

# **Integrity Assessment of Construction Dents Subject to Fatigue Loading**

**Report Prepared for UKOPA**

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# Integrity Assessment of Dents in Fatigue

## Proposed Scope of Work Phase 1: Feasibility Study

- Develop an understanding of the scale of the problem
  - Review pipeline dent failures
  - Review research being conducted by operators and regulators, particularly in the USA
- Critically review current published research findings and the feasibility of these approaches to enable operators to develop dent management strategies
- Advise UKOPA of the benefits of conducting specific additional work.
- If appropriate, develop a workscope for Phase 2.

# Presentation Structure

- Introduction
- Scope of Project
- Review of Pipeline Dent Failures
- Static Dent Research
- Dent Fatigue Research
- Dent Acceptance Standards
- Dent Measurement and Detection
- Dent Management Strategies
- Current Dent Research & Recommendations for Future Work
- Recommendations to UKOPA



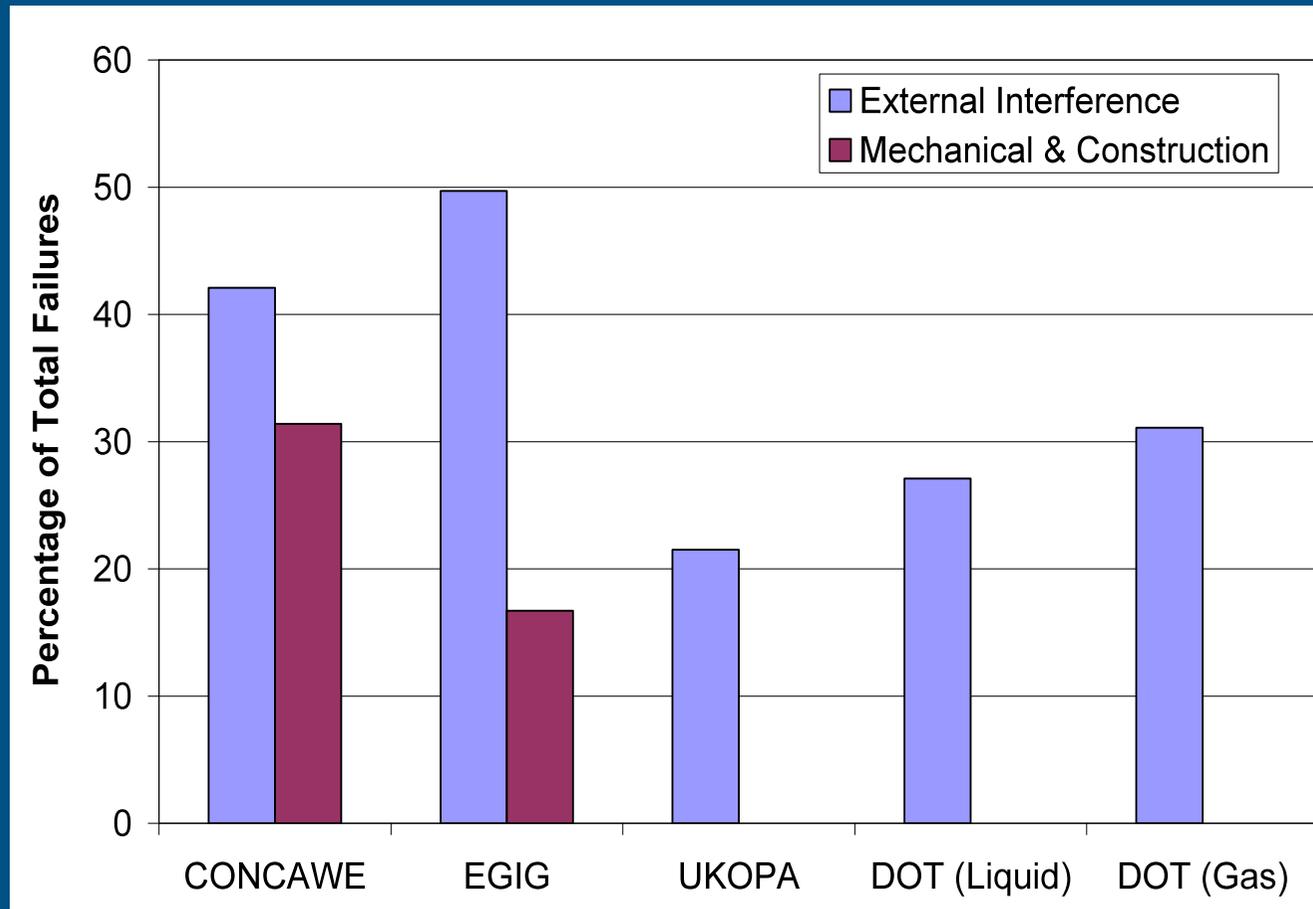
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# Review of Pipeline Dent Failures

