Current Practices in Pipeline Fitness for Service and Repair

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The Fitness for Service Process

- Inspect for defects by ILI or in-ditch NDE
- Recognize defect type and determine its size
- Evaluate severity considering material and stress level (ECA)
- Accept or reject condition considering severity, regulations, accepted practices, and company procedures
- Repair if necessary using approved method
Fitness for service and repairs
- What do codes and regs say?
- What are we able to do now?
- What needs to be better?

What is the role of R&D?
- Replace crude assumption with refined assumption
- Replace assumption with fact
Conditions of concern

Significant Incident Cause Breakdown
National, All Pipeline Systems, 1988-2008

- ALL OTHER CAUSES: 4.0%
- CORROSION: 8.5%
- EXCAVATION DAMAGE: 22.7%
- HUMAN ERROR: 15.4%
- MATERIAL FAILURE: 18.1%
- NATURAL FORCE DAMAGE: 25.9%
- OTHER OUTSIDE FORCE DAMAGE: 5.4%

Source: PHMSA Significant Incidents Files April 15, 2009
Conditions that submit to ECA

- Internal and external corrosion
- Deformations and mechanical damage
- Pipe seam defects
- Defective girth welds
- Stress-corrosion cracking
- Some other conditions
# Corrosion

<table>
<thead>
<tr>
<th>Reg or Std</th>
<th>Subpart/§</th>
<th>Accepted Method</th>
<th>Actionable Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 192</td>
<td>I/192.485</td>
<td>ASME B31G or procedure in PR3-805</td>
<td>Commensurate with actual remaining wall</td>
</tr>
<tr>
<td>Non-HCA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 192</td>
<td>O/192.933</td>
<td>B31G, RSTRENG, or alt. equivalent method;</td>
<td>Immediate = Pf/MAOP &lt; 1.1; Monitored per B31.8-S</td>
</tr>
<tr>
<td>HCA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 195</td>
<td>H/195.585</td>
<td>ASME B31G or procedure in PR3-805</td>
<td>Commensurate with actual remaining wall</td>
</tr>
<tr>
<td>Non-HCA</td>
<td>195.587</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 195</td>
<td>F/195.452</td>
<td>ASME B31G or procedure in PR3-805</td>
<td>Immediate = Pf/MOP &lt; 1.0 or d/t&gt;80%; 180-day = Psafe&lt;MOP or d/t&gt;50% at general corr or line crossing or girth weld; any corrosion along a seam</td>
</tr>
<tr>
<td>HCA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B31.4</td>
<td>451.6.2</td>
<td>B31G, mod B31G, or an effective area method</td>
<td>20% &lt; d/t &lt;= 80% assessable; d/t &gt; 80% must be repaired</td>
</tr>
<tr>
<td>B31.8</td>
<td>862.213</td>
<td>App. L (B31G)</td>
<td>10% &lt; d/t &lt;= 80% assessable; d/t &gt; 80% consider repair</td>
</tr>
<tr>
<td>B31.8-S</td>
<td>7.2</td>
<td>B31G or equivalent</td>
<td>Immediate = Pf/MAOP &lt; 1.1; Monitored = per Figure 4</td>
</tr>
</tbody>
</table>
Assessment of corrosion metal loss

- Reliable, mature technology
- Millions of successful applications
- Origins in classical fracture mechanics
- Various methods available
  - ASME B31G
  - Modified B31G
  - Effective Area Method ("RSTRENG")
  - API 579 Levels I, II, III
  - Shell92, CORLAS, KAPA, PAFFC, et al
- ASME B31G, §1.7(a) “The operator may make a more rigorous analysis of the corroded area ... by performing a fracture mechanics analysis based upon established principles and practices using the actual profile of the corroded region.”

- All methods present a trade-off between exactness and ease of use.
- Reduced conservatism associated with more exactness does not imply reduced safety.
Assessment of corrosion metal loss

<table>
<thead>
<tr>
<th>Basis</th>
<th>Fracture mechanics</th>
<th>Metal loss evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Dugdale</td>
<td>ASME B31G</td>
</tr>
<tr>
<td>Year</td>
<td>1961</td>
<td>1984</td>
</tr>
<tr>
<td>COD</td>
<td>CVN</td>
<td>No CVN</td>
</tr>
<tr>
<td>Mode</td>
<td>Ductile or brittle</td>
<td>Ductile initiation</td>
</tr>
<tr>
<td>S Flow</td>
<td>$S_Y$</td>
<td>1.1 x SMYS</td>
</tr>
<tr>
<td>Area</td>
<td>$t \times L$</td>
<td>2/3 dL</td>
</tr>
</tbody>
</table>

