THE QUEEN'S AWARDS FOR ENTERPRISE 2010 THE PENSPEN GROUP LIMITED

Penspen Group

PENSPEN

Managing Fatigue in an Onshore Pipeline System

Andre Goncalves, Malcolm Toft, Roland Palmer-Jones: Penspen
Wilson Santamaria: ExxonMobil

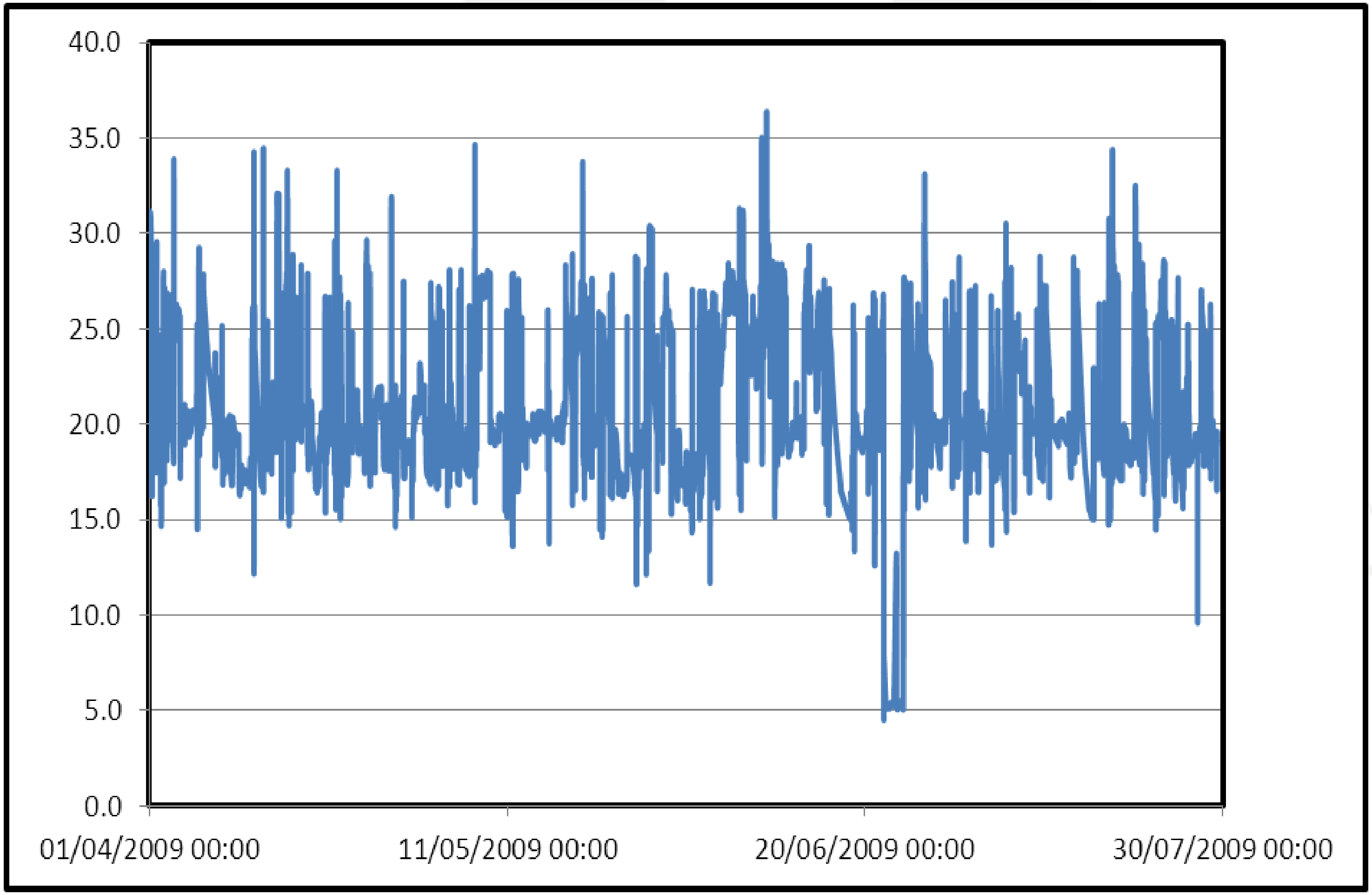
Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

