Derivation of CALM Buoy Coupled Buoy RAOs in Frequency Domain and Experimental Validation

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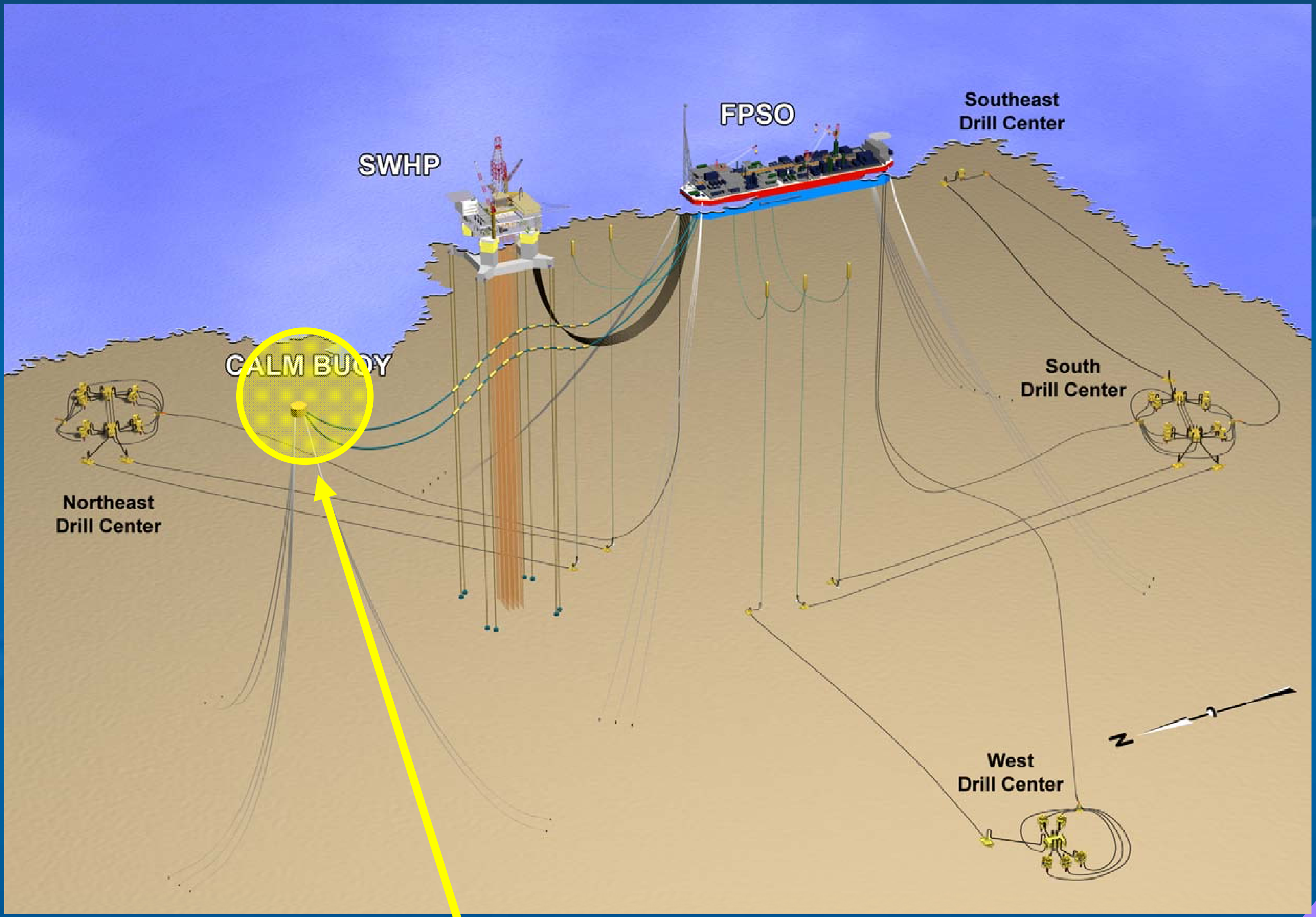
Outline

- Introduction: Deepwater CALM
  Theoretical background
- Comparison TD and FD
- Experimental Set-up
- Validation of Experimental Data
- Summary

Kizomba A Field Development



deepwater CALM buoy

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Coupled System in Time Domain

- Hydrodynamic Loads on the buoy
  - Hydrodynamic calculations via BEM method (Diodore / WAMIT)
  - Added mass, radiation damping, first order wave force
- Loads on the lines
  - FEM software (DeepLines)
  - Lines characteristics + Morison's formulation
- Coupled system
  - In FEM software: extra node with six DOF for the floating body
  - Solve the coupled equation:

$$\{M + M_a(\infty)\}\ddot{\vec{X}} + \int_0^{\infty} R(t-\tau)\dot{\vec{X}}d\tau + K\vec{X} = \vec{F}_d + \vec{F}_w^{(1)} + \vec{F}_w^{(2)} + \vec{F}_{line}$$

Frequency Domain Analysis

- Basic equation :

$$Kx + B\dot{x} + M\ddot{x} = F$$

- Assuming that the position at time t is given by:

- With

$$X(t) = X_{stat} + \sum_{i=1}^{Nbfreq} \left\{ \mathrm{Re} \left\{ \left[\sum_{imp=1}^{Nimp} a_{imp}(\omega_i) x_{imp} + x_f(\omega_i) \right] e^{-j(\omega_i t)} \right\} \right\}$$

