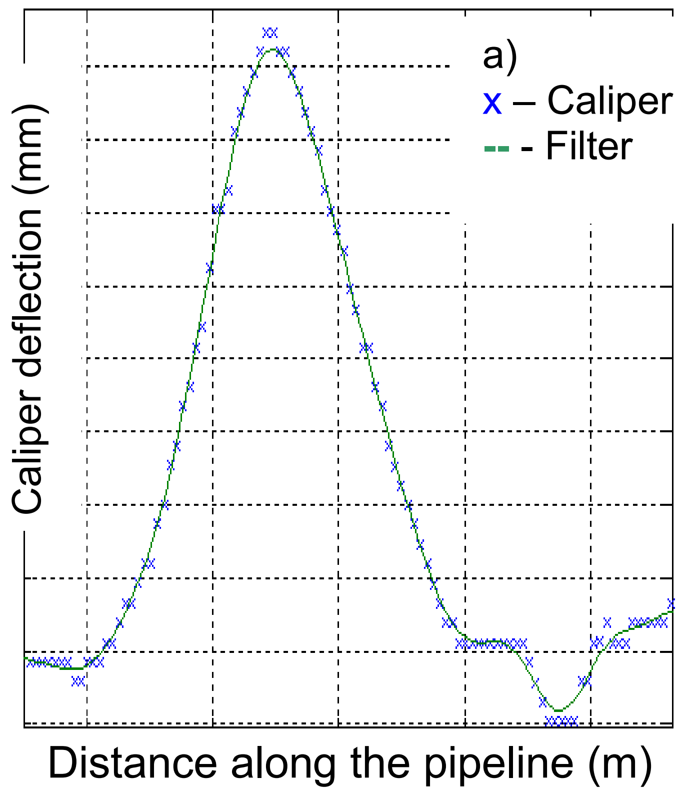
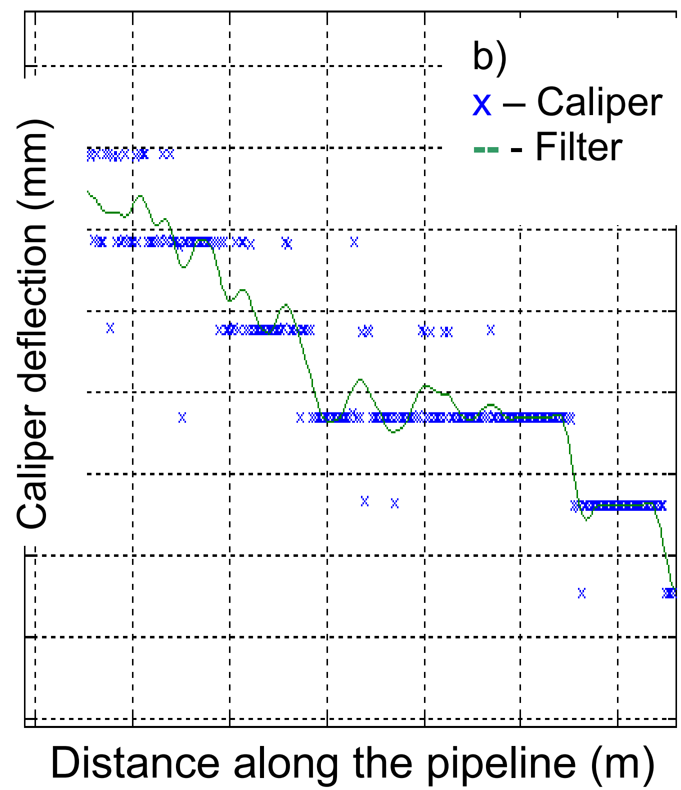
Geometric Data Filtering and Fitting, Using a Narrow Window.