- 3 Casualties
- Mechanical damage plus cyclic pressure load

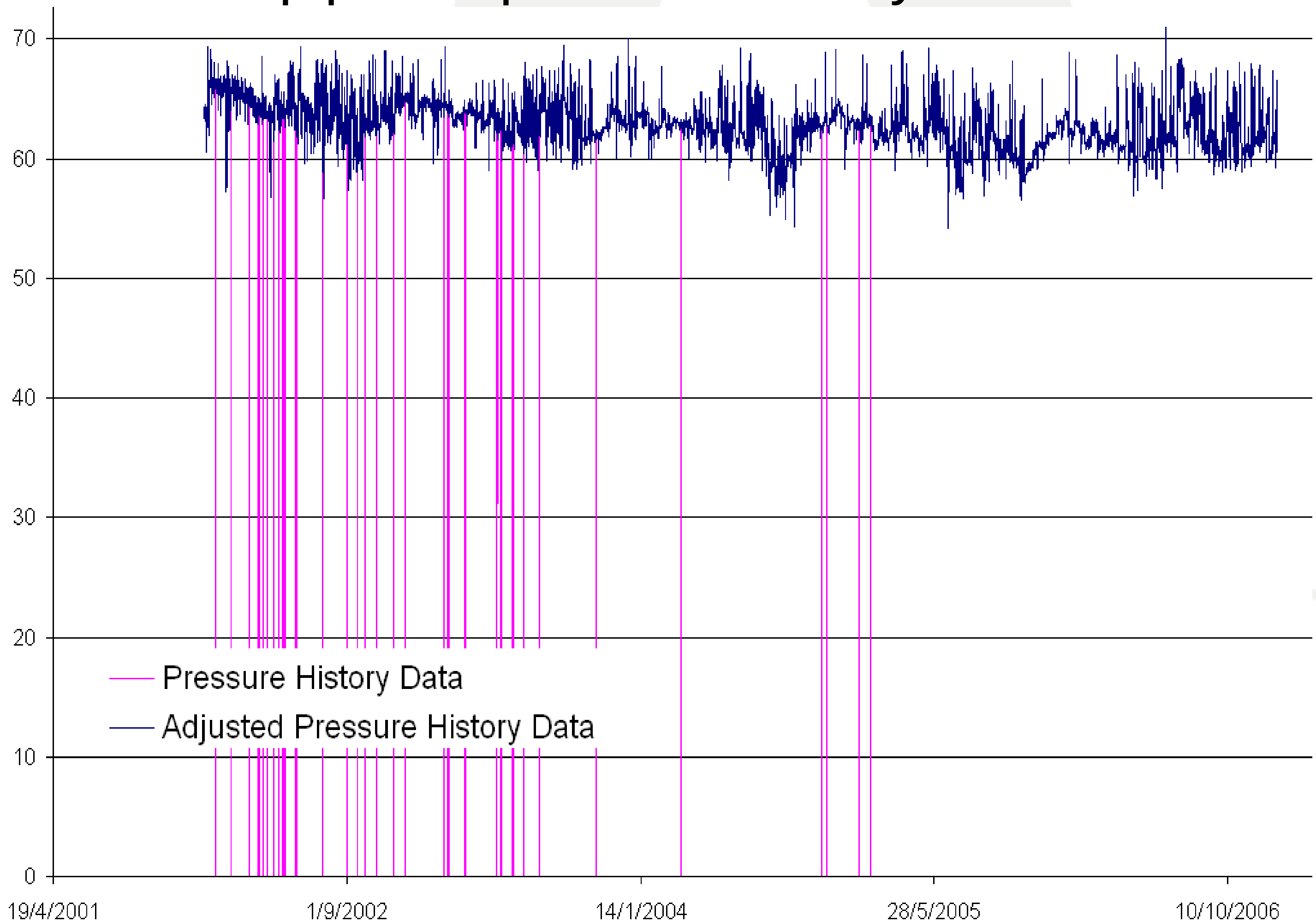
- 7 hectares contaminated
- Seam weld anomaly plus cyclic pressure load

- Fatigue loading is mainly a problem for pipelines transporting liquids.

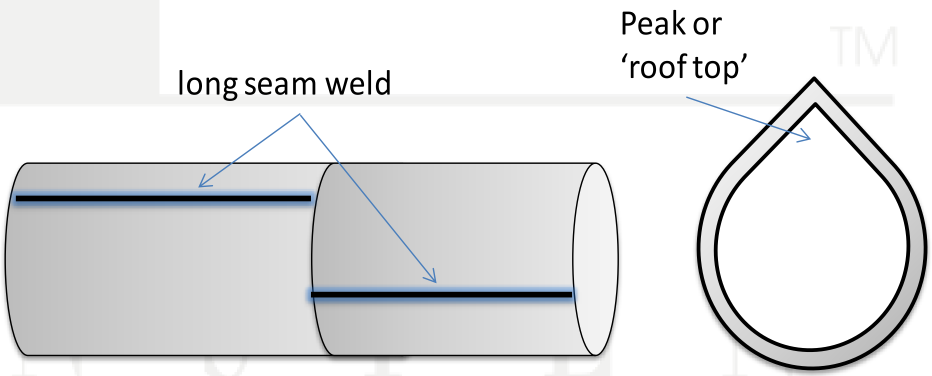
- Crude oil pipeline pressure history



- Gas pipeline pressure history



- When is fatigue a concern?
  - Significant pressure cycles
  - Stress concentrating features
    - Weld anomaly
    - Hook crack
    - Dent
    - Roof topping

