Tandem Offloading from an FLNG in Harsh Environments

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Outline

• Why Tandem Offloading for FLNG systems?
• Design Requirements
• Development of the Mooring System
• Analysis of System
• Validation with Model Test Data
• Focus on Extreme Design Cases and Operations
• Summary
Offloading from an F(P)SO
Typical Offload Operation Criteria

• **Tandem offloading using Nylon Hawser from FPSO to Tanker:**
  – Maximum Connect Hs = 2.5m
  – Maximum Offload Hs = 3.5m

• **Tandem Offloading using DP Shuttle Tankers**
  – Maximum Connect Hs = 4.5m
  – Maximum Offload Hs = 5.5m

• **Side-by-Side Offloading from FPSOs to Oil Tankers:**
  – Maximum Connect Hs ~ 1.5 to 2m
  – Maximum Offload Hs ~ 2.0 to 2.5m
Design Requirements

• Offloading from Floating LNG Platforms
• High Safety and Reliability Requirements
• Use Field Proven Technology
• Harsh Operational Environmental Conditions:
  – Offload in Hs = 5.5m seas
  – Connect mooring and LNG transfer system in Hs = 4.5m
  – No additional support vessels
• Offload Frequency ~ 2 offloads / week
LNG Tandem Offloading System Developed
Initial Analysis/Validation of System

• Global System Responses and Loads:
  – In-house frequency domain tools
  – Ignore wave interaction between two vessels
  – No wind/current shielding between the two vessels
  – Obtain System Load and Response Estimates

• Model Tests for Validation:
  – Complete FLNG – Mooring Yoke – LNGC System
  – Yoke Instrumented for Forces and Angular Displacements
  – Relative Motions between the Two Vessels
• **FLNG System:**
  - LBP ~ 300m
  - Beam ~ 55m
  - LNG Capacity: 240 m^3

• **LNGC System:**
  - LBP ~ 270m
  - Beam ~ 44m
  - LNG Capacity: 140 m^3
# Tandem Offloading Design Criteria

## Environmental Conditions

<table>
<thead>
<tr>
<th>Cumulative Probability</th>
<th>Maximum Offloading Seastates</th>
<th>Berthing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>99.999%</td>
<td>99.40%</td>
</tr>
<tr>
<td>Wave Only</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Crossed 1</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Crossed 2</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Crossed</td>
<td>64</td>
<td>64</td>
</tr>
</tbody>
</table>

### Water Depth

- 64 m

### Wave

- **Wave Spectral Model**: P-M, P-M, P-M, P-M
- **Significant Wave Height**: 5.5 m, 5.5 m, 5.5 m, 3.5 m
- **Peak Period**: 12 s, 10.5 s, 12 s, 9.5 s
- **Direction**: 180°, 180°, 180°, 180°

### Wind

- **Velocity**: 42.9 knots, 42.9 knots, 23.5 knots
- **Wind Spectral Model**: API, API, API
- **Direction**: 225°, 225°, 225°

### Current

- **Velocity**: 1.45 knots, 1.45 knots, 0.58 knots
- **Direction**: 270°, 270°, 270°
Model Tests: Connected System, $H_s = 5.5m$
Model Tests: Hook-up, $H_s = 3.5m$
## Comparison with Model Test Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Theory</th>
<th>Test</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative Vessel Motions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surge, Min</td>
<td>-7.10</td>
<td>-8.78</td>
<td>meters</td>
</tr>
<tr>
<td>Surge, Max</td>
<td>3.21</td>
<td>2.60</td>
<td>meters</td>
</tr>
<tr>
<td>Sway, Min</td>
<td>-9.19</td>
<td>-6.96</td>
<td>meters</td>
</tr>
<tr>
<td>Sway, Max</td>
<td>10.53</td>
<td>10.07</td>
<td>meters</td>
</tr>
<tr>
<td>Heave, Sig</td>
<td>4.50</td>
<td>4.78</td>
<td>meters</td>
</tr>
<tr>
<td>XY, Max</td>
<td>11.27</td>
<td>10.41</td>
<td>meters</td>
</tr>
<tr>
<td>XYZ, Max</td>
<td>12.13</td>
<td>11.74</td>
<td>meters</td>
</tr>
<tr>
<td><strong>Ball Joint Forces</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fx- Longitudinal Force</td>
<td>371</td>
<td>467</td>
<td>m. tons</td>
</tr>
<tr>
<td>Fy - Transverse Force</td>
<td>-560</td>
<td>-403</td>
<td>m. tons</td>
</tr>
<tr>
<td>Fz - Vertical Force</td>
<td>-165</td>
<td>-175</td>
<td>m. tons</td>
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<tr>
<td>Fxy - Resultant Force</td>
<td>591</td>
<td>488</td>
<td>m. tons</td>
</tr>
<tr>
<td>Fxyz - Resultant Force</td>
<td>605</td>
<td>516</td>
<td>m. tons</td>
</tr>
<tr>
<td><strong>Pendant Tension</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at Upper U-joint</td>
<td>1407</td>
<td>1291</td>
<td>m. ton</td>
</tr>
<tr>
<td><strong>Pulling Tension</strong></td>
<td>262.0</td>
<td>265.0</td>
<td>m. ton</td>
</tr>
</tbody>
</table>
Comparison: Model Test versus Analysis 1

Relative X Raos
Cr2, Tp=12s

Test
HOBEM
Wave Spec
Comparison: Model Test versus Analysis 2

Relative Y Raos
Cr2, Tp=12s

Freq (Hz)

Y Raos (m/m)

Test
HOBEM
Wave Spec
Comparison: Model Test versus Analysis 3

Relative Z Raos
Cr2, Tp=12s

- Test
- HOBEM
- Wave Spec

Freq (Hz) vs. Z Raos (m/m)
Time Domain Analysis

Analysis of the LNGC hook-up to the FLNG
- Time domain analysis using OrcaFlex
- LF motions calculated from wind, wave and current
- WF motions calculated from RAOs
- LF motions fully coupled through yoke and pull-in line
- Duplex yoke modeled in full detail with u-joint friction
- Pull-in winch in constant speed mode (3m/min) with slip clutch at 275 MT
- Stern thrust of 80 MT on LNGC
Response in Hs 5.5m seas (Connected)
Hawser Winch—Similar to 250HP Markey Softline Escort Tugboat Used for LNG Carrier Service

- Scalable to 1000 – 1200 HP, 300 ton
- Existing & Proven control technology
- High thermal energy dissipation for shock load and rendering operation
Winch Modeling in OrcaFlex

Winch, in constant speed mode with water-cooled slip brake

Pull-in Rope guided through yoke to LNGC bow

Friction Force

Sheave

FLNG
Connection Analysis
Analysis Results

- **Pull-in Line Tension**
- **Pull-in Line Length between Yoke Tip and Connector**
- **Slippage of winch line through clutch**
- **Clearance between Buoyancy Tank and LNGC Bow**

[Graphs showing various measurements over time]
Summary & Conclusions

• Robust Tandem Mooring System Developed for FLNG Offloading in Harsh Environments
• Can be used with existing LNG Transfer Systems
• Also suitable for use with Cryogenic Hoses (under qualification / not yet field proven)
• Global Responses Predicted Well by Frequency Domain Analysis
• Time Domain Model Used to Model Reconnection of System – also useful for developing site specific operational criteria.