Current Practices in Pipeline Fitness for Service and Repair

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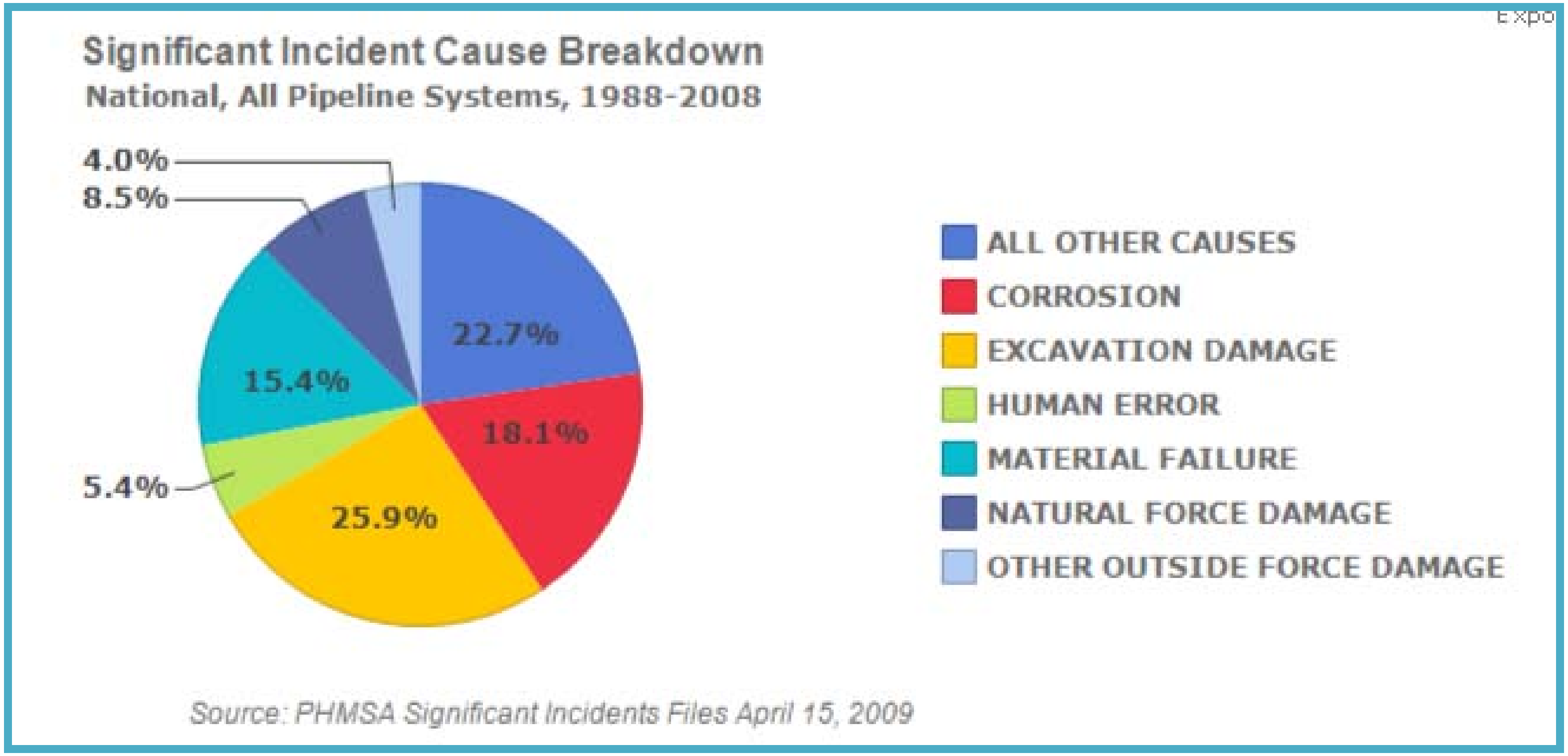
The Fitness for Service Process

