Detection and Characterization Panel

Technology Research – Issues and Opportunities

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Mechanical damage due to direct contact

Damage features:
- Coating damage, removal
- Dent (re-rounded), pipe ovalization
- Stress, strain concentrations
- Local wall thinning
- Metal removal, plowing, gouge
- Highly deformed surface layer
- Surface, sub-surface cracking
- Time/cycle-dependent cracking
- Nearby weld, corrosion
Mechanical damage is not a new issue!
• 80 PRCI projects completed, over 40 years
• Substantial API, EPRG, APIA activities
• DOT co-funded projects
• JIPs, individual company research

PRCI/GRI expenditure has been around $5 million/year in past years
Key background information

- Effect of smooth and rock dents on liquid petroleum pipelines. API 1156 (1997 & 1999)
- EPRG methods for assessing the tolerance and resistance of pipelines to external damage. (Roovers, Zarea et al, 1999)
- Proposed new guidelines for ASME B31.8 on assessment of dents and mechanical damage. GRI 01/0084 and IPC 2002 (Rosenfield, 2001/02)
Technology research – issues and opportunities

- **Current technology status**
  - Detection and characterisation
  - Assessment and remediation

- **Technology gaps**

- **Defining the way forward**
  - MD Workshop, January 2005
  - Roadmapping

- **Current PRCI project portfolio**

- **Issues still to be addressed**
Damage detection & characterization - status

- **High resolution caliper ILI**
  
  *High resolution calipers can find dents below 1% depth – how reliable and accurate are they?*

- **Current MFL, UT technology**
  - Caliper + simultaneous or sequential MFL
  - Axial, transverse field
  - Elastic wave, EMAT

  *MFL finds small dents, associated metal loss – can this become quantitative?*

  *Can UT find cracks at damage?*

- **Emerging ILI technologies**
  - Dual-field MFL, NLH

  *Mapping stress, strain distributions, finding cracks. How long before we have proven tools?*
Damage assessment - status

- Full-scale pipe burst and fatigue testing
  - Started in 1950’s
  - Battelle, Stress Engineering (AGA/GRI/PRCI)
  - British Gas, Gaz de France (EPRG)
  - API, DOT/OPS
  - Individual operators, Joint Industry Groups

  .....over 400 test results  But many tests are simplistic in representing damage and cannot be used for new model development
Damage severity modeling - status

- **Empirical and semi-empirical models:**
  - Dents, gouges and dents + gouges
    - Battelle fracture models
    - Battelle ‘Q’ factor, British Gas ‘Dent + Gouge Fracture model’
    OK for some types of damage (plain dents, gouges), but very large scatter for others (dents + gouges)
  - Dents on welds, corrosion
    - Fatigue life of dents with welds (Fowler & Alexander, 1994)
    - Guidance for assessing dents on welds (Kiefner, 1999)
    Dents on welds are not as good as plain dents, but better than dents + gouges.

- **Finite element modeling**
  Good for deformation, strain & stress distributions during denting & re-rounding, but not for crack formation

- **Fracture mechanics models of time-dependent failure**
  - Battelle and Advantica models
  - Fleet Dent Assessment model
  Still considerable scatter; models often lack supporting data
Guidance for damage assessment - status

- ASME B31.8 (US)
- API 1156 (US)
- EPRG (Europe)
- Pipeline Defect Assessment Manual (Europe)
- CSA Z662 (Canada)
- AS 2885 (Australia)
## Assessment rules - status

<table>
<thead>
<tr>
<th></th>
<th>Plain dents</th>
<th>Dents at welds</th>
<th>Dents with cracks or gouges</th>
<th>Dents with corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constrained</td>
<td>Unconstrained</td>
<td>Up to 2% OD or 4% max strain for ductile welds. No safe limit for brittle welds</td>
<td>No safe limit</td>
</tr>
<tr>
<td><strong>ASME B31.8</strong></td>
<td>Up to 6% OD or 6% strain</td>
<td>Up to 2% OD</td>
<td>Not allowed</td>
<td>Not considered</td>
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<tr>
<td><strong>API 1156</strong></td>
<td>No limit provided rock remains in place</td>
<td>Up to 6% OD. &gt;2% requires a fatigue assessment</td>
<td>Up to 2% OD</td>
<td>Not allowed</td>
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<tr>
<td><strong>EPRG</strong></td>
<td>Up to 7% at a hoop stress of 72% SMYS</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
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<tr>
<td><strong>PDAM</strong></td>
<td>Up to 7% of pipe diameter</td>
<td>Not allowed</td>
<td>Assess as dent and defect combination</td>
<td>Not allowed</td>
</tr>
<tr>
<td><strong>Z662</strong></td>
<td>Up to 6 mm for &lt;102 mm OD</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
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<tr>
<td></td>
<td>Up to 6% for &gt;102 mm OD</td>
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</table>

*Depth alone is insufficient – need to move to dent profile + strain and stress distributions, cracking, other features*
Detection, sizing
- Existing commercial ILI will detect damage, but accuracy and reliability are not quantified
- Next generation ILI (dual field MFL, NLH) has potential for improvement

Assessing severity
- Many full-scale tests are simplistic in representing damage
- Fundamental knowledge of the underlying failure processes is limited; models for some types of damage (e.g., dents + gouges) are prone to very high scatter
- Use of a fracture-mechanics-based algorithm will fill this gap
- Whatever approach is used, the results will require broader validation; existing full-scale data-sets lack the information needed for this purpose
- Much has been done on plain dents; main focus in future should be on dents + gouges, dents + other damage
Focus on issues, needs and priorities for PRCI’s work on all aspects of mechanical damage:

- Damage prevention
- Detection, sizing and characterization
- Severity assessment and repair
- Damage management strategies

