BUCKLE UP!

IMPROVING INTEGRITY ANALYSES OF OFFSHORE PIPELINE DEFLECTIONS

Adrian Lim
Society of Underwater Technology ETM· Perth · 9th Aug 2017
Credits: Brian Purvis (Woodside), Soren Hauch (ROSEN Consultant), Lanre Odina (Peritus)
Klaas Kole (ROSEN)

empowered by technology

AGENDA

Background

Concept of Pipeline Bending Strain, IMU and qualification.

Case Stud(ies) and Primary Benefits

Secondary Benefits

Other Considerations

BACKGROUND

ROSEN
empowered by technology

Why do new offshore pipelines curve?

1. Route that changes directions (eg due to geohazards)
2. Undulating seabed topography
3. Engineered spans
4. Crossings of features on seabed
5. Tie-in design
6. Start up designed buckle

BACKGROUND

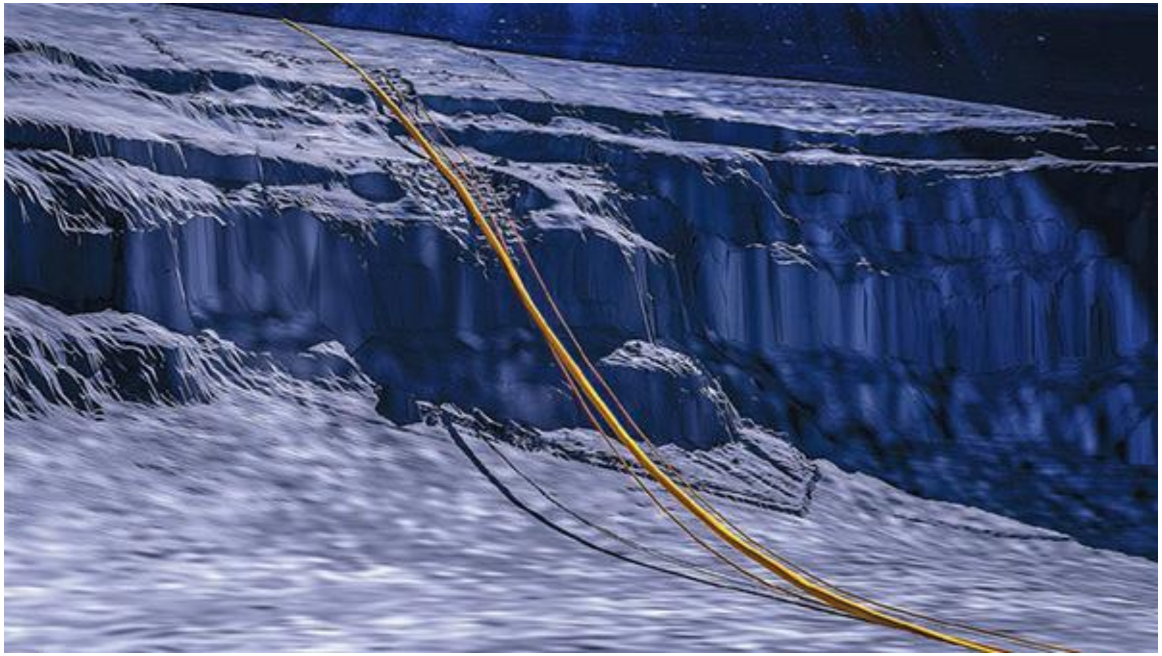
Why may pipeline curvatures change over time?

1. Buckling from thermal expansion and/or walking
2. Pipeline walking behavior ‘pulling/pushing’ curves
3. Third party
   a) Anchor drag
   b) Other construction work
4. Inclement Metocean conditions
5. Changes in seabed topography
   a) Scouring
   b) Sandwaves
   c) Geohazard events
      - Seismic
      - Subsea slips

BACKGROUND

Do we need to worry about pipeline curvature?

Not normally - if the pipeline is fit for purpose



‘Super Span’ Courtesy of Chevron (Public Domain)

BACKGROUND

Unplanned pipeline deviations have many potential causes including:

- Non conforming issues during pipelay(eg lay angle, lay weather/conditions etc)
- Pipeline movement due to more onerous metocean/environmental forces
- Poor understanding of on-bottom conditions/stability
- Geohazard events
- Excessive seabed mobility
  - As spans develop/scour
  - Calcareous

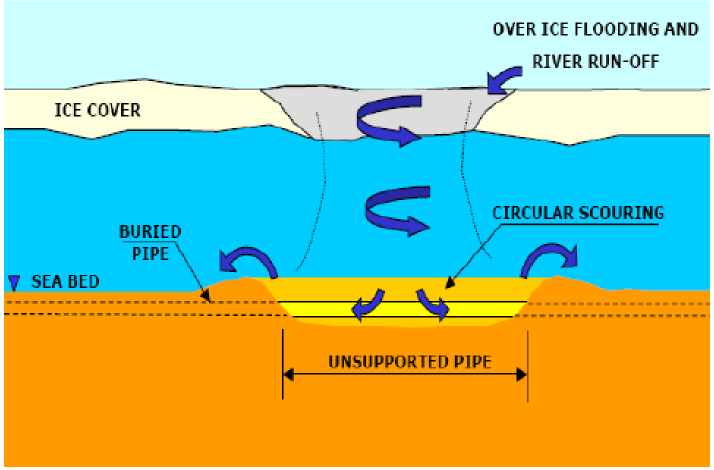
BACKGROUND

Unplanned pipeline deviations have many potential causes including:

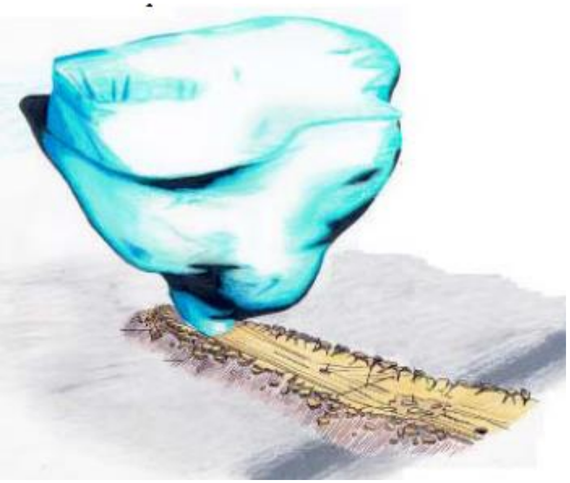
- Unforeseen operational upsets eg:
  - Design temperature/pressure
    - ➢ Unforeseen axial movement/walking/buckling
- Third party damage (eg anchor/trawl board damage)