- 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



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

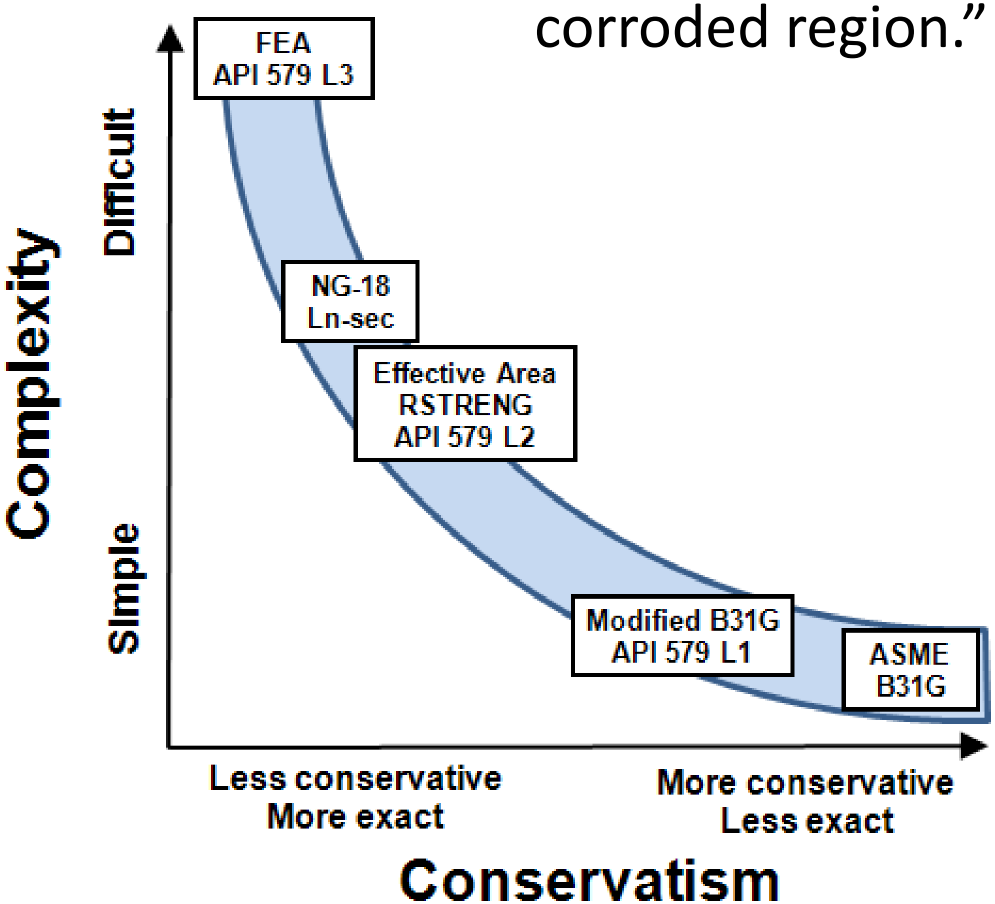
Corrosion

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

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.”



