



The Dynamics of Deep Water Offloading Buoys



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Fluid-Structure Interaction 2005

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Outline of Presentation

- **Background – Shallow Water CALM Buoys**
- **Extension of Shallow Water Technology to Deepwater**
- **Issues / concerns with Prototype Design**
- **Detailed Analysis of System Response**
- **Comparison with Experimental Data**
- **Application to Design**
- **Summary and Conclusions**

CALM Buoy Offloading System

**Catenary
Anchor Leg
Mooring**

**Most Popular
Shallow Water
Offloading
System**

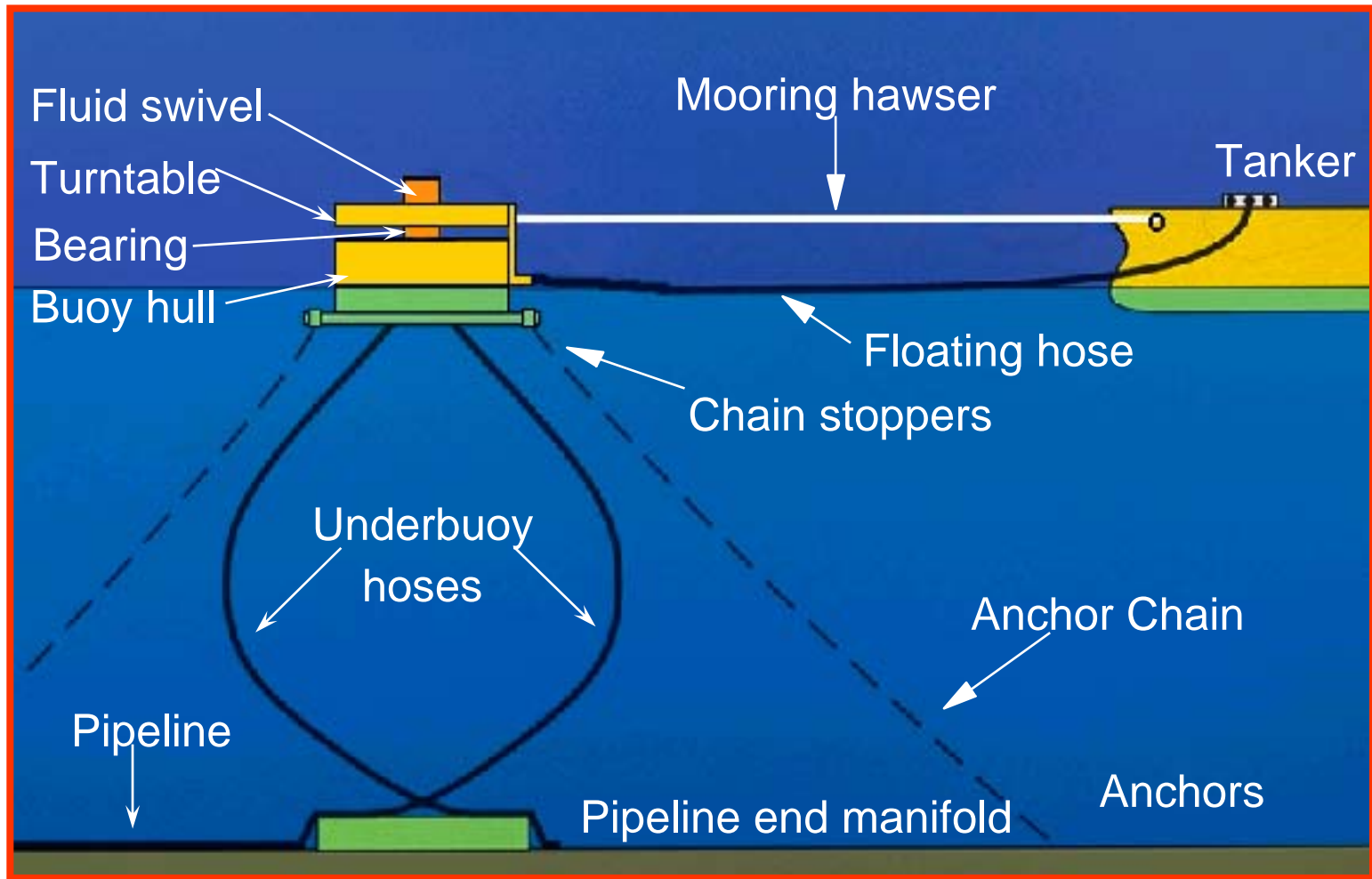
**Vessels of
Opportunity**

**Bearing and
Swivels above
Water Line**

Versatile



Shallow Water CALM Buoys

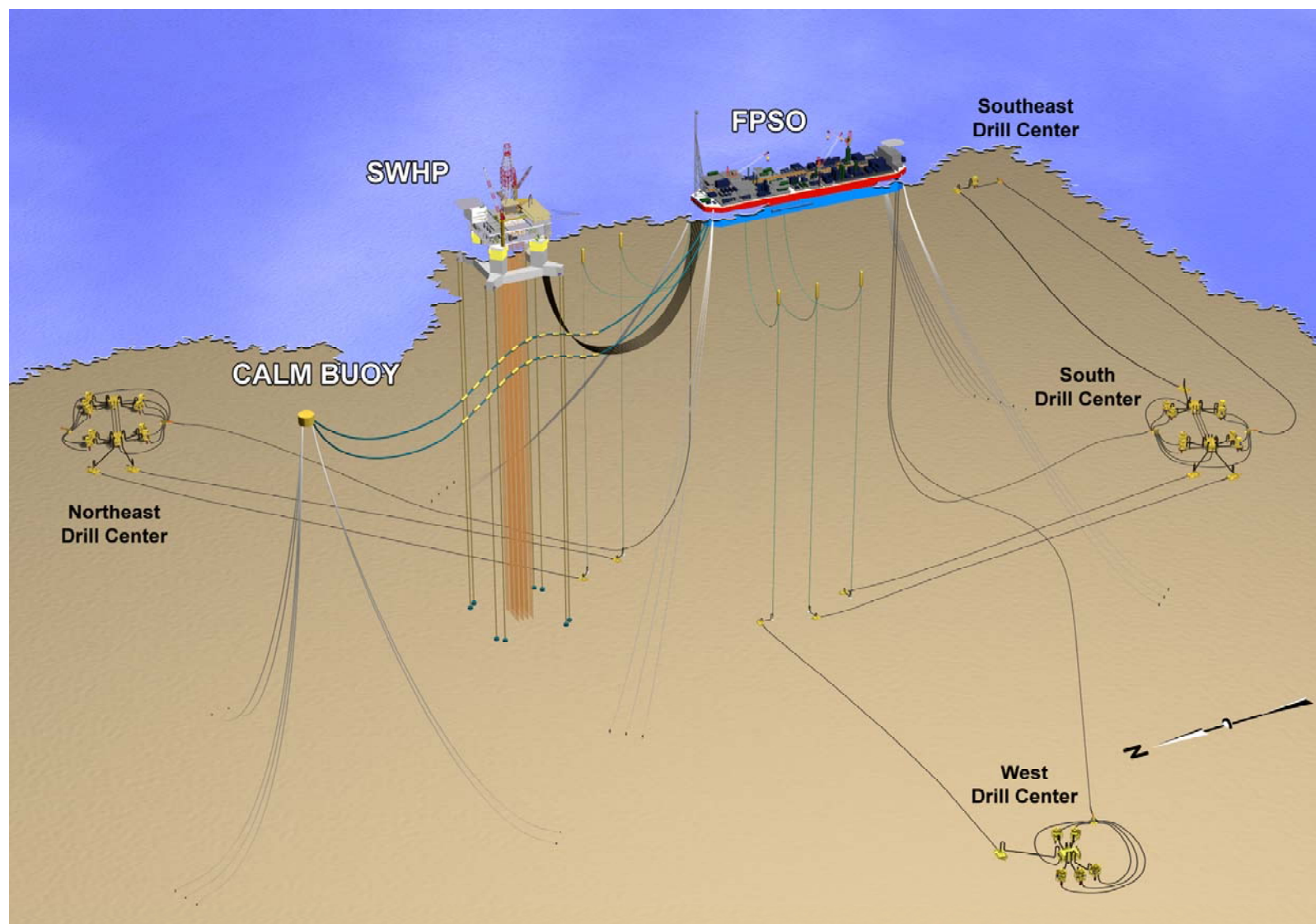


Why Deep Water Offloading Systems?

