Tripartite Interactions of Moored Deformable Body in Random Waves

Stress Resultants & Full Load-Mapping

Dr. HeonYong Kang

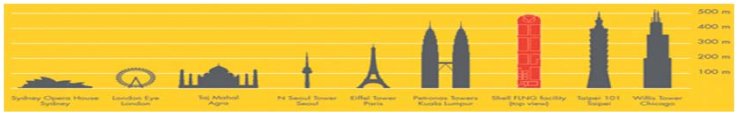
Oct 26, 2017

Ocean System Simulation and Control Laboratory

ENGINEERING
TEXAS A&M UNIVERSITY

Offshore Hydroelasticity: Examples

- **Larger moored offshore structures**



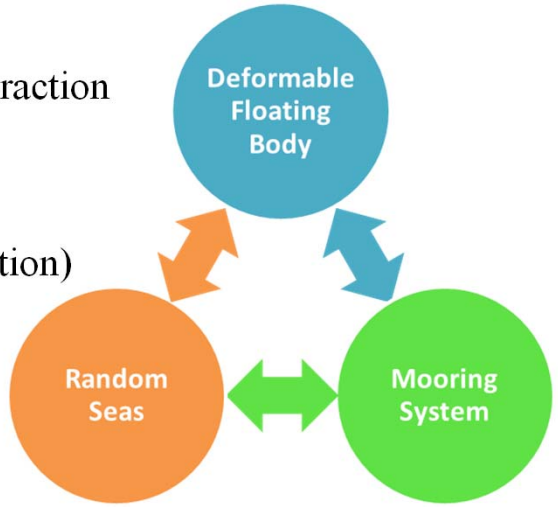
- **Large deformation**

- **Harsher environment**

Reference : courtesy of ExxonMobil (Kizomba) Shell (Prelude) , Pelamis, Shell Kulluk, and JTC

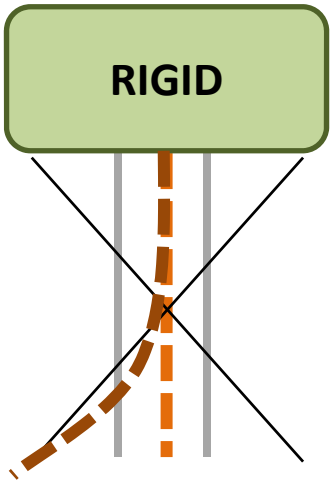
Keywords & Objective

- **Hydroelasticity or FSI**
  - Hydro(waves) + Elasticity(deformation) or Fluid-Structure Interaction
  - Deformation of a floating body and its interaction with waves
- **Dynamic Analysis**
  - 6 DOF motions (rigid body) + Elastic modes motions (deformation)
- **Structural Analysis**
  - Stress resultants (shear force, bending & torsional moments)
- **Time Domain Analysis**
  - Random sea + mooring-riser coupled analysis



- ✓ **To develop the new methodology solving tripartite interactions of deformable or rigid floating body, nonlinear mooring system and random waves.**
- ✓ **The new methodology provides with real-time stress resultants and full load-mapping without costly CFD or time-domain fluid solver.**
- ✓ **Identify mooring effects to stress resultants and elastic motions.**

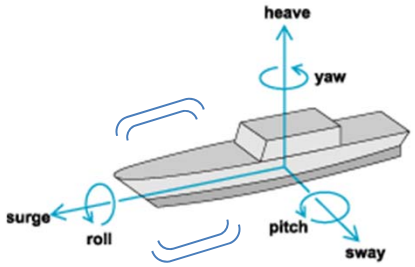
Conventional Global Performance Analysis



with or without nonlinear elastic mooring lines and risers coupled

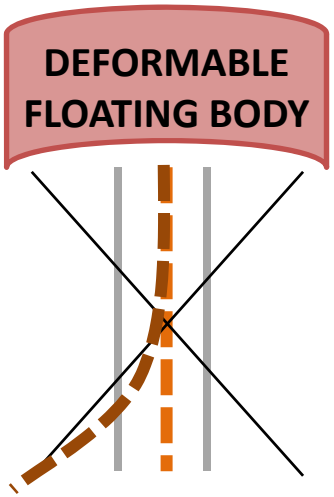
IRREGULAR WAVES

DYNAMIC RESPONSES



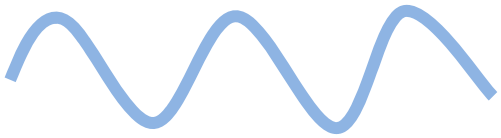
- ✓ **Obtain motion responses of the floating bodies, structural responses of the mooring-riser system in the random sea.**
- ✓ **Either full-load mapping or calculation of coupled stress resultants requires costly CFD or Hydroelastic Analysis even for the rigid bodies.**

What is New?



with or without nonlinear elastic mooring lines and risers coupled

REGULAR WAVES

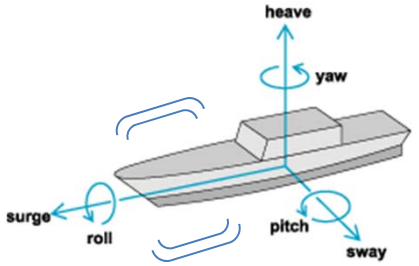


+

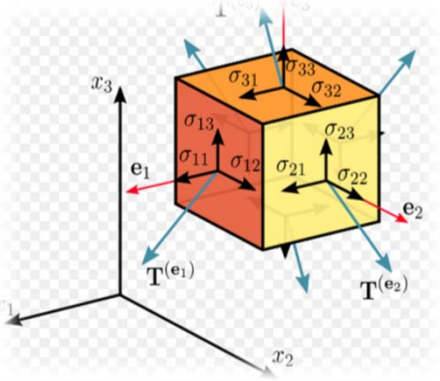
=

IRREGULAR WAVES

DYNAMIC RESPONSES

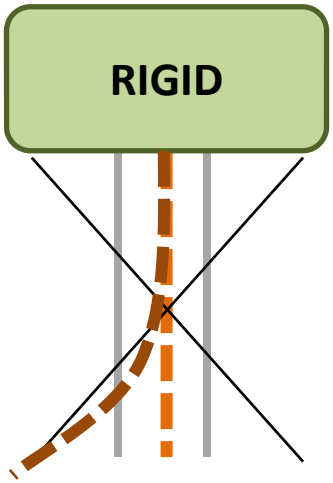


STRESS RESULTANTS



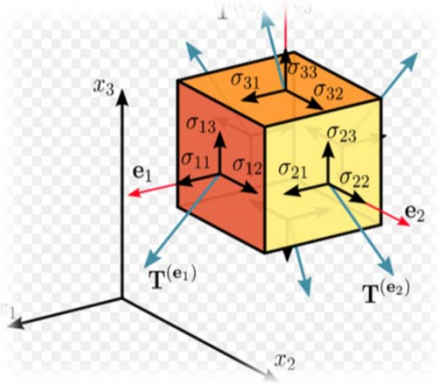
- ✓ **Solve tripartite interactions of the deformable floating body dynamics, nonlinear mooring-riser system dynamics, and random waves.**
- ✓ **Obtain coupled stress resultants (shear forces, bending moments, torsional moments).**
- ✓ **Provide with full load-mapping without CFD or other costly time-domain fluid dynamics solvers.**

