Reeling Analysis and Limit State Criteria

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Agenda

- Introduction to reeling installation of rigid pipe
  - General introduction
  - Pros and Cons of reeling
  - Design consideration (Wall thickness, strength, fatigue, etc.)
  - Limit states

- Finite Element Analyses
  - Global reeling analysis model
  - Global analysis results
  - Mismatch analysis
  - Mismatch analysis results

- Summary
### Introduction - General

- **Reeling Installation**
  - Pipe string is fabricated onshore
  - Spooled on to the reel at spool base
  - Transit to offshore site
  - Pipe is un-winded, straightened, before lunched off for installation
  - Some vessel use separable/exchangeable spools to keep continuous offshore installation

![Typical Reeling Vessel - Apache](image-url)
Introduction – Pros and Cons

- Pros
  - Fast
  - Reliable
  - Cost effective

- Con
  - Large stress/strain in the pipe
  - OD limit
  - Fatigue and crack sensitive
  - Residual ovality
  - Residual out of straightness (OOS)
Introduction – Design Consideration – Limit States

- Wall thickness

- Strength
  - Ultimate Limit State (ULS)
  - Strained based criteria
  - DNV OS F101
  - Recent installation JIP

\[ \varepsilon_{sd} = \varepsilon_F \cdot \gamma_F \cdot \gamma_c \leq \frac{\varepsilon_c}{\gamma_c} \]

\[ \varepsilon_c = 0.78 \left( \frac{t}{D} - 0.01 \right) \alpha_h^{-1.5} \alpha_{gw} \]

- Fatigue
  - Fatigue Limit State (FLS)
  - Low cycle fatigue damage during installation
  - Fatigue budget

- Fracture Mechanics
  - Fracture Limit State
  - ECA is general required
Finite Element Analysis – Global Model

- Purpose
  - Evaluate the global pipe response for reel-on, reel-off, and straightening processes;
  - Optimize the back tension for reel-on process;
  - For pipe-in-pipe system, the global model is also utilized to assess the centralizer spacing;
  - Provide input for fatigue assessment;
Finite Element Analysis – Global Model

- **Model Features (Abaqus)**
  - Pipe is modelled with pipe element (PIPE31), 400m in length;
  - Ramberg-Osgood material curve with a yield strength of 65 ksi
  - Combined hardening (isotropic/kinematic)
  - Reel, Aligner, Straightener, Tensioner are modelled with analytical rigid surface;
  - Contact pairs are defined between the pipe and all analytical rigid surfaces:
    - Hard contact in normal direction;
    - Isotropic friction of 0.1 in lateral directions;

- **Loading Steps**
  1. Apply back tension;
  2. Rotate the reel (CCW) to reel-on;
  3. Adjust straightener for reverse bend;
  4. Adjust tensioner position;
  5. Displace pipeline in the J-lay configuration.
FEA – Global Model - Results

Longitudinal strain after reel-on

Longitudinal strain during installation

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FEA – Global Model - Results

The diagram illustrates the section bending moment (Nm) along the pipe length (m). The graph compares different stages of pipe deployment:

- **On the Reel**
- **On the Aligner**
- **In the Straightener**
- **Off the vessel**

The blue line represents the 'Reel-on' condition, while the green line indicates the 'Installation' condition. Peaks and troughs in the graph correspond to specific areas of high bending moment, highlighting the stresses and strains during the installation process.
FEA – Global Model - Results

- Accumulated plastic strain vs. Curve length along the pipe (m)
- Reel-on, Reel-off, Straightener, Straightener only, Aligner

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Finite Element Analysis – Local Mismatch Model

- **Purpose**
  - Reeling is displacement controlled condition only when the pipe string has uniform section properties.
  - Any discontinuity in section properties introduces a partial load controlled situation.
  - A typical undesired mismatch situation is a strong pipe followed by a weak section during reel-on process.
  - A local mismatch model can be used to assess the tolerable mismatch, and give guidance to the pipe design specification or probability based risk assessment.
Finite Element Analysis – Local Mismatch Model

- **Model Features (Abaqus)**
  - The pipe section details around the mismatch interface are modelled with solid elements (strong pipe, weak pipe, and the weld)
  - The geometry of counter boring is considered
  - The solid weak pipe section is followed by a trailing beam (pipe) section, at the end of which the back tension is applied
  - Ramberg-Osgood material curve with a yield strength of 65 ksi
  - Reel is modelled with analytical rigid surface;
  - Contact pairs are defined between the pipe and all analytical rigid surfaces:
    - Hard contact in normal direction;
    - Isotropic friction of 0.1 in lateral directions;

- **Loading Steps**
  1. Apply back tension
  2. Rotate the reel until the entire solid section made contact with the reel surface
Finite Element Analysis – Local Mismatch Model

Strong and Week Section Properties

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<th>Section</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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<td></td>
<td>WT</td>
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<td></td>
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<tr>
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<td>Yield Strength</td>
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</table>

Material Curves

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**Strain Results**

- Stress/strain concentration in the weak section (counter bored area)
- The compressive strain (blue color) need to be checked to avoid local buckling
- The strain criteria in DNV OS F101 is not applicable for the compressive strain obtained from mismatch analysis (over conservative)
- The Installation JIP provide strain criteria that’s better applicable
With no initial ovality, the pipe ovality increased less than 2% after the reel on process.

Tension dependent, high tension, smaller range.

In the counter bored section, the pipe curvature is about the double of the nominal reel curvature;

The majority of the curvature will be corrected in the straightener.
Reeling Installation of rigid pipeline has been an attractive method, and is becoming a proven technology over years of evolution.

Advanced analyses with global and local models help improve the understanding of the phenomenon, and optimize the design.

Design and analysis results should be checked against appropriate limit state criteria.
Thank you!

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