- Attended by PRCI members (operators and vendors), DOT invitees
Prioritized needs – inspection/characterization

- Create database of dent/gouge features
- ILI technology to discriminate between plain dents and dents with other features.
- Tools to integrate geometry and metal-loss information
- ILI technology to better characterize and size critical damage features
- Quantify the resolution, accuracy and reliability of ILI and in-ditch inspection methods
Prioritized needs – severity assessment

- A validated method for ranking the severity of dents with/without associated corrosion, welds
- A validated method for assessing the safety margin on burst pressure for dents+gouges
- A validated method for assessing the remaining life of gouges, dents+gouges
Mechanical Damage - Roadmap

- **Five-year horizon**
- **Overall aims**
  - To develop tools and methods enabling a reduction in the frequency and consequences of in-service damage due to mechanical damage, dents and gouges
- **Concept**
  - Three-level assessment approach, compatible with ILI tool output
    - Screening and ranking
    - RSTRENG analogue
    - Bespoke models, case by case
## Mechanical damage – Roadmap

<table>
<thead>
<tr>
<th>Topic</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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<tbody>
<tr>
<td>Detection &amp; characterization</td>
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<td>Evaluate <em>current ILI capabilities</em></td>
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<td><em>Dual field MFL trials</em></td>
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<td><em>3-D discrimination of defects</em></td>
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<td><em>NLH ILI development</em></td>
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<td>Assessment of structural significance</td>
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<td><em>Develop ranking/screening models</em></td>
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<td><em>Develop mechanics-based models</em></td>
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<td><em>Validation using full-scale tests</em></td>
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<td>Remediation</td>
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<td><em>Safe inspection, repair procedures</em></td>
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<td>Damage management methodology</td>
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<tr>
<td><em>Assessment algorithms, procedures</em></td>
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<td><em>Guidance documentation, software</em></td>
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*Note: The table above outlines the roadmap for mechanical damage assessment, focusing on various aspects such as detection, characterization, assessment of structural significance, remediation, and damage management methodology. Specific activities and timelines are indicated for each year from 2005 to 2009.*
Damage inspection – new projects

- **MD-1 Tools to detect and discriminate mechanical damage**
  - Development of dual-field magnetic flux leakage inspection technology ($400k from PRCI, $1350k total, 2 years, submitted to PHMSA for co-funding)
    - *evaluate ability of prototype vehicle to discriminate between critical and benign anomalies in an operating pipeline*
  - Fundamentals and performance characteristics of current ILI technologies ($300 from PRCI, $600k total, 2 years, submitted to PHMSA for co-funding)
    - *define abilities of current ILI tools to detect, discriminate and quantify damage features*
  - Understanding MFL signals from damage ($120k, 1 year)
    - *Quantitative separation of stress and deformation contributions*
Damage assessment – new projects

- **MD-2 Ranking and screening mechanical damage defects ($150k, 1yr)**
  - Inventory of types of damage found in service, likelihood and severity etc, for correlation with severity assessment ranking
  - Model for predicting the likelihood and severity of damage. First-level discrimination, eg puncture v non-penetrating, crack formation.

- **MD-4 Structural significance of mechanical damage ($800k, 2yrs)**
  - Improved models for predicting the burst and delayed failure of dent + gouge damage
  - Full-scale validation of new models for dents, dents+welds/ corrosion and dents+gouges under monotonic and cyclic load (2nd year)

- **MD-5 Guidelines for inspection and repair of dent + gouge damage ($250k, 2yrs)**
  - Safe inspection and excavation procedures; redefinition of pressure reductions and safety margins, based on new models
  - Safe grinding repair procedures for dents, gouges, dent + gouges
Detection and Characterization - outcomes

- A quantitative understanding of the types, extent and distributions of mechanical damage experienced by pipelines
- ILI technology capable of identifying and measuring the features that discriminate between critical and benign anomalies in an operating pipeline
- A model for ranking the severity of damage (rupture, leak, non-penetrating dent+/gouge+/cracks) based on damage features, pipeline attributes and aggressor characteristics
- Validated state-of-the-art models for determining the burst and delayed failure behavior of damaged pipe
- New recommendations for determining safe pressure reductions and working practices during repair
- An Industry Guidance Document, based on these deliverables, to aid decisions on the characterization, severity assessment, and safe excavation and repair of damaged pipe
Summary - Key issues

- Detection
  - How accurately and reliably can we find damage?

- Characterization
  - Can well can we identify and measure the significant features?

- Assessment
  - How severely do the significant features influence pressure containment, now and during ongoing operation?
  - Can we create an analogue of RSTRENG for screening/Level 1?

- Repair
  - How safe is it to continue operating?
  - How safe is it to excavate?
  - What in-the-ditch tools do we have to measure/confirm damage severity?
  - What repair method is appropriate?
Summary - future research needs

- Better tools
  - ILI
  - In-the-ditch

- Better models
  - Screening and ranking
  - Burst, time-dependent failure
  - Environmental influence

- Better information exchange
  - Feedback from field – defect types, populations, ILI vs excavation
  - Integration of inspection and assessment – measuring and assessing the significant features

- Better regulations
  - Based on damage profile and features, not depth
Summary - the opportunity to deliver

- **PRCI’s roadmap is becoming well-developed**
  - Based on extensive consultation
  - Coherent inter-relationships between projects
  - Clear opportunities to deliver measurable improvements
  - Substantial benefits
  - Intermediate milestones will deliver value

- **Delivery will take time, effort and money**
  - Projected spend $3 million each year for five years
  - High priority; PRCI members have allocated $1.8 million for inspection/assessment in 2006
  - Substantial in-kind contributions from operators, vendors
  - PRCI is making every effort to secure other co-funding
Thank you for listening