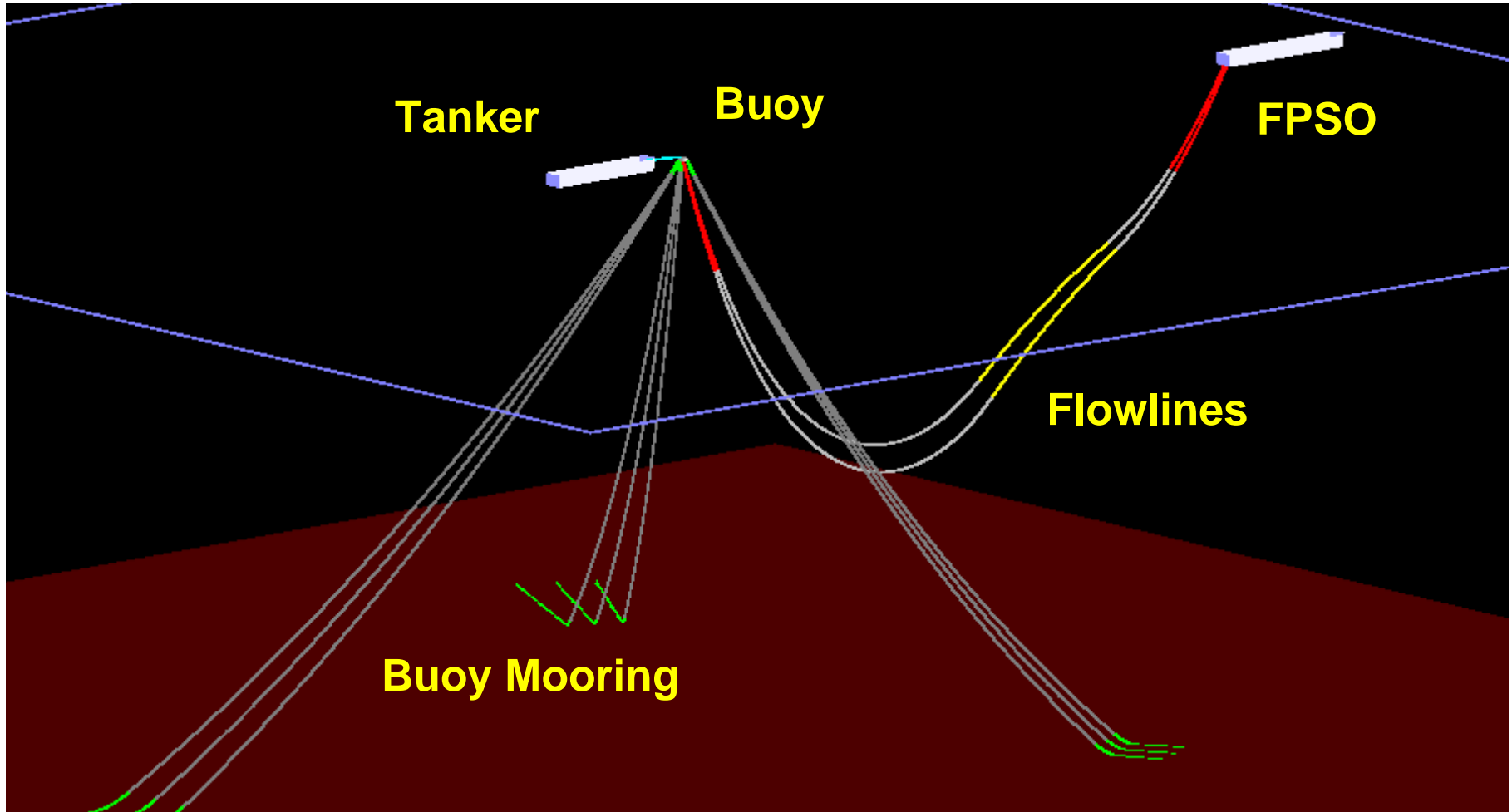


- **Spread-Moored (non-weathervaning FPSO's)**
- **West Africa & Brazil**
- **Mild to moderate environment**
- **Long Field Life (20 - 30 years)**
- **High Rates of Production (> 100,000 bopd)**
- **Frequent Offloading to Vessels of Opportunity**