- Analysis of data from US, UK and Europe



# Review of Pipeline Dent Failures

- In the US, **<0.2%** incidents on liquid pipelines and **<<0.1%** of incidents on gas pipelines are related to plain dents (DOT data)
- **83%** of failures in liquid pipelines and **90%** of failures in gas pipelines due to mechanical damage occur immediately (DOT data)
- No evidence that number of age related failures (CONCAWE data) is increasing *i.e.* due to fatigue
- One reported incident due to dent fatigue (CONCAWE)

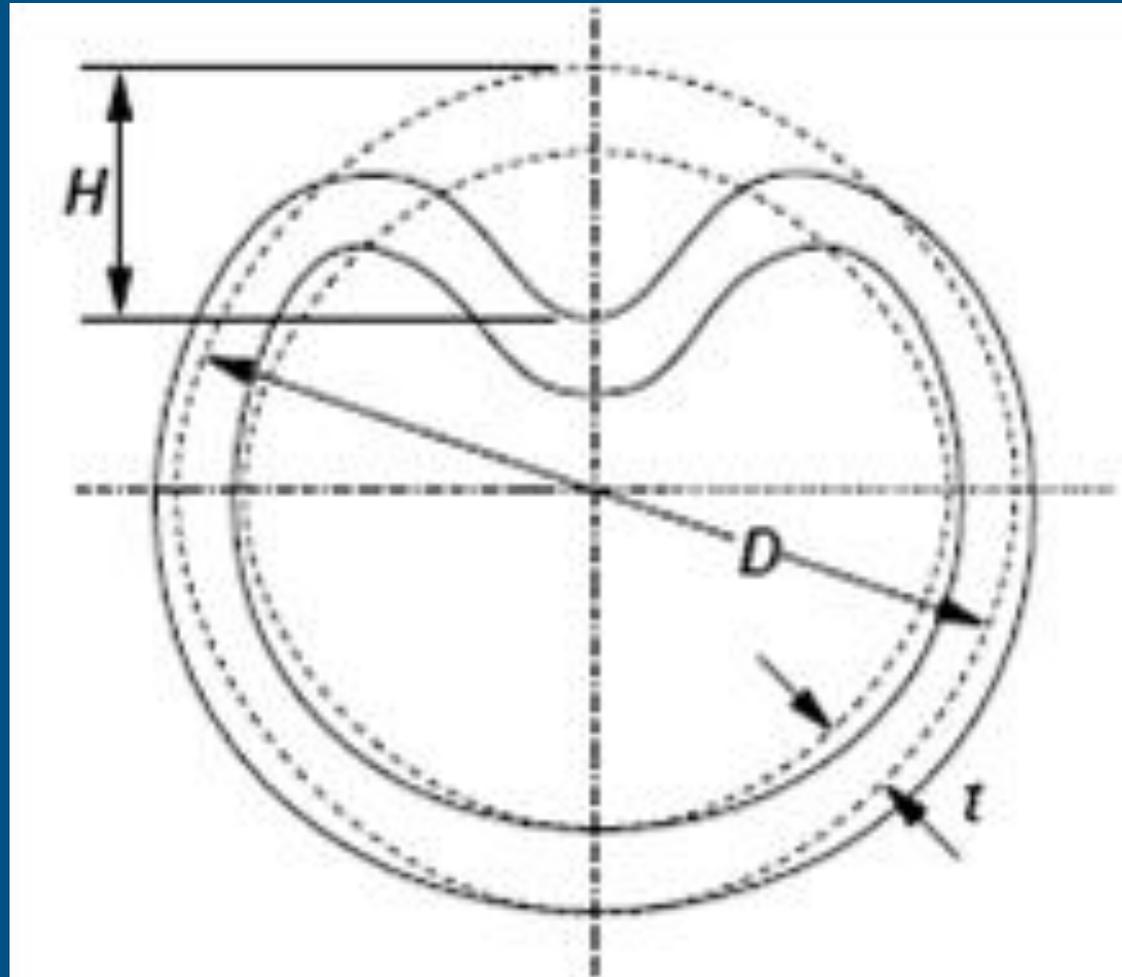


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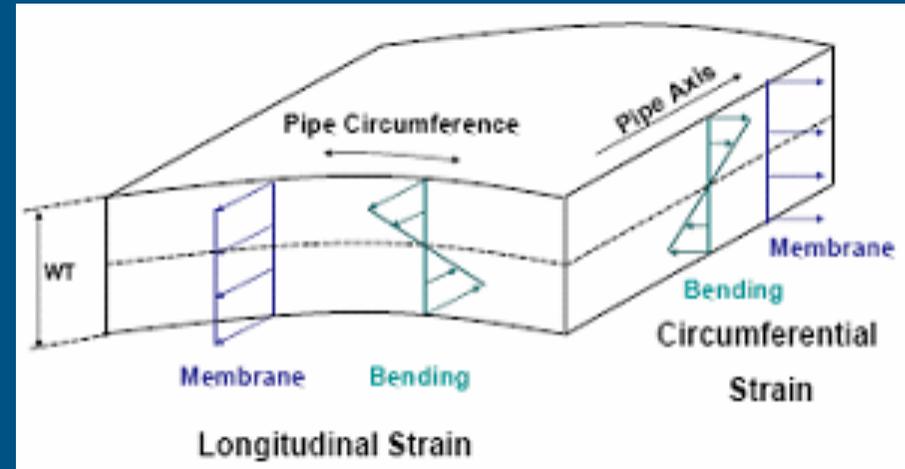


# Depth Based Assessments



# Strain Based Assessments

- Methodology detailed in ASME B31.8 (2003)
- Have to consider:
  - Longitudinal bending strain
  - Circumferential bending strain
  - Longitudinal membrane strain
  - Circumferential membrane strain
- Calculate strain in each direction (based on radius of curvature)
  - Literature divided on best method for calculation
- Compare against code limit of 6% strain
- Requires measurement of dent profile



# Static Assessment Methods

## Depth Based

	Plain Dents	
	Constrained	Unconstrained
ASME B31.8	Upto 6%OD	
ASME B31.4	Upto 6% OD in pipe diameters > NPS 4 Upto 6mm in pipe diameters < NPS 4	
API 1156	Upto 6%OD >2% OD requires a fatigue assessment	
EPRG	$\leq 7\%$ OD at a hoop stress of 72%SMYS	
PDAM	Upto 10%OD	Up to 7%OD
Z662	Upto 6mm for $\leq 101.6$ mm OD or <6%OD for >101.6mm	

# Static Assessment Methods

## Depth Based

	<b>Dents at welds</b>	<b>Dents with cracks or gouges</b>	<b>Dents with corrosion</b>
ASME B31.8	Not allowed	Not allowed	Not allowed
ASME B31.4	Not allowed	Not allowed	Not allowed
API 1156	Upto 2% OD	Not allowed	Not considered
EPRG	Not allowed	Not allowed	Not allowed
Z662	Not allowed	Not allowed	Not allowed