What is New
if Deformation of the Floating Body is Negligible?



with or without nonlinear elastic mooring lines and risers coupled

IRREGULAR WAVES

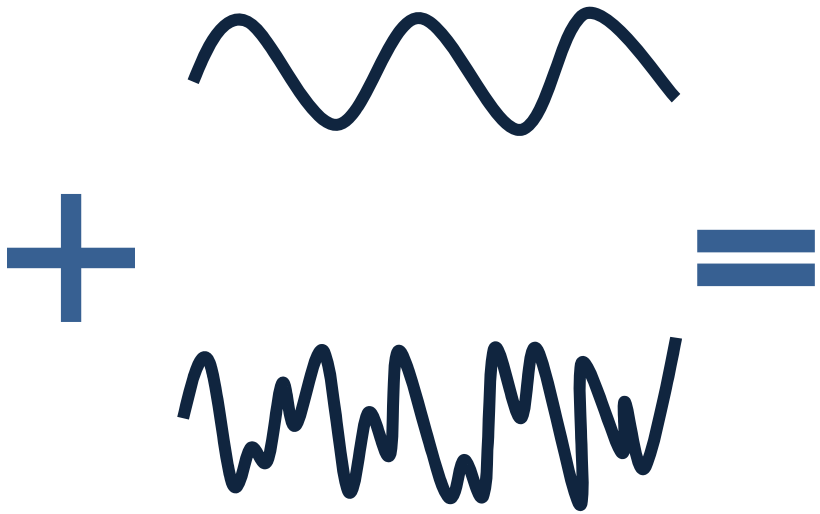


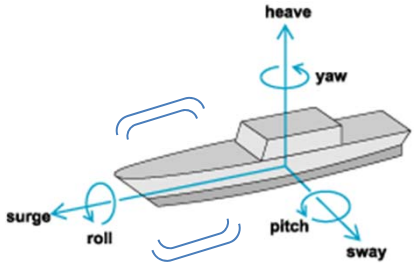
STRESS RESULTANTS

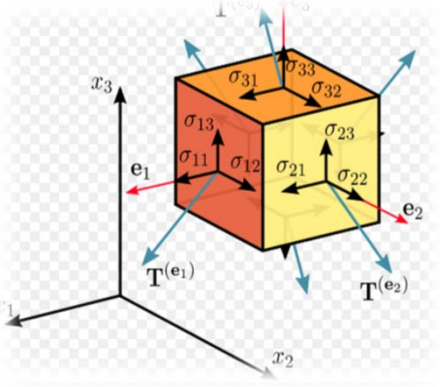
Contrary to existing numerical tools,

- ✓ **The new methodology also provides with the coupled stress resultants on rigid-assumed floating bodies even without hydroelasticity.**
- ✓ **The new methodology also provides with the fully load-mapping on rigid-assumed floating bodies without the CFD or other fluid dynamics solvers.**

What Else is New?







- ✓ **The new method is also applicable to multi-body problem which consists of some deformable floating bodies and other rigid floating bodies in coupling by mooring lines and risers.**

Offshore Hydroelasticity: Schematic View

Modal Analysis
-analytic solutions
-FEM

$$\frac{\partial}{\partial x^2}\left(EI\frac{\partial^2 w}{\partial x^2}\right)+m\frac{\partial^2 w}{\partial t^2}=q(x)r(t)$$

Extended BVP
-Potential flow (BEM)
-Extended rad. Con.

$$\frac{\partial\Phi_R^{(1)}}{\partial n}=i\omega n\cdot\left(\zeta+\alpha\times r+\upsilon_j\Xi_j\right)$$

$$K_{ij}^H=\rho g\left[\iint_{S_\delta} z\vec{n}_i dS-\iint_{S_o} z\vec{n}_i dS\right]$$

Hydrodynamics
Hydrostatics

Solving EOM
-Freely float, Linear K/D
-Regular Wave

$$(M^E+\Delta M)\ddot{X}+(D^R{}_\omega)\dot{X}+(K^E+K^H)X=F^{1st}.$$

Extended Cummins' Eq.
-Random Sea dynamics

$$R_{ij}(t)=\frac{2}{\pi}\int_0^\infty B_{ij}(\omega)\cos(\omega t)d\omega\cong\frac{2}{\pi}\int_0^{\omega_{\max}} B_{ij}(\omega)\cos(\omega t)d\omega,$$

$$\Delta M_{ij}^\infty=\Delta M_{ij}(\omega_{\max})+\int_0^\infty R_{ij}(t)\frac{\sin(\omega_{\max}t)}{\omega_{\max}}dt$$

$$\cong\Delta M_{ij}(\omega_{\max})+\int_0^{t_{\max}} R_{ij}(t)\frac{\sin(\omega_{\max}t)}{\omega_{\max}}dt,$$

$$F_i^C(t)=-\int_{-\infty}^t R_{ij}(t-\tau)\dot{X}_j(\tau)d\tau=-\int_{-t}^\infty R_{ij}(\tau)\dot{X}_j(t-\tau)d\tau$$

$$=-\int_0^\infty R_{ij}(\tau)\dot{X}_j(t-\tau)d\tau\cong-\int_0^{t_{\max}} R_{ij}(\tau)\dot{X}_j(t-\tau)d\tau.$$

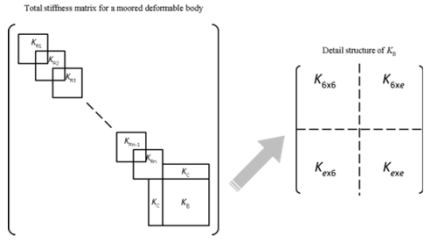
STRONG COUPLING

Finite Rod Element
-Tension & Bending
- Nonlinear FEM

$$\int_0^L\left[-\left(Br_j''\right)''+\left(\lambda r_j'\right)'+q_j-\rho\ddot{r}_j\right]\delta r_j ds=0,$$

$$\int_0^L\left[\frac{1}{2}\left(r_k'r_k'-1\right)-\frac{\lambda}{AE}\right]\delta\lambda ds=0$$

Solving EOM
-Fully coupled DB, EL
- Radom seas



2nd order Hydroelasticity
Rigid-assumption
Small or Large Deform.