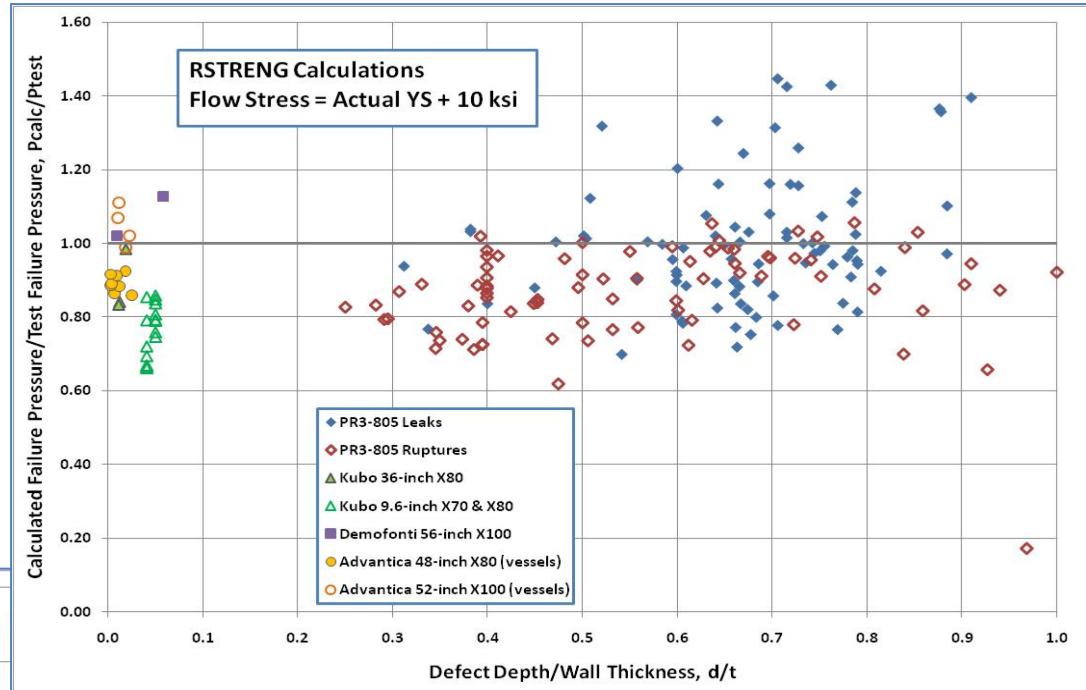
- All methods present a trade-off between exactness and ease of use.
- Reduced conservatism associated with more exactness does not imply reduced safety.