Kizomba A Field Development

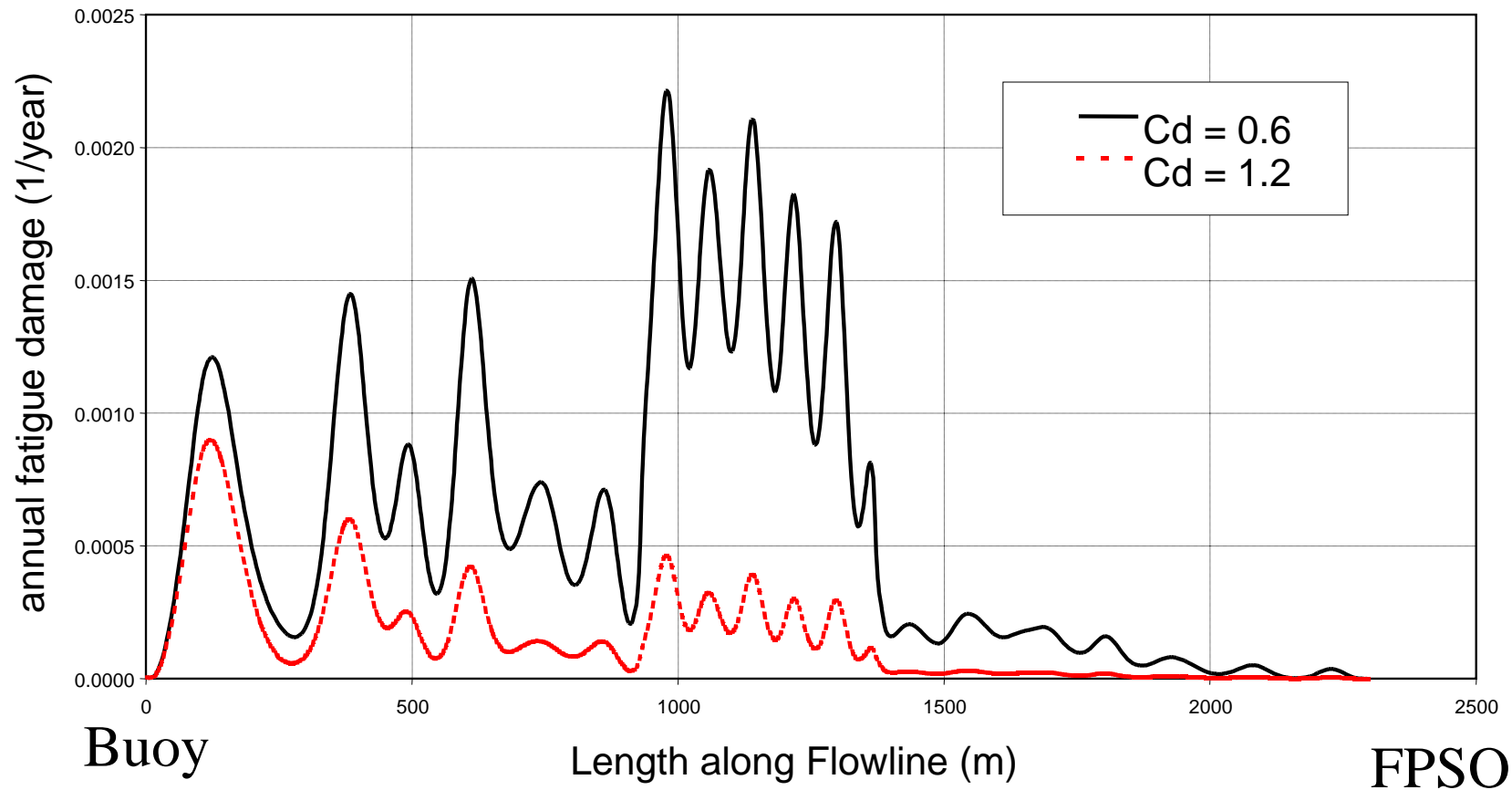


Deepwater Offloading System



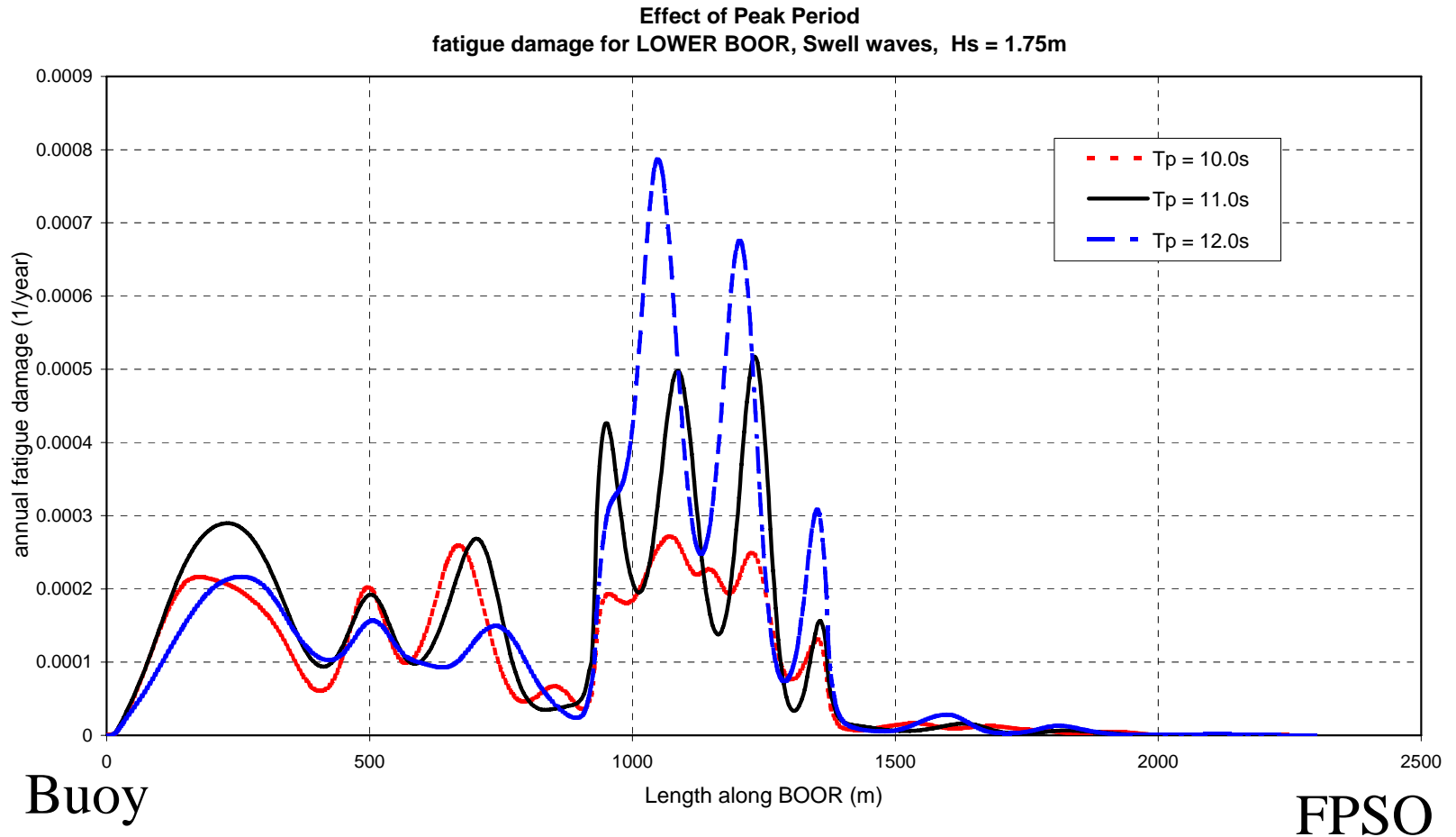
Previous Work: Flowline Response

Sensitivity to Drag Coefficient



Previous Work: Flowline Response

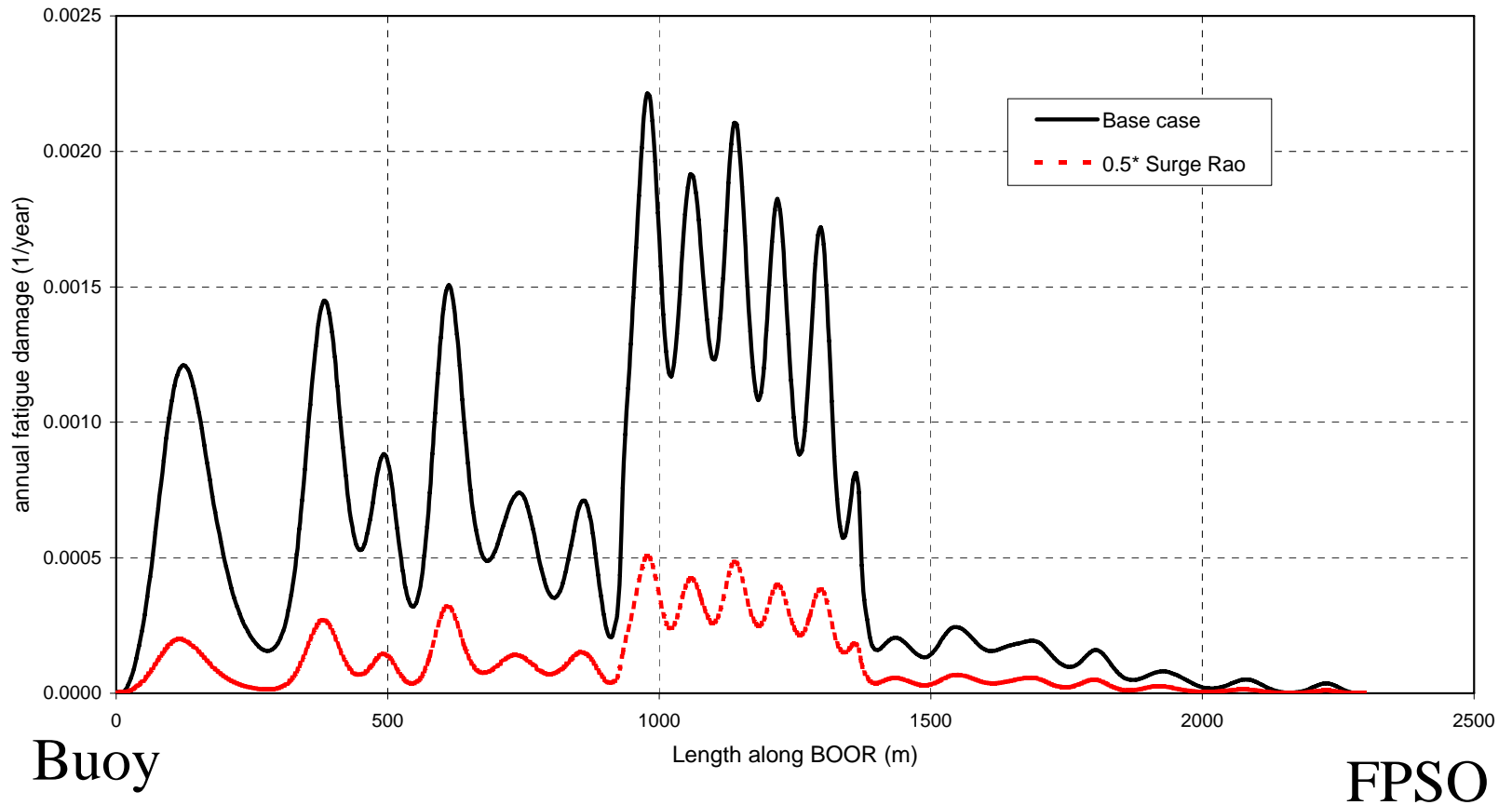
Influence of Swell Bin Width



Previous Work: Flowline Response

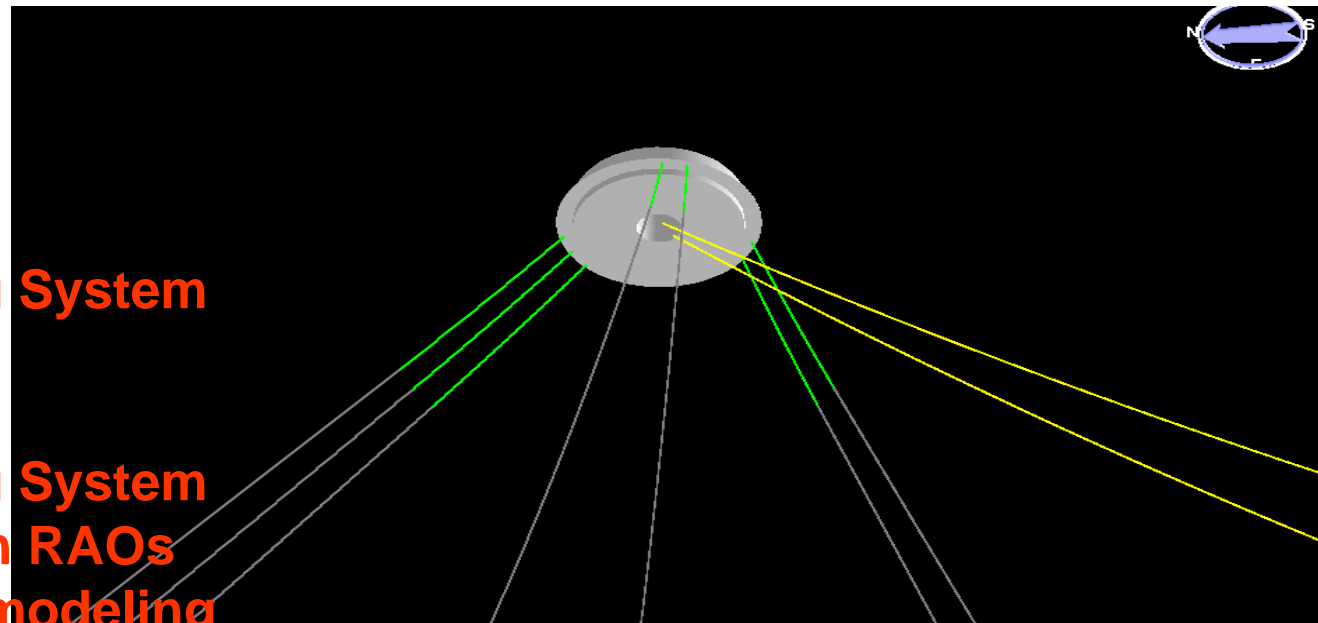
Influence of Surge Reduction

Effect of 50% reduction in Surge RAO
fatigue damage for LOWER BOOR Hs = 1.125m, Tp = 5.8s