Direct Structural Analysis & Load Mapping
FDB: Shear forces, Bending moments, Torsional moments
ML/RS: Axial tension, Shear forces, Bending moments

$$f(x,y)=g(x)h(y),\ \text{where } f(x,y) \text{ is a } A\times B \text{ measurable function,}$$

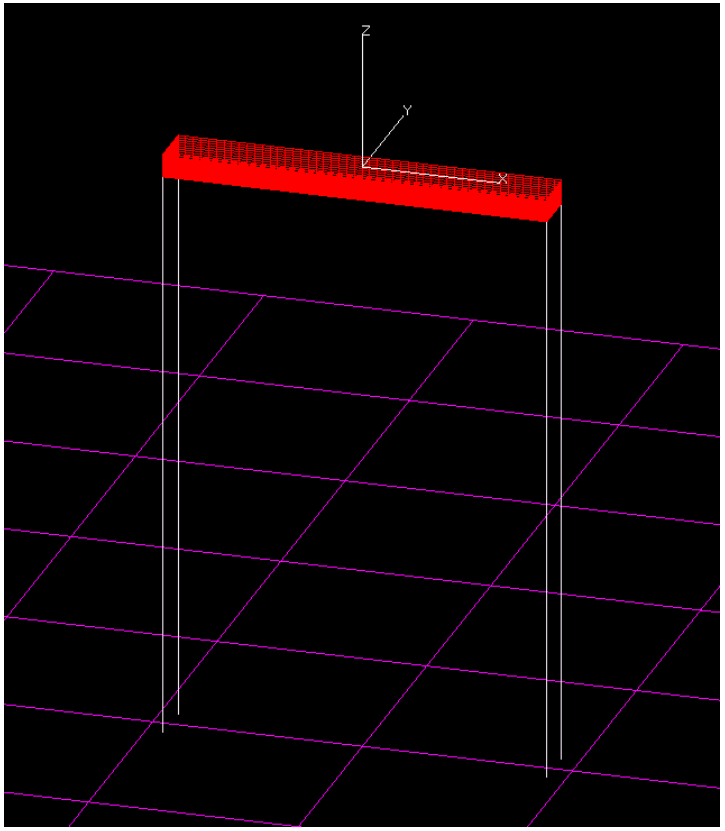
$$\int_A g(x)dx\int_B h(y)dy=\int_A\left(\int_B g(x)h(y)dy\right)dx=\int_B\left(\int_A g(x)h(y)dx\right)dy$$

$$=\int_{A\times B} f(x,y)d(x,y).$$

✓ **Since it's built based on conventional global performance analysis, identical accuracy still holds in the hydroelastic responses and full load mapping.**

Numerical Study of a Elastic Slender Pontoon with a mooring system

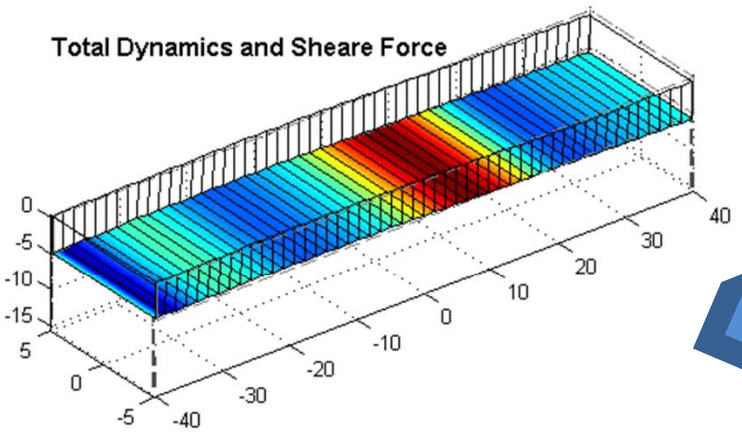
- **Schematic View**

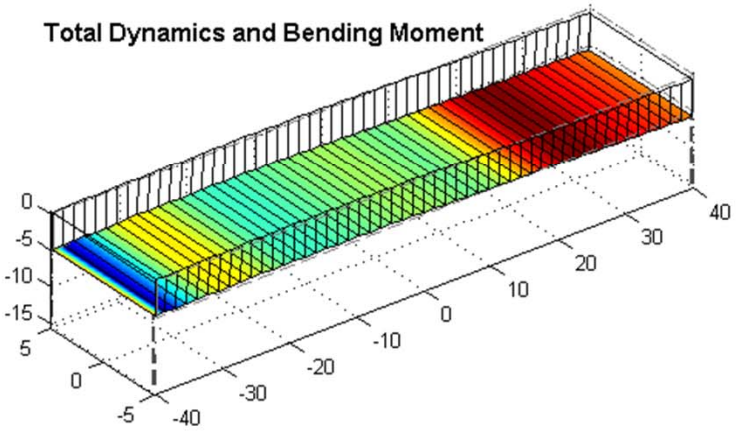


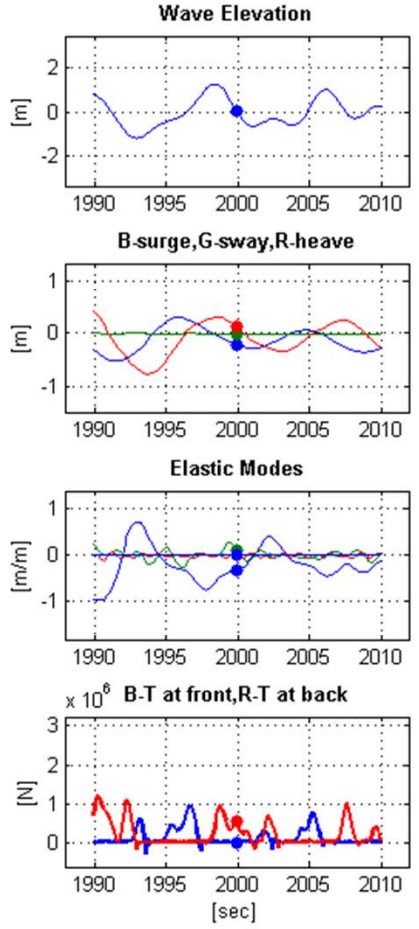
- Quarter *EI* case
- 4 taut vertical mooring lines
- Water depth 125 m
- Sea state 5 applied

Line length	120 m
Wet, Dry weight	24.79, 29.01 kg/m
Axial stiffness (EA)	3.53337E+08 N
Bending stiffness (EI)	1.37824E+05 Nm^2
Diameter	0.079 m
Ca, Cd	1, 1.5