# Static Assessment Methods - Depth Based

## In gas pipelines:

- Due to re-rounding effects dents  $>2\%OD$  are likely to be constrained
- Dents on the bottom of the pipe (particularly deep dents) assumed to be plain rock dents

## In liquid pipelines:

- Unconstrained dents  $>5\%OD$  extremely unlikely
- Acceptability of unconstrained dents  $>2\%$  should be based on a dynamic assessment

# Response Times - 49CFR195 & 49CFR192

Anomaly	49 CFR 192	49 CFR 195
A dent that has any indication of metal loss, cracking or a stress raiser	Immediate	Upper $\frac{2}{3}$ of the pipe – immediate Lower $\frac{1}{3}$ of the pipe – 60 day
A dent with depth greater than 6%OD	Upper $\frac{2}{3}$ of the pipe – one year* Lower $\frac{1}{3}$ of the pipe – monitored	Upper $\frac{2}{3}$ of the pipe – immediate Lower $\frac{1}{3}$ of the pipe – 180 day
A dent with depth greater than 3%OD on the upper $\frac{2}{3}$ of the pipe	Not defined	60 day
A dent with depth greater than 2%OD on the upper $\frac{2}{3}$ of the pipe	Not defined	180 day
A dent with depth greater than 2%OD that affects pipe curvature at a weld	One year*	180 day

\* can be downgraded to a monitored condition providing critical strain levels are not exceeded. In the case of a dent affecting a weld, the weld properties must also be considered

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# Dent Measurement & Detection

Dent Attribute	Geometry Tool	High Resolution Geometry Tool	Metal Loss Tool	Crack Detection Tool
Location along pipeline	✓	✓	✓	✓
Orientation	✓	✓	✓	✓
Size (%OD)	✓	✓		
Size and shape of dent		✓		
Detects dents on welds	✓	✓	✓	✓
Detects metal loss in dent			✓	
Detects cracks in dents				✓
Detects rock dents				

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# Requirements of Dent Management Strategy

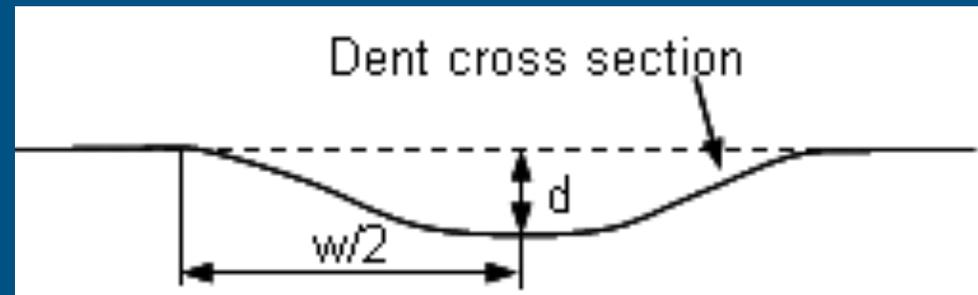
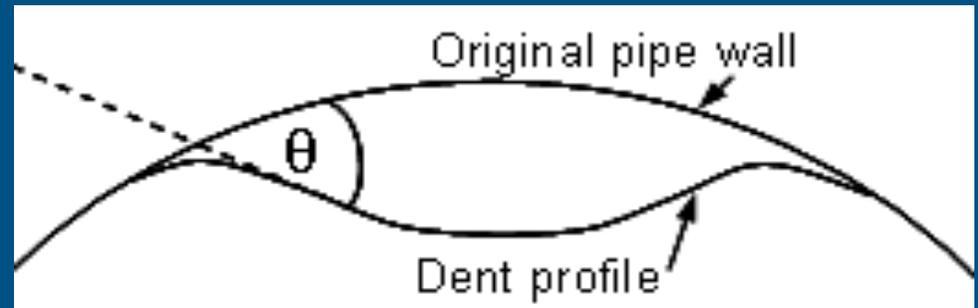
- Be easy to use with field measurements that can readily be taken in field
- Not require extensive or expensive FEA to be conducted on every dent
- Recognise key parameters for stress and strain concentration
- Relate to the pipeline pressure cycling regime