  – Static equilibrium :

$$K_{stat} x_{stat} = F_{stat}$$

  – Imposed displacement :

$$K_{stat} x_{imp} = 0$$

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Frequency domain analysis

- Loads on buoy from hydrodynamic calculations
- Dependency of matrices on frequency

$$\left[K(\omega) - j\omega\left(B + B_a(\omega)\right) - \omega^2\left(M + M_a(\omega)\right)\right]\{X(\omega)\} = \{F(\omega)\}$$

- Viscous damping linearisation (on buoy and lines)

$$\|v_{rel}\| v_{rel} \approx \Omega(v_{rel}) v_{rel}$$

  – Regular waves : $\Omega = \frac{8}{3\pi} A$ (A : norm of velocity)

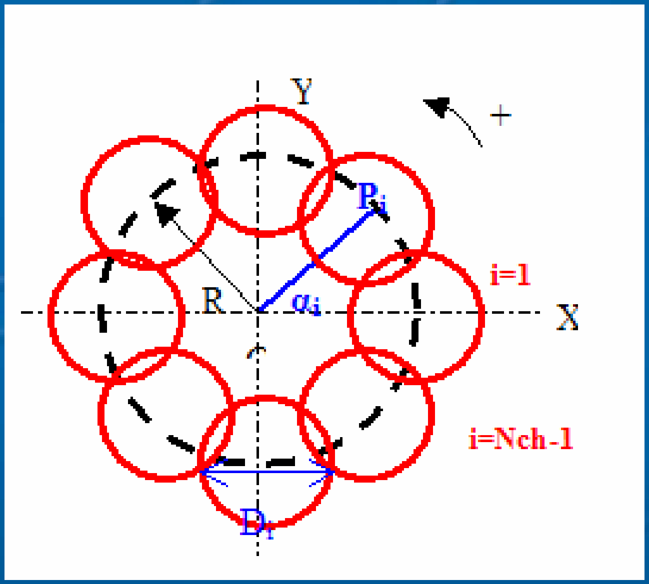
  – Irregular waves $\Omega = \sqrt{\frac{2}{\pi}}\, 2\sigma$ (σ : standard deviation)

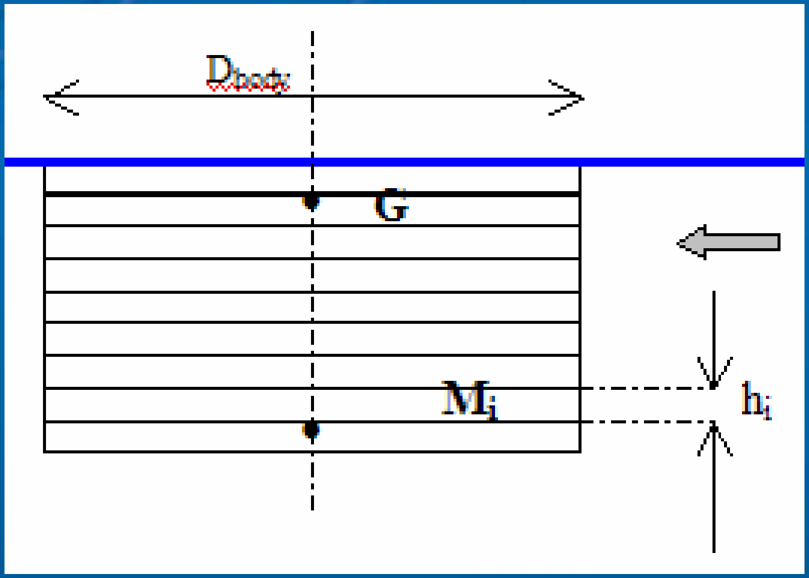
Buoy Viscous Damping

- Damping matrix on absolute velocity

or

- Morison formulation on bar elements





Coupled System & Relative Velocity Damping

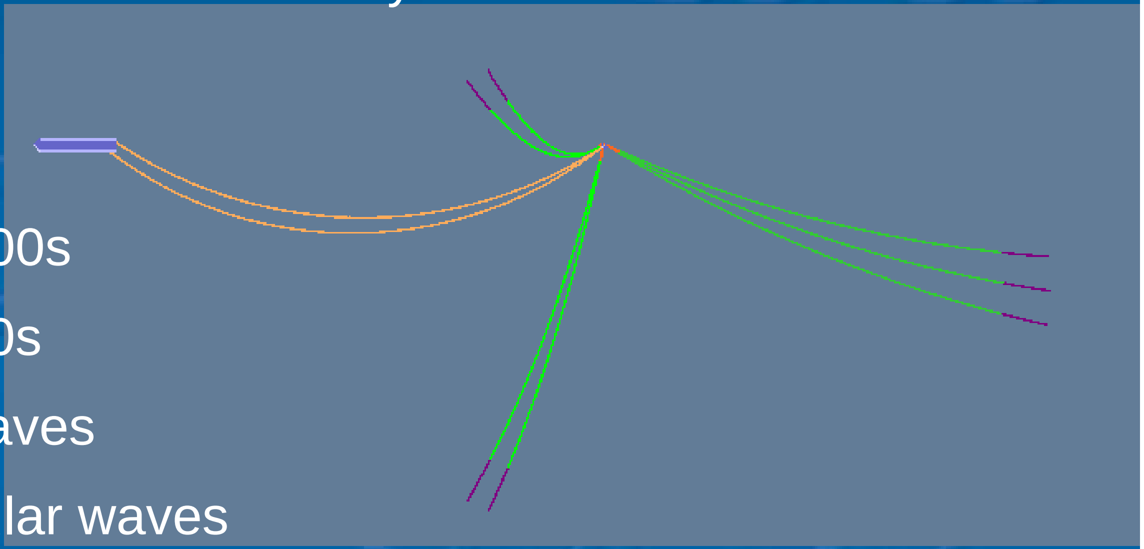
- Wave in the OOL plane towards the buoy
- JONSWAP Spectrum
- Comparison made

