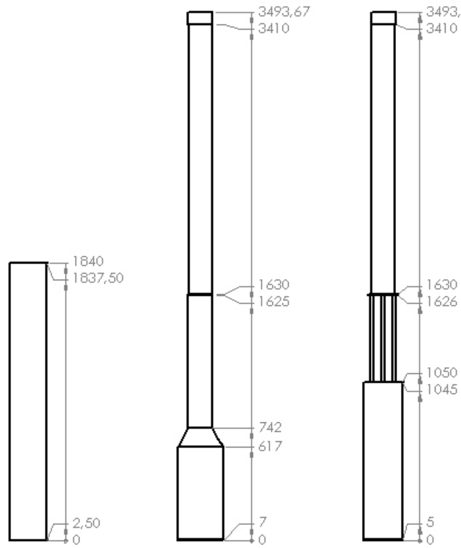
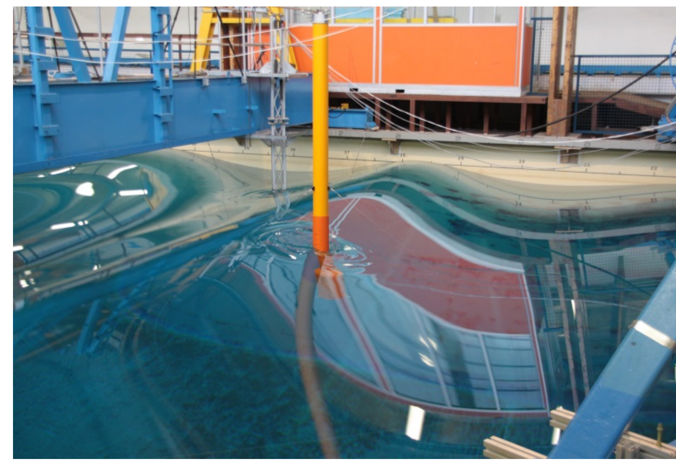
Tension-Leg-Buoy (TLB) Platforms for Offshore Wind Turbines

EERA DeepWind'2014 Deep Sea Offshore Wind R&D Conference, Trondheim, 22 - 24 January 2014





