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

Background

- **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

- GRI guidelines for locating and using pipeline industry research (Yellow Pages). Vol 9 – Mechanical damage (1999)
- 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)
- Bottom-side dent study. Baker Report OPS TTO10, November 2004

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

	Plain dents		Dents at welds	Dents with cracks or gouges	Dents with corrosion
	Constrained	Unconstrained			
ASME B31.8	Up to 6% OD or 6% strain		Up to 2% OD or 4% max strain for ductile welds. No safe limit for brittle welds	No safe limit	Up to 6% OD for dent and metal loss, as per corrosion criterion
API 1156	No limit provided rock remains in place	Up to 6% OD. >2% requires a fatigue assessment	Up to 2% OD	Not allowed	Not considered
EPRG	Up to 7% at a hoop stress of 72% SMYS		Not allowed	Not allowed	Not allowed
PDAM	Up to 7% of pipe diameter		Not allowed	Assess as dent and defect combination	
Z662	Up to 6 mm for <102 mm OD Up to 6% for >102 mm OD		Not allowed	Not allowed	Not allowed

Depth alone is insufficient – need to move to dent profile + strain and stress distributions, cracking, other features

Remaining gaps (Leis & Hopkins, 2004)

- **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 (eg 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

Mechanical Damage Workshop, January 2005

- **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

Topic	2005 2006 2007 2008 2009
Detection & characterization	
Evaluate *current ILI capabilities*	---------
Dual field MFL trials	----------
3-D discrimination of defects	----------
NLH ILI development	---------- - - - -
Assessment of structural significance	
Develop ranking/screening models	-------- -------
Develop mechanics-based models	----------
Validation using full-scale tests	---------- ----------
Remediation	
Safe inspection, repair procedures	----------
Damage management methodology	
Assessment algorithms, procedures	----------
Guidance documentation, software	--------

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, 1year)
    - ***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