# Fleet Technology (BMT) Dent Assessment Model

## Initial Model

- **Pipe characteristics:** diameter, wall thickness and material
- **Dent geometry:** shape, curvature, depth, shoulder radius, acuity
- **Operational characteristics:** line pressure history, indenter contact
- **Interacting localised effects:** metal loss and welds



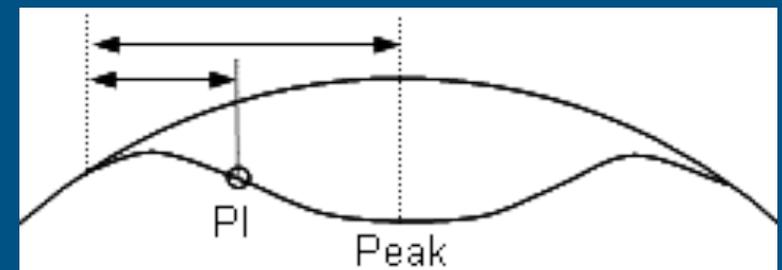
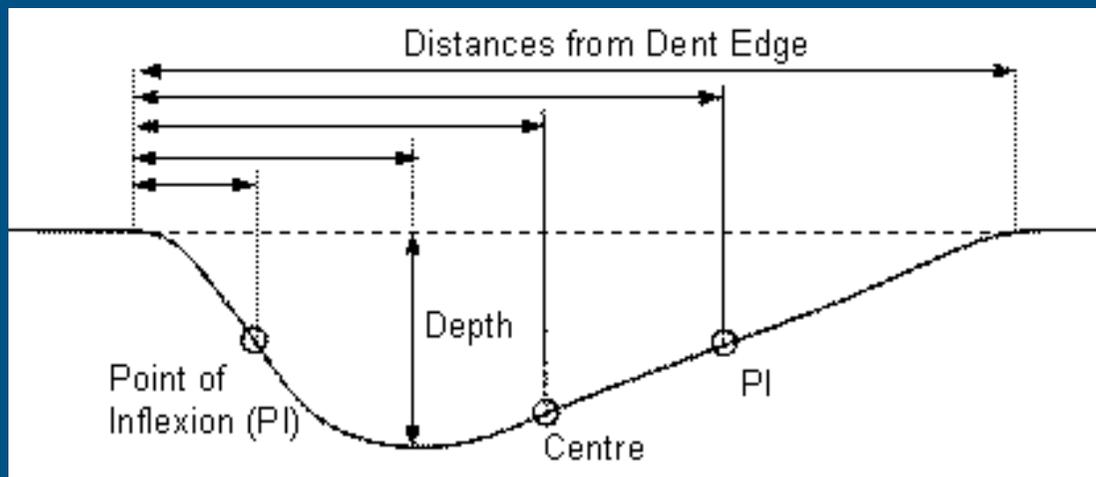
$$\text{Dent relative risk} = P \times \sum A_i$$