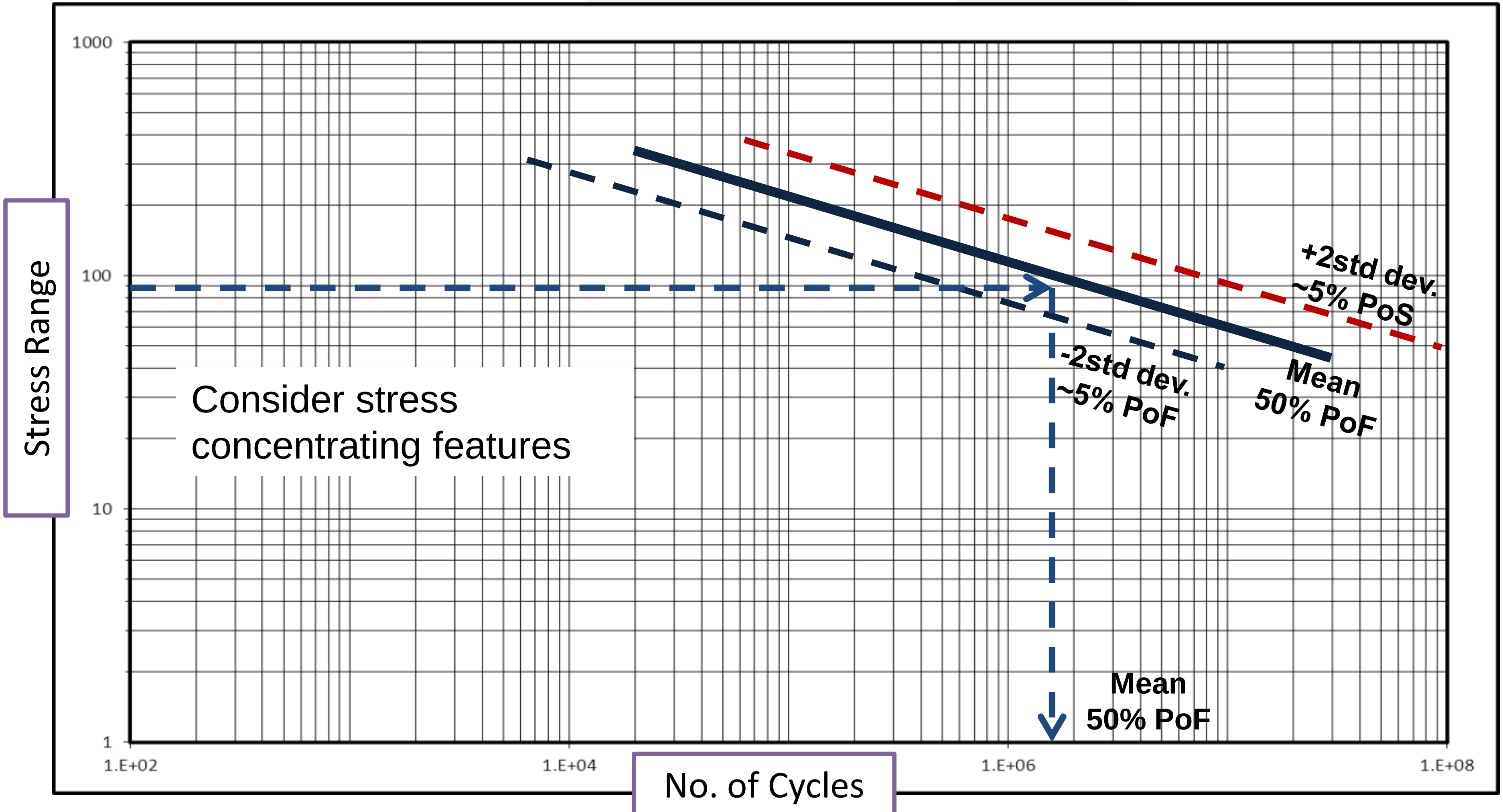


Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

- Requirements for Managing Fatigue
  - Awareness
  - Information on stress concentrating features (weld defects etc.)
  - Pressure data
  - Reliable analytical models for:
    - Critical defect sizes
    - Crack growth

- Awareness - Failures
  - Enbridge 2011
  - SPSE 2011
  - Others...

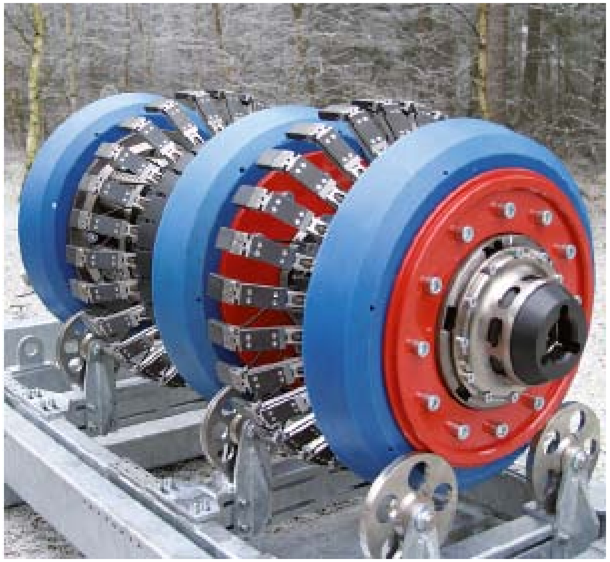
- Awareness – Design checks
  - Evaluation of expected fatigue performance can be completed using SN.



Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

- Hydrotesting
  - Will find (fail) critical defects

- Inspection
  - Ultrasonic Crack Detection and EMAT tools
  - Sizing remains difficult
  - Unusual seam welds can mask defects



- Inspection
  - High resolution geometry tools
    - Dent strain
    - Dent shape

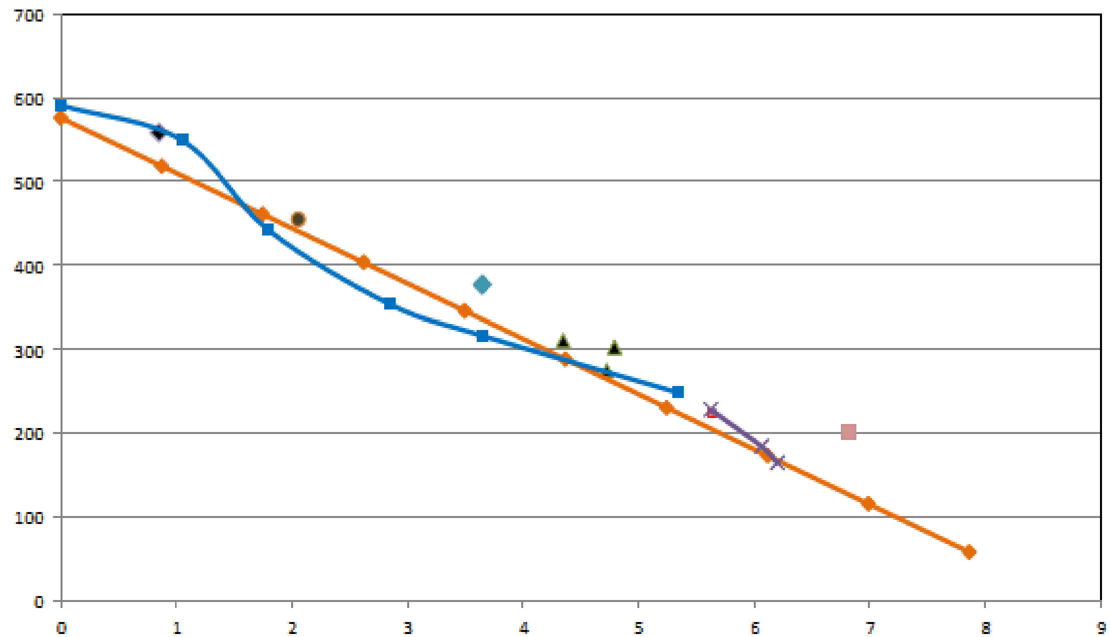
Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

- Pressure Data
  - High frequency
  - Time stamped
  - Upstream
  - Downstream
  - Understanding of hydraulic profile
  - Interpolation to estimate pressure at defect location

Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

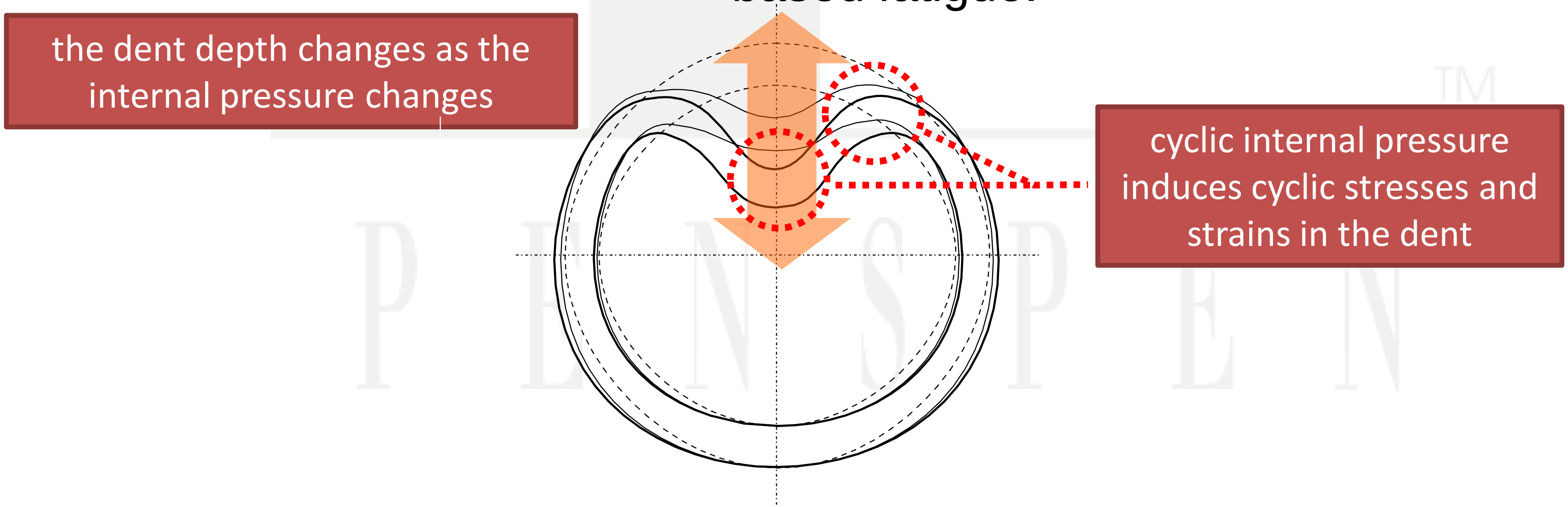
- Analysis of Weld Defects
  - Critical defect size
    - Toughness?
    - Strength?
    - Crack?
    - Brittle or ductile failure behaviour?
  - Crack growth rates
  - Stress concentrating features
    - Roof topping
    - Misalignment

