ADVANCES IN MODELLING METHODS FOR ULTRA-DEEPWATER MOORINGS AND RISERS

Madrid, Spain

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MCEDD 2014 Theme

- Demand – Deepwater field development
- Incidents/integrity
- Need for testing
- Innovation
DEEPWATER FIELD DEVELOPMENT - DEMAND

World energy Outlook 2013 – International Energy Agency (IEA)

- Deepwater contribution –
  - 1990: 60 thousand barrels per day
  - 2012: 6% of conventional crude
  - Projection in Brazil by 2035: 11% of conventional crude
Mooring Statistics (Mooring Integrity JIP – Noble Denton)

- 1980 to 2001
- Cost of single line failure
- Mooring integrity management (failure detection, inspection – corrosion / wear assessment, dealing with marine growth...)
  
  50% of units cannot monitor line tensions in real time,
  33% of units cannot measure offsets from the no-load equilibrium position,
  78% of units do not have line failure alarms,
  67% of units do not have mooring line spares available,
  50% of units cannot adjust line lengths.

- Design, analysis and testing

<table>
<thead>
<tr>
<th>Type of Unit</th>
<th>Number of Operating Years per Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling Semi-submersible</td>
<td>4.7</td>
</tr>
<tr>
<td>Production Semi-submersible</td>
<td>9.0</td>
</tr>
<tr>
<td>FPSO</td>
<td>8.8</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Description</th>
<th>Approx. Cost of Single Line Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000bpd N. Sea FPSO</td>
<td>≈ £2M</td>
</tr>
<tr>
<td>250,000bpd W. African FPSO</td>
<td>≈ £10.5M</td>
</tr>
</tbody>
</table>
The need for Model Testing

- Proof of concept
- Confirm assessment of hydrodynamic loads on vessel, verify design assumptions
- Validate numerical models – Global design verification of loads/motions/tensions
- Calibrate numerical models
- Unexpected and highly nonlinear phenomena – Wave steepness, wave impact/run-up, VIM
- High importance assets

Innovation

- Testing new floater/technology/territory
MOTIVATION

Challenges

- Numerical modelling – Excessive computational times
- Impossible to model test complete system using conventional scales
Industry has used line truncation techniques to tackle limited depth problem

*If done Correctly it Can*:
- Improve efficiency of numerical modelling for deepwater line dynamics (shorter line = less elements)
- Enable model testing at more than 1:100 scale

**Traditionally passive truncation preferred**
PASSIVE TRUNCATION

Setting up Truncated System

- Replicate static characteristics (stiffness) of full depth system
- Truncated water depth limited by lab capability
- Optimization function to maintain line geometric properties
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Performance
- Complex truncated line configuration (clumps/buoys)
- Vessel motions – increased water depth = increased importance of \textit{line dynamics}
- Poor estimation of \textit{dynamic tensions} – fatigue
- Complex segmentation corrupts modelling physical coupling between vessel and lines
MOORING DAMPING

Ref – Zhengqiang Xu, Strathclyde University

- Turret moored FPSO – LF and superimposed WF motions
- DNV recommendation for CD
- WF motions will dramatically increase mooring damping
- Riser damping comparable to mooring damping. Riser damping less sensitive to WF motions

<table>
<thead>
<tr>
<th>Vessel Dimension</th>
<th>L-270m; B-52m; T-12m</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_w ) of moored FPSO system</td>
<td>( \sim 150s )</td>
</tr>
<tr>
<td>( L_c ) of chain-wire-chain moorings (20)</td>
<td>1880m (Chain D=152mm)</td>
</tr>
<tr>
<td>( L_c ) of steep-wave risers (24)</td>
<td>629m</td>
</tr>
<tr>
<td>Water depth</td>
<td>400m</td>
</tr>
</tbody>
</table>

![Damping ratio graph](image)
Ref – Zhengqiang Xu, Strathclyde University

- Energy dissipation due to transverse motions highest at:
  - Fairlead, but motions decay quickly
  - Touchdown due to geometric coupling axial and transverse vibrations
- CD at touchdown area – monitoring/marine growth
LOCALIZED TRUNCATION

Ref – Alex Argyros & Robin Langley, Cambridge University

Method

- Computationally* - Upper sections modelled in detail terminating to an approximate analytical model
- Hybrid model testing – Using localised truncation to simulate lower section

Exploit Physical Features of System

- Close to water surface: Wave action, strongest currents and coupling
- Transverse line dynamics decay rapidly – Bottomless/semi-infinite line

