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Assessment of flaws in pipelines - an introduction

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Agenda

- Defect types for assessment
- Purpose of the assessment
- Where you obtain the data for the assessment
- Data from MFL intelligent pigs
- Methods for assessing volumetric corrosion
- The integrity assessment process and deliverables
- Assessment of dents
- Assessment of cracks
- Assessment of laminations
- Summary table of PDAM recommended assessment methods

Defect types for assessment

- Volumetric corrosion
- Dents
  - *Plain dents*
  - *Kinked dents*
- Gouges
- Cracks
  - *Fatigue*
  - *Stress corrosion cracking*
  - *Hydrogen induced cracking*
- Girth weld defects
- Manufacturing defects
  - *Laminations etc*

Purpose of the Assessment

- Pipelines deteriorate in service with time.
- We can inspect pipelines and find volumetric corrosion, damage such as dents and cracks – none of which would be acceptable to the original construction standards.
- We have to assess the fitness-for-purpose of the known defects.
- The objectives are:
  - *To determine the operational significance of the defects – determine their severity*
  - *To define if repair is necessary and to prioritise the repairs based on severity*
  - *To provide evidence for determining the cause of the defects*
  - *To inform the decisions on repair methods and the extent of the repairs*

Fitness for purpose
A pipeline is considered adequate for its purpose, provided the defined conditions for failure are not reached. This is based upon a detailed technical assessment of the significance of the defect. Consideration of consequences of failure is inherent in this assessment.

Summary of pipeline defect assessment methods

Pipeline defect assessment manual (PDAM)

PDAM is the result of a Joint industry Project sponsored by 15 oil and gas companies and regulatory bodies.

Objectives

- To present 'best' available method for assessment of pipeline defects, such as corrosion, dents, gouges and weld defects.
- To present guidance on their use.
- To be a simple easy to use guide.

Based on correlation of full scale test data and best analysis methods

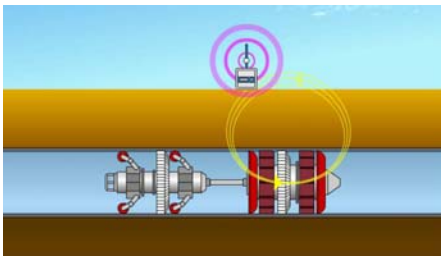
Further information available on http://www.penspen.com/capabilities/services/software-tools/pdam/

Pipeline condition data

- Visual and physical inspection
  - *Coating breakdown*
  - *External corrosion*
  - *Dents and gouges*
  - *Cracks and weld defects (using non-destructive testing)*
- Calliper pigs
  - *Dents and obstructions to flow*
- Magnetic flux leakage intelligent pigs
  - *Internal and external corrosion*
- Ultrasonic intelligent pigs
  - *Cracks*
  - *Internal and external corrosion*

Intelligent pigs

- Intelligent pigs collect information about the pipeline; including metal loss locations and sizes.
- Able to detect corrosion, cracking, and weld defects
- The principle type are magnetic flux leakage (MFL) tools which primarily detect volumetric corrosion



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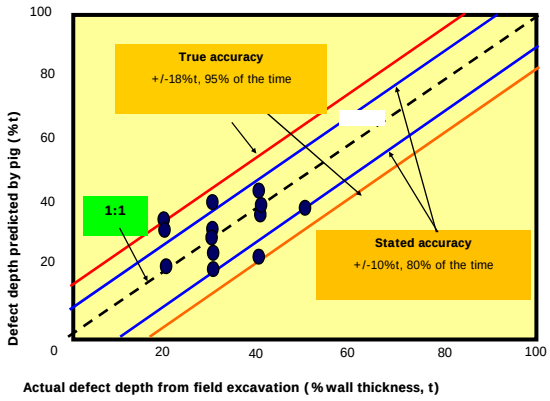
Challenges of data from MFL intelligent pigs

MFL pigs give data on volumetric corrosion.