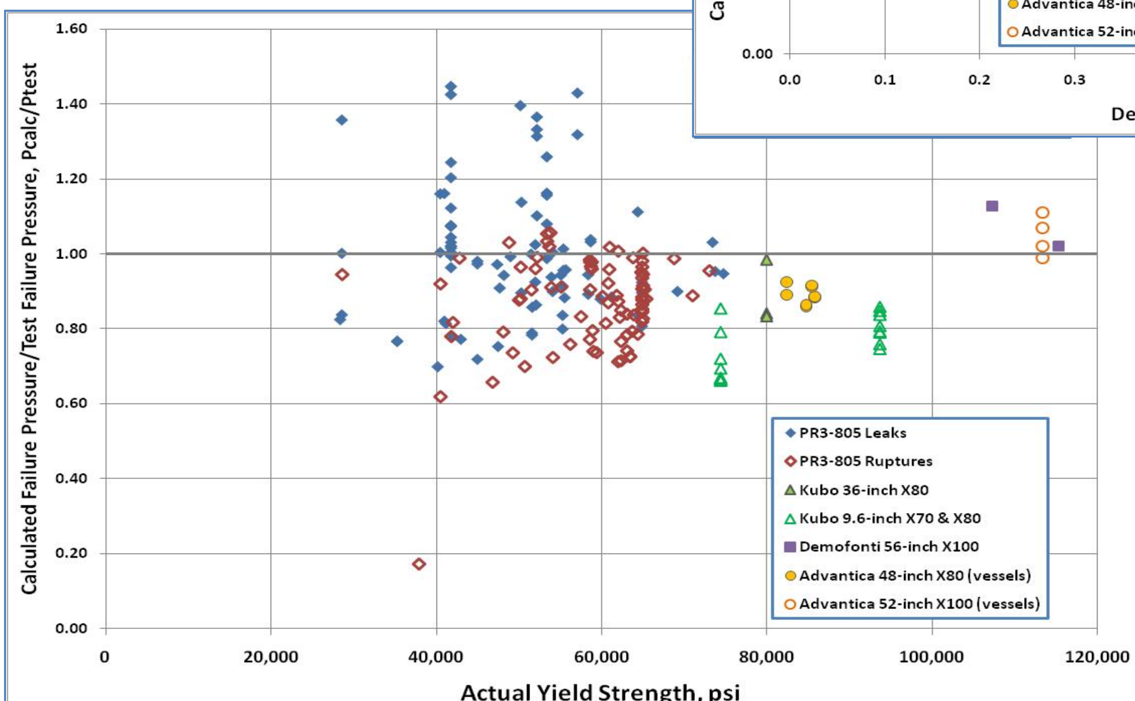
Assessment of corrosion metal loss

Basis	Fracture mechanics		Metal loss evaluation		
Method	Dugdale	Maxey NG-18 Eq'n	ASME B31G	Modified B31G	Effective Area ("RSTRENG")
Year	1961	1973	1984	1989	1990
Toughness	COD	CVN	No CVN	No CVN	No CVN
Mode	Ductile or brittle	Ductile or brittle	Ductile initiation	Ductile initiation	Ductile initiation
S_{Flow}	S_Y	S_Y+10 ksi	1.1 x SMYS	SMYS+10 ksi	SMYS+10 ksi
Area	t x L	(π/4)dL	2/3 dL	0.85 dL	Profile

Range of Attributes in Validation Tests		
Parameter	NG-18 In-sec Eq'n	Corrosion Methods
OD (inches)	6.625 to 48.0	10.75 to 48
Wall (inch)	0.195 to 0.861	0.197 to 0.500
D/t ratio	26.4 to 104.3	40.6 to 100.0
Actual YS (ksi)	32.0 to 106.6	28.4 to 74.8
Actual UTS (ksi)	53.4 to 131.7	40.2 to 85.5
CVN (ft-lb)*	15 to 100	n/a
No. of tests	130	215