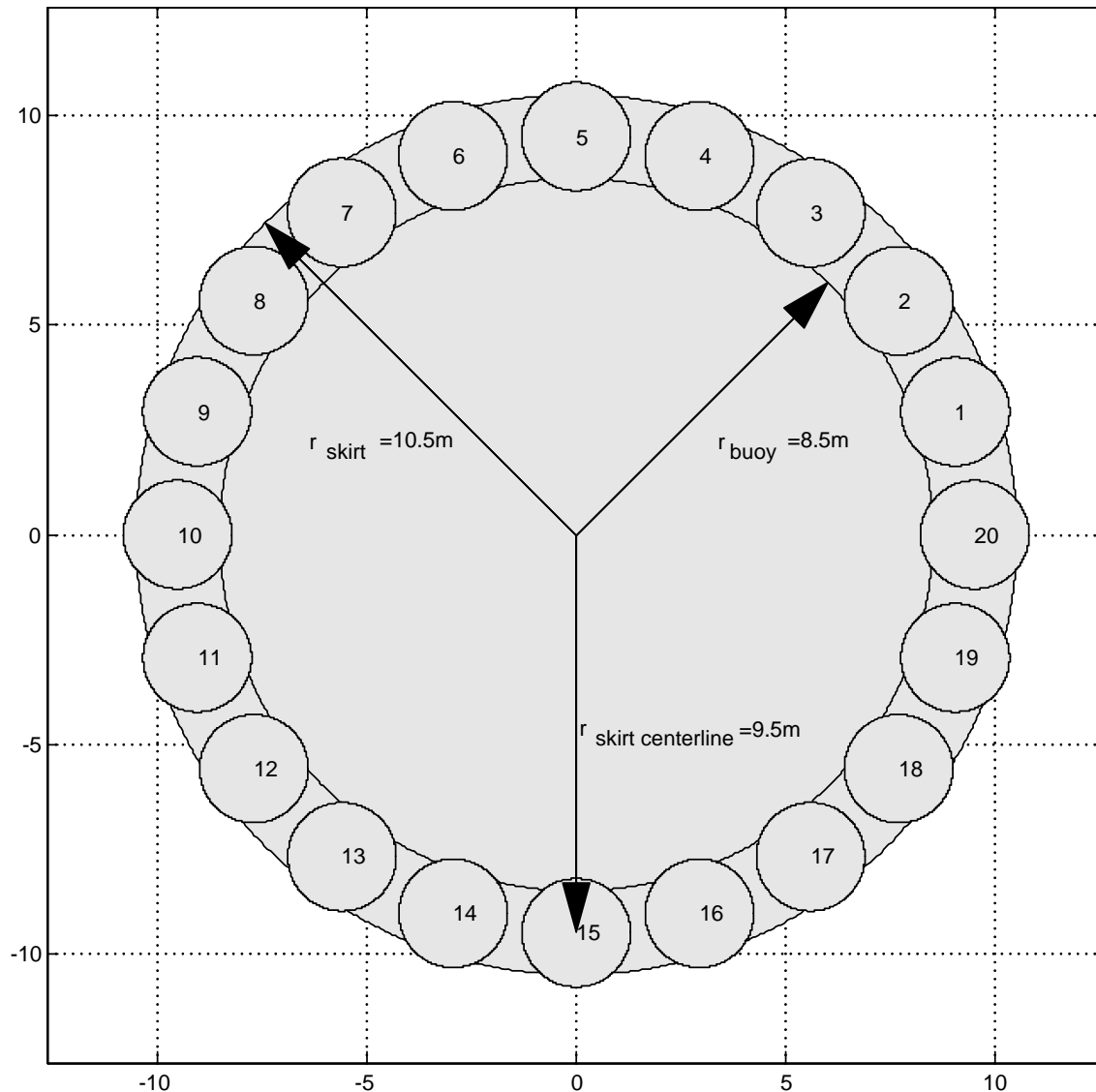
Objective: Better Prediction of Deepwater Buoy System Responses

- Model wave exciting forces and added mass/radiation damping using diffraction programs like WAMIT or HOBEM
- Study sensitivity of buoy skirt drag forces and added mass
- Perform time-domain coupled analysis of system (DeepLines)
- Compare to frequency-domain solutions (In-house)



- Asymmetric Mooring System
- Eccentric CoG
- Center well
- Asymmetric Mooring System
- Fully-coupled motion RAOs
- Skirt viscous / drag modeling

Skirt Modeling

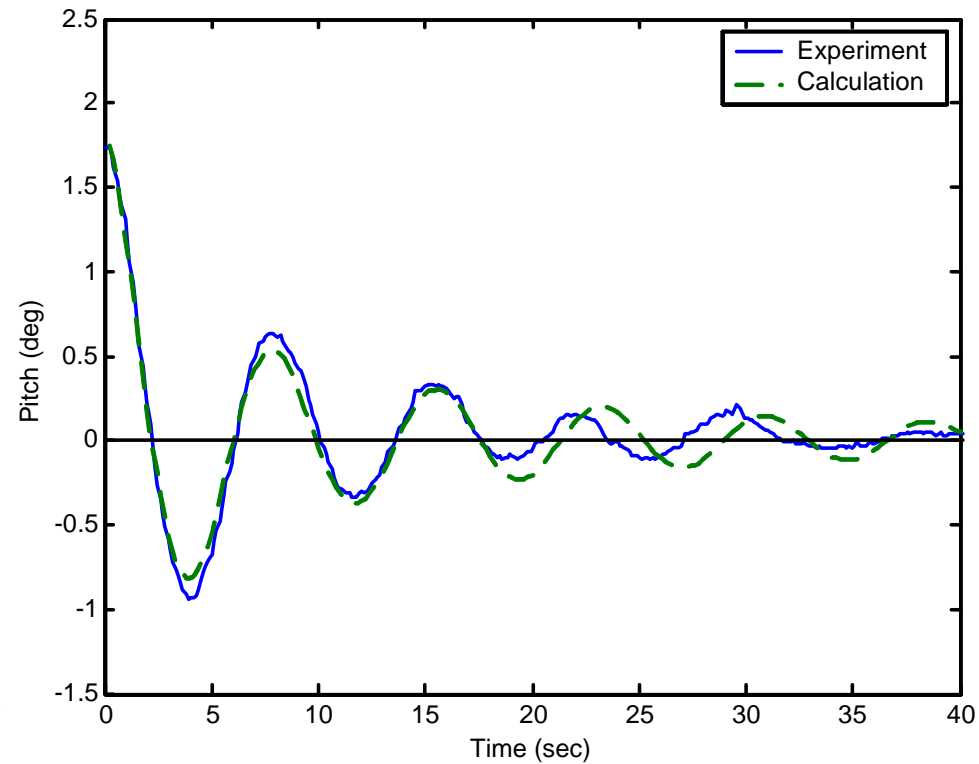
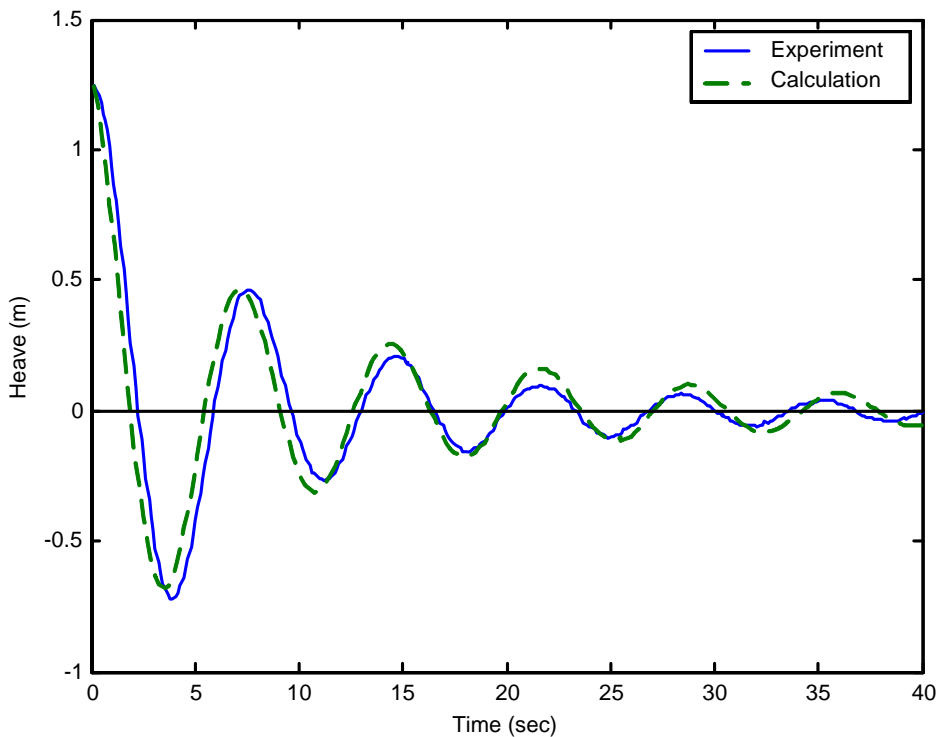


Summary of Buoy Viscous/Drag Modeling

| Mode | | Velocity Applied | | Linear or Quadratic | | Cd or D |
|-------|-------|------------------|----------------|---------------------|----------------|---------|
| | | Absolute | Relative | Linear | Quadratic | |
| Surge | | | $\sqrt{\quad}$ | | $\sqrt{\quad}$ | 1.2 |
| Sway | | | $\sqrt{\quad}$ | | $\sqrt{\quad}$ | 1.2 |
| Heave | | | $\sqrt{\quad}$ | | $\sqrt{\quad}$ | 4.5 |
| Roll | Hull | $\sqrt{\quad}$ | | | $\sqrt{\quad}$ | 8.56e8 |
| | Skirt | | $\sqrt{\quad}$ | | $\sqrt{\quad}$ | 6.0 |
| Pitch | Hull | $\sqrt{\quad}$ | | | $\sqrt{\quad}$ | 8.56e8 |
| | Skirt | | $\sqrt{\quad}$ | | $\sqrt{\quad}$ | 6.0 |
| Yaw | | $\sqrt{\quad}$ | | | $\sqrt{\quad}$ | 1.20e6 |