# Fleet Technology (BMT) Dent Assessment Model

## Updated Model

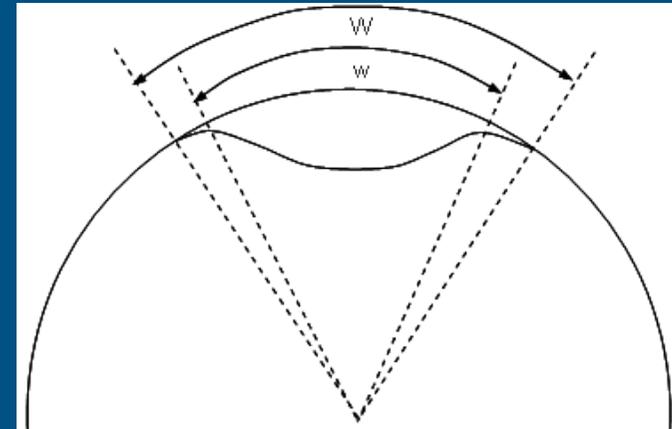
- Dent relative risk factor calculated from pressure factor and geometry factor:

$$\text{Dent Factor} = \frac{\sum \text{Geometric Parameter Contributions}}{\text{Equivalent Annual Number of Cycles}}$$



# Enbridge Pipelines Rapid Characterisation Model

- Used early results of Fleet Technology work
- Used three shape factors to produce a 'relative severity factor'



d/D (%)	Factor A	Theta (degrees)	Factor B	w/W	Factor C
≥ 4	4	90-100	5	0 - 0.25	4
3.5 - 4	3	100-110	4	0.25 - 0.5	3
2.5 - 3.5	2	110-130	3	0.5 - 0.75	2
≤2.5	1	130-150	2	>0.75	1
		>150	1		

# API Field Guide for Dent Assessment

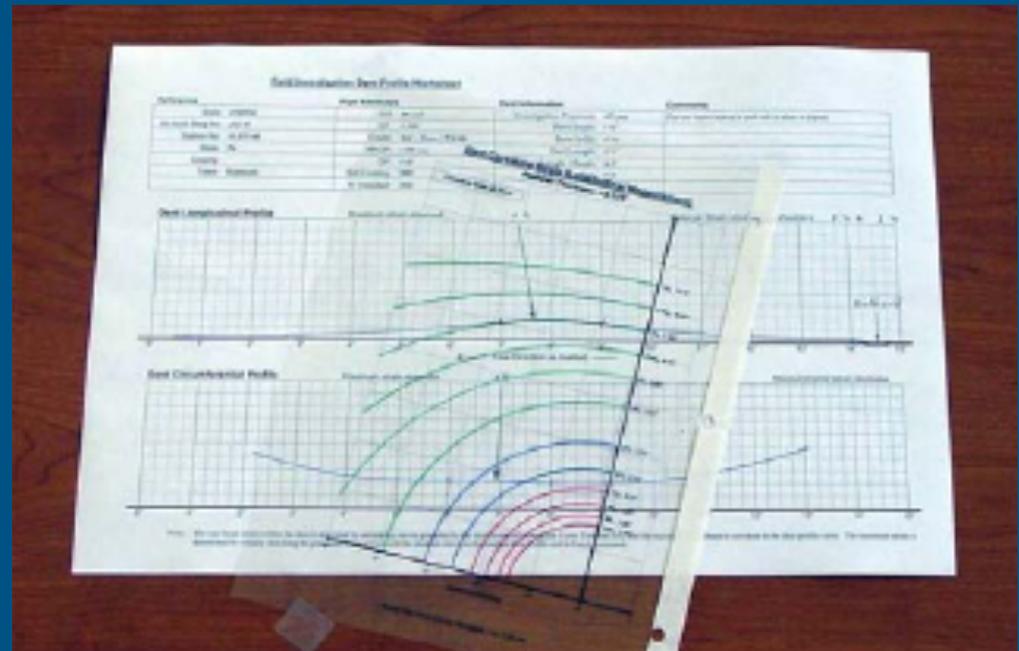
- Gives a risk-ranking methodology for dent severity

$$P = (P_m + P_i) \frac{d}{D} = (A + B + C + W + M + R) \frac{d}{D}$$

- $P_m$  represents the pipe properties and operational characteristics which depend on:
  - $A$  = geometry ( $D/t$ ) ratio
  - $B$  = relative risk of brittle fracture
  - $C$  = relative operational risk – pressure cycling factor
- $P_i$  represents ILI data
  - $W$  = presence of welds & severity of welds
  - $M$  = corrosion caused metal loss
  - $R$  = dent location