- Testing of cracks in SAW welded pipe indicates that failure is ductile and predicted by standard equations



- Recommended approach for weld defects
  - Pipelines a relatively thin, ductile material (weld zones are also generally ductile), operating at normal temperatures.
  - Critical defect sizes should be calculated using standard pipeline methods (NG-18). Testing can be used to confirm this.
  - Fatigue crack growth rates should be calculated using standard fracture mechanics methods (BS 7910). Careful consideration should be given to stress concentrating features.

- Recommended approach for dents
  - Check dent strain (ASME B31.8)
  - Depth based fatigue assessment
    - Consider constraint conditions
  - FEA to estimate stress concentrations followed by SN based fatigue.



Agenda
Background
Managing Fatigue
Testing and Inspection
Data
Analysis
Case Study
Conclusions

- Case Study

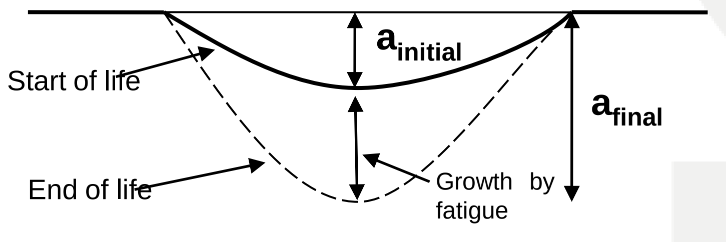
Pipeline System

Pipeline	Nominal outside diameter Inches	Type of Pipe	Material API Grade	Thk. mm	MAOP Bar	Comm. Date
ERW#1	10	ERW	X 52	4.8	79	1981
ERW#2	14	ERW	X 60	5.6	88.5	1985
ERW#3	12	ERW	X 60	5.4	88.5	1992
Seamless#1	6	Seamless	Grade B	5.6	99.3	1962
Seamless #2	12	Seamless	X42	6.35	71.5	1962
Seamless#3	10	Seamless	X 52	6.35	82.7	1969

- Awareness – 20 years ago
  - MFL inspections
  - Dents not reported
  - Gouges difficult to detect
  - Seam weld defects not detectable

  - Pressure records available
  - Evidence of failures around the world.

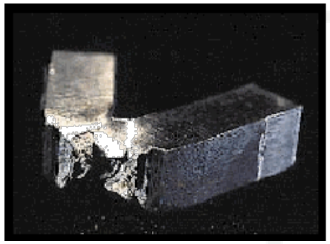
- 1994 first fatigue study on the Esso System.
- No data was available on seam weld anomalies.
- Remaining fatigue life calculated by:
  - Calculating the largest crack type defect that would have survived the pipeline's pre-commissioning hydrotest ;
  - Determining the smallest defect which would fail at the pipeline's MAOP; and,
  - Calculating the time for the defect to grow from its hydrotest survival size to the its MAOP failure size.



$a_{initial}$ = initial defect size
a_{final} = final defect size
a_{final} = final defect size

- Results
  - 3 pipelines predicted to have exceeded their design fatigue life
  - Hydrotest recommended
- Review
  - Assumption on initial defect conservative and did not include consideration of credible defects.
  - Limited pressure data (1 week).
  - Dents not considered.

- 1995 further study
  - Defect credibility
  - Measured material properties
- Results
  - 2 pipelines still exceeding 'design' fatigue life
- Review
  - Dents not considered



- 1999 Transverse Field Inspection for seam weld anomalies
  - No crack like anomalies reported
  - Detection threshold is high – significant defects could be missed.

- 1999 further studies
  - Fatigue study on inspected line assuming defect at limit of detection.
  - Probabilistic study of other lines
- Results
  - Fatigue life of inspected pipeline extended to 2008
  - 20% probability of failure due to fatigue estimated for other line.
- Review
  - Dents not considered

- 1994, 1995, and 1999 studies were generic, and relied on assumptions due to lack of data.
- Internal inspection specifically looking for seam weld anomalies in 1999. Since then all the pipelines in the Esso system have been inspected for fatigue-sensitive defects
- All inspections were followed by engineering assessments

Penspen Group

THE QUEEN'S AWARDS FOR ENTERPRISE 2010 THE PENSPEN GROUP LIMITED

PENSPEN

1994 - 1995
- Two generic fatigue assessments of the Esso pipeline system.