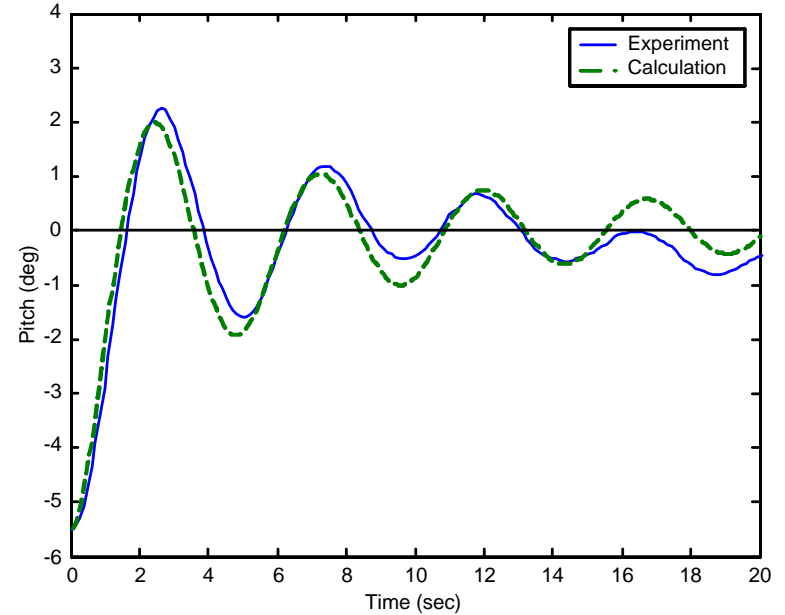
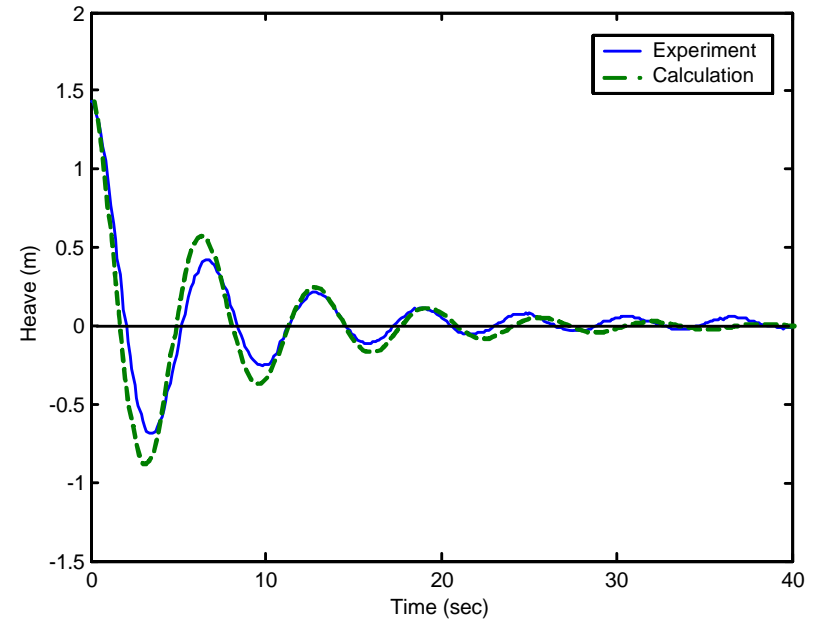
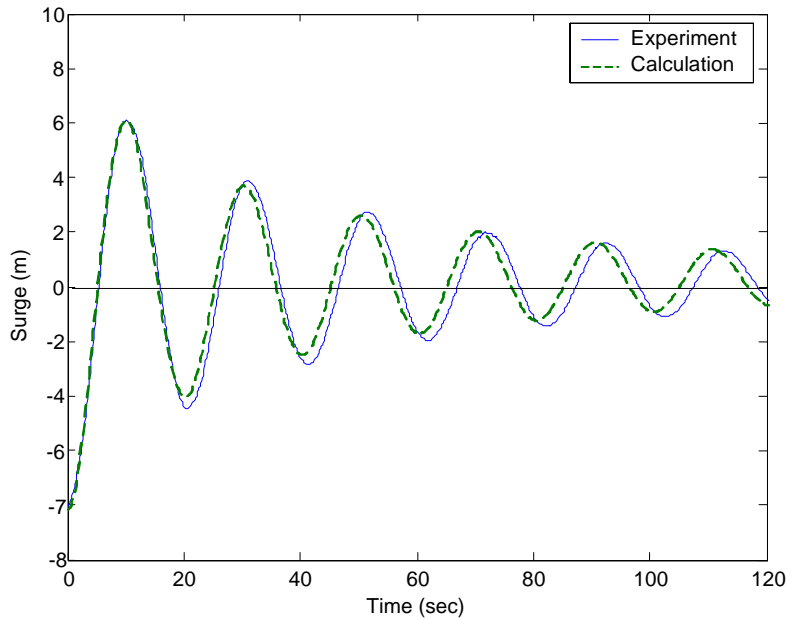
Comparison to Model Test Data: Free Decay Tests

(1) Freely Floating Case

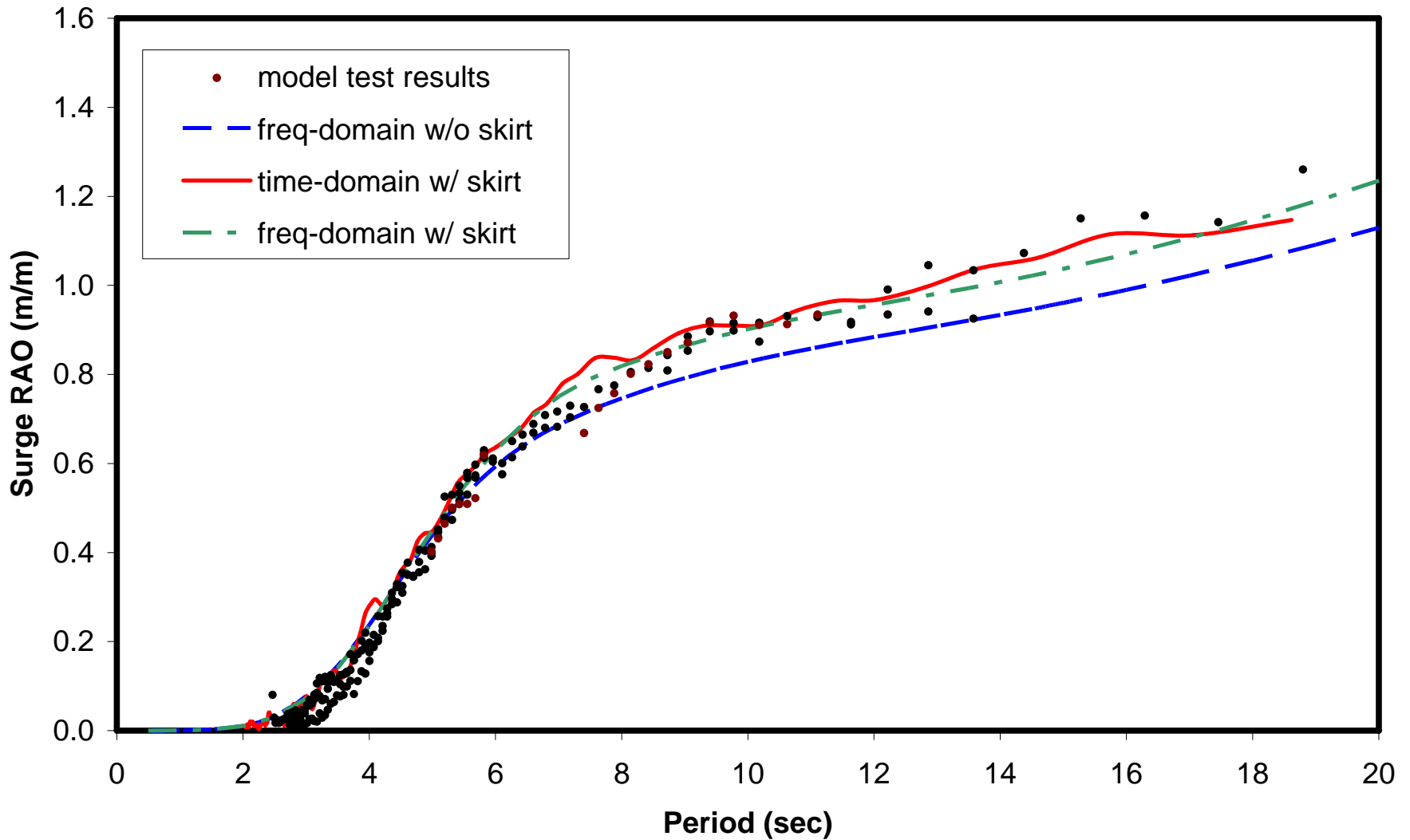


Free Decay Tests:

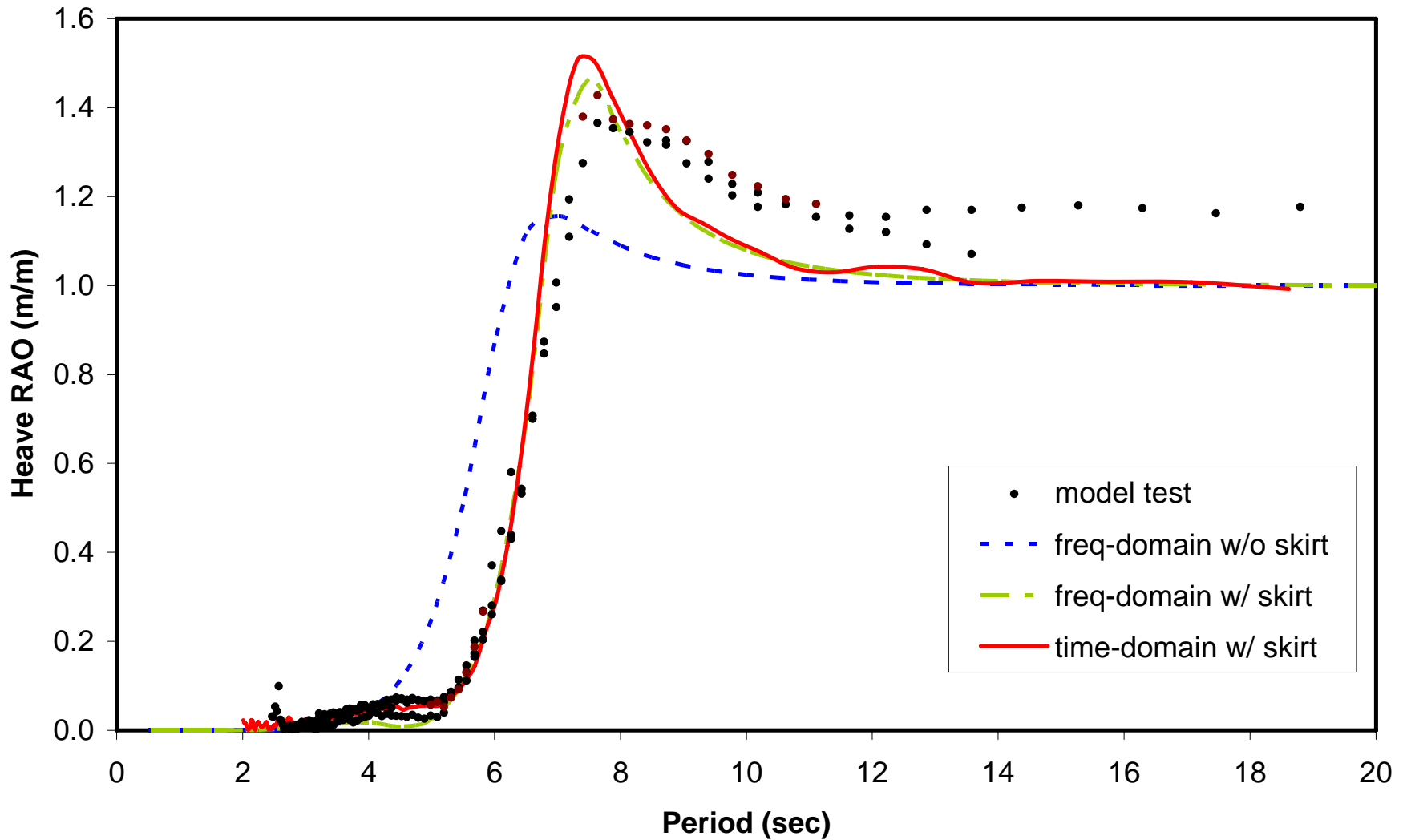
(2) Moored Case



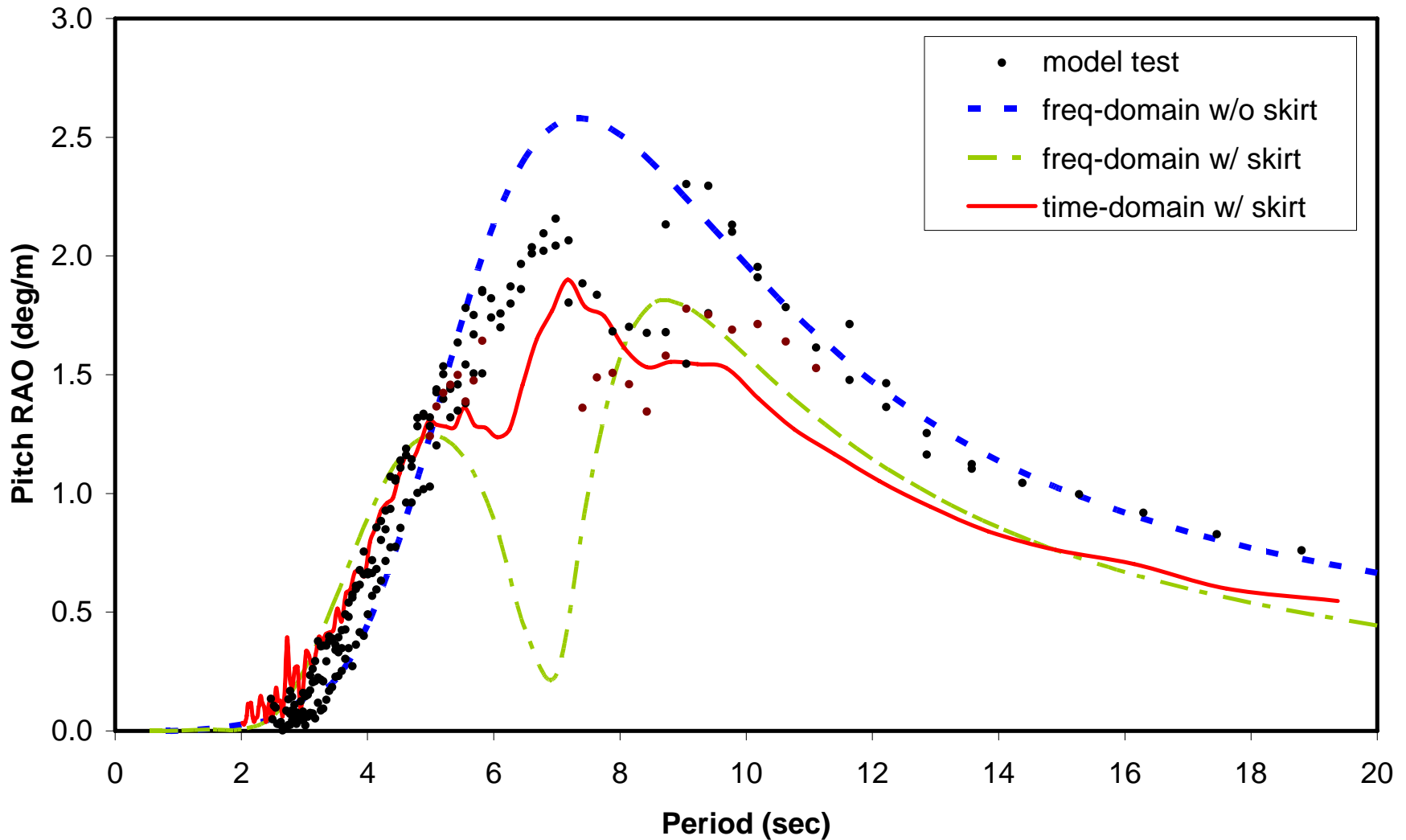
Surge – freely floating case



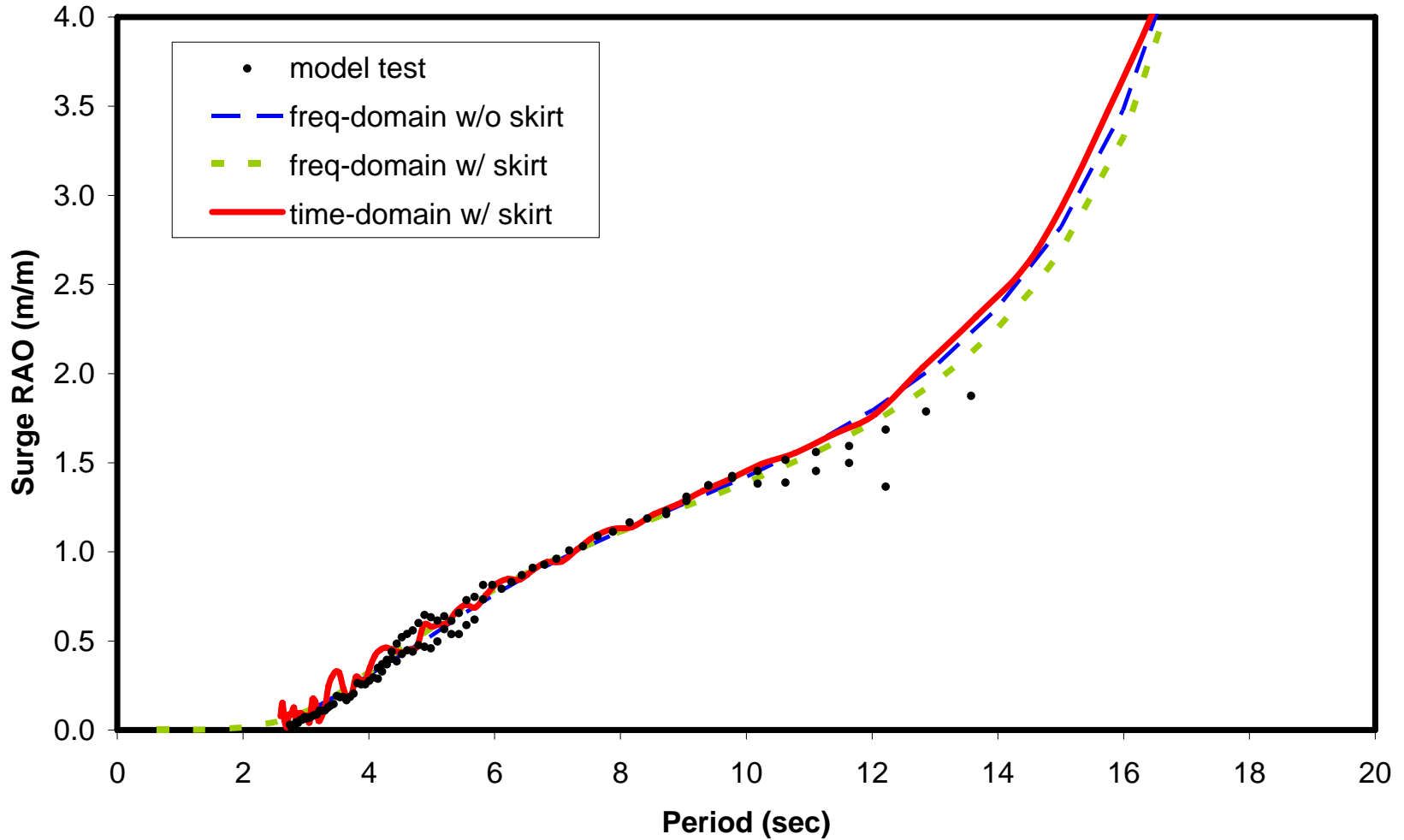
Heave – freely floating case



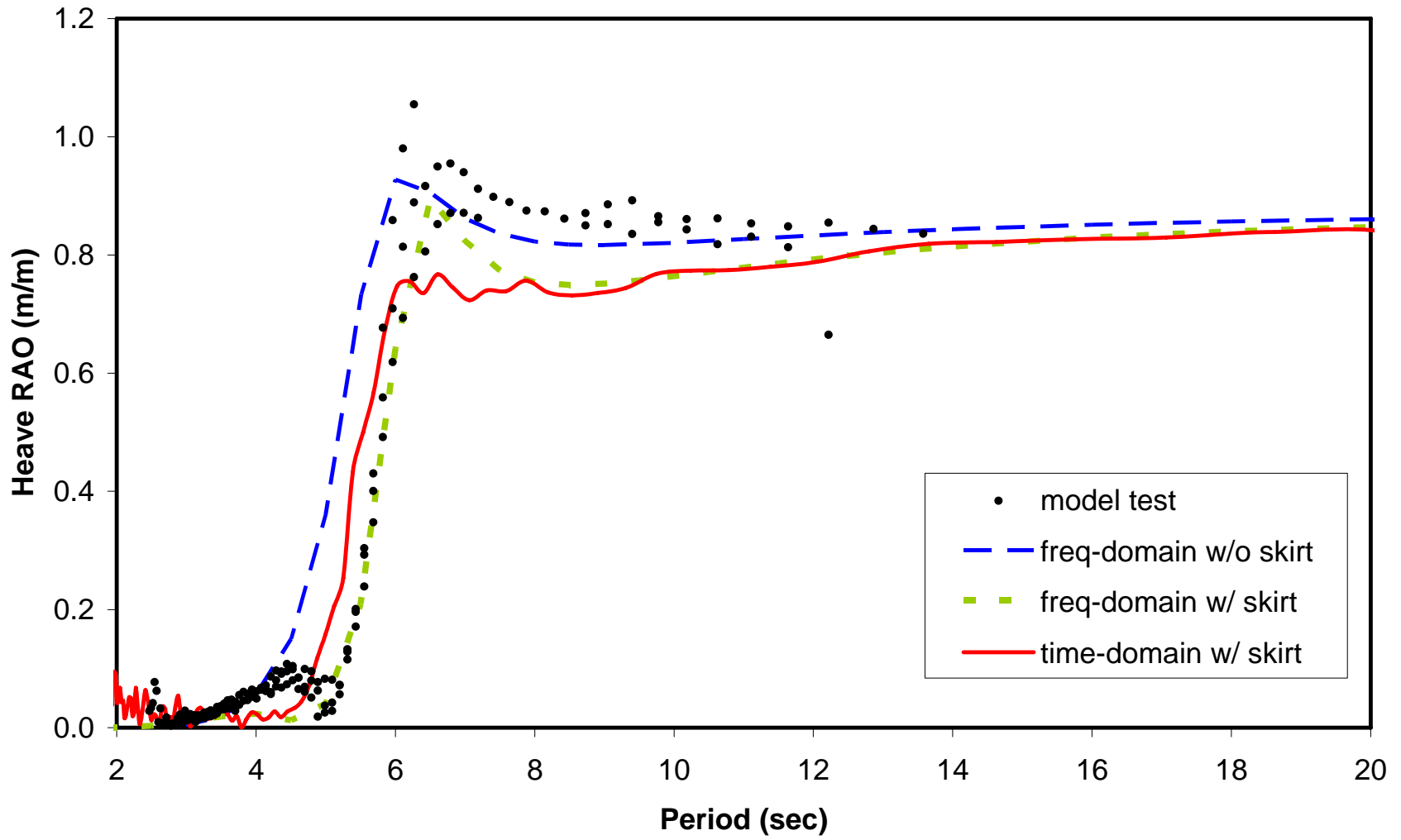
Pitch – freely floating case



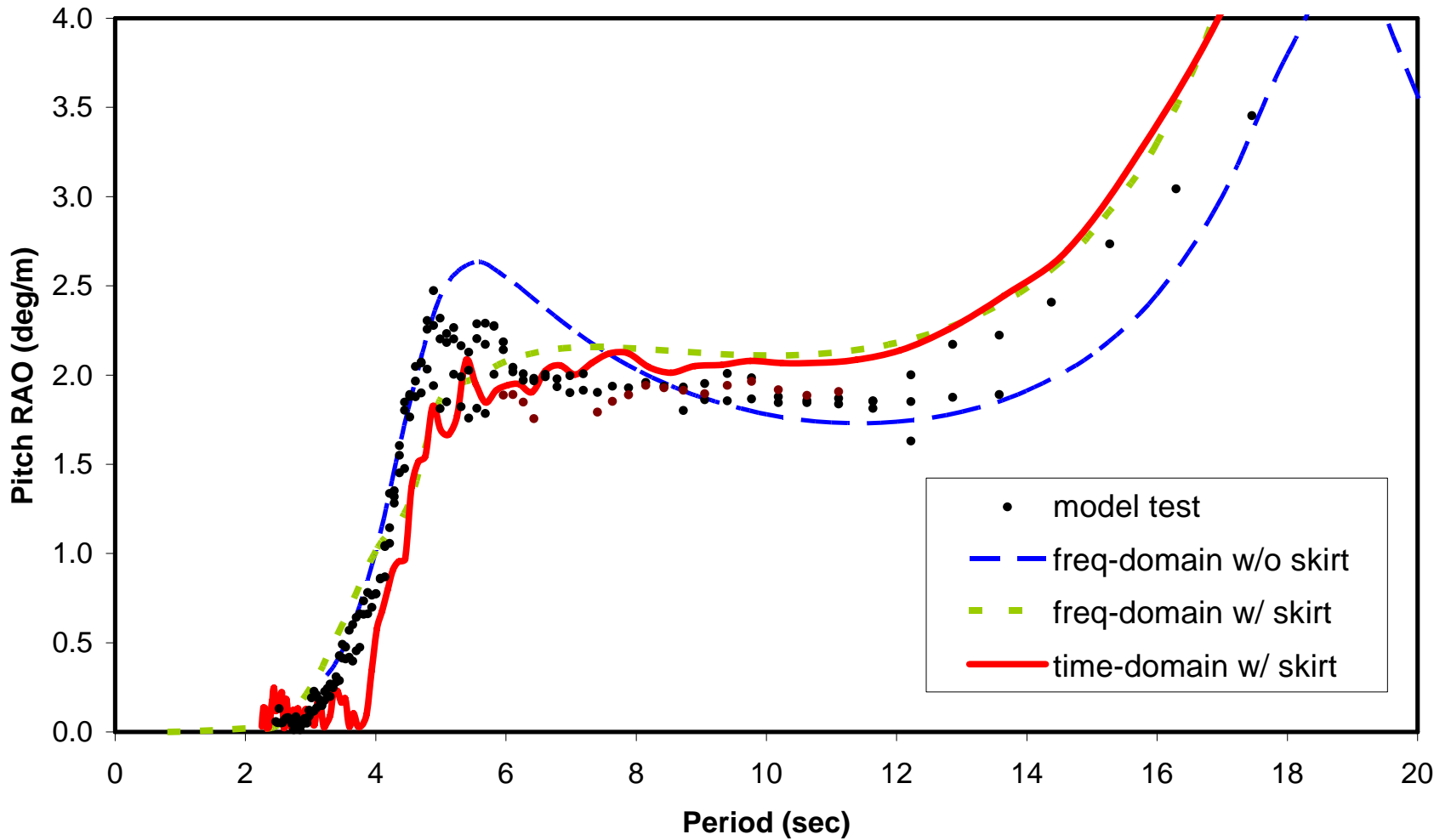
Surge - moored case



Heave - moored case

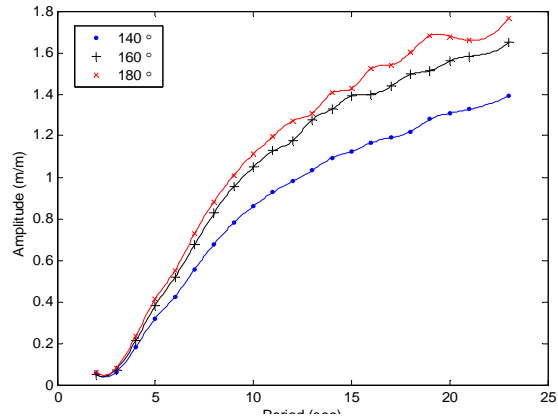


Pitch - moored case

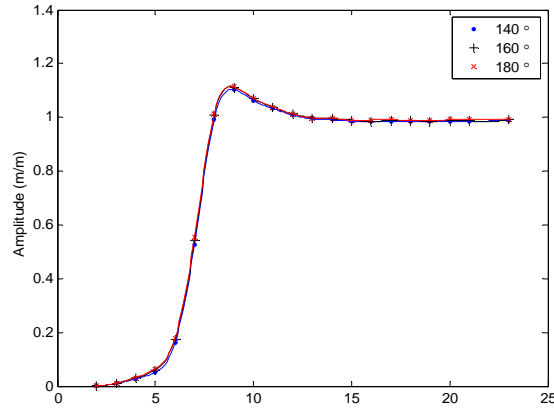


Moored Buoy RAOs

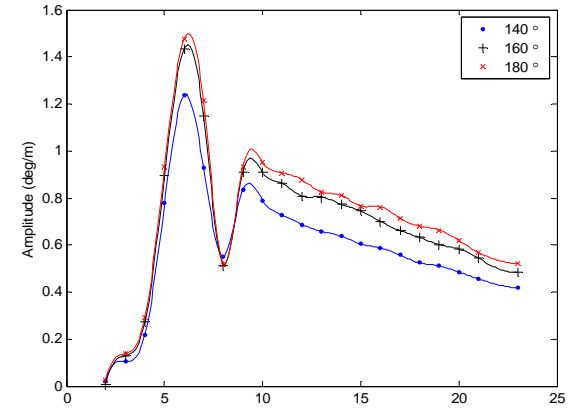
Surge



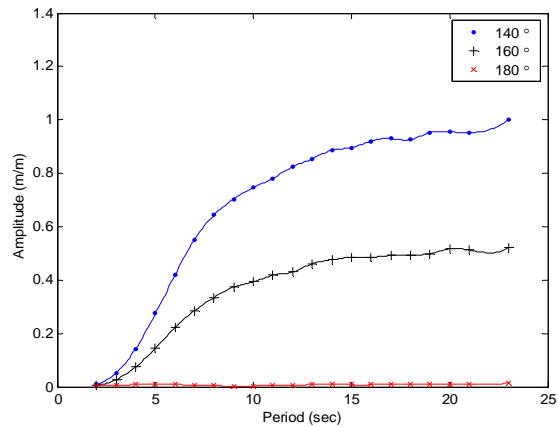
Heave