EXAMPLES - POST INSTALLATION

Ship’s anchors



Ice gouging



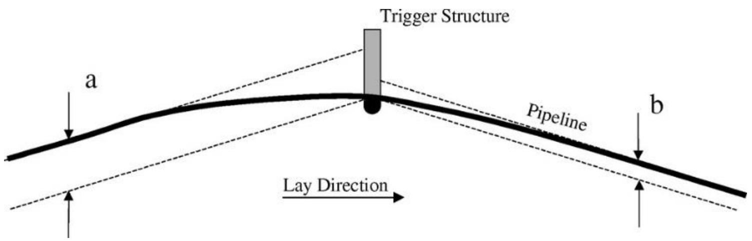
BACKGROUND – DRIVERS FOR MONITORING

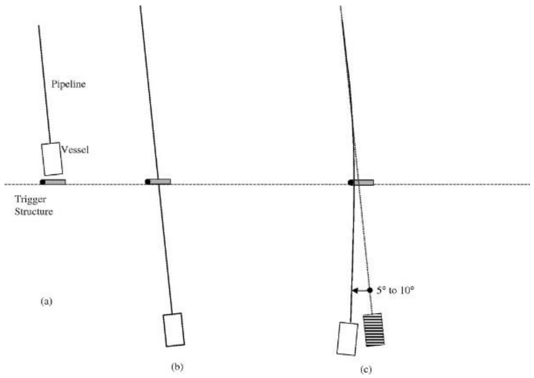
- Design calculations may indicate a pipeline is ‘borderline’ to experience ‘walking’ with potential buckling

  - Monitoring may be the mitigating factor to avoid considerable cost/effort required to design, procure and install hold back anchors, ZRB posts and the like.

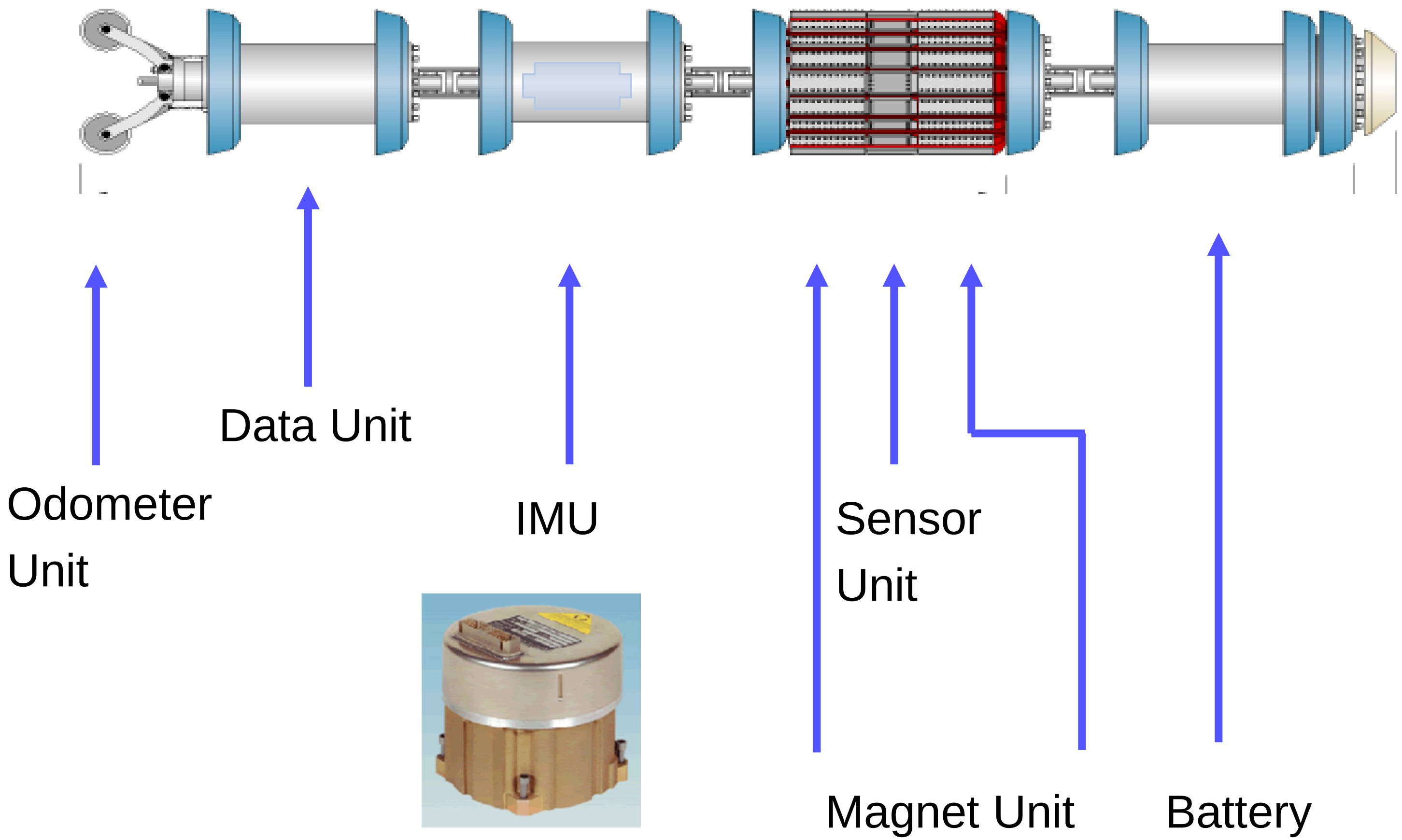
- In areas of higher seabed mobility, a similar situation may arise where operator may decide to monitor vs costly trenching or burial efforts.