- Volume of data
- Sizing data is relative to sound wall thickness and not absolute
- Locating the features relative to fixed points on the line
  - *Magnetic markers over the line*
  - *Test posts*
  - *crossings*
  - *Welds*
- Comparison of data with previous IP surveys
  - *Different sensitivities of different pigs*
  - *Different pig types*

Validation of the data

- MFL pigs give magnetic signals relative to full wall thickness
- Assessed defects are normally validated by carrying out field excavations



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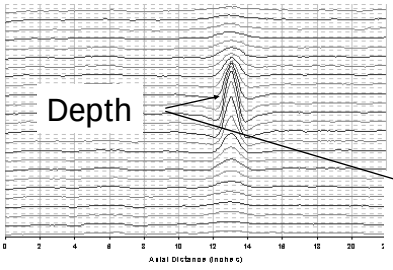
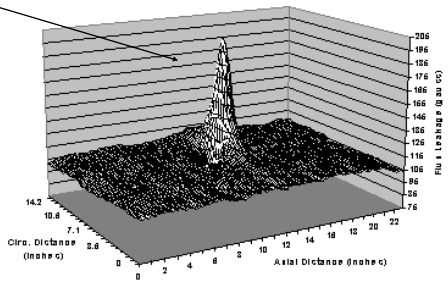
MFL Signals

The sensors record information that can be translated into metal loss dimensions:



Width (note - Estimating defect width is not straightforward. This is because the signal spreads in the circumferential direction, and the amount of spread depends on the defect length, depth, and width.



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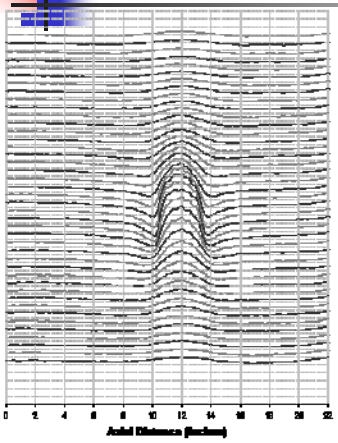
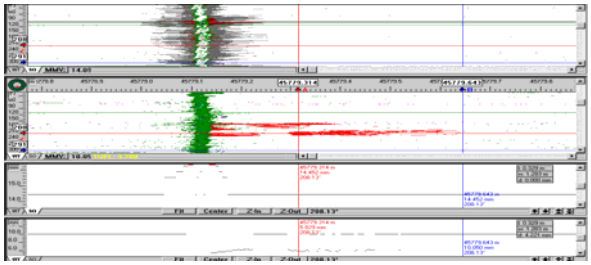
MFL data presentation





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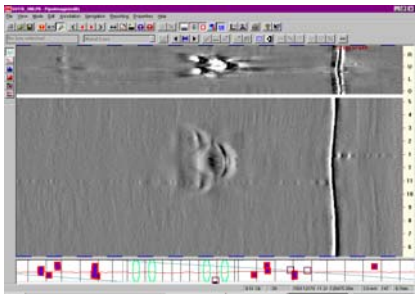
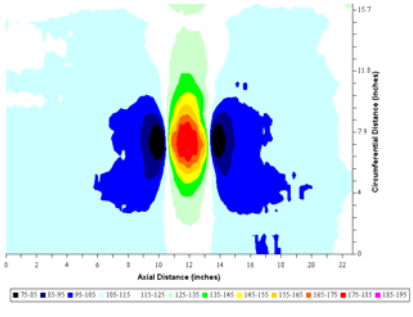
MFL data visualisation