Truncated Water Depth based on Line Dynamic Response

- Assessment for decay of transverse line dynamics – **Stage 1**
- Minimum truncation length: Transverse vibrational characteristics are inertia driven – **Stage 2**
- Approximate termination: Local quasi-static line properties – **Stage 3**
- Simple truncation mechanism for model testing
Numerical truncation using Passive vs Localized Approach

- Details
  - 2700m WD
  - Taut mooring system
  - Fairlead/seabed segment 200m
  - Polyester rope 3700m
  - Pretension 300Te
  - Hs = 15m; Tp = 14s

Ref – Alex Argyros & Robin Langley, Cambridge University
Numerical truncation using Passive vs Localized Approach

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Numerical truncation using Passive vs Localized Approach

Passive Truncation
- 6 segments – 3 line types
- 2 buoys + 1 clump weight

Localized Truncation
- Stages 1 & 2 – Truncation within rope segment with minimum $d:dT \sim 1:4.5$
- Upper section modelled exactly as the full depth line
- End termination – 3 non-linear coupled springs in X, Y, Z

Ref – Alex Argyros & Robin Langley, Cambridge University
Numerical truncation using Passive vs Localized Approach

System statics (stiffness)
- Passive truncation → stiffer system

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EXAMPLE TRUNCATION

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- Passive truncation → some disagreement in surge/sway

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- Additional large amplitude higher frequency peak tensions

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Ref – Zhengqiang Xu, Strathclyde University

- Numerical modelling (coupled analysis) of moored FPSO
- CD varied by factor of 2.0
- Reduction of LF motion near natural frequency
- Reduction of LF tension
- Increase of WF tension
CD VARIATION

CD Variability due to:

- Marine growth – inspection
- Motion

\[ C_D, C_M = f(Re, KC, k) \]

Range of KC and Re numbers for R3s chain (D=152mm) around touch-down zone

Ref – Zhengqiang Xu, Strathclyde University
CD DETERMINATION BY CFD

CFD Model Validation – Flow past a smooth cylinder

- Turbulence models: LES vs k – w SST (URANS)
- Near wall treatment for wall boundary flows
- Steady flow and oscillating flow
- Steady flow – LES more recommended – 3D vortex in wake
- Oscillatory flow – flow in the wake is more 2D (suppression of 3D by harmonic motion of cylinder)
- k – w SST (URANS) uses a coarser mesh and so is selected

Ref – Zhengqiang Xu, Strathclyde University

<table>
<thead>
<tr>
<th>Fourier-averaged</th>
<th>Case1</th>
<th>Case2</th>
<th>Case3</th>
<th>Case4</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC</td>
<td>20.6</td>
<td>29.6</td>
<td>20.6</td>
<td>29.6</td>
</tr>
<tr>
<td>β</td>
<td>3123</td>
<td>3123</td>
<td>5260</td>
<td>5260</td>
</tr>
<tr>
<td>Calculated</td>
<td>0.78</td>
<td>0.65</td>
<td>0.53</td>
<td>0.52</td>
</tr>
<tr>
<td>Experimental ( C_D^{(1)} )</td>
<td>0.86</td>
<td>0.68</td>
<td>0.70</td>
<td>0.62</td>
</tr>
<tr>
<td>Calculated</td>
<td>0.44</td>
<td>0.54</td>
<td>0.79</td>
<td>0.82</td>
</tr>
<tr>
<td>Experimental ( C_L^{(1)} )</td>
<td>0.52</td>
<td>0.61</td>
<td>0.76</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Values of experiments obtained from the curves drawn by Sarpkaya (1976)
**Chain Numerical Models**
- 2 links (1 full & 2 half)
- Periodic boundary conditions
- No slip wall
- Inlet/outflow boundaries
- Symmetry in lateral sides
- 8 million cells

Ref – Zhengqiang Xu, Strathclyde University
Results for studless chain

- Flow direction
- Re and KC number
  - Considering only Re CD variation is small
  - For oscillating chain in still water the effect of KC on CD is significant for flow with low Re

Ref – Zhengqiang Xu, Strathclyde University
SUMMARY

- Need for deepwater/model testing
- Present difficulties and challenges
- Innovative method for truncation
- Line dynamics
  - LF damping
  - Zones of importance
  - Motions and tensions
- CD determination using CFD
Thank you

Alex Argyros
Naval Architect
DNV GL

www.dnvgl.com

SAFER, SMARTER, GREENER