- Conventional Inspection/Monitoring Methods include ROV/SSS/Divers/AUV



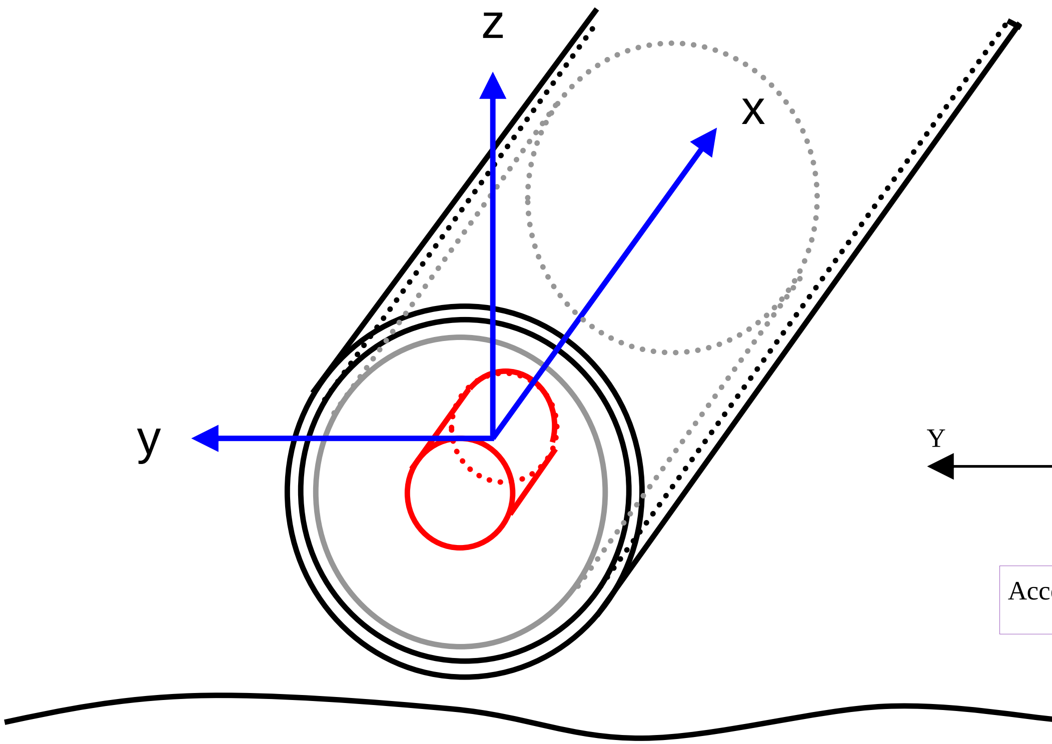


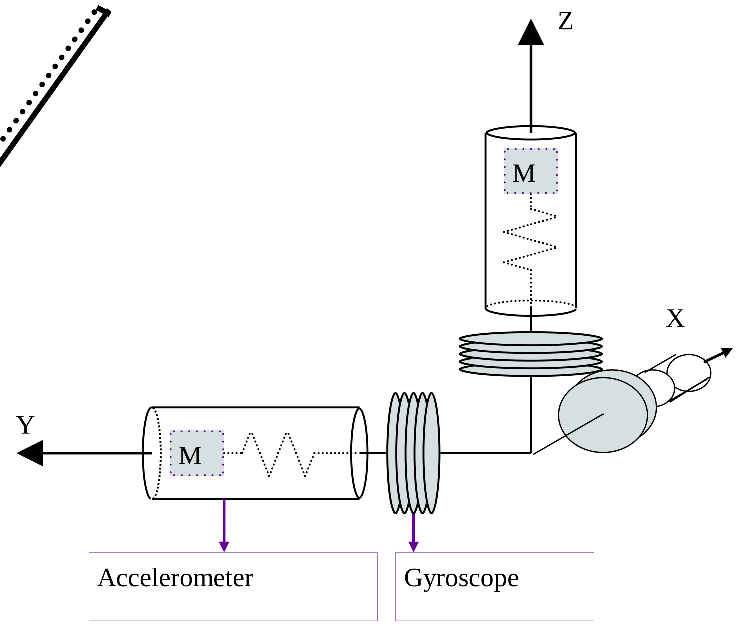
BEND STRAIN CONCEPT - MEASUREMENT SYSTEM



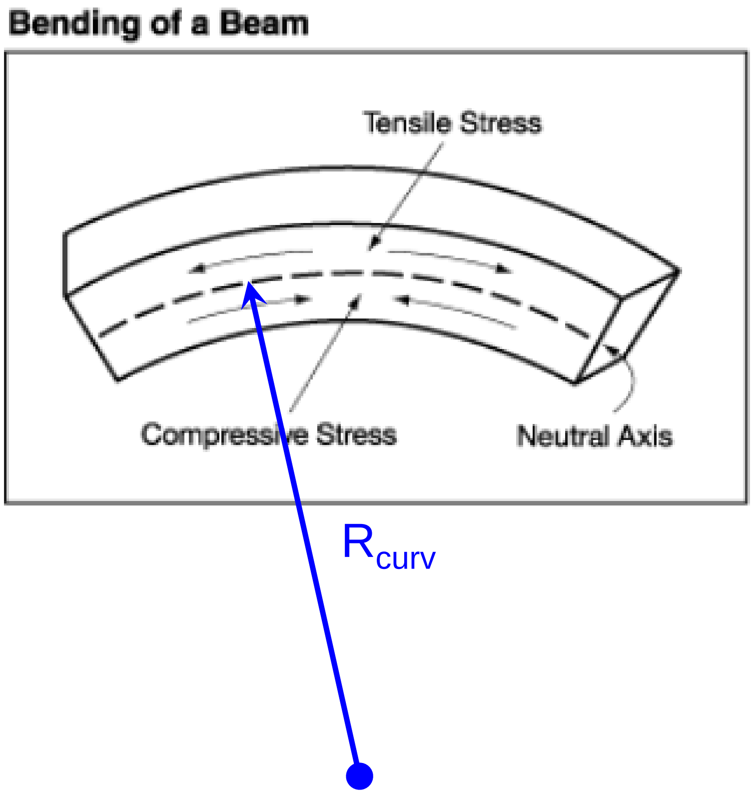
MEASUREMENT SYSTEM

- Angles are measured via the Inertial Measurement Unit (IMU)
- IMU Comprises of 3 accelerometers and 3 gyroscopes





BENDING STRAIN



Bending of the pipe

$$\varepsilon_{bending} = \frac{D}{R_{curv}2} = \frac{\kappa D}{2}[\%]$$

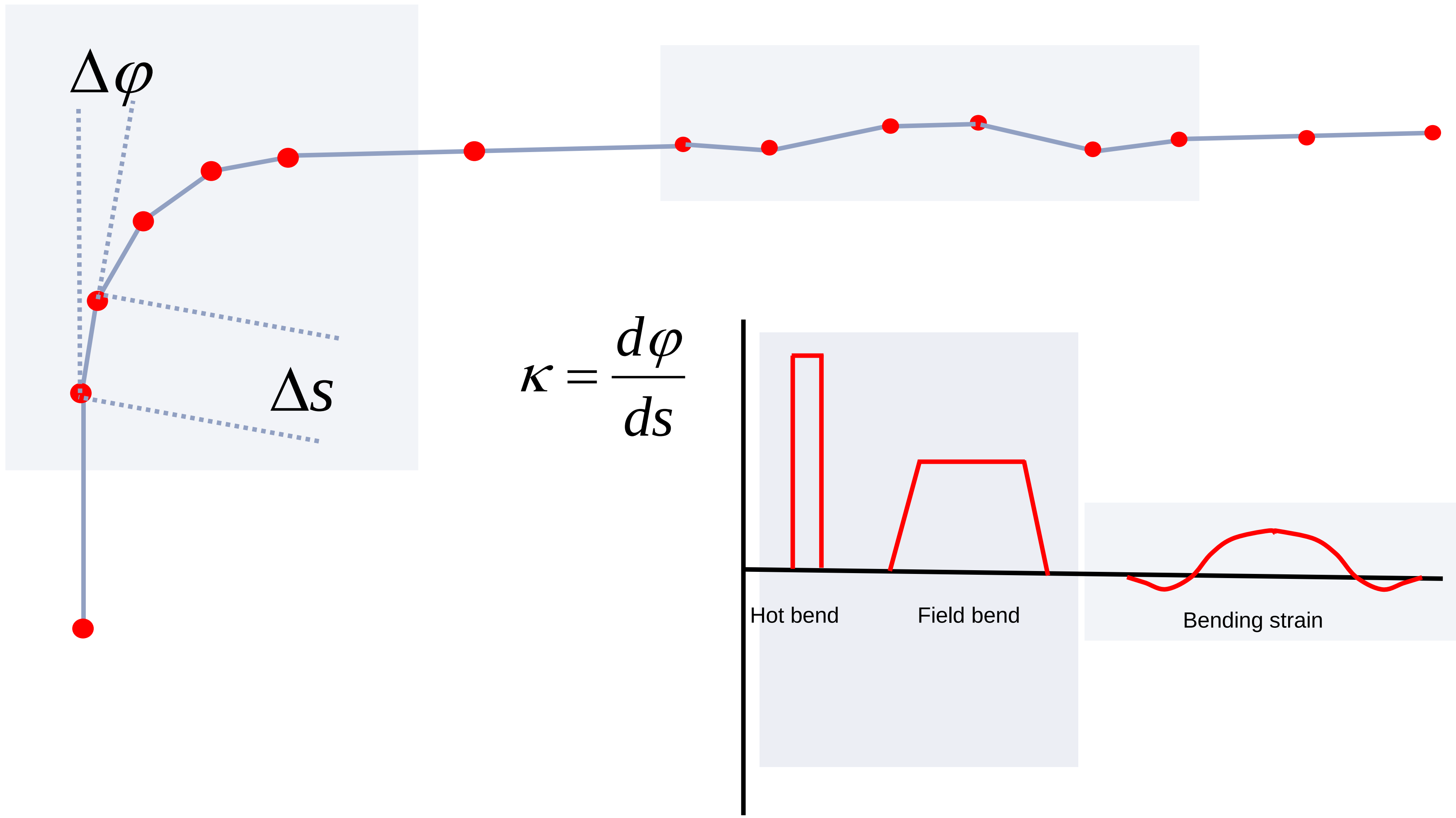
Neutral axis has same length.