  Time domain over 10,800s

  Time domain over 2,000s

  Time domain regular waves

  Frequency domain regular waves



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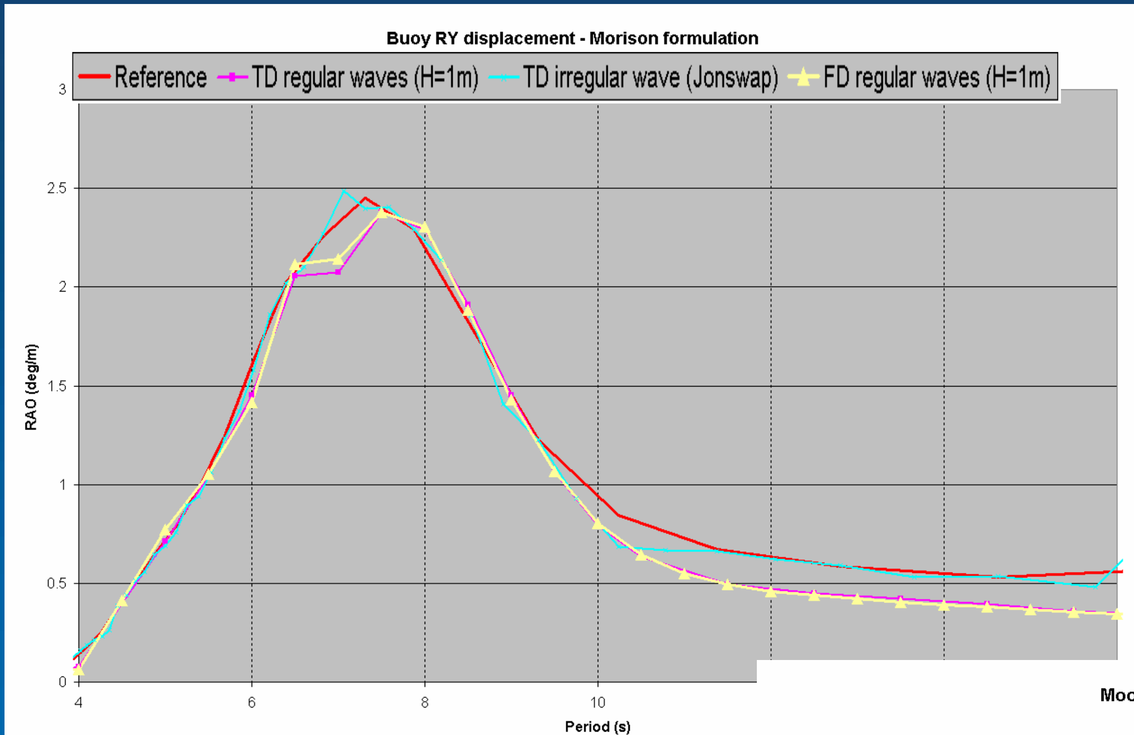
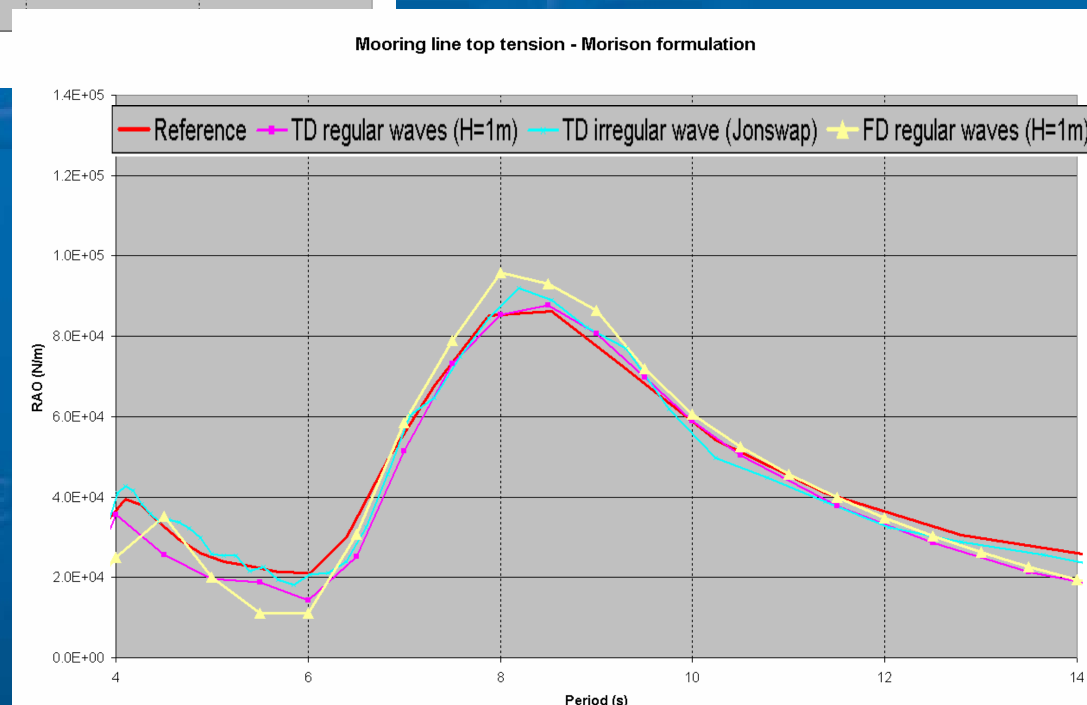
RAOs Comparisons

