Summary of Dent Assessment Methodologies and use of ILI Calliper Data

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• Difficult to quantify the number of failures relating to dents due to the absence of data

• Kiefner et al: 90% of failures on gas pipelines relating to mechanical damage occur at the time of damage

• Delayed failure of dents due to fatigue damage have been reported (even on plain dents less than 2% OD)

• CONCAWE: 5% of all failures (1971 - 2013) were delayed (incidental) failures following mechanical damage
Requirement for Accurate Dent Assessment

- Failure statistics suggest that only a small percentage of failures will be caused by dents that are detected by ILI (<5% on gas pipelines) – however:
  - Dents are commonly reported on UK Gas pipelines with up to 10 dents reported per kilometre
  - Requirement to ensure the severity of dents can be accurately quantified to avoid unnecessary repair costs and associated disruption

What assessment tools are available?
FACTORS AFFECTING DENT SEVERITY

• Dent dimensions (e.g. depth, length, width)
• Pipe dimensions
• Material properties (strength, ductility)
• Dent shape (sharp, smooth, kinked etc.)
• Association with welds (and ductility of weld)
• Association with other anomalies (corrosion, cracks, gouges, laminations….)
• Restraint
• Static loading (internal pressure, axial stresses, thermal loads)
• Cyclic loading
• Springback / rerounding
**DENT - DEFINITIONS**

**Dent (ASME B31.8):** “a permanent deformation of the circular cross section of the pipe that produces a decrease in the diameter and is concave inward”

**Plain Dent:** a dent that is not associated with any welds or other anomalies (e.g. cracking / gouging)

**Dent on a weld:** a dent that affects the curvature of a pipeline at a girth or seam weld

**“Kinked” dent:** Subjective, but commonly taken to be a dent with a minimum radius of curvature less than 5t
DENT ASSESSMENT LEVELS (EXAMPLES)

Level 1
- Depth based – static and fatigue
- Considers association with welds and other defects
- Orientation around pipe circumference

Level 2
- Analytical solutions
- Basic strain-based approach (e.g. ASME B31.8)
- Fatigue based on estimate of SCF

Level 3
- Typically involving FEA to provide a more accurate estimate of SCF and strain
- SCF calculated either using dent shape directly from inspection or modelling denting process

Increasing demands on inspection data
• Allows plain dents up to 12% OD (depending on pipe grade and operating stress)
• Acceptance criteria provided for dents containing gouges
• Smooth dents on welds classed as extreme damage regardless of depth (pipelines operating >20% SMYS)
• Specific guidance given on assessing dents reported by ILI
ASSESSING DENTS REPORTED BY ILI

• Consideration must be given to ILI technology used
  o MFL / UT tools can detect dents but not always size them
  o Dents may contain cracking / gouging below the detection capabilities of the tool
  o Calliper tools may not have adequate resolution to support a strain assessment

• Consider risk of third party damage
  o Pipeline location and history of activity
  o Top of line / Bottom of line (TOL: 8 to 4 o’clock)
  o Check for coating damage
DENT DIMENSIONS FROM ILI

- Depth (excluding ovality)
- Depth (including ovality)
- Dent Dimensions (excluding ovality)
- Dent Dimensions (including ovality)
DENT STRAIN ASSESSMENT – PRINCIPLE

Strain assessment

Formulas based on ASME B31.8 (2012)

Circumferential bending strain

\[ \varepsilon_1 = \frac{t}{2} \left( \frac{1}{R_0} - \frac{1}{R_1} \right) \]

Longitudinal bending strain

\[ \varepsilon_2 = -\frac{t}{2R_2} \]

Extensional strain

\[ \varepsilon_3 = \frac{1}{2} \left( \frac{d}{L} \right)^2 \]

Total effective strain of dent in the pipe

\[ \varepsilon_{eff} = \sqrt{\varepsilon_1^2 + \varepsilon_1 \varepsilon_2 + \varepsilon_2^2} \]