Outer side will elongate

Inner side will compress

BENDING STRAIN

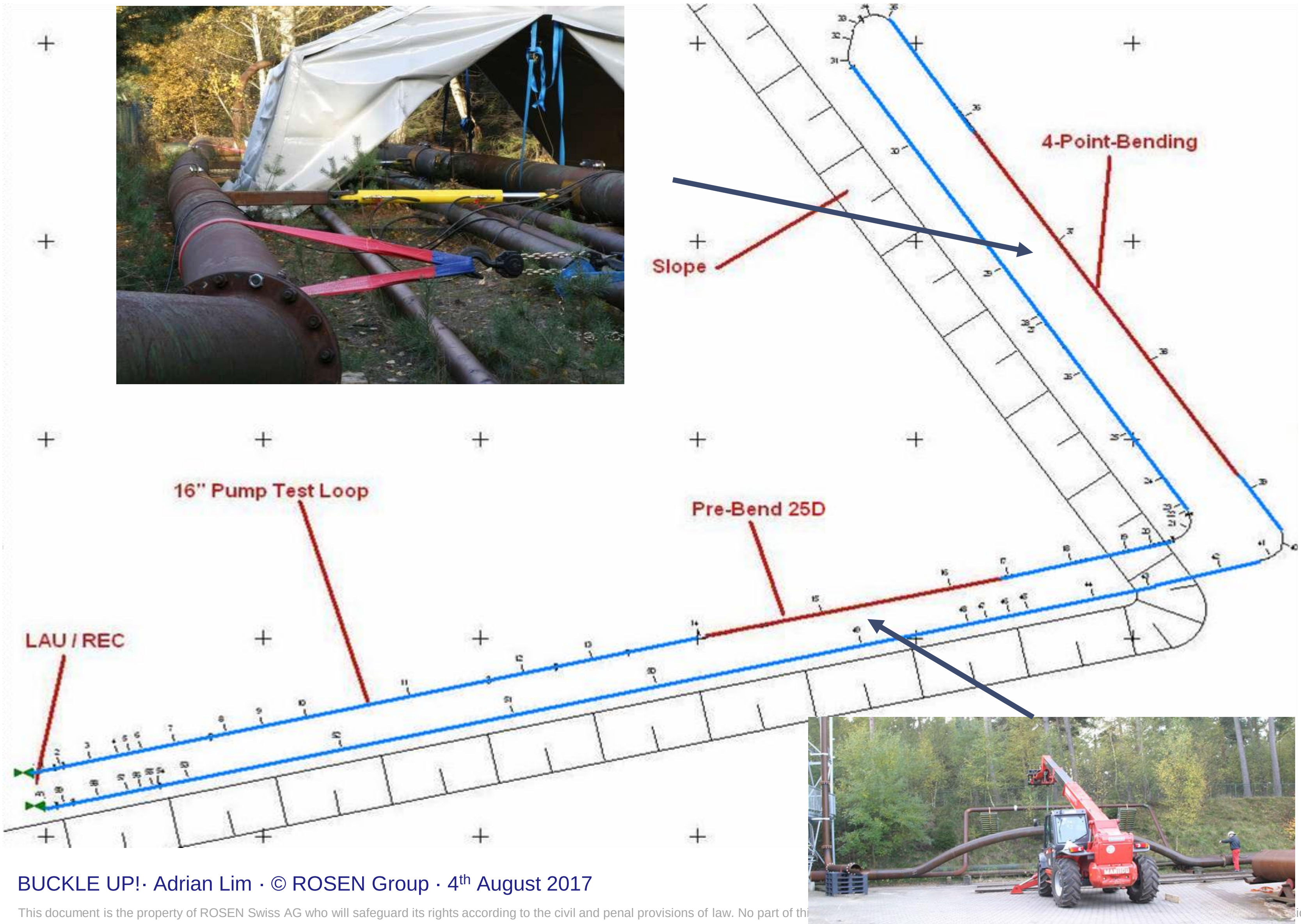
$$\varepsilon_{bending} = \frac{D}{R_{curv}2} = \frac{\kappa D}{2}$$