a) around the top of a buckle,

b) at a distance from the buckle top





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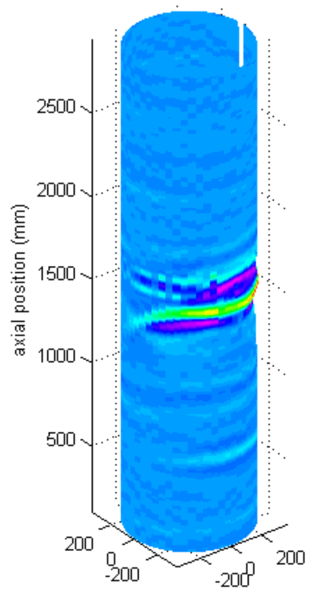
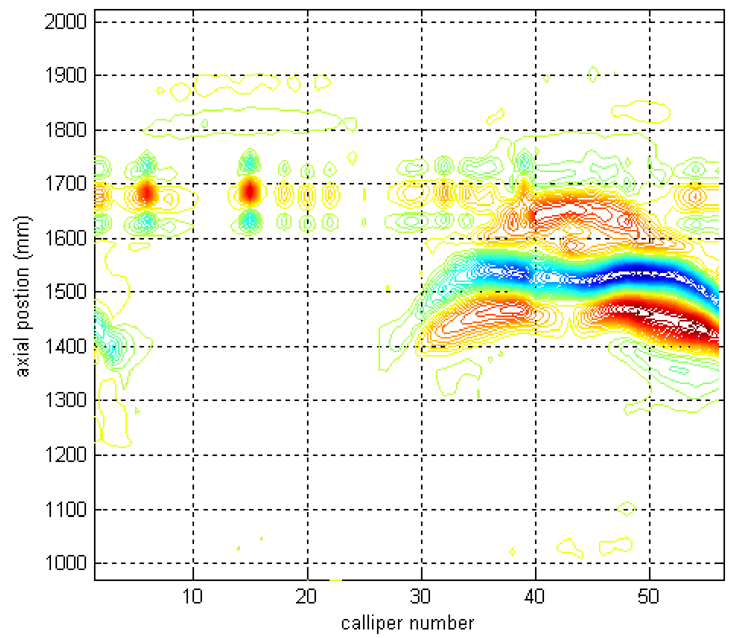
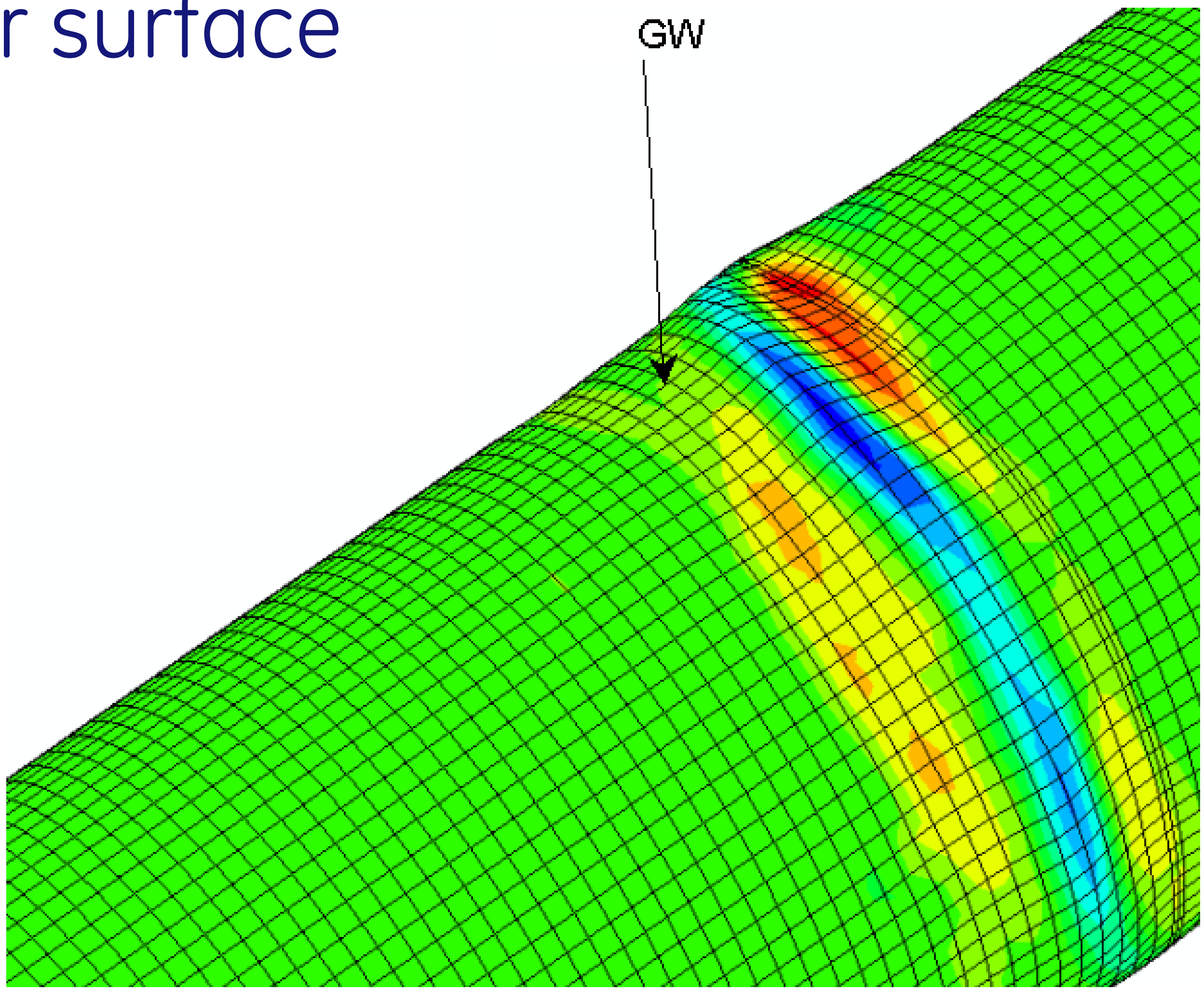
Strain calculation for a Buckle