1999
- TFI inspection of ERW#3 pipeline
- Probabilistic assessment of Esso Lines

2003 - 2004
- TFI and calliper inspection of ERW#1 pipeline
- TFI and calliper inspection of Seamless#2 pipeline

2005
- Calliper inspection of the Seamless#1 pipeline

2006
- Ultrasonic Crack Detection inspection of ERW#1 Pipeline
- Ultrasonic Crack Detection and calliper inspection of ERW#2 Pipeline

2007
- Ultrasonic Crack Detection inspection of ERW#3 Pipeline

2010
- Ultrasonic Crack Detection inspection of ERW# 1Pipeline
- Calliper inspection of the White Oil pipeline

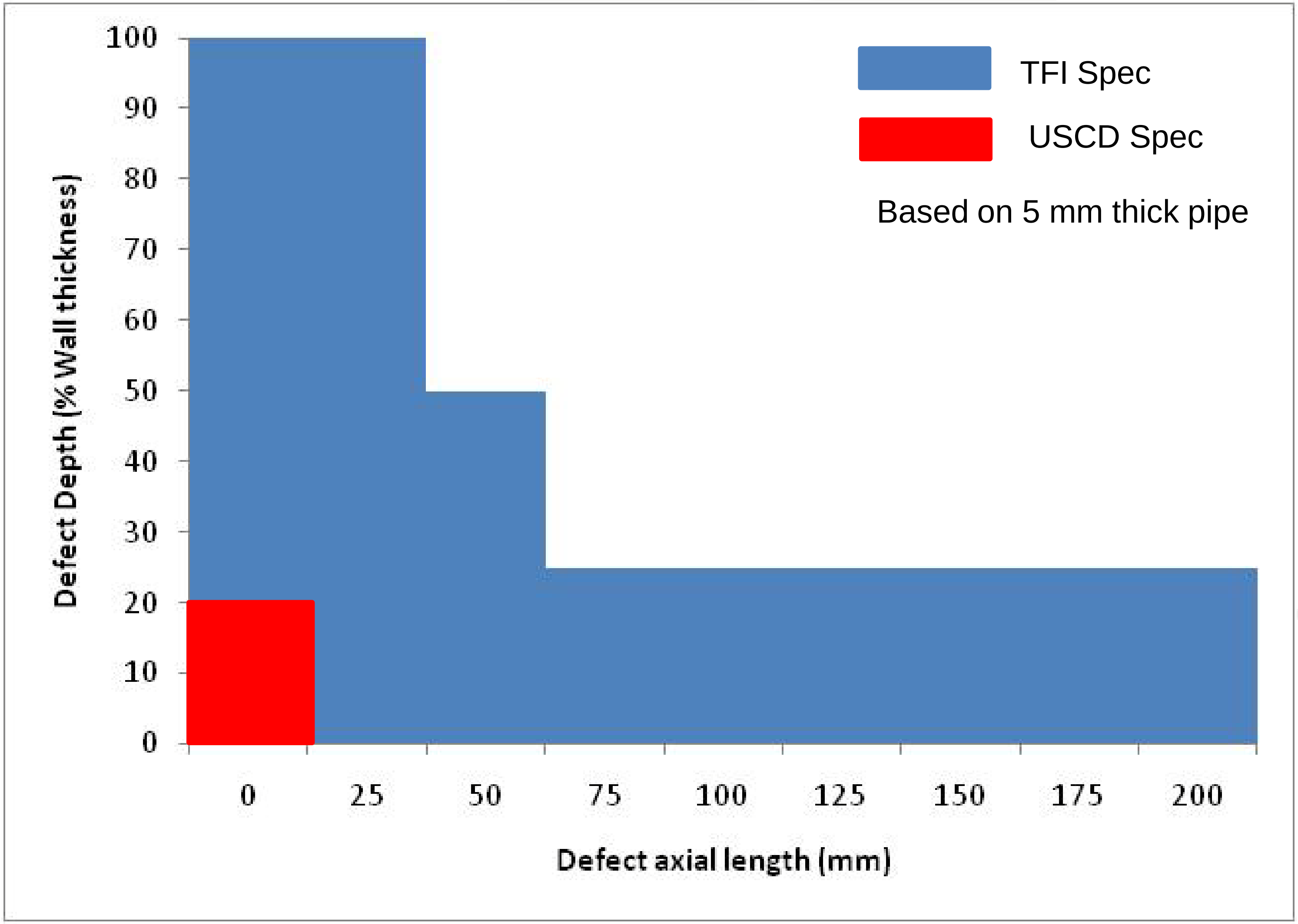
Pre-inspection assessments (1994 - 1995 to 1999)

TFI & Calliper Inspections (1999 to 2005)

USCD & Calliper Inspections (2006 to 2007)

USCD re-Inspections (2010)