$$\kappa = \frac{d\varphi}{ds}$$

BENDING STRAIN QUALIFICATION AT ROSEN TECHNOLOGY CENTRE

ROSEN
empowered by technology

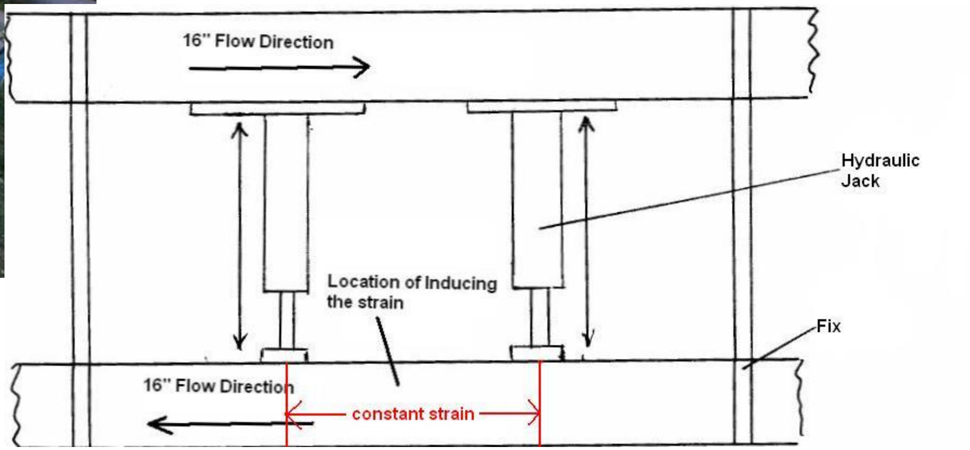


BENDING STRAIN QUALIFICATION AT ROSEN TECHNOLOGY CENTRE

ROSEN
empowered by technology

Elastic out of straightness setup

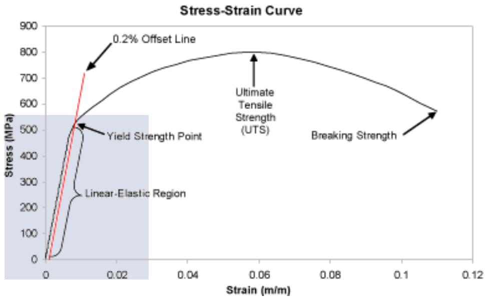
- Repeatability test
- Measurement limit

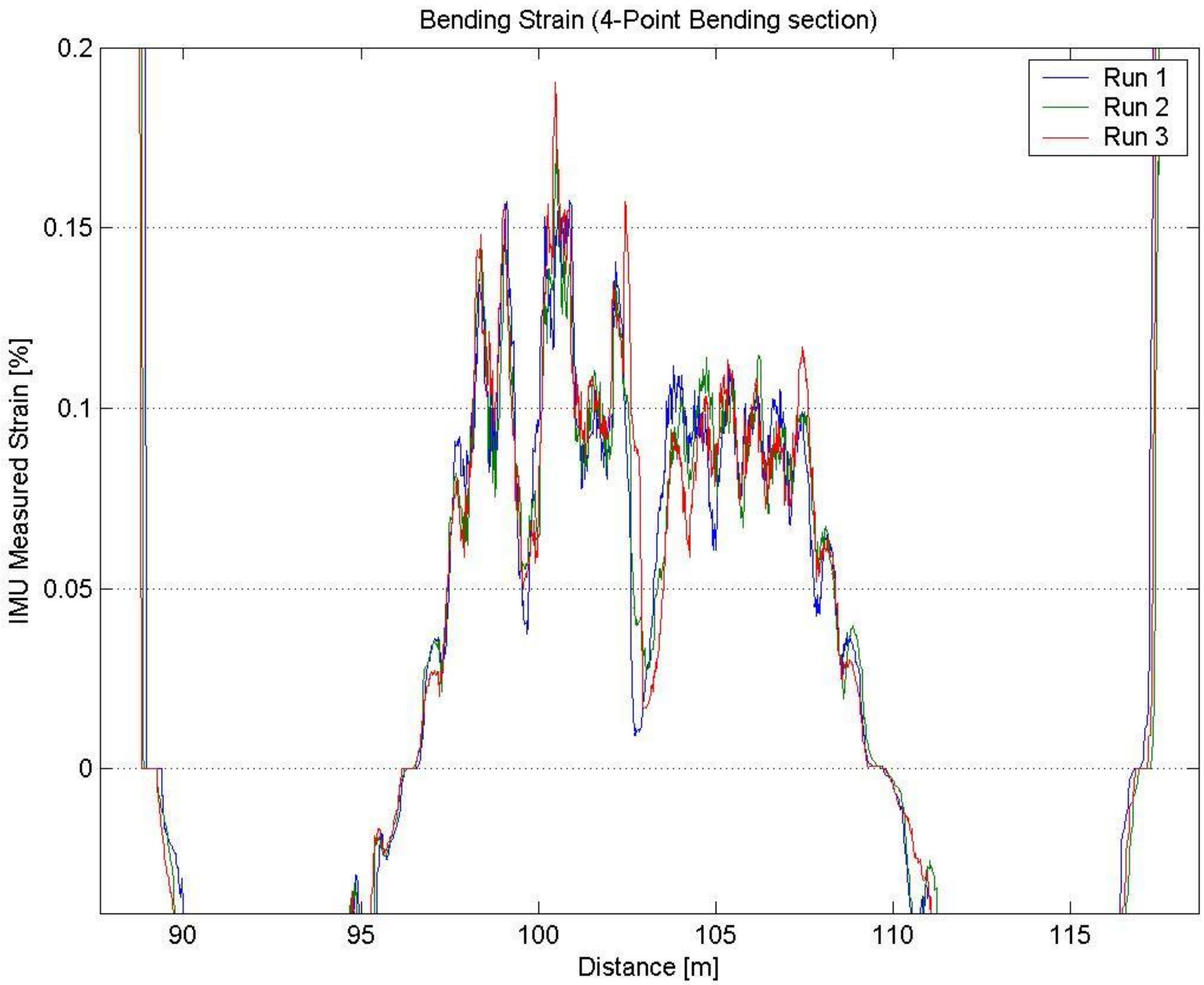


BENDING STRAIN TEST AT RTRC/LINGEN

Elastic region:

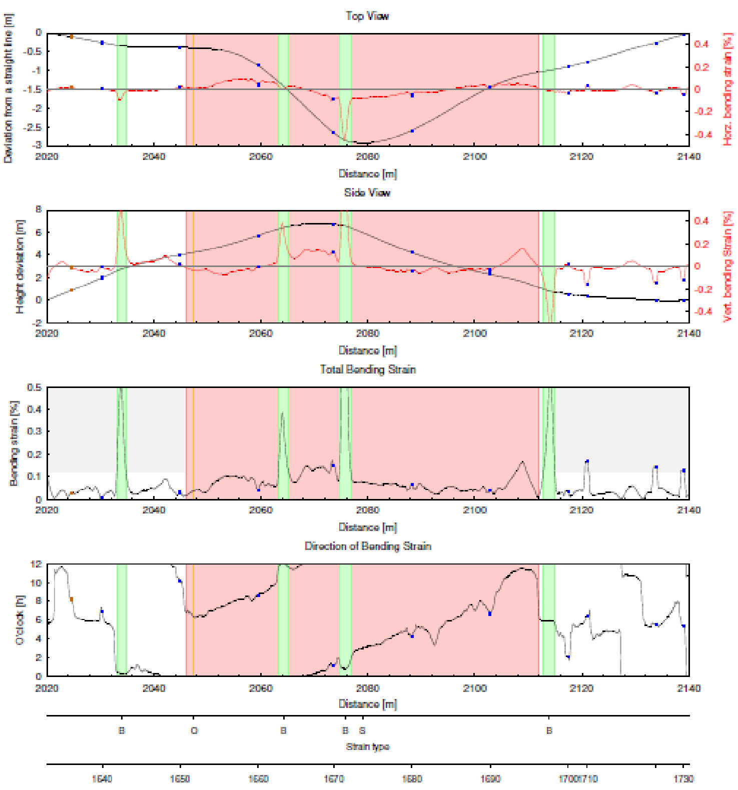
Repeatability test





BENDING STRAIN REPORTING

Anomaly No.	BSTR #001
Anomaly	bending strain
Start distance	2046.000 m
End distance	2112.000 m
Length (rounded)	66 m
Max. strain value	0.16 %
Strain direction	various
Start coordinates	W
End coordinates	W
Comment	bending strain u/s of bend, combined with bends and dent (2047.481 m; 1.0 %)