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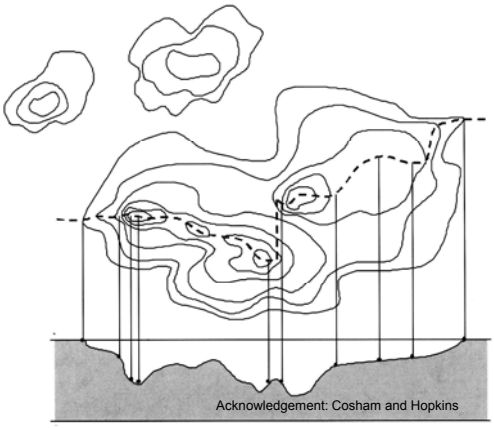
The challenge of defect dimensions



The irregular length, width and depth of a typical corrosion defect

Methods for assessing volumetric corrosion defects

The main methods are flow stress dependent and assume that the steel is notch ductile. Based on Battelle NG 18 formulae.

- *ASME B31.G*
- *Modified B31.8 (Rstreng 0.85) (1989)*
- *RSTRENG (1989)*
- *Shell 92 (1995)*
- *DnV RP F101*
- *LPC*

- There are other newer models which are not based on NG-18
  - *PCORRC (Battelle/PRCI 2000)*
  - *CPS*
  - *SAFE*

Basis of method of assessment

- If stress due to the defect (anomaly) exceeds the flow stress failure will occur

Hoop stress

- Stress increases as wall is thinned
- Simple codes look at anomaly depth and hoop stress effects

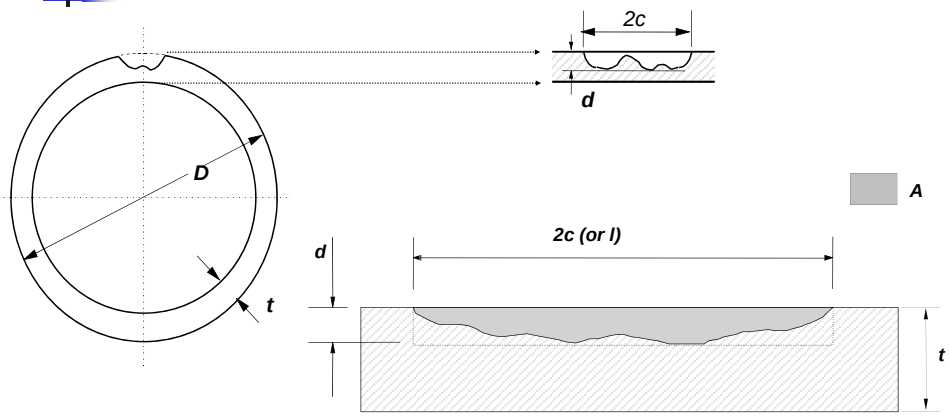
$$\sigma_H = \frac{pD}{2t}$$

Axial stress

- More complex codes link hoop and axial stress
- This a more accurate measure of failure

$$\sigma_A = \frac{pD}{4t}$$

Axial dimensions



d	=	defect depth
2c (or l)	=	defect axial length
t	=	pipe wall thickness
D = 2r	=	pipe diameter

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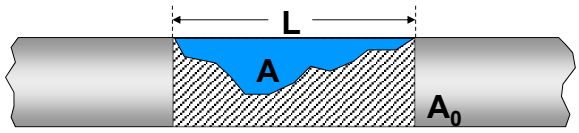
Methods for assessing volumetric corrosion defects

The main methods of assessment of the burst pressure of blunt part-wall defects all use the Battelle NG-18 part-wall failure criterion:



$$\sigma_f = \overline{\sigma}\left[\frac{1-\frac{A}{A_0}}{1-\left(\frac{A}{A_0}\right)\frac{1}{M}}\right] = \overline{\sigma}\left[\frac{1-\frac{d}{t}}{1-\left(\frac{d}{t}\right)\frac{1}{M}}\right]$$

Where:

σ_f = Failure stress
$\overline{\sigma}$ = Flow stress
A = Area of metal loss
A_0 = Original Area
M = Folias Factor

The differences between the methods are:

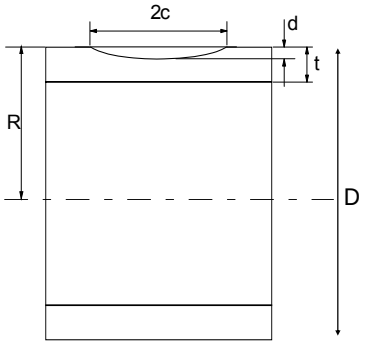
- The definition of flow stress
- The geometry correction factor/Folias factor
- Treatment of defect profile

$$M = \sqrt{1 + 0.26\left(\frac{2c}{\sqrt{rt}}\right)^2}$$

NG-18 equations in terms of pressure

We can replace failure stress, σ_f by the pipelines internal pressure at failure

$$P_f = \frac{\sigma_f 2t}{D}$$



$$\text{Failure Pressure}, P_f = \frac{2t\overline{\sigma}}{D}\left[\frac{1-\frac{A}{A_0}}{1-\frac{A}{A_0}\frac{1}{M}}\right]$$

or

$$\text{Failure Pressure}, P_f = \frac{2t\overline{\sigma}}{D}\left[\frac{1-\frac{d}{t}}{1-\frac{d}{t}\frac{1}{M}}\right]$$

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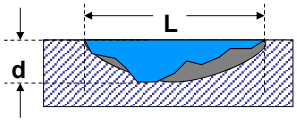
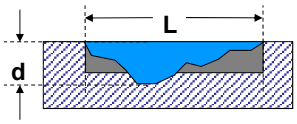
Corrosion area (A) approximations

ANSI/ASME B31.G



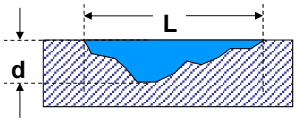
2/3dL (parabolic) area

Simplified RSTRENG



0.85dL area approximation

Detailed RSTRENG



actual area

DNV and PCORR use a rectangular profile

Differences between the common methods

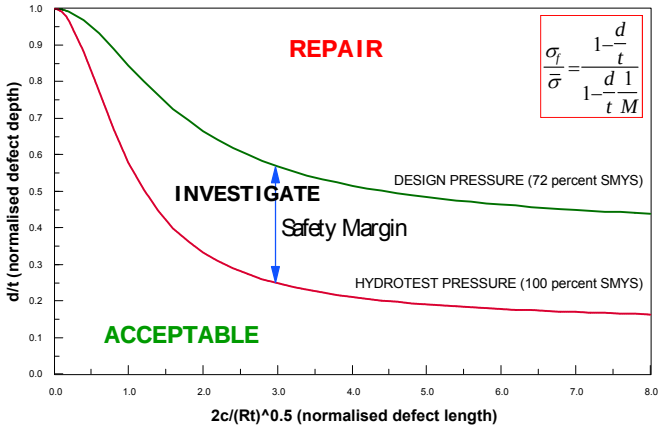
METHOD	BASIC EQUATION	'FLOW STRESS'[2]	DEFECT SHAPE ASSUMED	BULGING FACTOR
NG-18	NG-18[1]	σ_Y + 10 ksi	Rectangular (d/t) or defect area (A/Ao)	$\sqrt{1+0.6275\left(\frac{2c}{\sqrt{Dt}}\right)^2-0.003375\left(\frac{2c}{\sqrt{Dt}}\right)^4}$
ASME B31G	NG-18	$1.1\sigma_Y$	Parabolic 2/3(d/t)	$\sqrt{1+0.8\left(\frac{2c}{\sqrt{Dt}}\right)^2}$
modified B31G	NG-18	σ_Y + 10 ksi	Arbitrary 0.85(d/t)	$\sqrt{1+0.6275\left(\frac{2c}{\sqrt{Dt}}\right)^2-0.003375\left(\frac{2c}{\sqrt{Dt}}\right)^4}$
RSTRENG	NG-18	σ_Y + 10 ksi	Effective area, effective length (river bottom profile)	$\sqrt{1+0.6275\left(\frac{2c}{\sqrt{Dt}}\right)^2-0.003375\left(\frac{2c}{\sqrt{Dt}}\right)^4}$
SHELL92	NG-18	σ_U	Rectangular (d/t)	$\sqrt{1+0.8\left(\frac{2c}{\sqrt{Dt}}\right)^2}$
LPC	NG-18	σ_U	Rectangular (d/t)	$\sqrt{1+0.31\left(\frac{2c}{\sqrt{Dt}}\right)^2}$
DNV-RP-F101	NG-18	σ_U	Rectangular (d/t) (and river bottom profile)	$\sqrt{1+0.31\left(\frac{2c}{\sqrt{Dt}}\right)^2}$