# Duke Energy (DEGT) Dent Strategy

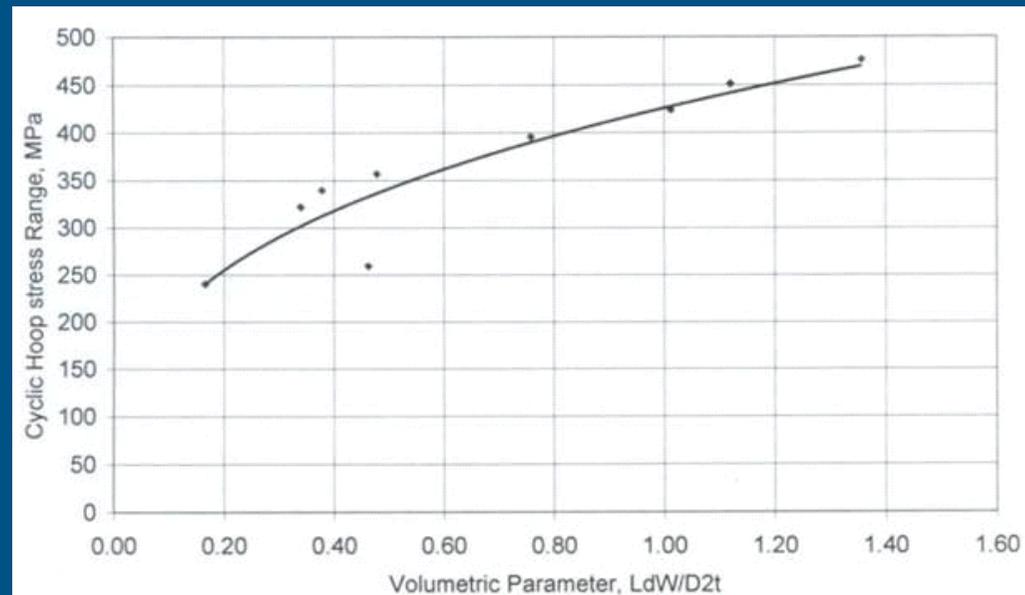
- Uses dent strain and dent depth as governing criteria
- Dents are initially characterised based on HR-MFL data
- HR caliper inspection run if there are a number of high risk dents
- Strain measured using radius of curvature templates
- Compared to 6% strain criterion but could be unconservative
- Only conducted on dents that fail depth criterion



# GE Energy Dent Strategy

- Applies longitudinal dent strain criterion to rank dents in lines not heavily pressurised
- Applies fatigue risk assessment to pressure cycled pipelines