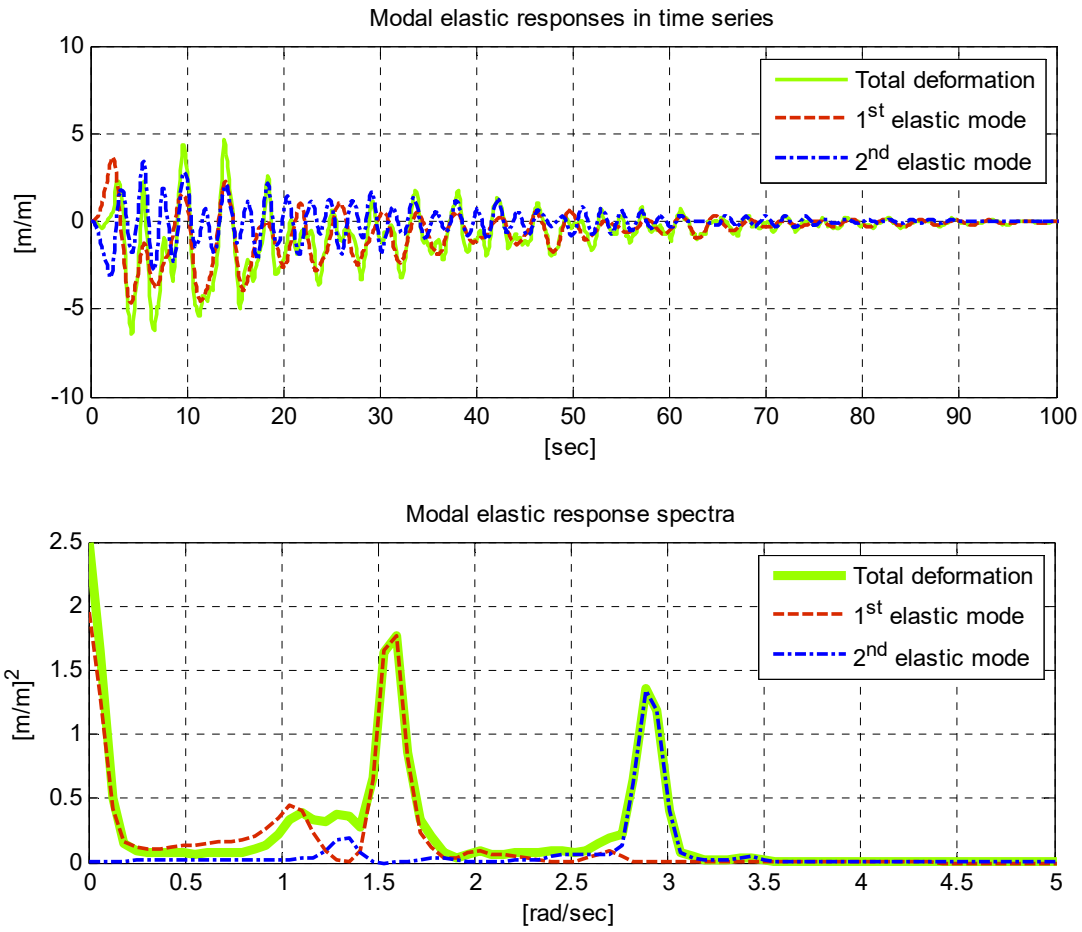
Exemplary Final Results







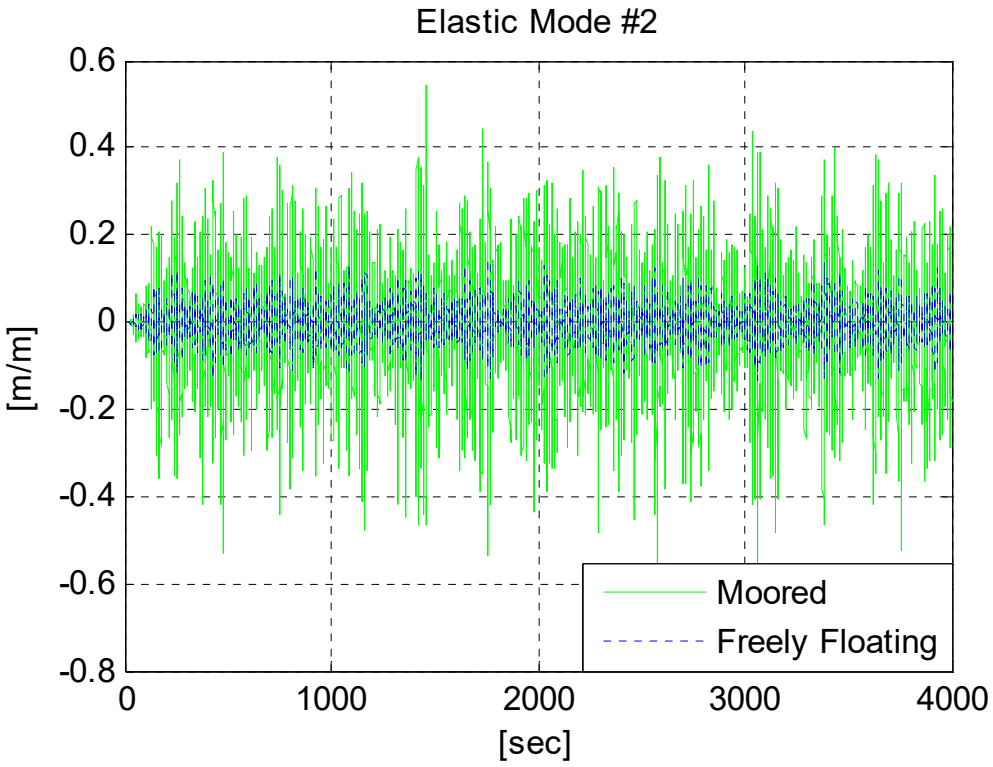
More Accurate Natural Frequencies by Numerical Hammer Test