pitch motion

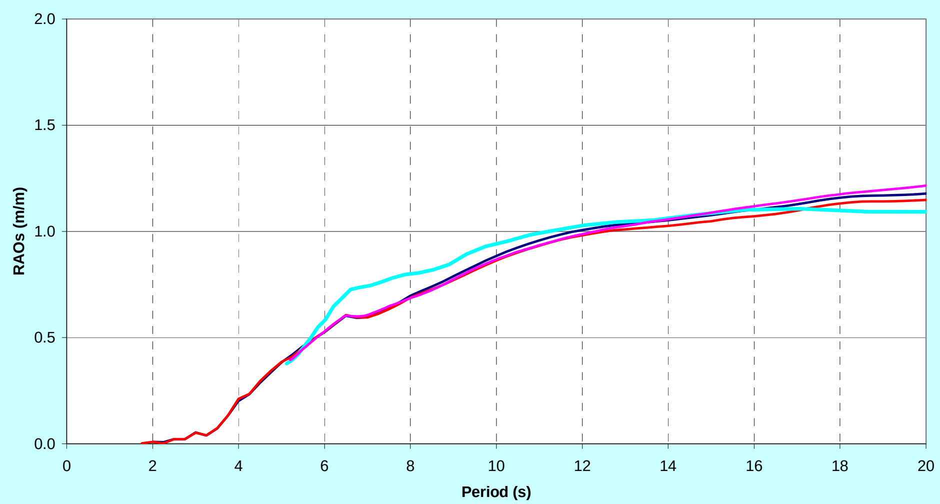


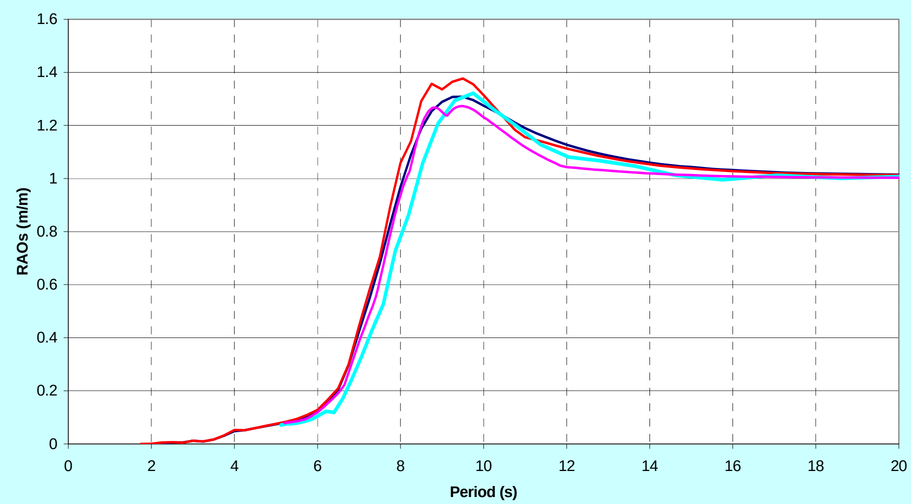
mooring line top tension

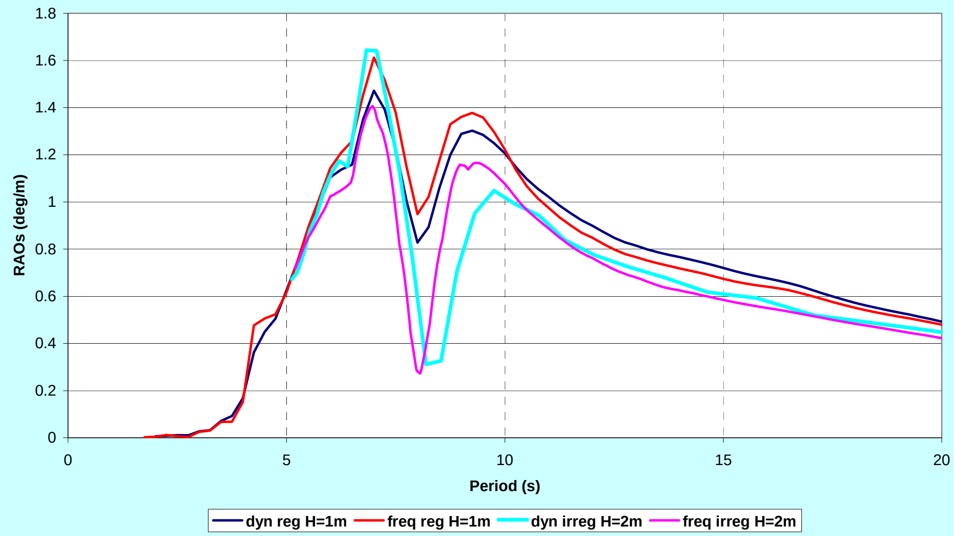


Absolute Velocity Damping

Comparisons between TD/FD in regular/irregular waves



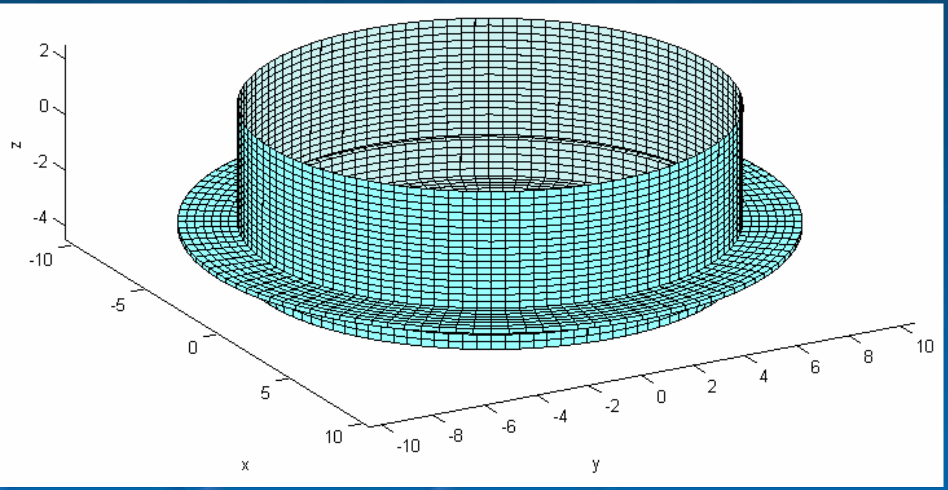


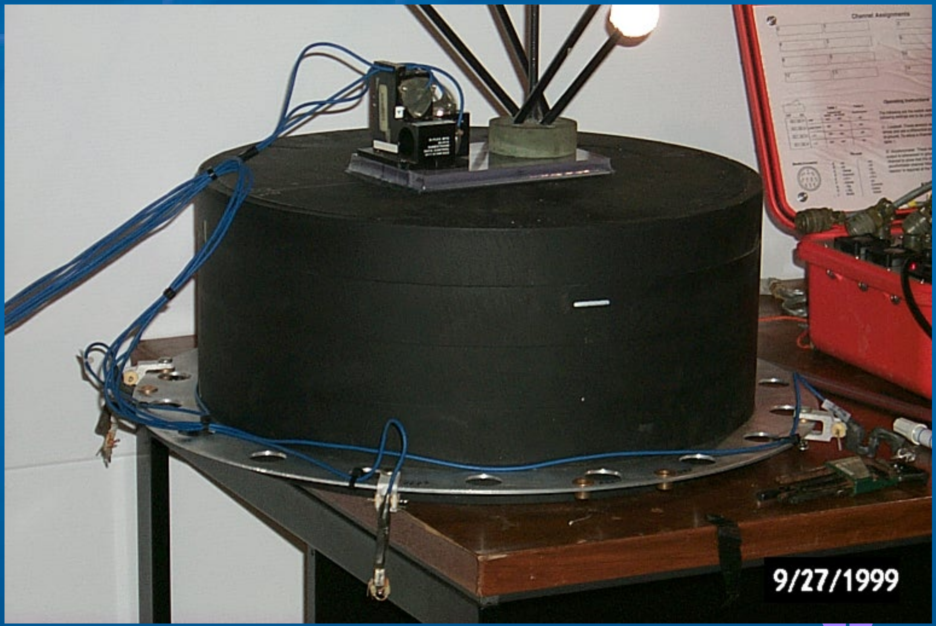


Experimental Set-up: CALM Buoy Model

Particulars	Value
Buoy Hull Dia. (m)	17.0
Skirt Dia. (m)	21.0
Buoy Height (m)	7.65
Draft (m)	5.65
Displacement (ton)	1,293.2
KG (m)	3.82
Water depth (m)	106.8

* 4 weak spring moorings
  (Length: 350m, EA:180MT)