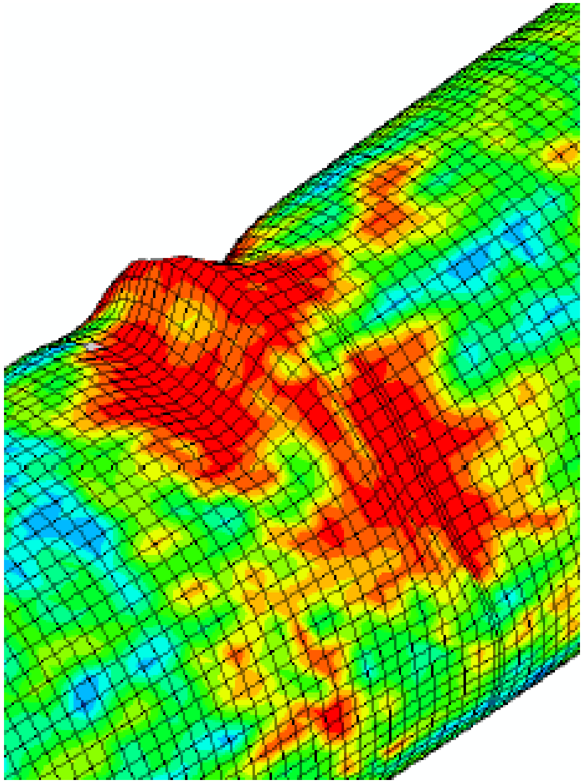




Plastic Strain Contour Plot of a Buckle at inner surface



Results of Environmental Loading of a Buckle



Loads, equivalent to dynamic environmental conditions (wave loading of a pipe freespan), were applied to the results of the FE displacement modelling of a buckle.

An equivalent bending moment of 130 KNm and an equivalent axial load of 10 KN were used as well as an internal pressure of 10 MPa.

Equivalent stress is approaching 600 MPa. Stress concentration factor in the buckle exceeds 2.0.

Concluding remarks

Releases still occur in-service from 'latent' geometric anomalies

Current research supports methods beyond depth-based rules

Advanced techniques for plain dents - static & fatigue behaviour

Strain-based assessment for plain dents to identify susceptibility to cracking

Fatigue assessment for unconstrained dents with cyclic pressure

The approach proposed in this paper for the severity assessment of a buckle is as follows:

1) Use the strain-based criteria to assess the acceptability of a buckle in terms of static behavior.

2) Prepare raw data, recorded by the geometry tool, for a strain assessment by filtering and smoothing it accordingly.

3) When additional factors of failure mechanisms should be considered in assessing an immediate and future integrity of the pipeline, conduct an FE analysis of the buckle to determine the stress concentration and estimate fatigue life of the geometric anomaly.

Q & A