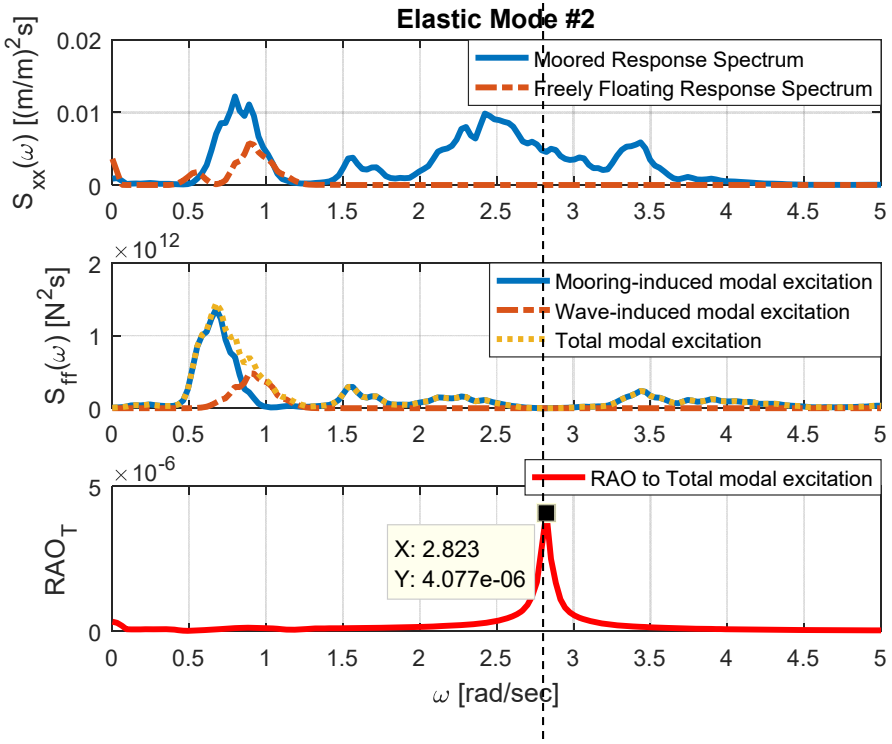
True natural frequencies by hammer test

Condition	Elastic mode #1	Elastic mode #2
Wet moored	1.59	2.88
Wet freely floating	1.44	2.82
Dry	1.25	3.44

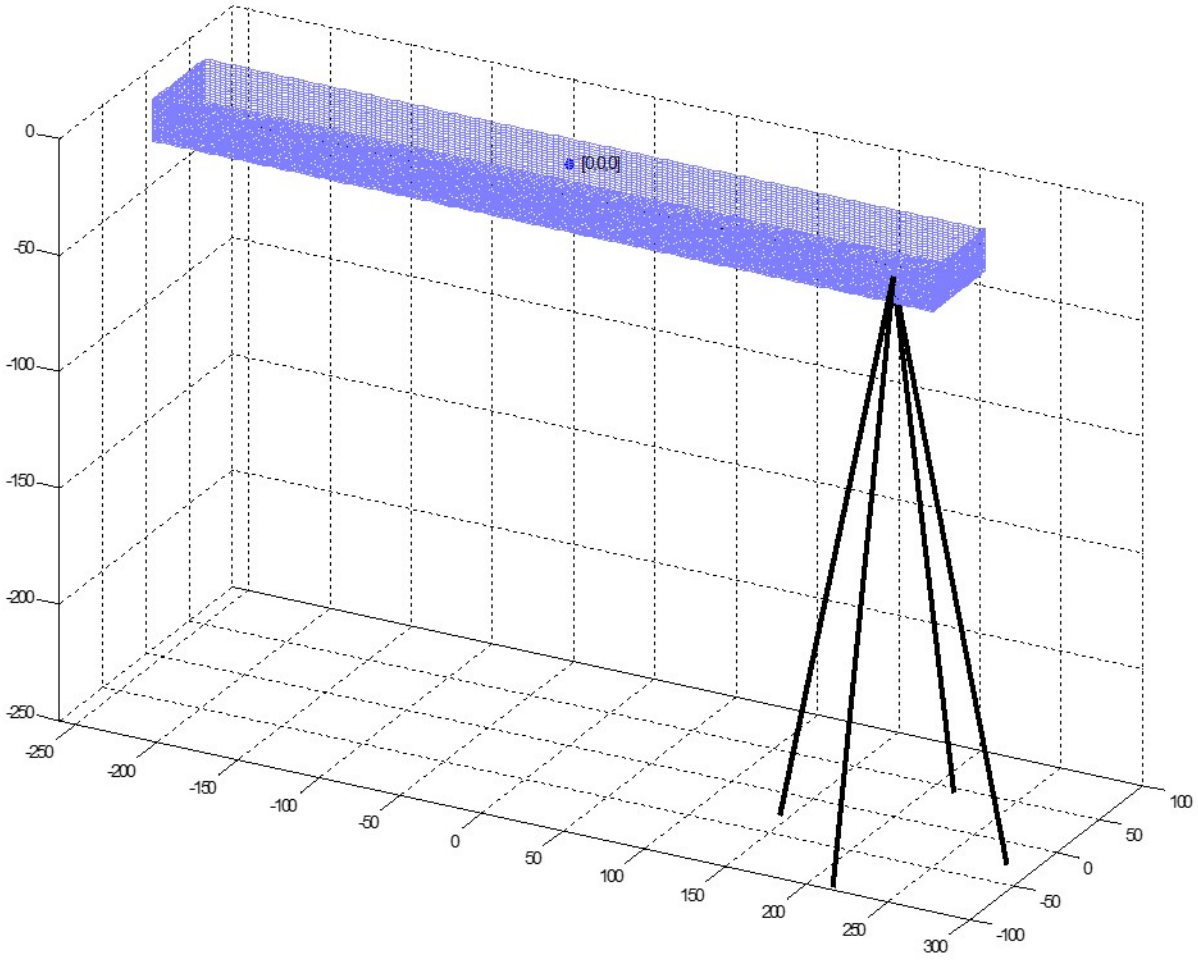
Resonated Deformation of Floating Body by Mooring Tension



Elastic Mode #2 resonated by mooring tension



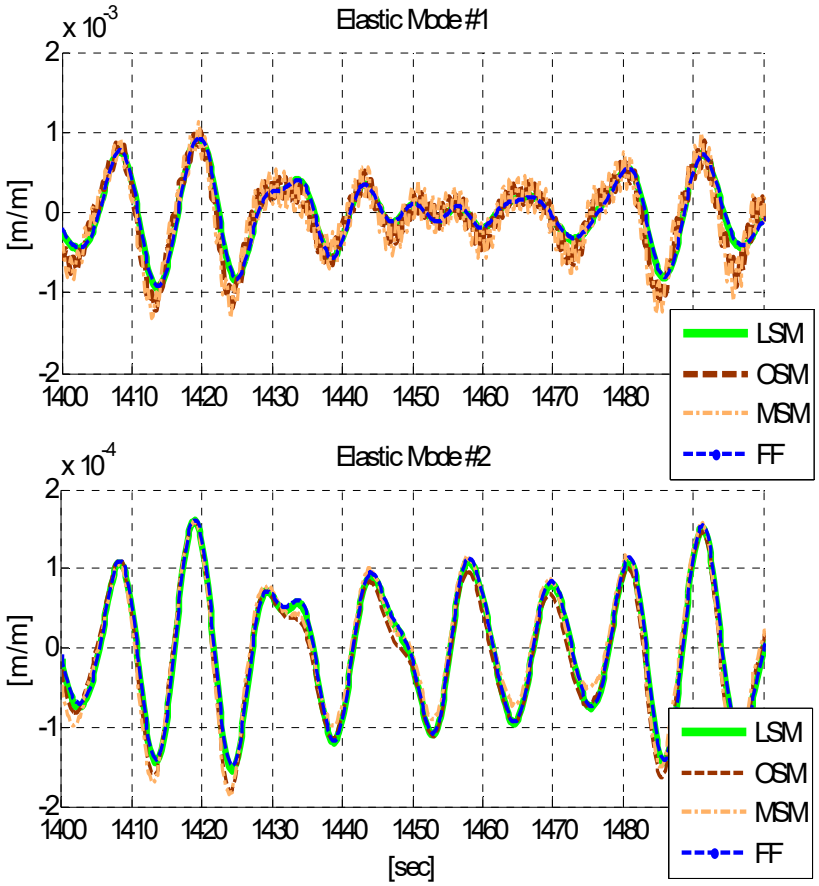
Offshore Hydroelasticity: Real Scale FLNG