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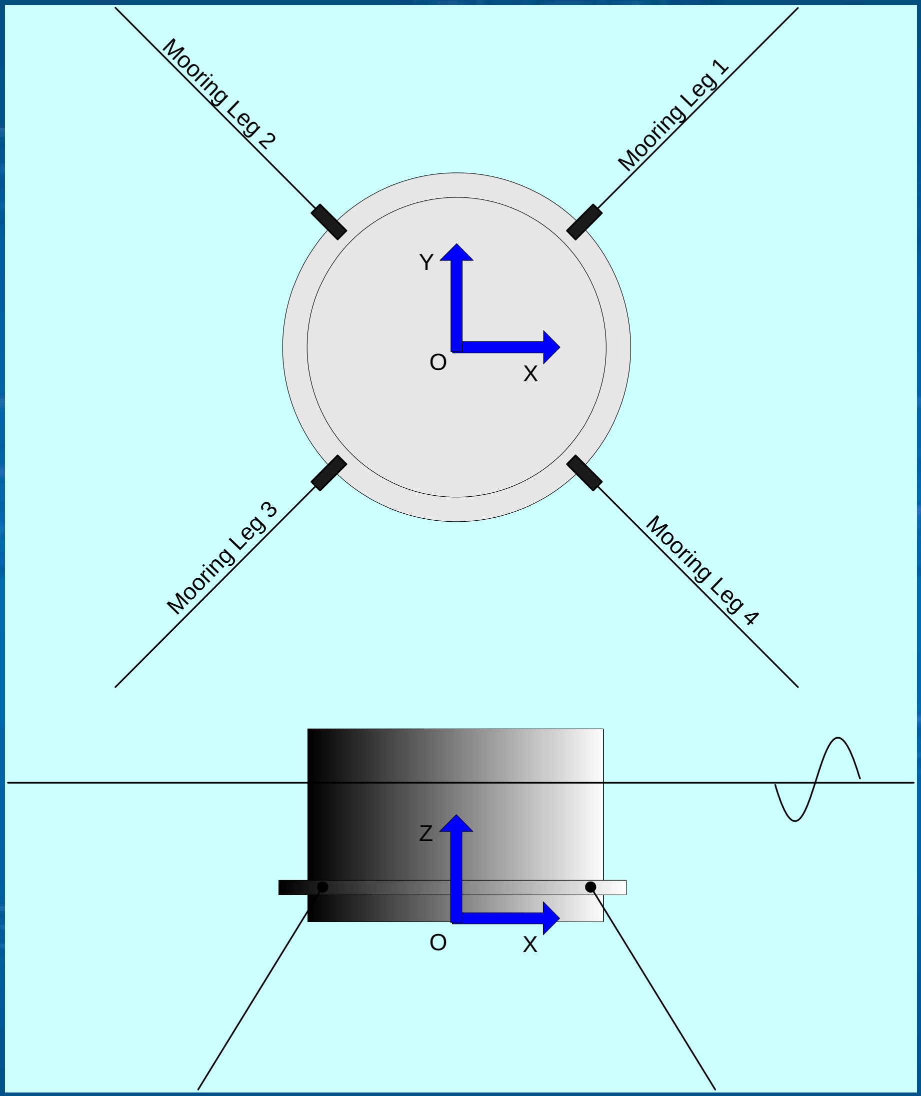
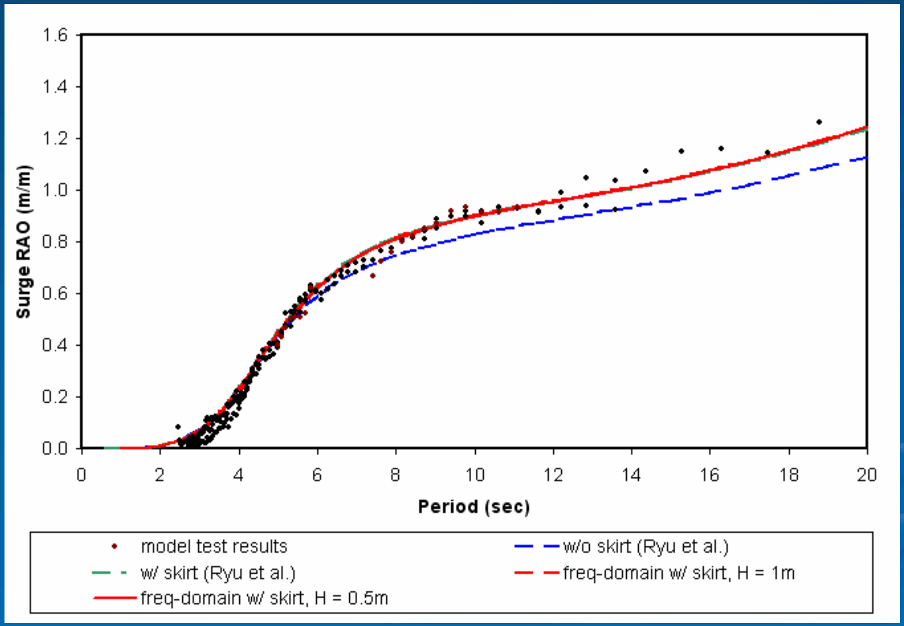