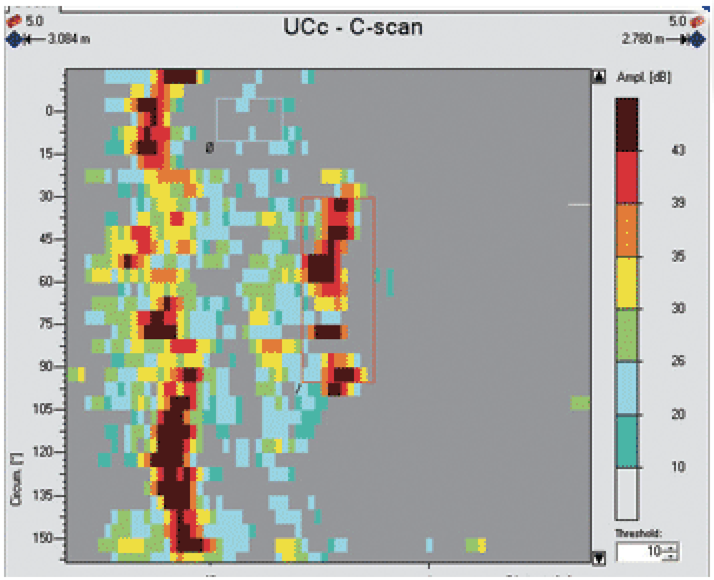
- Initial inspections for seam weld anomalies were carried out using TFI
- TFI
  - Detection threshold ~20% wt and ‘open’
- USCD
  - Detection threshold 1 mm depth for defects longer than 25 mm
- Since 2006 all inspections looking for seam weld cracks have been USCD


TFI Spec
USCD Spec
Based on 5 mm thick pipe
Defect Depth (% Wall thickness)
100
90
80
70
60
50
40
30
20
10
0
0
25
50
75
100
125
150
175
200
Defect axial length (mm)

- Comparison of results of TFI and USCD inspections

Inspection Technology	TFI	USCD
Inspection Year	1999	2007
Findings	No Crack-like anomalies	42 Crack-like 148 notches 252 Weld anomalies

- USCD tools are sensitive to a variety of anomalies. The following anomaly categories are often reported
  - Crack-like
  - Crack-fields
  - Weld Anomalies
  - Mill Anomalies
  - Notch-like

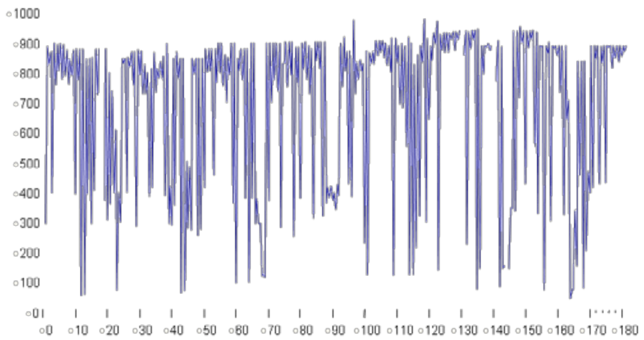


- Crack-like anomalies and weld anomalies are the most susceptible to fatigue.
- Notches and mill anomalies are less susceptible.
- Classification of anomalies is critical.
- The operator relies on competent ILI data-analysis.

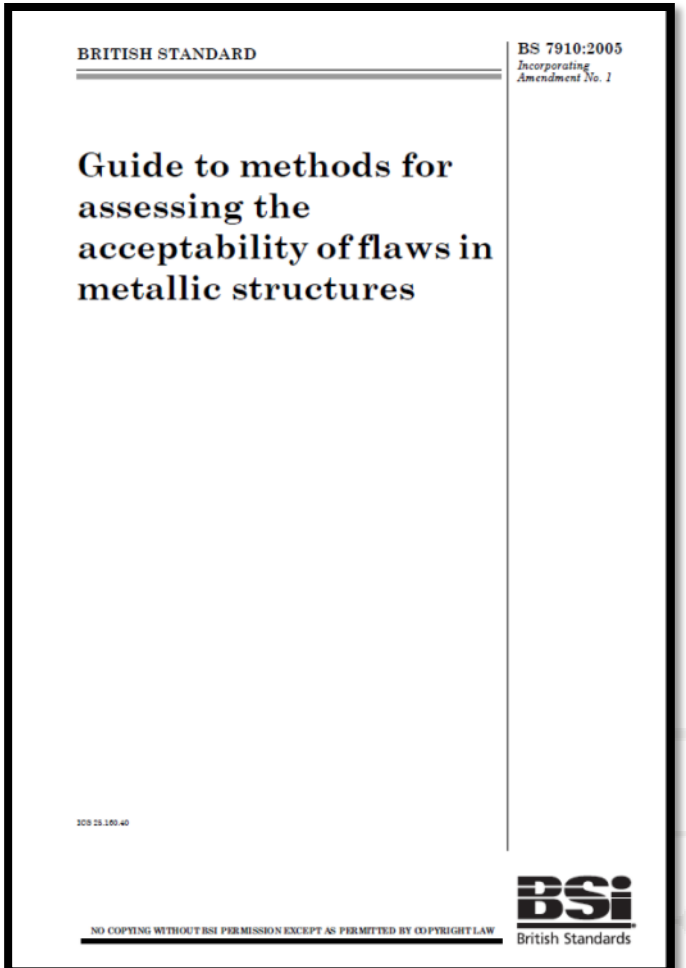
- 2006 data

	Crack Fields	Crack - Like	Notch Like	Not Decidable
Nº Reported	6	1,857	5,549	140

- 93 digs and associated repairs
- 11% of crack-type defects actually contained planar anomalies
- 2% of defects in which the USCD had not detected crack-like anomalies were found to actually contain planar defect types



- Pressure Data
  - 1994 study used one week of pressure data
  - 2003 to 2007 assessments used 1 year of pressure data
  - Recent assessments used 9 years of pressure data
  - Pressure now recorded every 2 minutes.