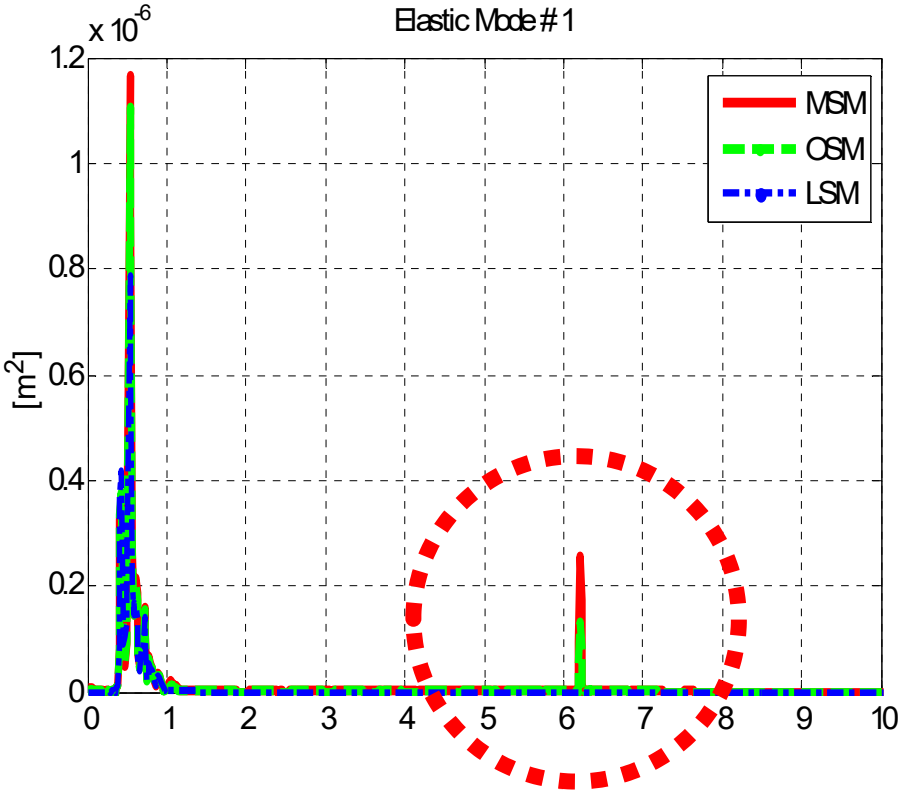


Items	Values
L (m)	480
B (m)	60
D (m)	18
Dry ω (rad/sec)	9.4248
k	9.8542E-3
m (kg/m)	1107000
EI (Nm^2)	1.0428E+16

Parametric Hydroelastic Dynamic Analysis

- **Coupled Deformations and Resonances**

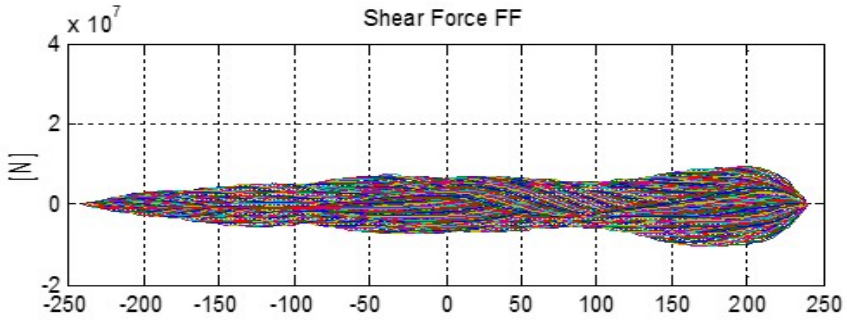




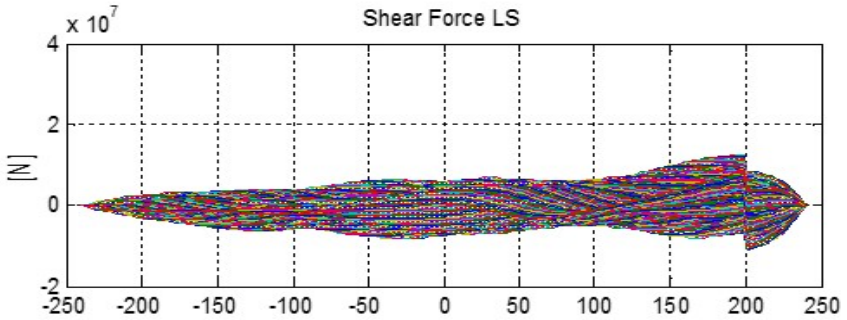
Resonance by mooring tension

Offshore Hydroelasticity: Key Results VI

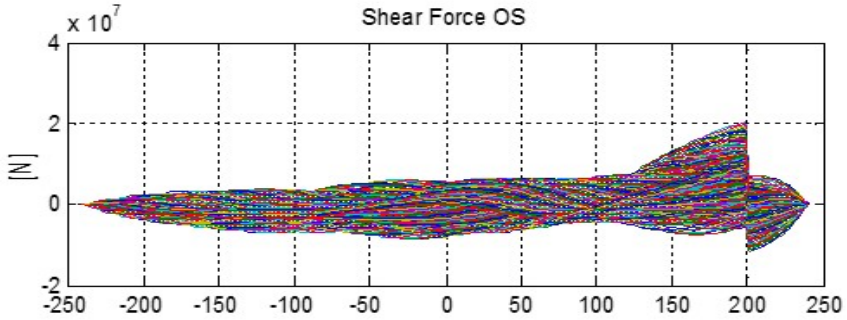
- **Stress resultants (V) interacting with mooring lines**