Acceptable strain limit: <6% (plain dents)

- \( t \) = wall thickness
- \( R_0 \) = initial pipe surface radius
- \( R_1 \) = radius of curvature in transverse plane, negative for reentrant dents
- \( R_2 \) = radius of curvature in longitudinal plane, negative for reentrant dents
- \( L \) = dent length
- \( d \) = dent depth
DENT STRAIN – CALCULATION FROM ILI DATA

- Accurate Sampling
- Spline Approximation
- Curvature Determination
- Extension Determination
- Strain Calculation

Sampling → Spline → Extension

\[ r_3 \rightarrow r_1 \rightarrow r_4 \rightarrow r_2 \]

Radius → Curvature
• Data smoothing needs to consider ILI resolution

• Manual / visual checks to validate the results of the strain assessment (is the radius of curvature realistic?)

• Consider the impact of any welds or other anomalies on the geometric profile and avoid significant influence on the strain results
DENT – FATIGUE ASSESSMENT (EPRG METHOD)

• “EPRG recommendations for the assessment of the resistance of pipelines to external damage”

Predictions of Plain Dent Fatigue Life Using the EPRG Approach with Safety Factors Recommended by PDAM (95% One-Tail Confidence Level) Versus Full-scale Test Results
DENT – FATIGUE ASSESSMENT (EPRG METHOD)

\[ N = 1000 \left[ \frac{(\sigma_u - 50)}{2\sigma_A k_s} \right]^{4.292} \]

Where,
\[ N \quad \text{= Predicted number of cycles to failure,} \]
\[ \sigma_u \quad \text{= Ultimate tensile strength (MPa),} \]
\[ K_s \quad \text{= Stress concentration factor,} \]
\[ 2\sigma_A \quad \text{= Cyclic stress range at R = 0} \]

In order to account for the large scatter in the published full scale test data PDAM recommends the following safety factors to ensure a 95% confidence level for predicting a conservative result:

1. A safety factor of 13.3 for plain dents, and
2. A safety factor of 133 for dents affecting welds i.e. a factor of 10 reduction in fatigue life for a plain dent
DENT FATIGUE ANALYSIS

**SCADA System**

**Pressure Data**

**Rainflow Counting**

**Stress range (S)**

**Fatigue Assessment**

**Pipeline with dent**

**RoGeo XT**

**Automated data conversion**

**FEA**

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<th>ID SCF</th>
<th>OD SCF</th>
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<td>3.99</td>
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DENT STRESS ASSESSMENT – DATA EXAMPLES

Stress distribution – overview

Stress distribution – detailed view

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<tr>
<th>Orientation</th>
<th>Length [mm]</th>
<th>Depth [%OD]</th>
<th>OD SCF</th>
<th>ID SCF</th>
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<tbody>
<tr>
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DENT STRESS ASSESSMENT – VALIDATION

- 16” diameter pipe
- Tests conducted in lab conditions
- External laser scans
- Pull tests with RoGeo XT
- Pressure cycled to failure

*Typical SCF range for dents between ~2 to 6*
COMPARISON OF REPEAT CALLIPER DATA

- Repeat calliper data can be compared to identify new dents and dents that have changed between inspections
- Results affected by:
  - Differences in calliper technology
  - Reporting thresholds
  - Sizing methods (e.g. including / excluding ovality)
- Can compare calliper signal data to increase confidence in result
• Although third party damage is one of the major causes of pipeline failures, delayed failures of dents that could be detected by ILI and assessed prior to failure are rare

• A wide range of dent assessment tools are available

• Detailed dent assessments requires high resolution and high accuracy data

• The pipeline industry has moved away from relying on dent depth to determine severity and increased focus on strain and SCF estimation

• Research is ongoing to further improve the accuracy of dent assessments. Current focus is on improving the accuracy of dent fatigue estimates
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