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

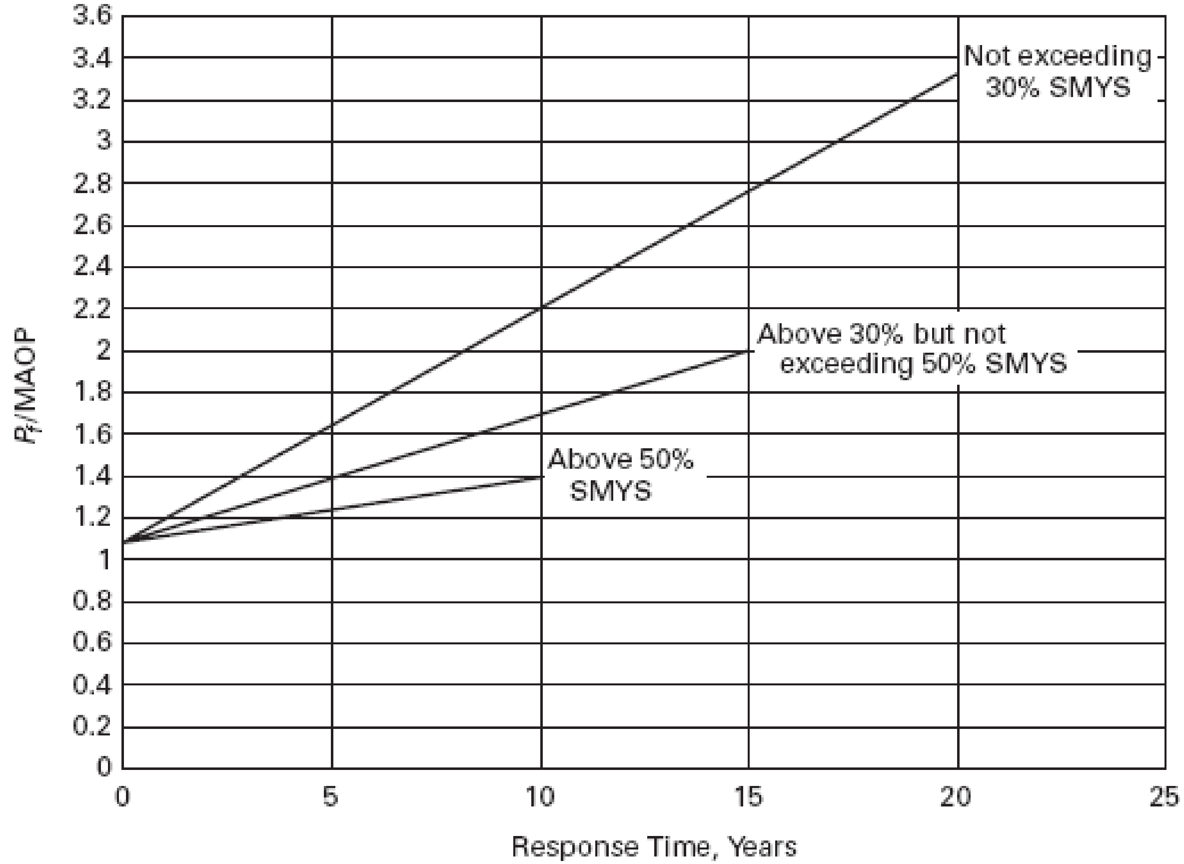


Fig. 4 Timing for Scheduled Responses: Time-Dependent Threats, Prescriptive Integrity Management Plan

Basis for B31.8-S Figure 4

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

$$\boxed{\frac{rwt_F}{t} = \left[\frac{F \times SMYS}{Flow\ Stress}\right]}$$

$$\boxed{\frac{R_F}{t} = \left[\frac{rwt_{100} - rwt_F}{T_{\max}}\right]}$$

- 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

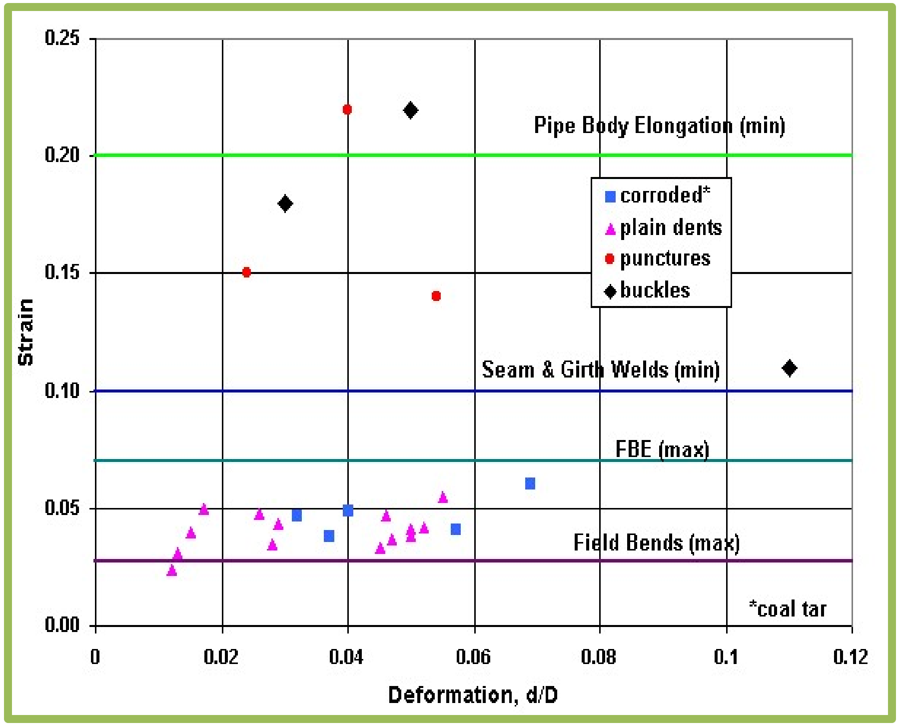
Areas for R&D in corrosion assessment

- 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. (SMYS+SMTS)/2
- Methods for determining corrosion rates
- Improve ILI sizing, probability of detection, and accounting for tool error