### Range of Attributes in Validation Tests

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NG-18 In-sec Eq’n</th>
<th>Corrosion Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD (inches)</td>
<td>6.625 to 48.0</td>
<td>10.75 to 48</td>
</tr>
<tr>
<td>Wall (inch)</td>
<td>0.195 to 0.861</td>
<td>0.197 to 0.500</td>
</tr>
<tr>
<td>D/t ratio</td>
<td>26.4 to 104.3</td>
<td>40.6 to 100.0</td>
</tr>
<tr>
<td>Actual YS (ksi)</td>
<td>32.0 to 106.6</td>
<td>28.4 to 74.8</td>
</tr>
<tr>
<td>Actual UTS (ksi)</td>
<td>53.4 to 131.7</td>
<td>40.2 to 85.5</td>
</tr>
<tr>
<td>CVN (ft-lb)*</td>
<td>15 to 100</td>
<td>n/a</td>
</tr>
<tr>
<td>No. of tests</td>
<td>130</td>
<td>215</td>
</tr>
</tbody>
</table>
Metal loss tests (except rings) using Flow Stress = Actual YS + 10 ksi

- No strong evidence that method fails for d/t>80%, however, it does not address failure by perforation
- No strong evidence that method fails for X65+, however data suggests Flow Stress = Avg(SMYS+SMTS) might be better
New ASME B31G-2009

- Formally recognizes prevalent techniques
- Multilevel analysis options:
  - Level 0 = Original tables
  - Level 1 = Max depth and length methods
  - Level 2 = Detailed profile method
  - Level 3 = User defined method
- Various flow stress definitions not to exceed SMTS
- User definable Factor of Safety for Levels 1,2,3
- Applicable to widened range of situations including corrosion on bends and ductile girth welds and seam welds.
Corrosion reassessment interval for HCA gas pipelines per B31.8-S

Fig. 4 Timing for Scheduled Responses: Time-Dependent Threats, Prescriptive Integrity Management Plan
Basis for B31.8-S Figure 4

- Assumes long uniform-depth corrosion
- Longest response time $T_{\text{max}} \approx 25(1.1-F)$

\[
\frac{r\omega t_F}{t} = \left[ \frac{F \times \text{SMYS}}{\text{Flow Stress}} \right]
\]

\[
\frac{R_F}{t} = \left[ \frac{r\omega t_{100} - r\omega t_F}{T_{\text{max}}} \right]
\]

- Implied $R$ varies with $t$, $F$, SMYS between 2.3% and 3.1% nominal wall per year
B31.8-S cautionary words:

- §7.2.4 Limitations to Response Times for Prescriptive-Based Programs: “When time-dependent anomalies such as ... corrosion ... are being evaluated, an analysis utilizing appropriate assumptions about growth rates shall be used to assure that the defect will not attain critical dimensions prior to the scheduled repair or next inspection.”

- This requires reliable estimates of defect size and growth rates
Probability of Exceedance (POE)

- Risk-based reassessment interval
- Accounts for statistical tool error
- Processes have been well described
- Some operators were using this before formal IMP requirements
- Could be allowed for HCA and non-HCA
- May indicated longer or shorter reassessment interval than standard fixed interval
- Corrosion rate = important variable determined from:
  - Indicated pit depth over time (e.g. half pipeline age)
  - Indicated pit change over multiple tool runs
  - Statistical models (e.g. Monte Carlo)
  - Repair records and CP history
Areas for R&D in corrosion assessment

- Perform burst tests of X70 and X80 pipe with real or simulated corrosion pitting
  - Ring tests or long machined defects with flat profiles are not suitable
- Validate flow stress definition more suited to high-strength pipe, e.g. \((\text{SMYS} + \text{SMTS})/2\)
- Methods for determining corrosion rates
- Improve ILI sizing, probability of detection, and accounting for tool error
# Dents and mechanical damage