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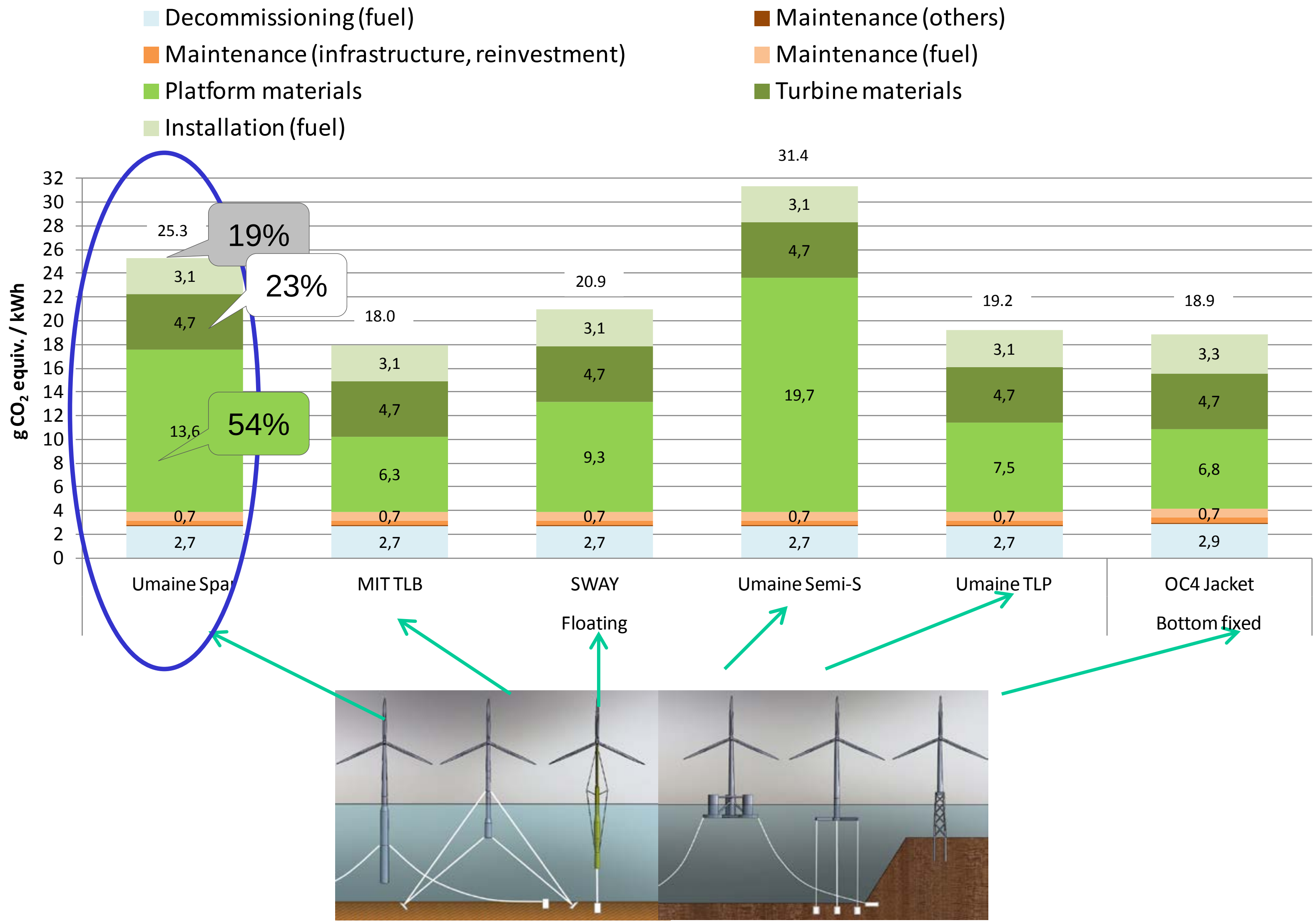
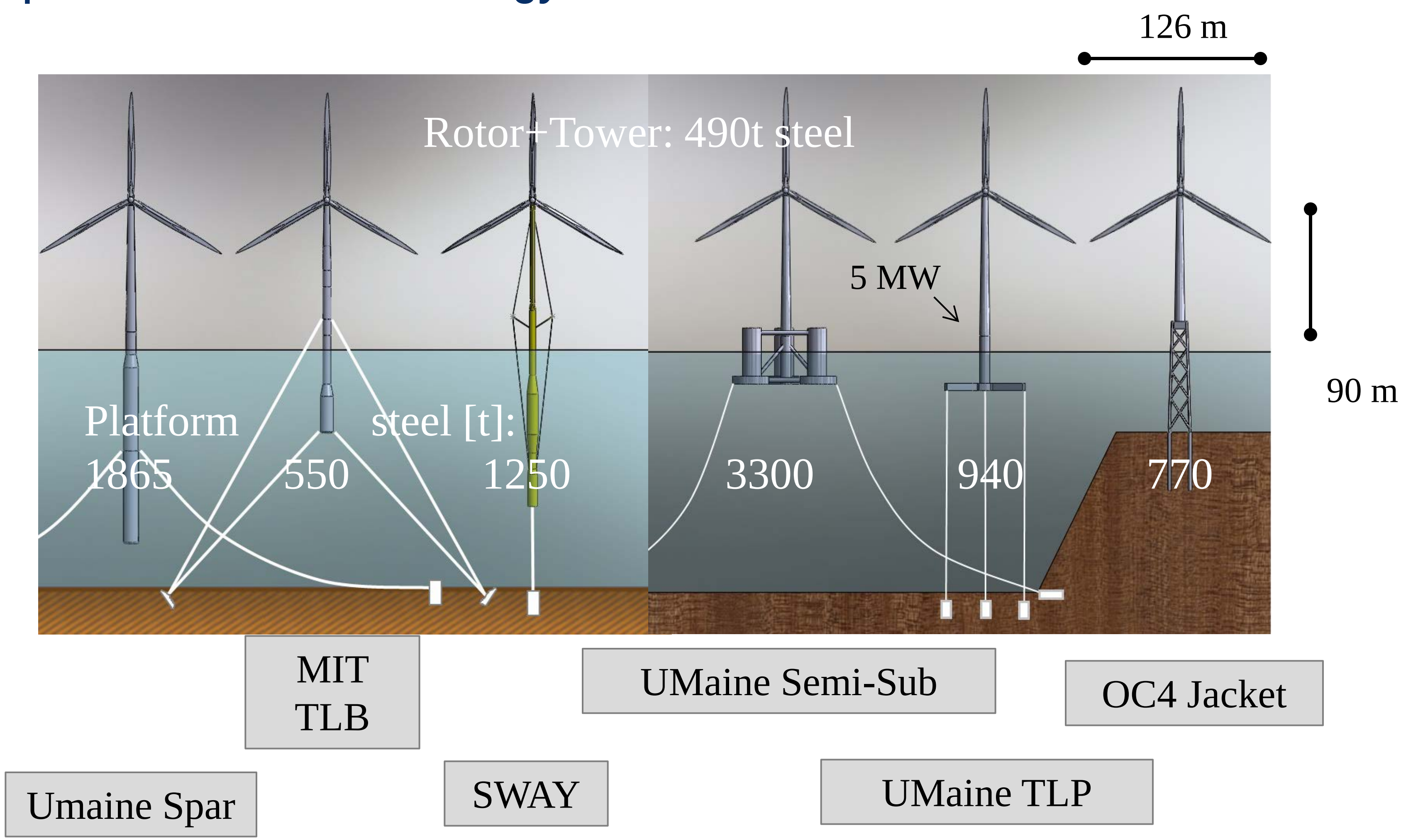
Outline

