MCE Deepwater Development 2015

Slug induced fatigue analysis in Riser Base Spools
HYBRID RISER

- For Deepwater fields, Hybrid risers may be considered as an alternative to SCRs or flexible risers.

- **Main advantages**
  - Simple field layout
  - Good insulation performance
  - Good gas lift efficiency
  - Installation not on critical path
  - Low tension on FPSO
  - Open contractor market / Local content
  - Low overall CAPEX

- **Main Operators in West Africa, GOM, Brazil**
  - BP
  - Exxon
  - Total
  - Petrobras
Riser Base spool:
Transition piece between flowline and riser

Critical interface riser base spool allows the production fluid to flow into the riser
RISER BASE SPOOL DESIGN

- Riser base spool subject to complex design criteria
  - Riser oscillation due to wave/current along water column
  - Riser thermal expansion
  - FLET sliding due to flowline thermal expansion
  - Installation/Lifting requirements
  - Allowable load at connection points

- Fatigue assessment at welds need to be performed due to
  - Slugs
  - Thermal loading
  - Riser tower motions
  - VIV (possible)
  - Waves (no impact)

=> What is the contribution / impact of slugs on the overall fatigue?
FATIGUE PRINCIPLES

• Damage to the material caused by repeatedly applied loads

• General method: DNV-RP-C203 Fatigue Design of Offshore steel structure

• Palmgren-Miner’s rule

• SN fatigue approach: Combination of Stress Range AND Number of cycles

• Girth welds are categorized
  • \(0 \leq D_{fat} \leq 0.2\) \(\rightarrow\) FS0 – Not fatigue sensitive
  • \(0.2 \leq D_{fat} \leq 1\) \(\rightarrow\) FS1 – Fatigue sensitive
  • \(1 \leq D_{fat}\) \(\rightarrow\) FS2 – Design unacceptable

• Fatigue assessment performed at most critical point = Weld
SLUG FATIGUE METHODOLOGY

• Hydrodynamic slugging in normal flowing conditions
  => Slugs characterization: from Flow Assurance analyses

- FA studies
  - Reservoir Model
  - Selected Scenarios
  - Slug tracking

  Slug Tracked
  - Density: $\rho$ liquid slug / $\rho$ gas slug
  - Length
  - Velocity
  - Frequencies
  - Years

• Methodology

  Load calculation
  $\Delta \rho$
  Velocity / length

  Bending Moment
  $\Delta M$

  Stress ranges
  $\Delta \sigma$

  Fatigue Damage

  Slug Frequencies
Fatigue assessment at welds

- Thermal loading approx 0,5%
- Riser tower motions approx 0,5%  TOTAL DAMAGE
- VIV (possible) negligible
- Waves (no impact) negligible

=> very small < 1 %

Reserve for slugging > 99%

How does the riser base spool react to slugs?
**INPUT DATA**

- **SLUG Data**

<table>
<thead>
<tr>
<th>Year</th>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
<th>Type 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y1 to Y2</td>
<td>Y2 to Y8</td>
<td>Y8 to Y15</td>
<td>Y15 to Y25</td>
</tr>
<tr>
<td>Liquid Slug Density $\text{kg/m}^3$</td>
<td>765</td>
<td>705</td>
<td>610</td>
<td>720</td>
</tr>
<tr>
<td>Gas Slug Density $\text{kg/m}^3$</td>
<td>283</td>
<td>253</td>
<td>276</td>
<td>302</td>
</tr>
<tr>
<td>$\Delta \rho$ $\text{kg/m}^3$</td>
<td>482</td>
<td>452</td>
<td>334</td>
<td>418</td>
</tr>
<tr>
<td>Slug Length (Average) $\text{m}$</td>
<td>130</td>
<td>210</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>Velocity $\text{m/s}$</td>
<td>4,5</td>
<td>5,8</td>
<td>6,2</td>
<td>3,8</td>
</tr>
<tr>
<td>Slug Frequency $\text{slugs/hr}$</td>
<td>40</td>
<td>140</td>
<td>65</td>
<td>175</td>
</tr>
</tbody>
</table>