<table>
<thead>
<tr>
<th>Code</th>
<th>Status</th>
<th>Smooth dent</th>
<th>Dent on weld</th>
<th>Dent w/ scrape, gouge or crack</th>
<th>Dent w/ corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 192</td>
<td>New, all</td>
<td>d/D&gt;2%, repair</td>
<td>Remove</td>
<td>Grind to pipe tolerance</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>In-svc, HCA</td>
<td>1-yr: d/D&gt;6% top, Monitor: d/D&gt;6% bot, d/D&gt;6% top and strain OK</td>
<td>1-yr: d/D&gt;2%, Monitor: d/D&gt;2% and strain OK</td>
<td>Immediate: All</td>
<td>Silent</td>
</tr>
<tr>
<td>Part 195</td>
<td>In-svc, HCA</td>
<td>Immed: top and d/D&gt;6% 60-d: top and d/D&gt;3% 180-d: top and d/D&gt;2%; bottom half and d/D&gt;6%</td>
<td>180-day: d/D&gt;2%</td>
<td>Immediate: top half 60-day: bottom half 180-day: gouge &gt; 12.5% WT and no dent</td>
<td>Silent</td>
</tr>
<tr>
<td></td>
<td>New, all</td>
<td>d/D&gt;6%, remove</td>
<td>Remove</td>
<td>Remove</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>In-svc, all</td>
<td>d/D&gt;6%, repair</td>
<td>Repair</td>
<td>Remove</td>
<td>Metal loss &gt; 12.5% WT</td>
</tr>
<tr>
<td>B31.8</td>
<td>New, all</td>
<td>d/D&gt;2%, remove</td>
<td>Remove</td>
<td>Remove; grind to pipe tol. if no dent</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>In-svc, all</td>
<td>d/D&gt;6% or strain &gt; 6%</td>
<td>d/D&gt;2% or strain &gt; 4%</td>
<td>Repair; grind out max depth = 40% WT</td>
<td>Use B31G</td>
</tr>
<tr>
<td>B31.8-S</td>
<td>In-svc</td>
<td>1-Yr: d/D&gt;6%</td>
<td>1-Yr: d/D&gt;2%; any on nonductile welds</td>
<td>Immediate: dent w/ gouge 1-Yr: Gouge w/ no dent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Dent strain criterion

- Recognized that dent depth alone is not meaningful
- Screening for dents which might have cracking due to severe deformation
- Alternative for large restrained indentations
- Simplified approach with SF>2 for Code purpose
- Not a fatigue criterion
- Not a criterion for evaluating a dent with gouge
- Not a substitute for NDE in the ditch if pipe is exposed
Mechanical damage fitness for service

- Estimate approximate failure pressure and time to failure using standard crack models with stress concentration factors from FEA
- More recent research considers crack formation due to contact stress and other factors
- Nonlinear and path-dependent, problem is still too complicated to model with high degree of accuracy

EPRG model

PR218-063510 FAD
Areas for R&D in mechanical damage

• Tribology of damage process, contact stresses, thermal effects
• Depth of damage zone and its effect
• Detection of cracks in mechanical damage by in-line inspection
• Define “non-threatening” damage
• Damage tolerance of low-stress pipelines
Seam defects

- Relationship between pressure and critical flaw size, e.g. API 579 or Modified NG18 eq’n
- Representative operating pressure spectrum
- Paris Law fatigue crack growth considering assumed initial flaw defined by HT or known present flaw defined by ILI, acted on by operating pressure cycles
- Calculate incremental crack growth to failure
Seam assessment issues

- Sometimes predicts very short time to failure for historically reliable lines
- Less often, overestimates safe service life
- Initial hydrotest is often a poor measure of pipe initial quality, resulting in very pessimistic results
- ILI probability of detection and flaw sizing limitations
Areas for R&D for seam assessment

• Improve accuracy of ILI seam defect detection, characterizing, and sizing
• Appropriate crack growth rate constant
• Appropriate pressure sample rate for pressure signal analysis
• Understand vintage pipe initial quality
• Develop reliability approaches
Girth welds

• Evaluating girth welds for construction loads, live loads, soil movement, accidental loads

• Fitness for service methods include
  — API 1104, Appendix A
  — CSA Z662, Appendix K
  — API 579

• Well established, mature technology

• Requires some expertise, material data, and estimate of applied stresses
Areas for R&D with girth welds

- ILI detection, characterizing, and sizing of girth weld defects
- Describe fracture toughness and ductility properties of vintage in-service welds
- Applied stresses associated with loadings
Assessment of SCC

• Theoretically, can be analyzed like other forms of cracking, if the depth is known
• Time to failure can be estimated, if growth rate is known
• R&D issues for SCC:
  — Probability of detection and flaw sizing of SCC using ILI
  — NDE in the ditch
Repairs

- **Corrosion:**
  - Steel sleeves and composite wrap (either FG or CF) generally accepted

- **Dents and mechanical damage:**
  - Steel sleeves with filler are the standard
  - Composite wraps with grinding of gouges and filler added are accepted by testing and analysis provisions

- **Defective seams:**
  - Type B steel sleeve still the standard
  - Thermal interference sleeve sees some use
  - Composite wrap not suitable
  - No tests validating weld repair schemes on vintage seams

- **Girth welds:**
  - Type B steel sleeves are the standard for preventing separation
  - Some others can work for leak containment (e.g. corrosion)
R&D issues with repairs

• Are concerns for crack initiation in vintage ERW seams under steel sleeves legitimate?
• Can selective corrosion of seams be repaired by welding?
• Proper support and backfill procedures
• Use of O-let fittings for hot taps
• Performance of CF versus FG composite wraps