EFFECTS OF ELASTIC SHAKEDOWN AND BULK CORROSION THINNING AT A LATERAL BUCKLE

Arek Bedrossian
Jens Fernández-Vega

Subsea Expo 2017 1 – 3 February 2017
Our history – Petrofac Subsea & pipelines

1999
KW Ltd founded as a high technology pipeline consultancy

2000
KW pioneers pipeline OOS (out of straightness) Analysis. First integrity management, deepwater and HPHT projects for KW

2002
Design of deepest 36" pipeline at 900m

2003
Design of first subsea pipeline to gain DNV Certification without Hydrotect

2004
Design of Deepest reeled PiP at 1500m (Baobab)

2007
First extension of life/rehabilitation project for KW - BP, Gulf of Suez

2011
Established presence in Mexico

2012
First full field detailed subsea facilities design for Enquest Don Southwest and West

2012
KW acquired by Petrofac

2013
Established subsea capability in Malaysia: 30 engineers

Owners Engineer on Lakach, Pemex' first deepwater tie-back in GoM

2014-onwards
Integrated within Petrofac, focus of subsea and pipelines design expertise and consultancy

2014-Onwards
Routing design of longest, highest output power and optical cable at 106km and 123kV, 75MW (Eni Goliat)
Global footprint, local capability

Main operational centres
- Woking
- London
- Moscow
- Atyrau
- Muscat
- Delhi
- Mumbai
- Chennai
- Kuala Lumpur
- Singapore

Other operating locations
- Houston
- Villahermosa
- Anchorage
- Beijing
- Sakhalin
- Abu Dhabi
- Sharjah
- Basra
- Tunis
- Khobar
- Doha
- Algiers
- Milan
- Aby Dhabi

Corporate services
- Perth
- Brisbane
- Perth
- Brisbane

Legend:
- Main operational centres
- Other operating locations
- Corporate services
Background

Lateral Buckling and Bulk Corrosion of Offshore Pipelines

• Relevant Aspects
  – Lateral buckling
  – Local concentration near girth welds
  – Cyclic lateral buckling
  – Shakedown
  – Bulk long term internal corrosion
  – Combined Loading - Displacement Control Criteria (DCC) of DNV OS-F101
  – DNV general guidance on designing with bulk corrosion

• How do all these interact together?
Aim and Scope of Work

Visualise/understand the effects for a typical case

- **Objective of work**
  - Examine the behaviour of pipelines and strain concentrations under repeated lateral buckling and gradual corrosion thinning of the pipe wall

- **Assumptions and scope**
  - A typical deep water offshore pipeline – not a parametric study
  - Uniform corrosion along the pipeline and around the inner bore
  - Natural on-bottom lateral buckling; effect of soil berms considered
  - Local strain concentration within DNV guidelines
  - Operating conditions of pipeline (temperature and pressure) do not change over design life
Geometry, Conditions & Material

• Pipeline Geometry & Material
  – Length: 1500m (VAS model, fixed at both ends)
  – OD: 323.85mm (12.75”)
  – Wall thickness: 15.9mm

• Operation
  – Allowed Corrosion: 3.0mm
  – Allowed Ovalisation by construction: 2.5%
  – Water Depth: 1200m
  – Internal Pressure: 130 bar
  – Temperature: 95°C (constant along the length)

• Materials
  – Pipeline: Material Steel X65 Linear elastic, perfectly plastic
  – Weld: 20% Steel Overmatch
FE Model

FE Model Description

• Abaqus 6.14
• Elastic-plastic, large deformation and frictional contact; static equilibrium
• Hybrid between PIPE31 pipe & C3D8 3-D solid continuum elements
• C3D8 elements embedded in PIPE31 elements
• Beam section is 1496m long. The central solids section is 4m long
• Solid section made of: 3 un-corroded + 1 or 2 layers that could be ‘corroded away’
• Solid to Beam model interface is seamless: Ovalisation of the solids is allowed
• FE model capable of simulating inner corrosion over whole length by incrementally shaving off layers of solids and replacing beam elements by thinner beam elements
• Axial and lateral pipe-soil frictional resistance applied to both beam & solids sections
FE Model

Pipe (PIPE31) and 3-D solid bricks (C3D8) embedment

Solid elements

Rendered Pipe elements

Pipeline model (pipe elements not rendered)
FE Model

Solids-to-pipe element general-purpose interface

- Kinematic Coupling
- PIPE31 master node coupled to rim face nodes of solids
- Allows radial deformation of solids at interface
- No stress-strain concentration at the edge of the solid
- End Cap forces from PIPE31 elements transferred to C3D8 solid elements
- Effective under elastic-plastic and large deformation conditions
Verification of PIPE31/C3D8 Hybrid model – No mismatch
FE Model