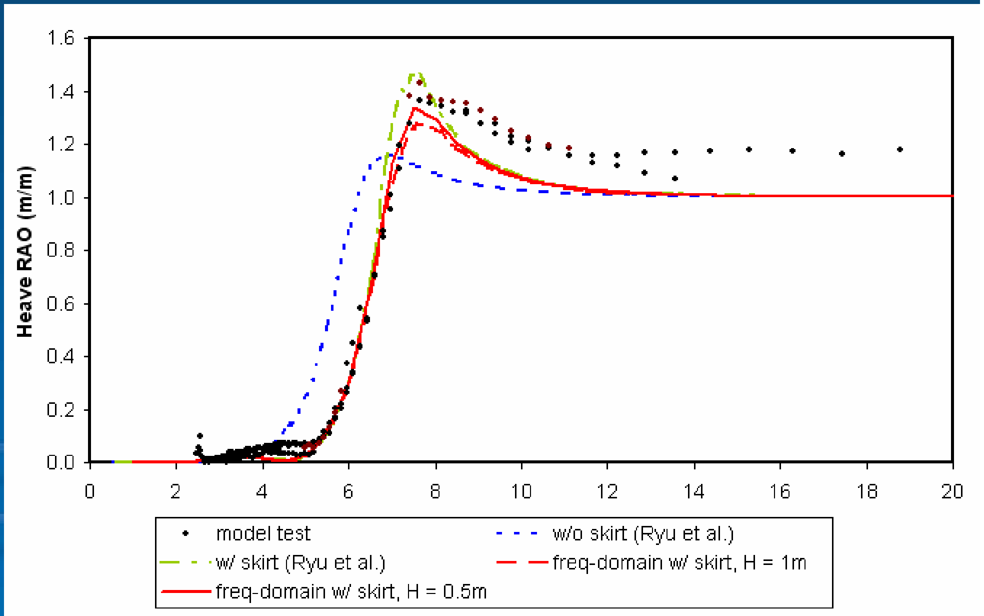
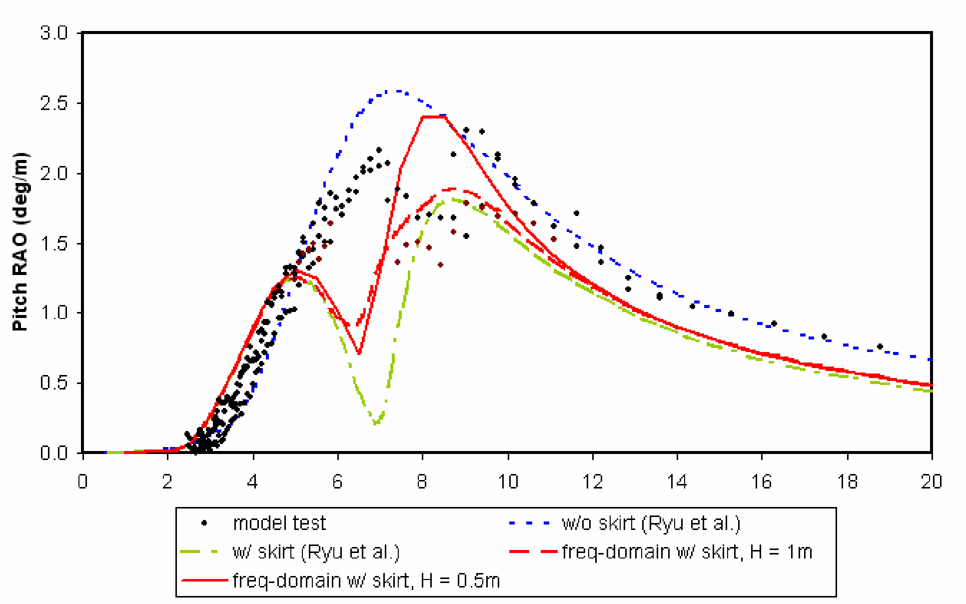
Experimental Set-up: Mooring Pattern