Detailed description:

- Table with information
- Top view / horizontal bending strain
- Side view / vertical bending strain
- Total bending strain
- O'clock position of the elongation strain
- Type of Strain

  'B' bend / green marked

  'S' bending strain / red marked

  'O' other i.e. ID anomaly / yellow
- Coloring codes for different entries
- Joint numbers are at the bottom

BENDING STRAIN REPORTING

Available in the report:

Lists

- List of Maximum Bending Strain
- List of Bending Strain
- List of Possible Construction Irregularities

- Detailed Graphs for each bending strain area
- Kilometer plots of the complete pipeline

Rules for List of Maximum Bending Strain:

•Standard reporting: 25 Bending Strain Areas with largest bending strain values

BEND STRAIN ACCURACIES/SAMPLING INTERVALS

Method	Accuracies (m or %)	Sampling Intervals	Comments
SD ROV*	1 (x,y) 0.1 (z)	every 1 second	N/A
HD ROV*	0.1 (x,y,z)	every 1 second	With wheels on ROV
Standard SSS *	4-5 (x,y)	Between 400 to 900kHz	125m WD, (High frequency)
Multibeam AUV*	0.2 (x,y,z)	0.25 m grid size	13m above Seabed
ILI - XYZ	1 – ABS 2km(1) 0.1 – REL 200m(2)	0.004m possible^ 0.1m standard	1m/s inspection speed 0.1m reporting^
ILI - Geo	0.01 (L,W). Depth: 0.5% of OD (=<16 “) 0.3% of OD (18-28”) 0.2% of OD (30-38”) 0.15% of OD (40-48”)	0.0025m (long) 0.011m (circ) – 8inch	1m/s inspection speed Dent/Wrinkles sizing.
ILI – MFL	Varies	0.0025m	1m/s. MELO sizing

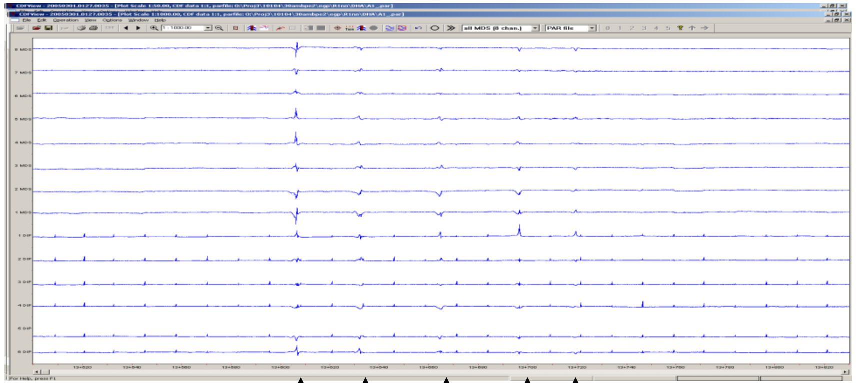
GLOBAL

LOCAL

* Turbidity dependent

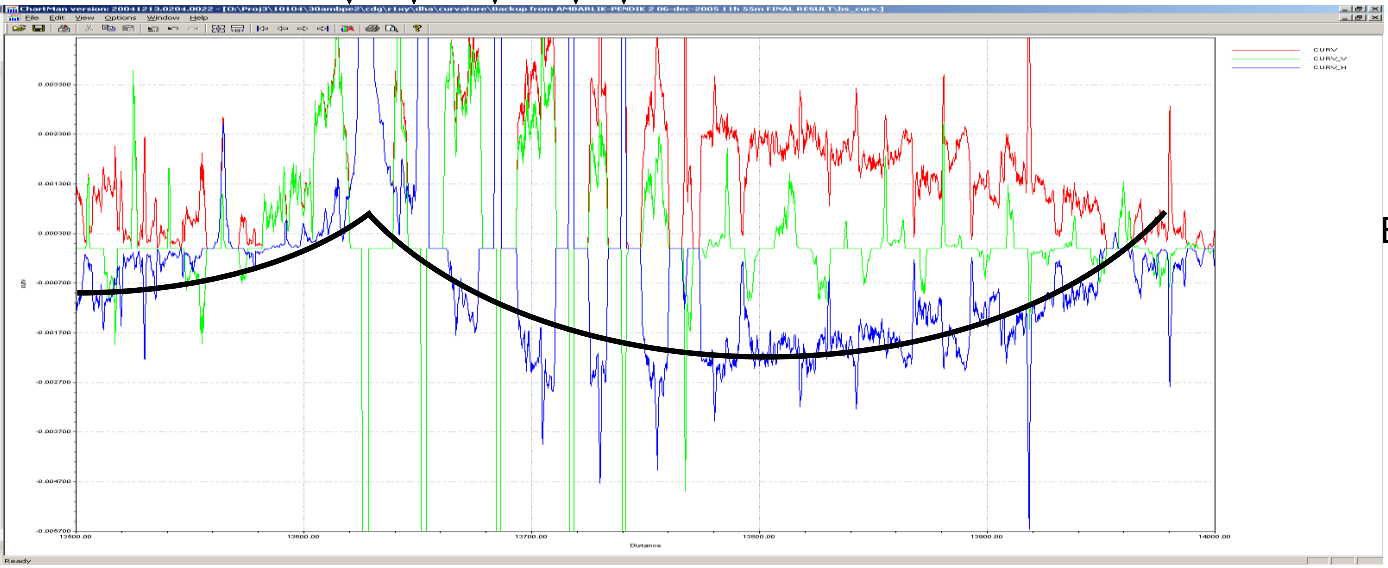
^ Post processing time is limiting factor but in theory can get even better definition