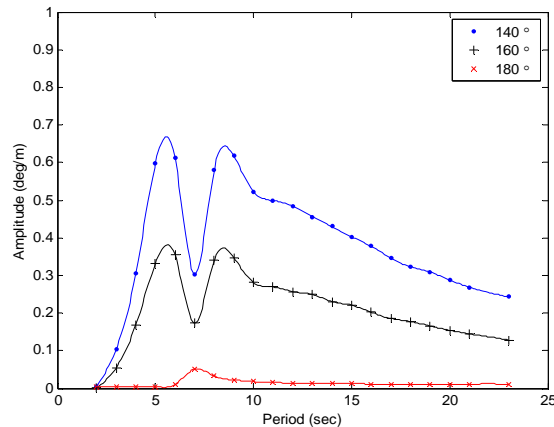
Pitch



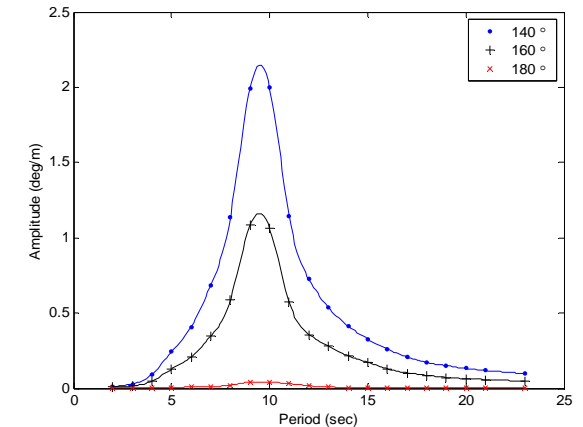
Sway



Roll

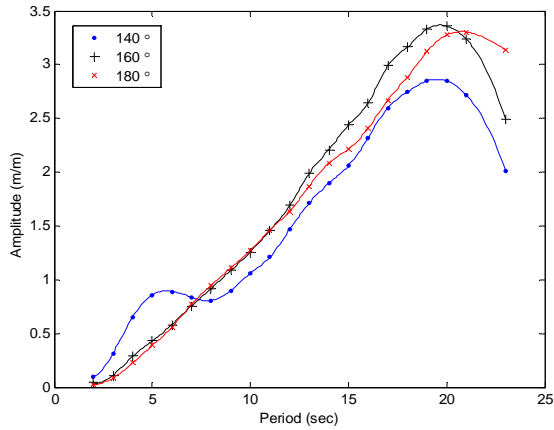


Yaw

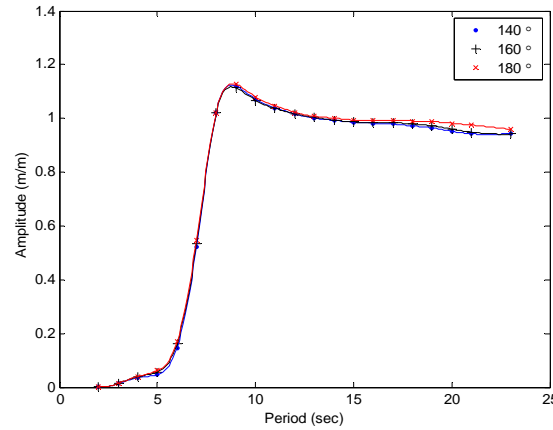


Moored Buoy with Tanker RAOs

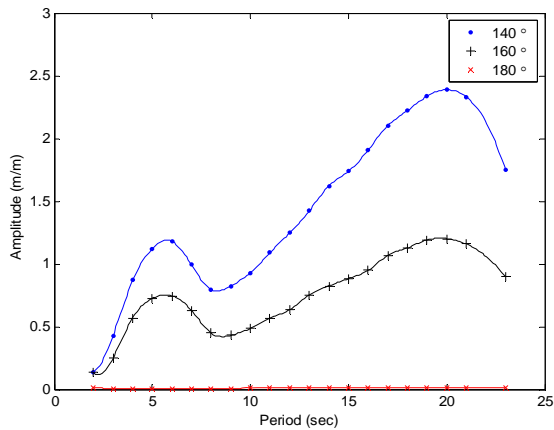
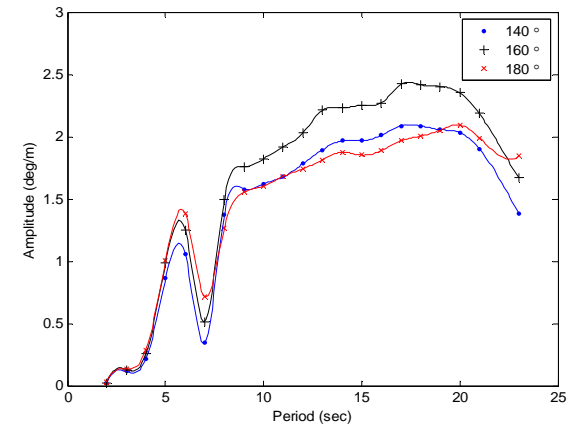
Surge



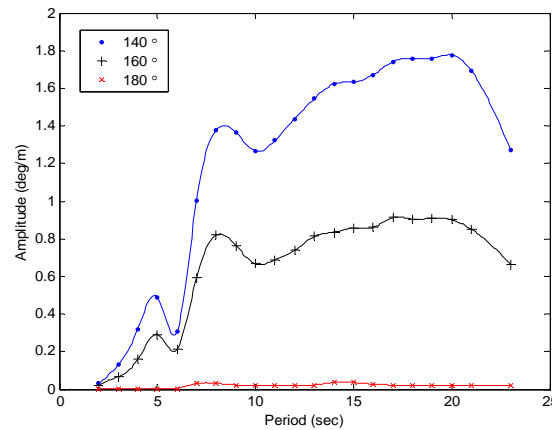
Heave



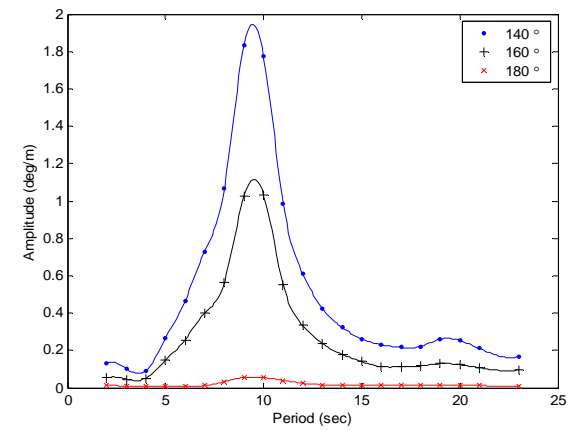
Pitch



Sway



Roll



Yaw

Summary

Extension of Shallow Water Calm Technology to Deep Water:

- results in system with complex response characteristics
- sensitivity of responses strongly related to viscous forcing and damping of the system
- **Numerical Model of Buoy, Mooring System, and Flowlines**
 - paper illustrates success in capturing buoy responses with reasonable accuracy
 - accurate modeling of buoy skirt critical for accurate response prediction (especially pitch and roll)
- **Tanker loading from buoy affects the buoy responses**
 - must be accounted for accurate estimation of system fatigue life
- **Analyses of the type described above has had an impact on the design (buoy, flowlines, mooring system) of several offloading buoys under construction**