BRITISH STANDARD

BS 7910:2005
Incorporating Amendment No. 1

Guide to methods for assessing the acceptability of flaws in metallic structures

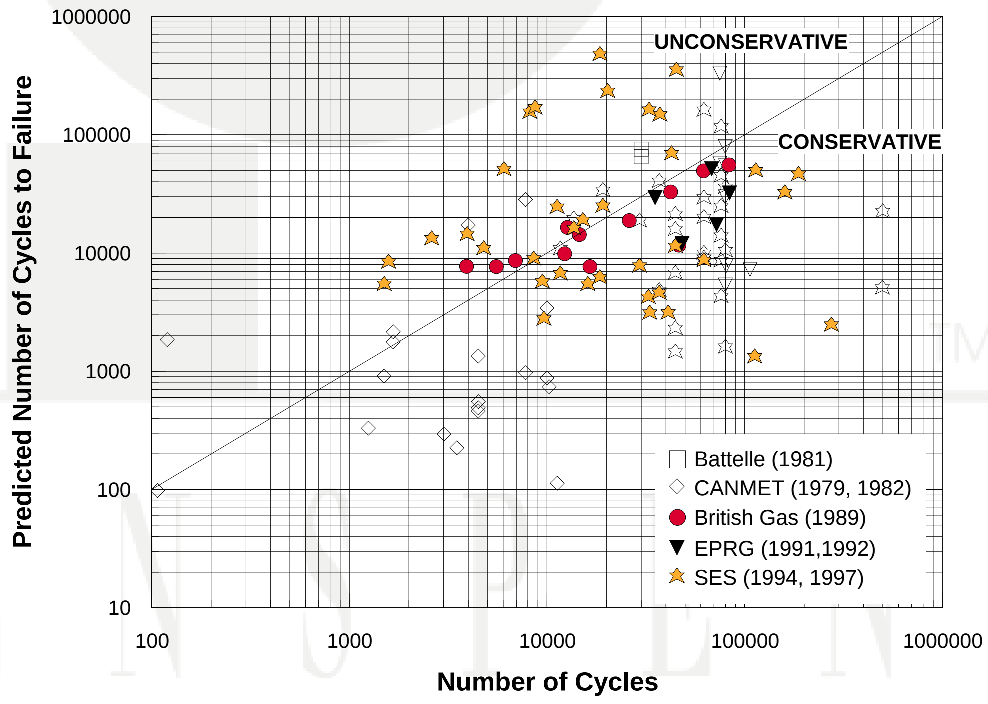
ICS 25.160.40

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSi British Standards

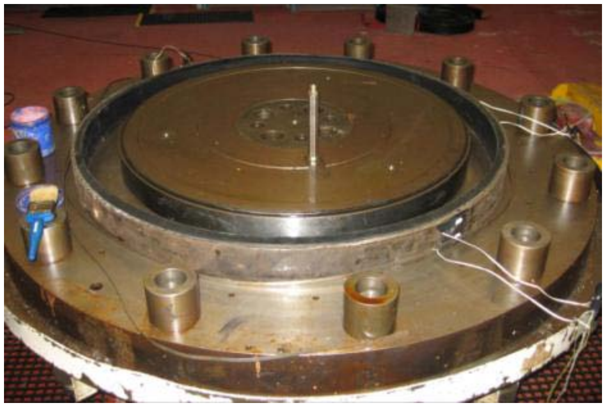
- Assessment - Cracks
  - BS 7910, recommended in PDAM
  - Conservative
    - Assessments generally predict numerous defects to have already failed
    - However no fatigue induced failures have occurred to date
  - Sources of conservatism
    - Correlation between Charpy impact strength and true material fracture toughness.
    - Fatigue crack growth rates, which are known to be a "upper-bound" estimate.

- Assessment – Dents
  - EPRG recommended in PDAM
  - Conservative due to genuine variance in the test data



- Future management - Inspection
  - Continue multiple technology inspection regime
  - Understanding & supporting latest technology for inspection
  - Cooperation with ILI companies to improve classification of defects – reduce bias

- Future Management – Operation
  - Better understanding of pipeline operation – reduce pump & valve transients, and unnecessary fatigue loading of pipeline.
  - Education of operating staff on fatigue (development of operating philosophy).
  - Pressure transient analysis of system to assess anomalies to local pressure rather than inlet or outlet pressure.
  - Communication/MoC ensure operational changes are communicated.



- Future Management – Assessment
  - Material (ring) testing to get better understanding of fatigue susceptibility and critical defect sizes
  - Correlation of successive inspections to infer dent dates and crack growth.
  - Promoting awareness of fatigue in the pipeline industry – pipelines are getting older

Thank you

Roland Palmer-Jones
Penspen Limited
Units 7&8 Terrace Level
St Peters Wharf
Newcastle upon Tyne
NE6 1TZ
www.penspenintegrity.com