WRINKLES WITHIN DEFLECTED SHAPES



EGP

Wrinkle example

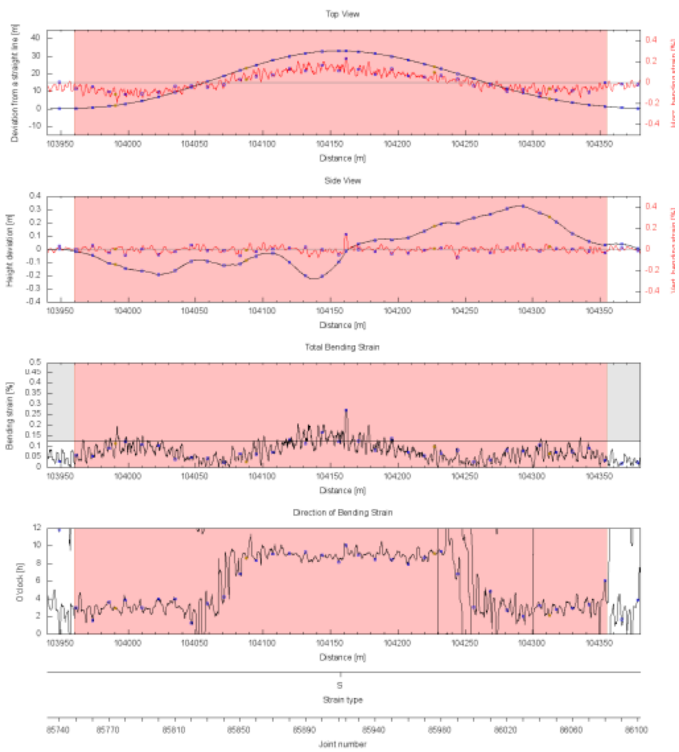


XYZ, bending strain

Bending strain indication:
Confirmation
of wrinkled bends existence

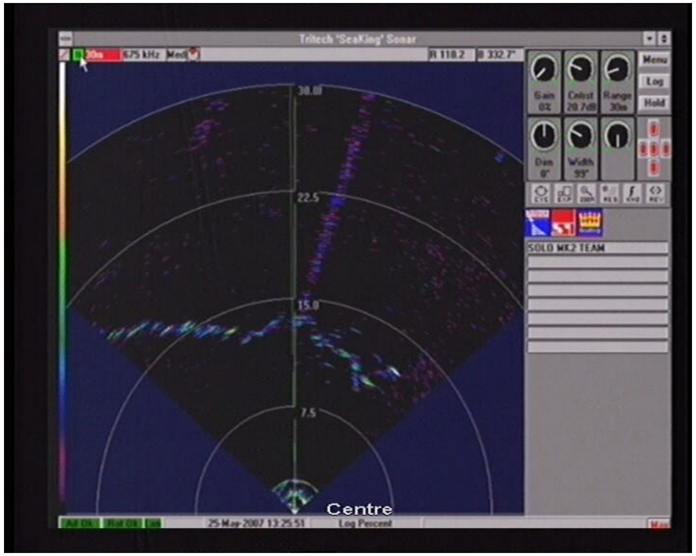
CASE STUDY: LATERAL (1ST ORDER) GLOBAL BUCKLE

Anomaly No.	BSTR #002
Anomaly	bending strain
Start distance [m]	103960.0
End distance [m]	104355.0
Length (rounded) [m]	395.0
Max. strain value [%]	0.15
Strain direction	various
$Coord_{Start}$ (Lon [°] | Lat [°] | Height [m])	
$Coord_{End}$ (Lon [°] | Lat [°] | Height [m])	
Comment	horizontal bending strain, combined with anodes



CASE STUDY: SHIP ANCHOR

ROSEN
empowered by technology



- Side sonar scan
- Pipeline angular deviation 18° to the right
- Metal object crossing pipeline

- Picture from ROV
- Last ROV survey showed no angular deviation at this location (2006)
- Picture from 2007 ROV inspection showing pipeline damage and 18° angular deviation to the right
- Anchor chain crossing under pipeline

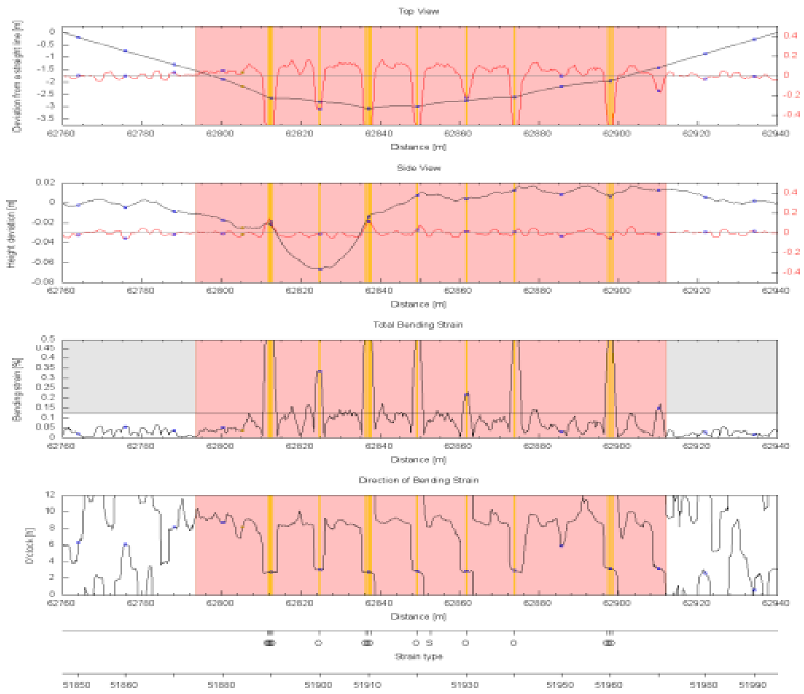
CASE STUDY: SHIP ANCHOR

- ROV pictures (both from right)
- Severe buckle including dent

CASE STUDY: SHIP ANCHOR (LOCAL BUCKLING)

ROSEN
empowered by technology

Anomaly No.	BSTR #001
Anomaly	bending strain
Start distance [m]	62793.5
End distance [m]	62912.0
Length (rounded) [m]	118.5
Max. strain value [%]	1.07
Strain direction	various
Coord_{Start} (Lon [°] | Lat [°] | Height [m])	
Coord_{End} (Lon [°] | Lat [°] | Height [m])	
Comment	horizontal bending strain, combined with anode and dents ((62811.709 m; 1.70 %), (62812.017 m; 1.60 %), (62812.361 m; 1.40 %), (62812.908 m; 1.40 %), (62824.486 m; 1.30 %), (62836.142 m; 1.40 %), (62836.842 m; 1.70 %), (62837.260 m; 1.40 %), (62849.106 m; 1.90 %), (62861.513 m; 1.70 %), (62873.673 m; 2.10 %), (62897.086 m; 1.00 %), (62897.688 m; 2.00 %), (62898.201 m; 1.00 %)); reduced accuracy



PRIMARY BENEFITS

1. **Accuracy of strain assessment improved**
   a) **Improves bend strain estimates. Optimises focus on strain estimation which historically focuses on residual axial strain (notorious).**
   b) **Avoid unnecessary repairs/intervention (COMMON benefit)**
   c) **If IMU ran in combination with Geometry or MFL or UT ILI tools – bending strain/stress can be accurately correlated to other features (corrosion/dents/gouges/ wrinkles) within or in close proximity to the buckle/deviated shape and local effects can be modelled.**
2. **For buckles/deviated shapes in stable seabed and stable operational conditions (little upsets) – potential to optimize external subsea inspection intervals.**
3. **ILI internal and strain assessments would be very useful for HPHT buried pipelines with propensity for buckles (that may not be able to be detected visually).**
4. **In context of conditions in Point 2, approximately 80% cheaper than normal focused close visual inspection of a single deflected area with added benefit of full route, internal and close interval pipeline survey.**

SECONDARY BENEFITS

1. Aid in Spans Assessments (if through-life span, not engineered span)
    a) In-situ approximation of actual strain at ‘plastic hinge’ locations.
    b) Multiple surveys (not just ILI) will give holistic model of span
        - Actual deviation angle at shoulders of span
    c) Whole pipeline coverage not just one span

2. For areas of ‘walking’ concern and close to reference markers (spools/tie-in flanges) – IMU will give you an indication of axial displacements.
    - Also changes in bend strains and angles of spools and jumpers could provide good estimates of potential walking.