1 2c is equivalent to L
2 SHELL 92, LPC and DNV-RP-F101 state that using $0.9\sigma_u$ gives a conservative bias to the predictions

Corrosion acceptance charts

The IP surveys identifies the ‘anomalies’ by KP, depth range, length and clock position

The objective is to determine if the anomaly is acceptable or unacceptable for particular pipeline stresses



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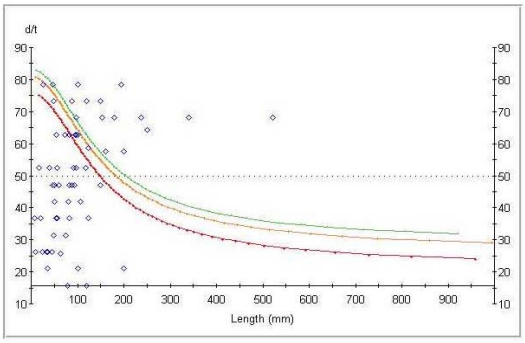
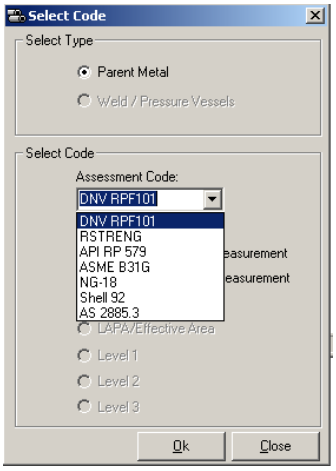
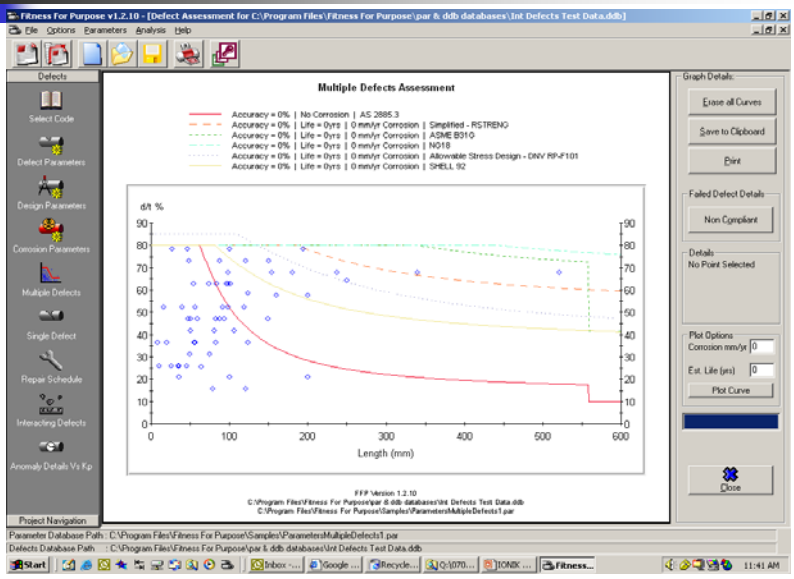
Example figure from software