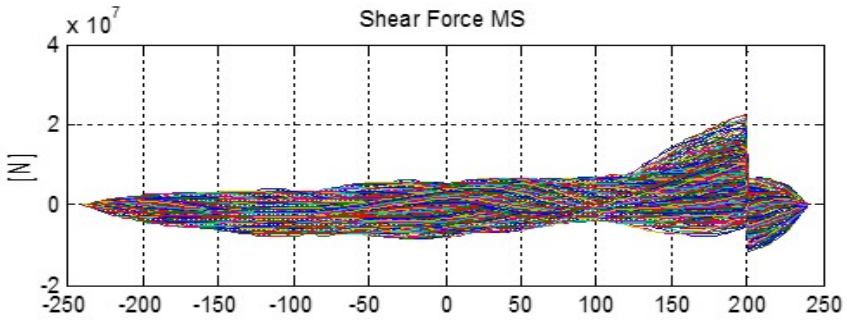
Shear force (freely floating)



Shear force (less stiff mooring)



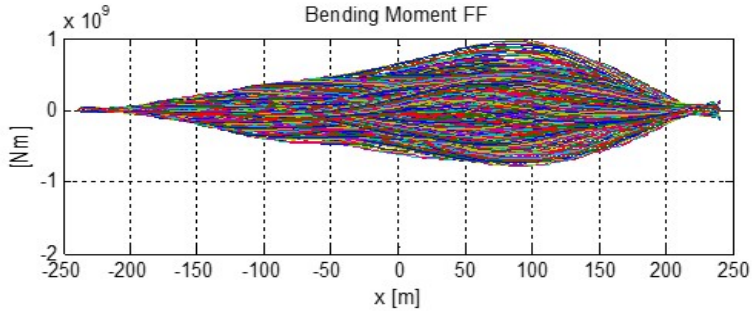
Shear force (original stiff mooring)



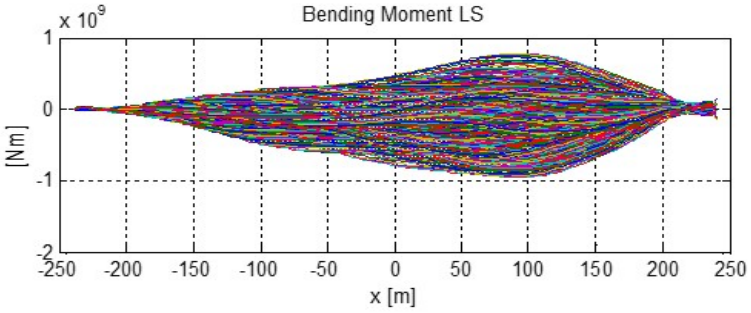
Shear force (more stiff mooring)

Offshore Hydroelasticity: Key Results VII

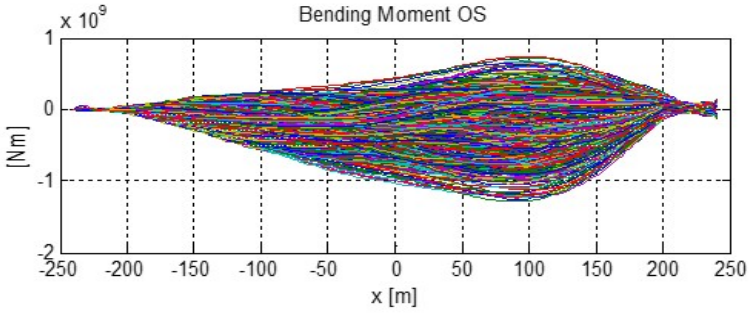
- **Stress resultants (M) interacting with mooring lines**



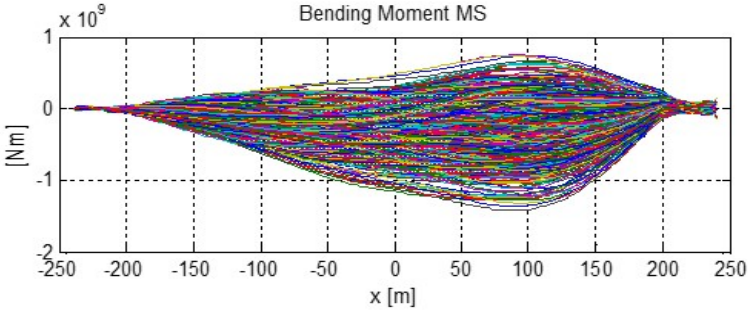
Bending moment (freely floating)



Bending moment (less stiff mooring)

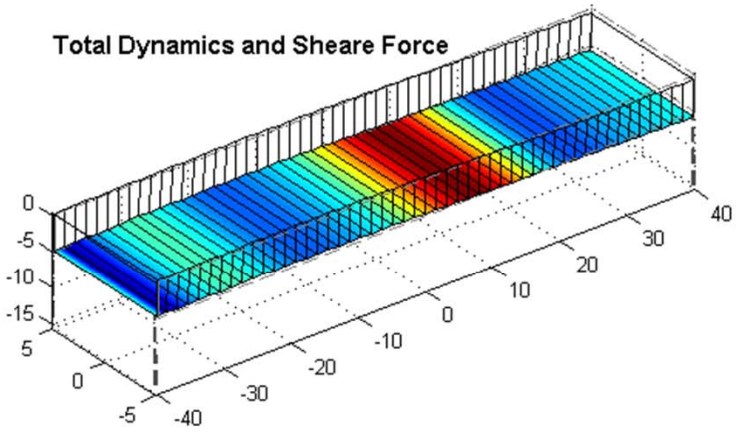


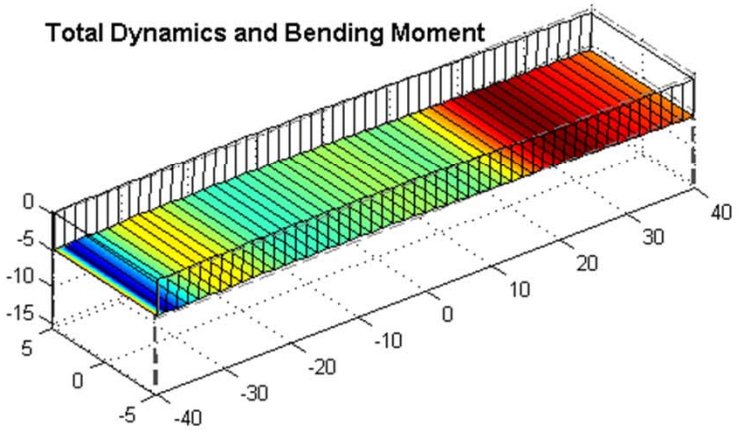
Bending moment (original stiff mooring)