OTHER CONSIDERATIONS

1. **Doesn't negate the need for external visual or sonar or multi-beam inspections**
2. **When coupled with other external inspection techniques, understanding of in-situ localized strain conditions and deflections (multi-run) is greatly improved eg – aid in assessment of wrinkles, dents etc in buckled areas.**
3. **Doesn't negate the need for FEA but provides greatly improved close interval input data which should improve FEA approximations and possibly improve engineering time (ie minimal smoothing)**

Figure 4: Global Mesh Structure

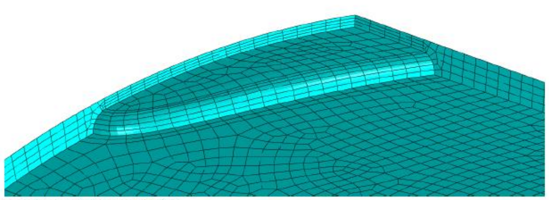


Figure 5: Defect Mesh Structure (Defect #5)

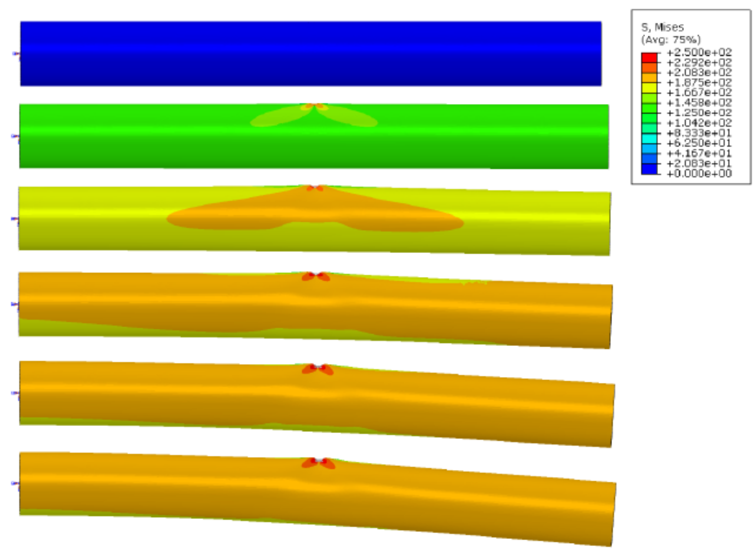


Figure 9: Von-Mises Contour Plots (MPa)Showing Collapse of Defect #5 Pipeline Model Under Axial Tension (Deformation Scales by Factor of 20, Stress Contours Capped at 250 MPa). Note. Global Collapse of the Cross Section Has Occurred.

THANK YOU FOR JOINING THIS PRESENTATION.

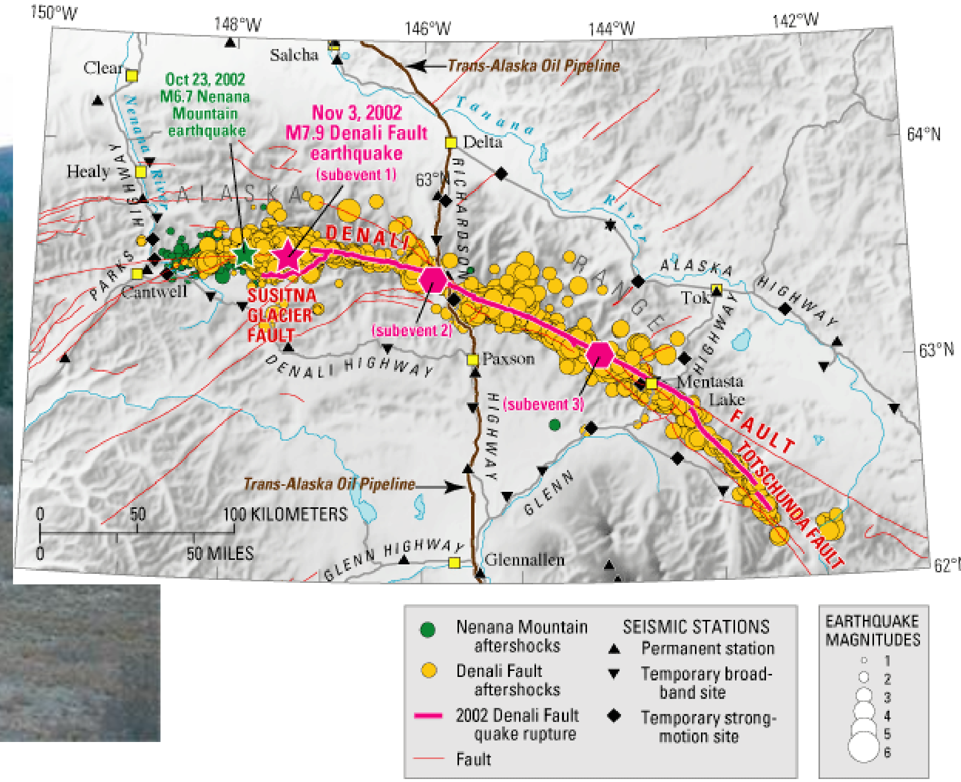
ROSEN

empowered by technology

www.rosen-group.com

THANK YOU

Denali Fault rupture
Built-in bends



Oct 23, 2002 M6.7 Nenana Mountain earthquake
Nov 3, 2002 M7.9 Denali Fault earthquake (subevent 1)
(subevent 2)
(subevent 3)
Trans-Alaska Oil Pipeline
SUSITNA GLACIER FAULT
DENALI FAULT
TOTSCHUNDA FAULT
ALASKA RANGE
Salcha
Delta
Healy
Cantwell
Paxson
Tok
Mentasta Lake
Glennallen
0 50 100 KILOMETERS
0 50 MILES
Nenana Mountain aftershocks
Denali Fault aftershocks
2002 Denali Fault quake rupture
Fault
SEISMIC STATIONS
Permanent station
Temporary broad-band site
Temporary strong-motion site
EARTHQUAKE MAGNITUDES
1
2
3
4
5
6

EMAIL CONTACT

Adrian Lim
Regional Manager Asia Pacific
Integrity Management Services
alim@rosen-group.com