Mismatch at weld location

Blue elements: Weld
FE Model

Mismatch due to fabrication ovality 2.5%

Solids Left End: Circular shape
Solids Right End: Oval shape

Oval minor axis in the bending plane
FE Model – Simulating Corrosion

Blue elements: Un-corroded layers
Yellow elements: Corrosion layers
FE Simulation Sequences

Loading-Unloading Cycles & Corrosion Stages

1. Lay down the empty pipeline
2. Apply OP weights, pressure & temperature
3. Depressurise & cool down

Load Cycle

Corrode Pipeline

Load Cycle

P On

P Off

T On

T Off

1

2

3

4

Apply Pressure & Temperature
Freeze BEAM Model DoF
Swap SOLIDS Pressure layers
Degrade SOLID corroded layer E value
Release Beam Model DoF
Swap Beam model
Remove Pressure & Temperature

Lay down the empty pipeline
Apply OP weights, pressure & temperature
Depressurise & cool down
Configurations Investigated

Models

- Corroded thickness is always 3.0 mm in total
- Corrosion elements removed in 1 or 2 steps (layers)
- Ovality 0% or 2.5%
- Weld overmatch 20%
- But this is NOT a parametric study

<table>
<thead>
<tr>
<th>Model name</th>
<th>Layers removed</th>
<th>Corroded layer thickness (mm)</th>
<th>Beam model corroded</th>
<th>Ovality %</th>
<th>Weld overmatch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Layer 1</td>
<td>Layer 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>Model 2</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>Model 3</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>Yes</td>
<td>2.47</td>
</tr>
<tr>
<td>Model 4</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>No</td>
<td>2.47</td>
</tr>
<tr>
<td>Model 5</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>Yes</td>
<td>2.47</td>
</tr>
<tr>
<td>Model 6</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>Yes</td>
<td>2.47</td>
</tr>
</tbody>
</table>

(with and without soil berms)
Results

Stress Strain Plots

- The plots show the compressive side of the solid section and the peak concentration element (intrados)

Element showing the maximum response at the concentration is selected to construct the $\sigma$-$\varepsilon$ plots that follow
Results: DCC Strain: DNV limit

DNV OS-F-101 DCC limit: Functional compressive strain

![Graph showing functional compressive strain DNV-OS-F101 limit.](image-url)
Results: Stress-Strain: MODEL 1

- Ovality 0%
- 1 Corroded Layer (3.0mm)
- Weld overmatch 1.0

CORROSION ALONG WHOLE MODEL:
The whole length of the beam and solid models gets corroded
Results: Stress-Strain: MODEL 2

- Ovality 0%
- 1 Corroded Layer (3.0mm)
- Weld overmatch 1.2

CORROSION ALONG WHOLE MODEL:
The whole length of the beam and solid models gets corroded
Results: Stress-Strain: MODEL 3

- Ovality 2.5%
- 1 Corroded Layer (3.0mm)
- Weld overmatch 1.2

**CORROSION ALONG WHOLE MODEL:** The whole length of the beam and solid models gets corroded.
Results: Stress-Strain: MODEL 5

- Ovality 2.5%
- 2 Corroded Layers (1.5+1.5mm)
- Weld overmatch 1.2

CORROSION ALONG WHOLE MODEL:
The whole length of the beam and solid models gets corroded
Results: Stress-Strain: MODEL 4

- Ovality 2.5%
- 2 Corroded Layers (1.5+1.5mm)
- Weld overmatch 1.2

**CORROSION SOLIDS MODEL ONLY:**
Only the length of the solid model gets corroded. Beam model remains intact
Results: Effect of Localisation of Corrosion

- DNV DCC Functional Strain Limit
- Whole pipeline corroded (black)
- Local corrosion only (red)
Results: Stress-Strain – Effect of Soil Berm: **MODEL 6**

- Ovality 2.5%
- 2 Corroded Layers (1.0+2.0mm)
- Weld overmatch 1.2

**CORROSION ALONG WHOLE MODEL:**
The whole length of the beam and solid models gets corroded
Results: Stress-Strain: FULL CORROSION
Results: Stress-Strain: LOCAL CORROSION
Bulk corrosion, concentration and cyclic buckling examined

- **No evidence of local cyclic plasticity or ratcheting at concentration**
- **Shakedown is achieved both locally and globally**
- **Soil berms restrict the range of strain on shutdown with corrosion**
- **But, magnitude of response depends on interpretation of DNV guidance on corrosion**
- **If response obtained from nominal wall thickness is applied to corroded section as required by DNV OS-F101 then:**
  - Limited ratcheting with increasing corrosion at local concentration is likely
  - Target allowable strain from DNV DCC for fully corroded pipe may not be sufficient if local concentration factor is around 2.5
- **If corrosion is assumed to be over entire length of pipeline then:**
  - One stable reversed plasticity is likely at local concentration before shakedown
  - Strain range for this cycle is not likely to be large (typically 1%)
Thank You

Any Questions?