Dents and mechanical damage

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

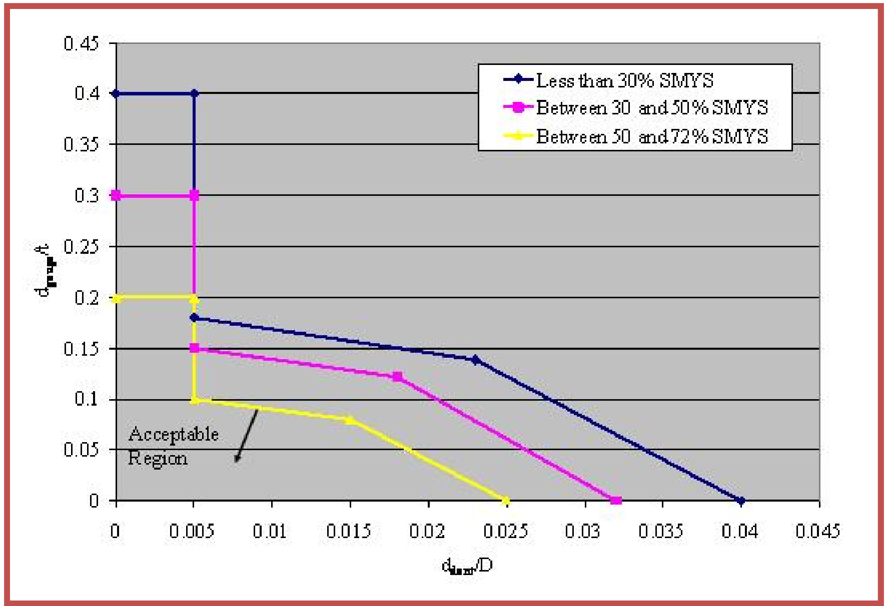
Dent strain criterion



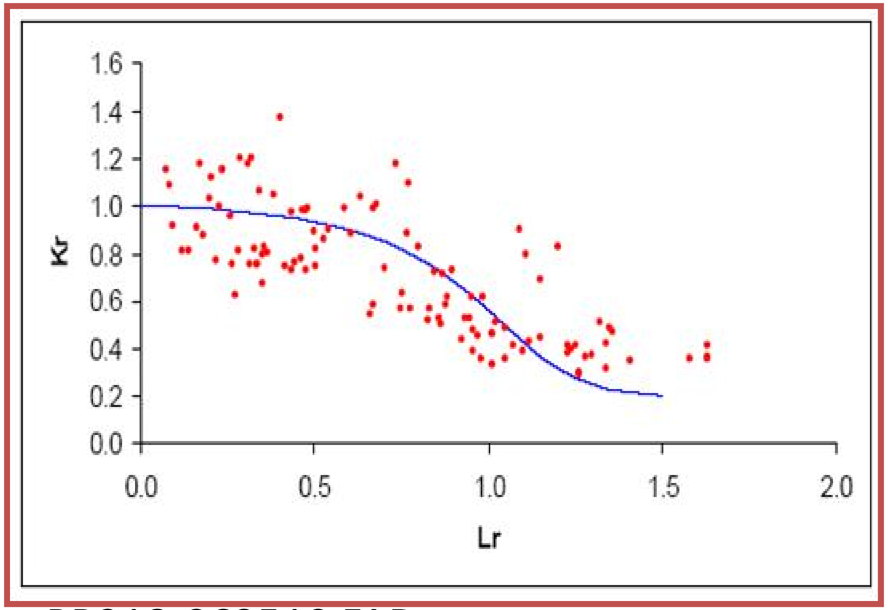
- Recognized that dent depth alone is not meaningful
- Screening for dents which might have cracking due to severe deformation
- Alternative for large restrained indentations
- Simplified approach with SF>2 for Code purpose
- Not a fatigue criterion
- Not a criterion for evaluating a dent with gouge
- 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