Validation with Model Test Results







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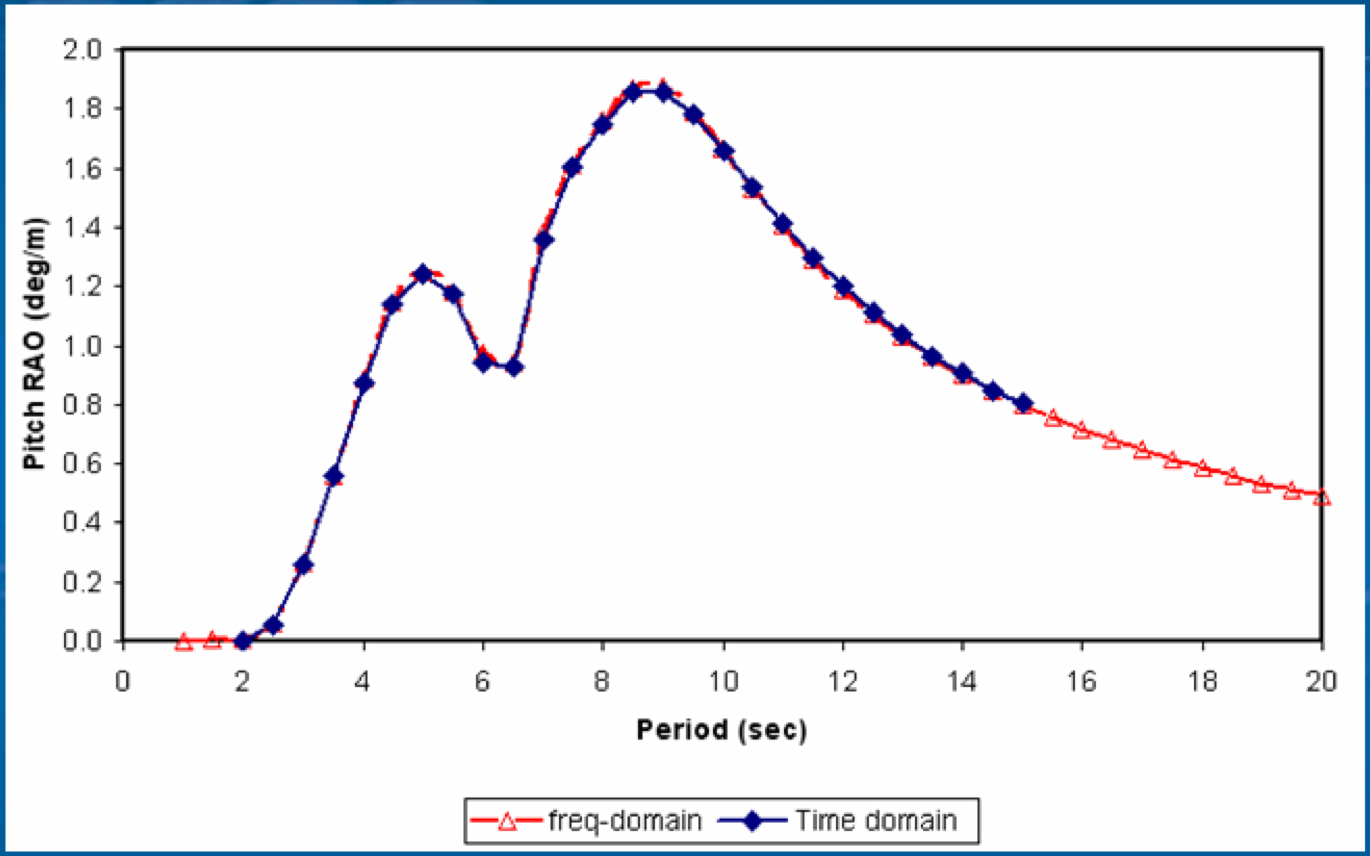
Comparisons between TD and FD (Pitch Motion)



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Summary (1/2)

- Coupled system can be captured by a linear method (with drag linearization)
- Regular and irregular waves
- Frequency domain analysis has been applied to derivation of RAOs for CALM buoys with mooring.
- Comparison with time domain simulations shows that the results are very reliable at a fraction of the computer time.
- Suggested FD approach, restricted to first order wave load, is especially useful for parametric study and can help design of the coupled system.

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Summary (2/2)

- Tension and bending RAOs in the mooring and export lines as well as buoy motion can also be captured.
- It is possible to use FD analysis to quickly estimate the performance of CALM system in terms of fatigue life.
- Comparison with experimental results shows good agreement between the frequency domain calculations and the measurements. As viscous damping is one of the key elements to model buoy coupled motion, it indicates that both the damping methodology and its linearization are properly taken into account.