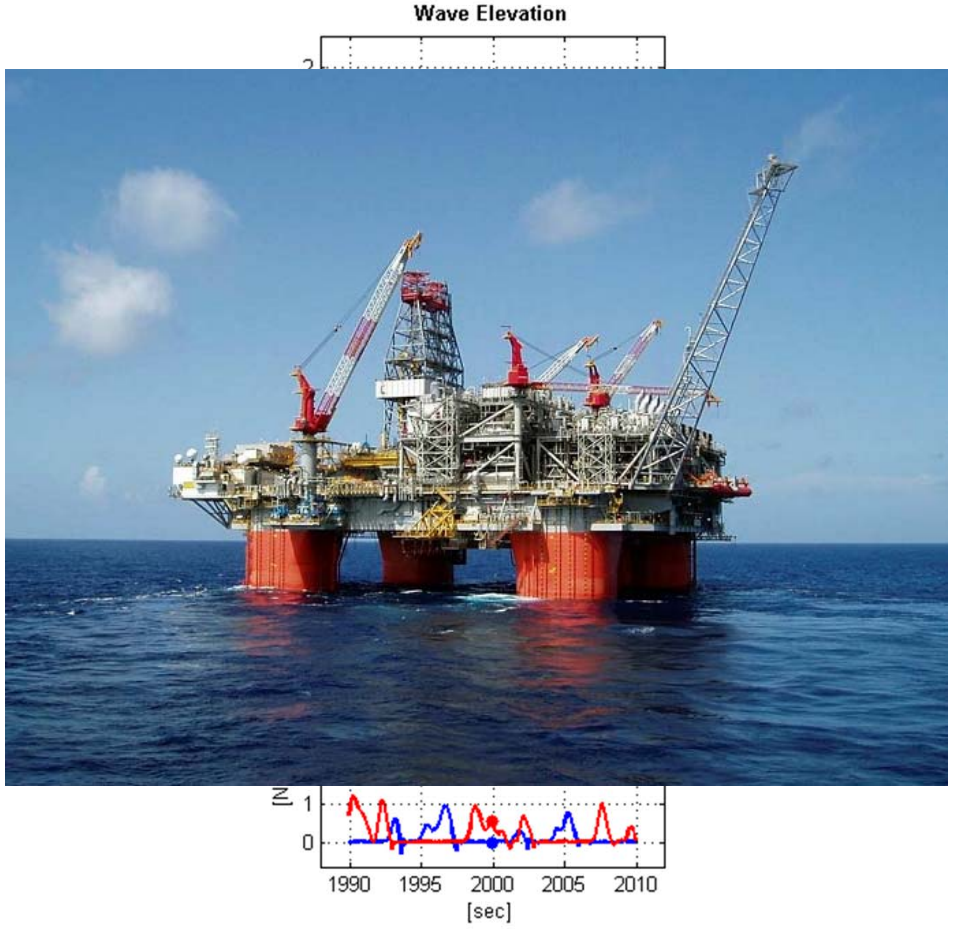


Bending moment (more stiff mooring)

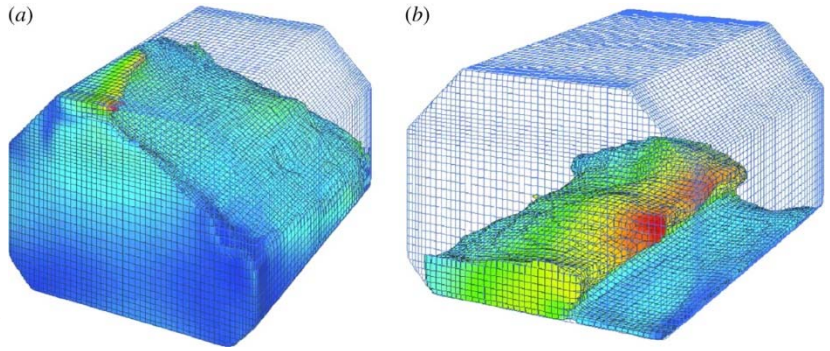
Potential Prospective Study I: Coupled Stress Resultants for SEMI or FPSO or Other Offshore Platforms

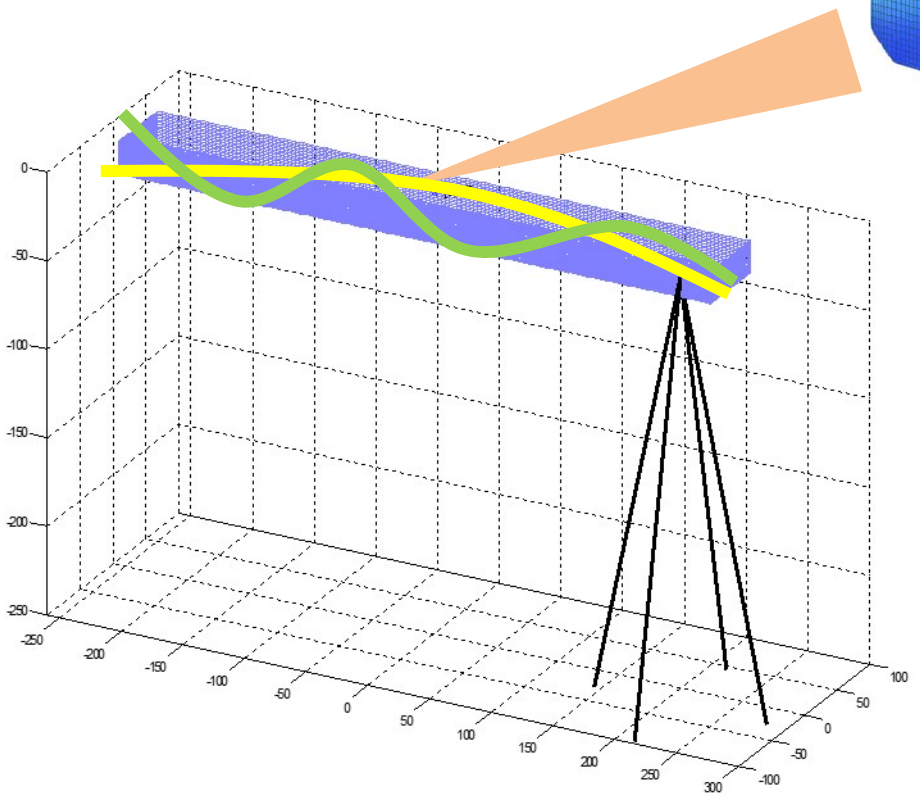






Potential Prospective Study II: Sloshing-coupled Hydroelastic Analysis for FPSO/FLNG





Picture adopted from
Semi-analytical models of hydroelastic sloshing impact in tanks of liquefied natural gas vessels

Potential Prospective Study III: Hybrid-Hydroelastic Analysis for Various Offshore Platforms

Conclusion

- **The coupled hydroelastic analysis solves tripartite interactions of a fully or partially deformable floating body, nonlinear mooring dynamics, and random waves.**
- **It provides motion responses including deformation and dynamic stress resultants for both of the floating body and mooring system.**
- **It provides real-time full load mapping for either deformable or rigid floating body moored in the random seas without costly CFD.**