Sensitivity testing



The integrity assessment process

- Inspection
- Locating and characterising the anomalies
- Assessing their dimensions
- Agreeing the input parameters for the analysis (diameter, wall thickness applicable operating pressures, other pressures to be investigated)
- Selecting the analysis tools
- Fitness for purpose analysis
  - *for present use*
  - *for future use*
- Recommendations for future operations

The deliverable from an FFP assessment

- Prioritised repair list
- Identification of critical areas
- Estimate how the number of defects will increase with time
- Diagnosis of probably types of corrosion
- Further investigations to confirm diagnosis and remedial measures

and this provides an input to

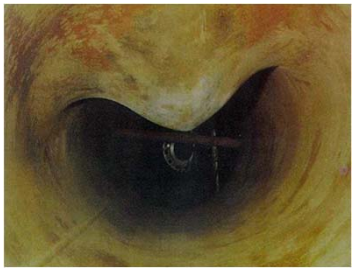
- The selection of proposed repair and remedial methods
- Developing a strategy for rehabilitation of CP or coating systems
- Develop a strategy for dealing with internal corrosion issues

Other related activities and deliverables

- Comparison with previous surveys to assess corrosion rates
- Assessments to understand the cause of the anomalies
  - *Site investigations*
- Recommendations on corrosion mitigation measures
- Detailed recommendations on rehabilitation strategies

Assessment of dents

- 'a depression that produces a gross disturbance in the curvature of the pipe wall'
- Dents can be described as:
  - *plain*
  - *kinked*
  - *smooth*
- Plain Dents
  - *No big problems under static loading if free from gouges or welds.*
  - *Empirical limits apply*
- Use EPRG or 'SES' model for fatigue life
  - *Dent depth is most significant factor*



	Plain Dents	
	Constrained	Unconstrained
ASME B31.8	Up to 6%OD	
New ASME B31.8	Up to 6% OD or 6% strain in pipe body	
ASME B31.4	Up to 6% OD in pipe diameters > NPS 4 Up to 6mm in pipe diameters < NPS 4	
API 1156	No limit provided rock remains in place	Up to 6%OD >2% OD requires a fatigue assessment
EPRG	≤7%OD at a hoop stress of 72%SMYS	
PDAM	Up to 10% pipe diameter	
Z662	Up to 6mm for ≤ 101.6mm OD or <6%OD for >101.6mm	

Critical dent categories

- Dents on welds
  - *Low failure stress and short fatigue lives*
- Dents with gouges
  - *Very severe damage and low failure stresses*
  - *Very short fatigue life*
  - *EPRG model for burst strength, but inaccurate, probably better to repair*

	Dents at welds	Dents with cracks or gouges	Dents with corrosion
ASME B31.8	Not allowed	Not allowed	Not allowed
New ASME B31.8	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 & metal loss as per corrosion criterion
ASME B31.4	Not allowed	Not allowed	Not allowed
API 1156	Up to 2% OD	Not allowed	Not considered
EPRG	Not allowed	Not allowed	Not allowed
PDAM	Not allowed	Assess as dent and defect combination	
Z662	Not allowed	Not allowed	Not allowed

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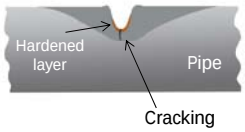
Gouges

- A gouge is mechanical damage – the physical removal of part of the pipe wall.
- Gouges and dents have caused ruptures on pipelines operating below 30% SMYS, but none known below 25% SMYS.

- A gouge in a dent is more severe than a gouge in plain pipe
- Gouges can be assessed providing your pipeline has a toughness >20J.
- Gouges have a work hardened layer which may have a resulting crack



Magellan pipeline rupture

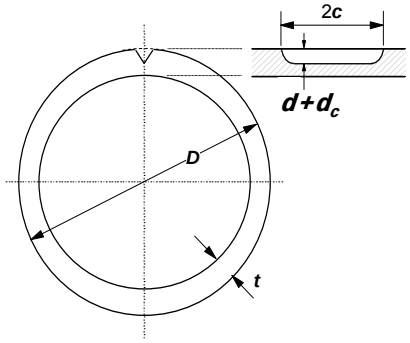
Assessment of an axial gouge

We can use modified NG-18 equations on gouges to take account of possible cracking at the gouge:

$$\frac{\sigma_f}{\overline{\sigma}} = \frac{1 - \frac{d + d_c}{t}}{1 - \frac{d + d_c}{t}\frac{1}{M}}$$