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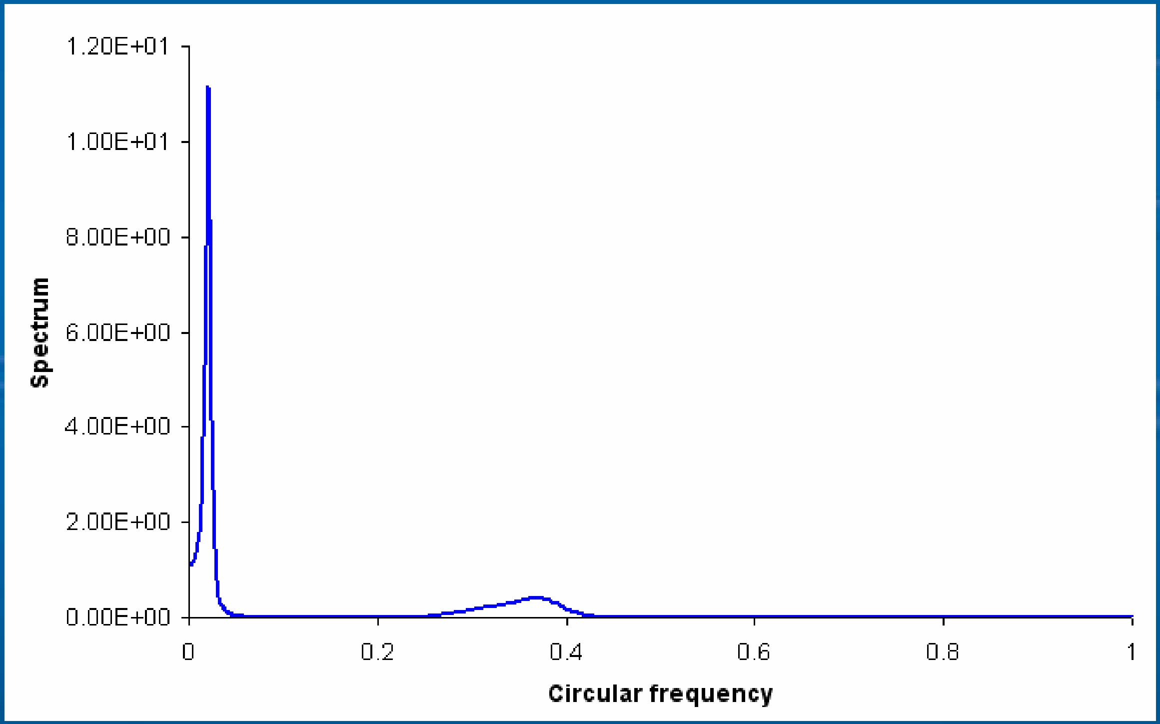
Future Work

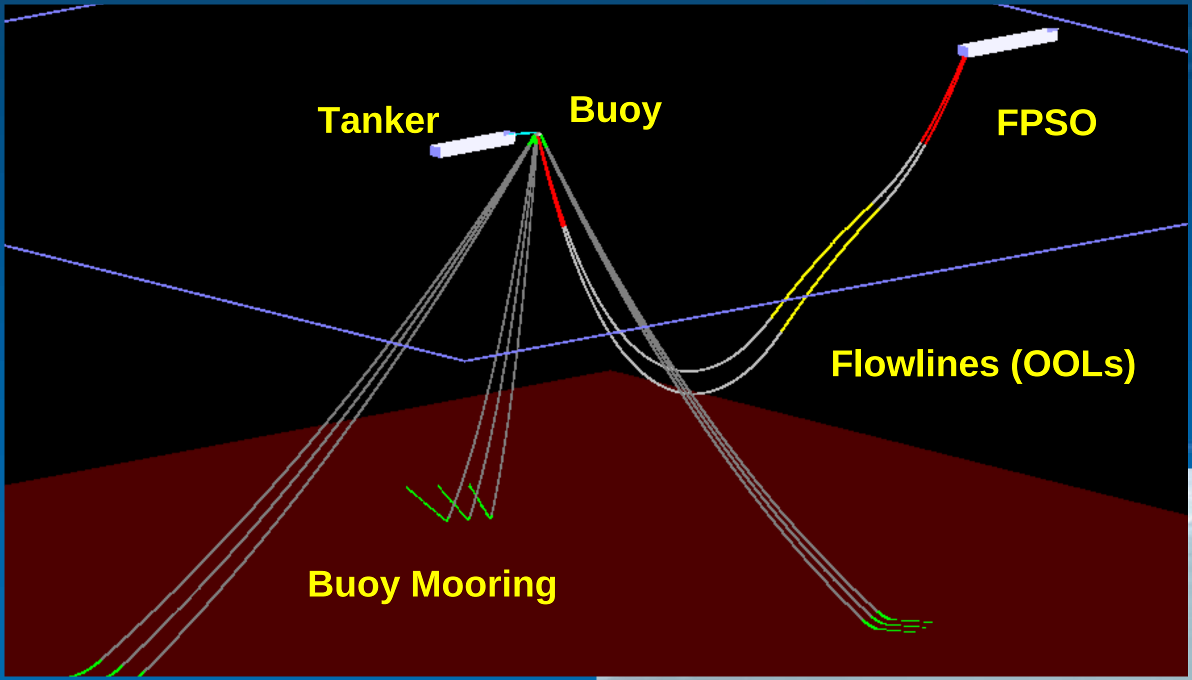
- 2nd order wave loads and wind loads

  - low-frequency motion

  - moored FPSO case: spectrum of surge motion



Example: Tanker Connected CALM Buoy System



Thank you!

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