- **Simplified Model**

<table>
<thead>
<tr>
<th>FreeSpan length in $\text{m}$</th>
<th>$\Delta \sigma$ (Mpa)</th>
<th>Fatigue damage @Weld Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ liquid slug = 705 $\text{kg/m}^3$</td>
<td>$\rho$ gas slug = 253 $\text{kg/m}^3$</td>
<td>140 cycle/hour during 6 years</td>
</tr>
<tr>
<td>5</td>
<td>0,9</td>
<td>0,00</td>
</tr>
<tr>
<td>10</td>
<td>3,6</td>
<td>0,00</td>
</tr>
<tr>
<td>15</td>
<td>8,7</td>
<td>0,02</td>
</tr>
<tr>
<td>20</td>
<td>15,4</td>
<td>0,28</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>2,85</td>
</tr>
</tbody>
</table>
3 models are used with 2 different programmes (AUTOPIPE and SAMCEF)

**AUTOPIPE**

- Static approach
- Load combinations: step by step of the slug within the spool
- Reflect the movement of the slug within the spool

**SAMCEF Model**

- Model with loading as a function of time
- CPU Time = 52 s

**SAMCEF – Full Calibration**

- Fluid as mass flowing through the spool
- CPU Time = 3 h 02 min
- Used for calibration
The 2 different programmes (AUTOPIPE and SAMCEF) lead to comparable results and are complementary.

The results given by SAMCEF should be taken as the reference results as all the effects are accounted for, but they also allow the order of magnitude of the results given by the simpler, pseudo-static approach with AUTOPIPE to be validated.
• AUTOPIPE modelisation reflects $\Delta \sigma$ due to $\Delta$ densities

• SAMCEF modelisation reflects $\Delta \sigma$ due to $\Delta$ densities AND dynamic effects depending on spool modes and slug velocity
Passage d'un spool V=7.6m/s l=150m d=173/694/173 kg/m3
Calculs de temporels de contraintes pour fatigue

Contrainte equivalente
Deplacements nодаux (DX, DY, DZ)
Pas 0
Temps 0.
Echelle geometrique
10.

Echelle numerique 1/2.43248
Echelle de la deformee 10.00
Valeur*1.66

Hydrodynamic coeff.
Buoyancy module Cd=0.5 Cdt=0.9
Pipe Cd=0.5

Vertical displacement Buoyancy n°8

Soil Contact
Cf=0.5 k=1100N/m3

X Z Y
Main effect of slugging is the static deflection due to density variations.

Bending moments induced by impact loads on bends can be neglected.

Dynamic effects are small compared with static deflection.
• Vibration aspects are influenced by the slug length variation

• Density range and slug length are much more detrimental than the number of cycles

• Fatigue due to spool vibration is negligible compared to fatigue induced by $\Delta\sigma$ due to $\Delta$ densities
CONCLUSION

RIGID SPOOL => ATTRACTIVE SOLUTION
• Not limited by depth/pressure combination
• No cool down time issue
• Local content and Cost effective

FATIGUE DUE TO SLUGS => COMPLEX PHENOMENON DEPENDING ON
• Velocity / Length
• Frequency / Densities - $\rho$ liquid slug / $\rho$ gas slug
• Pipe/Spool shape (location of elbow, unsupported pipe)

RIGID SPOOL / JUMPER DESIGN REQUIRED SPECIAL EXPERTISE
• Multi discipline approach,
• Complex design (In Place, Fatigue induced by Slug, Lifting....)
• Sensitivity studies with Flow Assurance provides range of fatigue life
• Iterative process
• Operators experiences
• Monitoring
• Flow Assurance input data
• Slugging analysis
• OLGA vs LEDA
• Slug management
Your independent engineering partner for optimized solutions

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