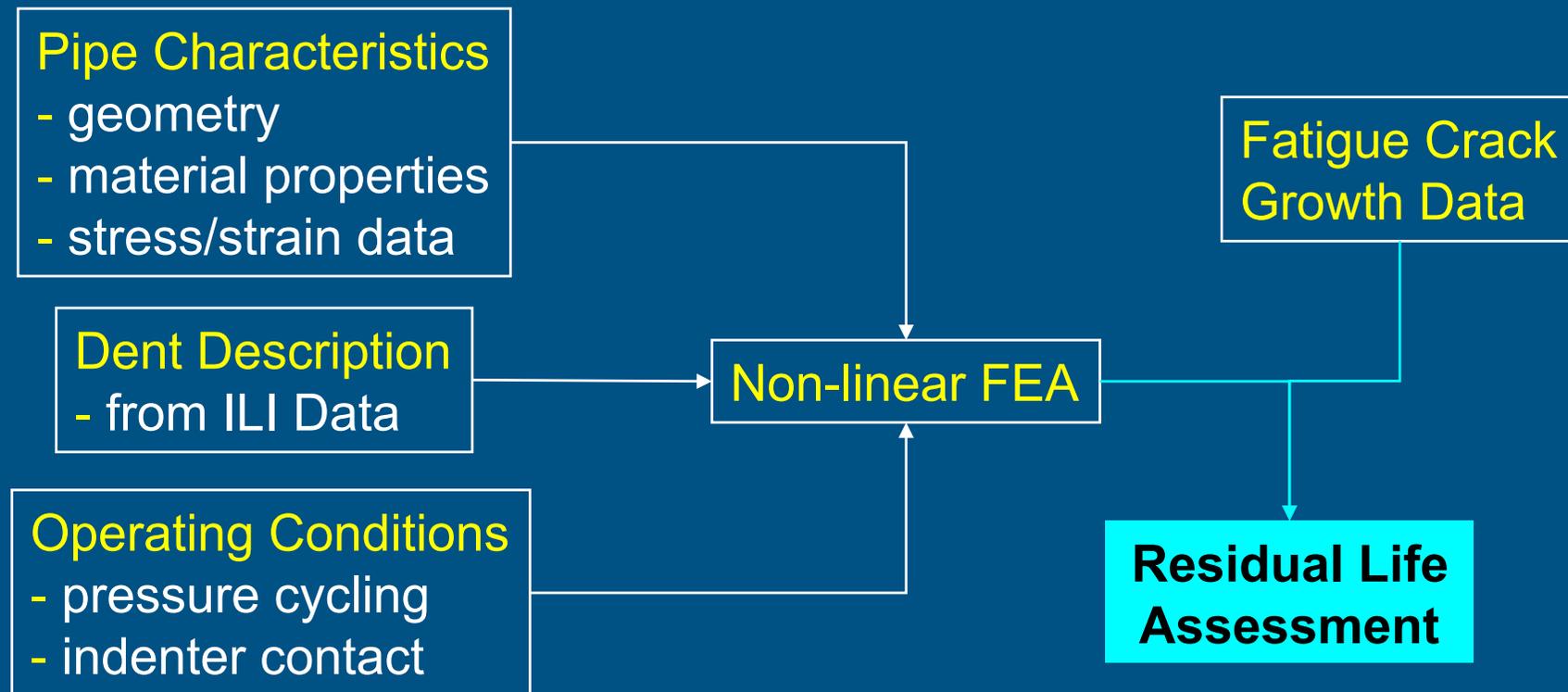
$$\text{Fatigue Life} \propto \frac{1}{\frac{LdW}{D^2t}}$$



- Correlation between dent volume parameter and cyclic hoop stress range and therefore fatigue life

# Trans Alaska Pipeline System

- Developed for the assessment of 35 dents on the TAP
- Fracture mechanics approach based on crack data from previous excavations



# Conclusions

- Failure from plain dents (*i.e.* those not associated with mechanical damage) does not form a significant proportion of the total number of pipeline failures in the US and Europe
- Evidence that dents that are acceptable to the current codes and guidance are failing
- Historically, plain dent acceptance criteria under static loading were based on the depth of the dent, however, recent research has suggested that the strain in the dent may be a better indicator of dent severity for repair



# Conclusions

- No standard method exists for calculating strain and neither is there an industry best practice for interpreting high resolution caliper data for strain assessment
- Fatigue life of a dent is dependent on the dent constraint, the dent geometry (e.g. dent length, depth, width, shoulder angle), the pipe geometry (e.g. pipe diameter and wall thickness), pipe material and the pressure cycling range experienced by the pipeline.
- All of these factors should be taken into account in a fatigue life assessment.



# Conclusions

- No codified methodology for calculating the fatigue life of a dent
- Six dent management strategies employed by pipeline operators and consultants have been reviewed. These strategies are either based on geometry factors, strain calculations or fatigue life calculations to determine dent severity.
- The approaches adopted by DEGT and GE Energy appear to warrant further research and investigation





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