Allow for any hard layer and any cracking by adding 'd_c', e.g. 0.5mm

s_f	=	hoop stress at failure
$\overline{\sigma}$	=	flow stress*
d	=	gouge depth
$2c$	=	axial length of gouge
t	=	pipe wall thickness
r	=	pipe radius (=D/2)
M	=	Folias factor



$$\overline{\sigma} = \frac{\sigma_Y + \sigma_U}{2}$$

σ_Y = Yield Strength
σ_U = Ultimate Tensile Strength

Assessing Gouges: summary

- For bursting- use NG-18 equations but add d_c to allow for any hard layer/cracking
- Fatigue: pipes subject to cyclic stresses
  - *Use BS 7910 or API 579 fatigue assessment methods*
- Gouges associated with dents generally not allowed
  - *(see PDAM which has a model for assessment)*
- ASME B31.8 does not allow gouges: they all must be repaired.
  - *Gas pipelines*

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Cracks

- Failure from blunt corrosion defects is generally in plastic collapse mode
- Failure for planar and crack-like defects can fail by sudden fracture - in a toughness dependent mode
- Appropriate assessment methods include:
  - BS 7910
  - API 579

BS 7910+A1:2015. Guide to methods for assessing the acceptability of flaws in metallic structures
API 579-1/ASME FFS-1, Fitness-For-Service, Second Edition 2007

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Laminations and other manufacturing defects

Limited Guidance is available in published 'integrity' codes

- Their criticality depends upon geometry, location and operating environment
- Size and characterise the defect on the basis of the findings of an ultrasonic inspection (and magnetic particle inspection if surface-breaking)
- Assess significance using accepted manufacturing codes and standards
- Planar flaws – not parallel with the surface – assess as cracks
- API 579 – gives methods for laminations. Categorise
  - *Parallel to pipe surface*
  - *Non parallel*
  - *Bulging*

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Lamination and planar flaw classification

Category A	
laminations parallel to pipe surface	Normally insignificant. Possibly significant if used in pipeline with H_2S in product
Category B	
non parallel planar defects ▪ **Evident on surface** ▪ **Bulging** ▪ **In proximity to other defects**	Significant defects. Further investigation required.
Category C	
sloping planar defects ▪ **interacting with other defects** ▪ **surface breaking adjoining welds** ▪ **burst planar flaws or blisters**	Severe defects. They require investigation and possible repair.

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PDAM summary

PDAM recommended methods for assessing the burst strength of defects subject to internal pressure

Flaw type	Internal pressure (static) longitudinally	Internal pressure (static) circumferentially
Corrosion	DNV-RP-F101 modified B 31G RSTRENG	Kastner local collapse solution
Gouges	NG-18 equations PAFFC BS 7910 or API 579	Kastner local collapse solution BS 7910 or API 579
Plain dents	Empirical limits	
Kinked dents	No method	
Smooth dents on welds	No method	
Manufacturing dents in the pipe body	NG-18 equations BS 7910 or API 579	Kastner local collapse solution BS 7910 or API 579
Girth weld defects	Workmanship standards BS 7910 or API 579	No assessment carried out
Seam weld defects	BS 7910 or API 579 PAFFC	
Environmental cracking	BS 7910 or API 579 PAFFC	
Leak and rupture	NG-18 equations PAFFC	Schulze global collapse solution

Acknowledgments

- This presentation has used, with permission material from Wood Group Integrity Management.
- I also acknowledge the use of material presented in papers by Andrew Cosham and Phil Hopkins of Penspen Integrity.

The end