Dent Assessment
Natural Gas Pipelines Perspective
September 11, 2018

TransCanada
Agenda

• Background
• Screening Dents for Excavation and Further Assessment
• ECA for Dents with ML or at a GW
• Areas for Further R&D
TransCanada Dent Assessment Process

• Compliance with CSA Z662

• Due to limitation of ILI technology (ML in dents, cracks, gouges) introduced additional criteria for screening dents – a combined approach:
  • Strain calculated from both ASME B31.8 and modified equations (initiated 2007)
    • Screen dents based on plastic strain damage criterion
  • MFL signal characterization criterion (initiated in 2009)

• Issue with caliper tool and data resolved by high resolution caliper specification development
Screening Approach

- Dent is characterized by strain for all analyses
  - Geometric Strain Assessment (for screening purposes) – input is detailed caliper data or in ditch laser data
    - Circumferential & Longitudinal Bending Strain
    - Circumferential & Longitudinal Membrane Strain
  - Dent can develop a crack during its formation –
    - Convert the strain into a plastic damage parameter DFDI (uses a material property called critical strain) plus MFL signal analysis

- Not a depth or a strain level criteria
- DFDI (for screening) is a ratio of total strain to critical strain (factored for stress)
Screening Criteria

- ASME B31.8 (2003 Edition) – Introduced 6% strain limit for plain dents (empirical)

- Limitations of ASME B31.8 criterion
  - Plastic strain level of 12% for cracking is below the actual measured strain limit for cracking for most line pipe steels.
  - One strain limit for all steel grades is not appropriate.

- Critical-strain-based Ductile Failure Damage criterion
  - Quantify progressive damage limit for avoiding onset of failure in ductile materials.
  - Ductile Fracture Damage Index (DFDI) Criteria
  - DFDI >1 is onset of cracking
  - Conservative Screening criteria DFDI >0.6
  - DFDI = $\varepsilon_{eq}/(\varepsilon_0/1.65)$ —— simplified for screening
Denting (NPS 34, X52, 1.5”Dia. Indenter) – Pipe body and weld (seam/girth)

**Test Setup**
- MTS Hydraulic Actuator with Indenter
- LVDT for displacement measurement (OD%) 
- Strain gages for strain measurement 
- Video camera for real time monitoring and recording 
- In-situ Laserscan for real time strain measurement
- Acoustic sensor was mounted close to the dent deformation area to monitor the cracking sound if any during the test

**Strain Criteria – Validated With Experiments**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Pipe Specimen</th>
<th>Dent Location</th>
<th>Max. Eqv. Strain</th>
<th>Upper bound DF/DI</th>
<th>DF/DI ≥ 1 Criterions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NPS 34 X52 grade; 2.5”/1.5” Indenter</td>
<td>Pipebody</td>
<td>30.1%</td>
<td>0.98</td>
<td>Yes. Validated</td>
<td>Several small cracks were found between 12% to 15% OD depth</td>
</tr>
<tr>
<td>2</td>
<td>NPS 36 X65 grade; 1.5” Indenter</td>
<td></td>
<td>37.5%</td>
<td>1.22</td>
<td>Yes. Validated</td>
<td>Pipe was severely ovalized. Test abandoned &amp; no crack found</td>
</tr>
<tr>
<td>3</td>
<td>NPS 34 X52 grade; 1.5” Indenter</td>
<td></td>
<td>34.9%</td>
<td>1.136</td>
<td>Yes. Validated</td>
<td>Several micro cracks were found</td>
</tr>
<tr>
<td>4</td>
<td>NPS 36 X65 grade; 1.5” Indenter</td>
<td>Seam weld</td>
<td>31.2%</td>
<td>0.88</td>
<td>Not Validated</td>
<td>Cracks formed in seam weld/MAZ region at 6%OD</td>
</tr>
<tr>
<td>5</td>
<td>NPS 34 X52 grade; 1.5” Indenter</td>
<td>Girth weld</td>
<td>31.5%</td>
<td>0.95</td>
<td>Yes. Validated</td>
<td>Cracks formed in girth</td>
</tr>
<tr>
<td>6</td>
<td>NPS 36 X65 grade; 1.5” Indenter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When characterizing the MFL signals in combination with the dent strain level, some new insight is gained into unique features of the signals that may be associated with ML in a dent:

- Rule #1: A single strong MFL signal and located at the dent apex or highest strain spot in the dent, then the metal loss feature is most likely to be a crack.
- Rule #2: Many general metal loss signals distributed within the dent area, then it is most likely to be corrosion.
- Rule #3: A strong metal loss feature signal oriented circumferentially and located at dent apex or highest strain spot, then it is probably associated with gouge.
- Rule #4: A strong metal loss feature signal located at dent apex or highest strain spot surrounded with general shallower metal loss features, then it is probably either a gouge or crack.
Examples Findings – 15 Cases

- Three pipeline segments with combo ILI reporting 6361 dents, 150 selected using screening method.
  - Strain, DFDI and MFL analyses identified 15 dents for further validation.
    - Model prediction
      - 7 dents crack or gouges
      - 8 dents metal loss
  - Excavation Results:
    - 7 dents with cracks or gouges.
    - 8 dents, corrosion or manufacturing defects (negative-negative)

<table>
<thead>
<tr>
<th>Case</th>
<th>+S+</th>
<th>O6:T20</th>
<th>$\varepsilon_{eq}$ (%)</th>
<th>Upper bound</th>
<th>Prediction</th>
<th>Excavation</th>
<th>Prediction-Excavation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.20%</td>
<td>0.6</td>
<td>Possible crack</td>
<td>Through wall crack</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15.00%</td>
<td>0.8</td>
<td>Possible crack</td>
<td>Through wall crack</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16.90%</td>
<td>0.9</td>
<td>Possible crack and gouge</td>
<td>Gouge</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>13.00%</td>
<td>0.7</td>
<td>Low confidence of possible crack</td>
<td>ID crack</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>31.00%</td>
<td>1.7</td>
<td>Crack with gouge</td>
<td>Gouge</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>17.60%</td>
<td>1</td>
<td>Possible crack</td>
<td>ID / OD crack</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>11.50%</td>
<td>0.6</td>
<td>Possible crack</td>
<td>Through wall crack</td>
<td>Positive-positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>6.80%</td>
<td>0.4</td>
<td>no crack</td>
<td>6% ML dent on rock</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>7.10%</td>
<td>0.4</td>
<td>no crack</td>
<td>16% ML dent on rock</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10.50%</td>
<td>0.6</td>
<td>no crack</td>
<td>12% ML dent on rock</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>9.90%</td>
<td>0.5</td>
<td>no crack</td>
<td>16% ML dent on rock</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>5.00%</td>
<td>0.3</td>
<td>no crack</td>
<td>36% OD corrosion</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>9.00%</td>
<td>0.5</td>
<td>no crack</td>
<td>10% ML dent on rock</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>7.80%</td>
<td>0.4</td>
<td>no crack</td>
<td>15% OD corrosion</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3.60%</td>
<td>0.2</td>
<td>no crack</td>
<td>37% OD corrosion</td>
<td>Negative-negative</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Examples of Findings – Further Validation
Screening Approach - Summary

- Follow code requirements and complement with the combined approach to identify critical features:
  - DFDI assessment using geometric strain
  - Assess MFL data when DFDI greater than 0.6
- EPRG fatigue analyses check (no FEA strain required)
- If the above filtering identifies the dent then - Excavate to repair or perform an ECA
Approach for ECA for Dents with ML and/or on a GW

- Assess ILI data in detail + run comparison
- Identify all loads on the dent (welds, external and other local deformation)
- Geometric & FEA strain
- DFDI analyses
- If the above identifies dent then perform detailed fatigue analyses with FEA strain:
  - Apply the pressure differential
  - Obtain strain differential
  - Strain differential used for estimating fatigue life
  - Lowest fatigue life between Markl and SWT is used

DFDI = 0.18 to 0.19

- API 1156 – 111,816 cycles
- Markl – 19,921 to 2621 cycles
- SWT – 66,740
GAPS & Opportunities – Mechanical Damage Assessment

• ILI delineation of dents (caliper and MFL)
  • Definition of high resolution caliper
  • Better identification and characterization of features interacting with dents
• Further validation of the DFDI
• Fatigue analyses model comparison to dents modeled with critical strain and other results