- Introduction: Life Cycle Greenhouse Gas (GHG) emissions and cost drivers for offshore wind turbine platforms
- The simulation tool 3DFloat for analysis and optimization
- TLB application example, 75m water depth
- MARINET wave tank test at IFREMER, Brest, France, January 2013, and comparison with simulations
- Conclusions and outlook

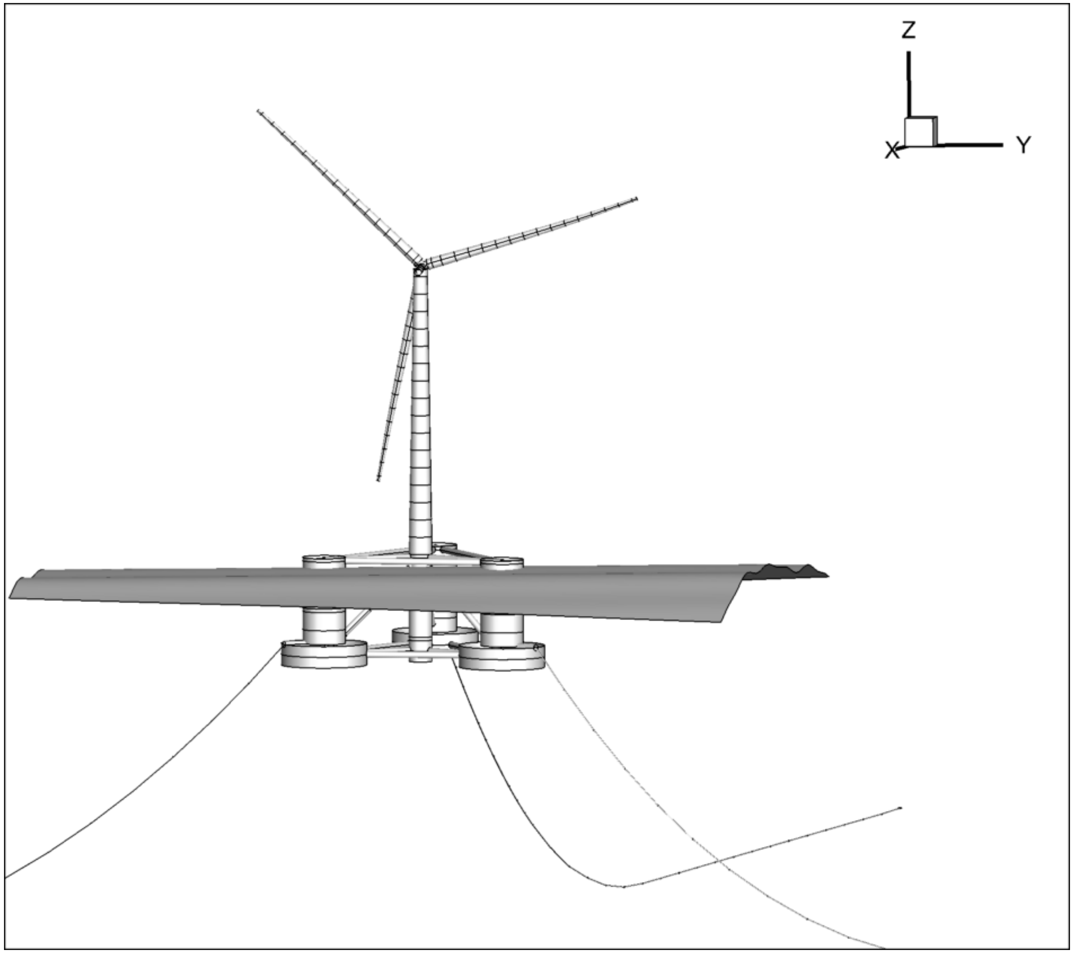
GHG emissons per kWh



Raadal, H. L., Vold, B. I., Myhr, A. and Nygaard, T. A. (2014). GHG emissions and energy performance of offshore wind power. Renewable Energy, 2014, Vol. 66, 314-324



3DFloat Simulation Tool



- General nonlinear Finite-Element Model
- Engineering models for aerodynamics, hydro-dynamics and control systems
- Verified (code-to-code) for Spar-Buoy, Jacket and Semi-Submersible (IEA OC3/OC4)
- Validation against experiments ongoing for Tension-Leg-Buoy and Semisubmersible platforms (MARINET)

TLB History

- First application presented by Prof. Sclavounos, MIT in 2005 as the MIT Double Taut Leg.
- The TLB has been developed at MIT in a commercial project.
- The TLB has been used for optimization studies and experiments at UMB.

Butterfield, S, Musial, W, Jonkman, J and Sclavounos, P (2005).“Engineering Challenges for Floating Offshore Wind Turbines”*. Proc 2005 Copenhagen Offshore Wind Conference*, Copenhagen, Denmark, October 26–28, 2005

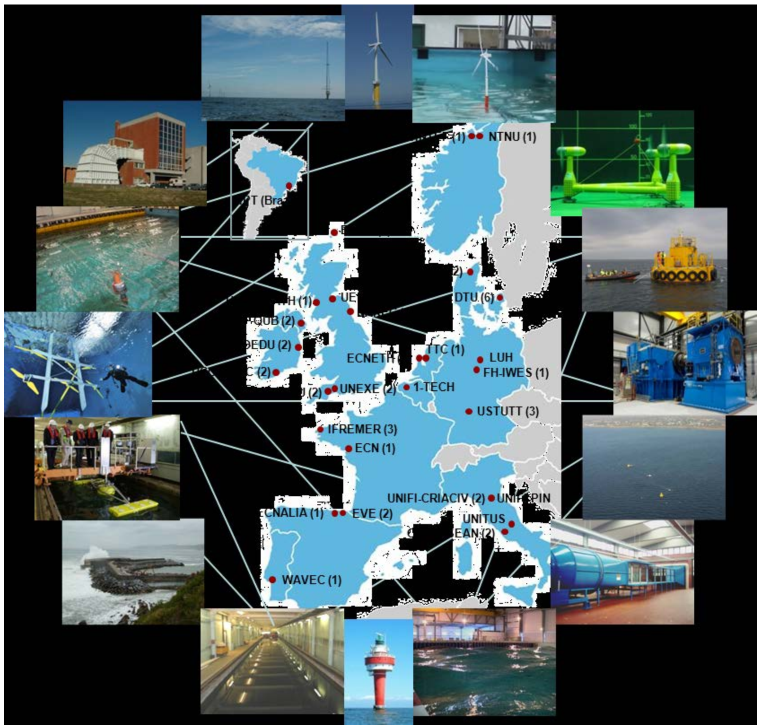
TLB Application Example

- NREL 5MW 126m rotor, hub height 90m
- Draft 50m, water depth 75m
- Mooring line axial stiffness governed by eigen frequencies
- Buoyancy governed by requirement on taut mooring lines
- Survival: 30m wave height, parked rotor fully exposed to steady wind wind of 62m/s.
- Deplacement 3000t, Excess buoyancy 1900E4 N
- Anchor uplift peak: 1800E4 N
- Steel mass: Floater 455t, Tower/nacelle 666t, Anchors 190t

Myhr, A. and Nygaard, T. A. (2012). *Load Reductions and Optimizations on Tension-Leg-Buoy Offshore Wind Turbine Platforms*. International Offshore and Polar Engineering Conference (ISOPE), 2012.

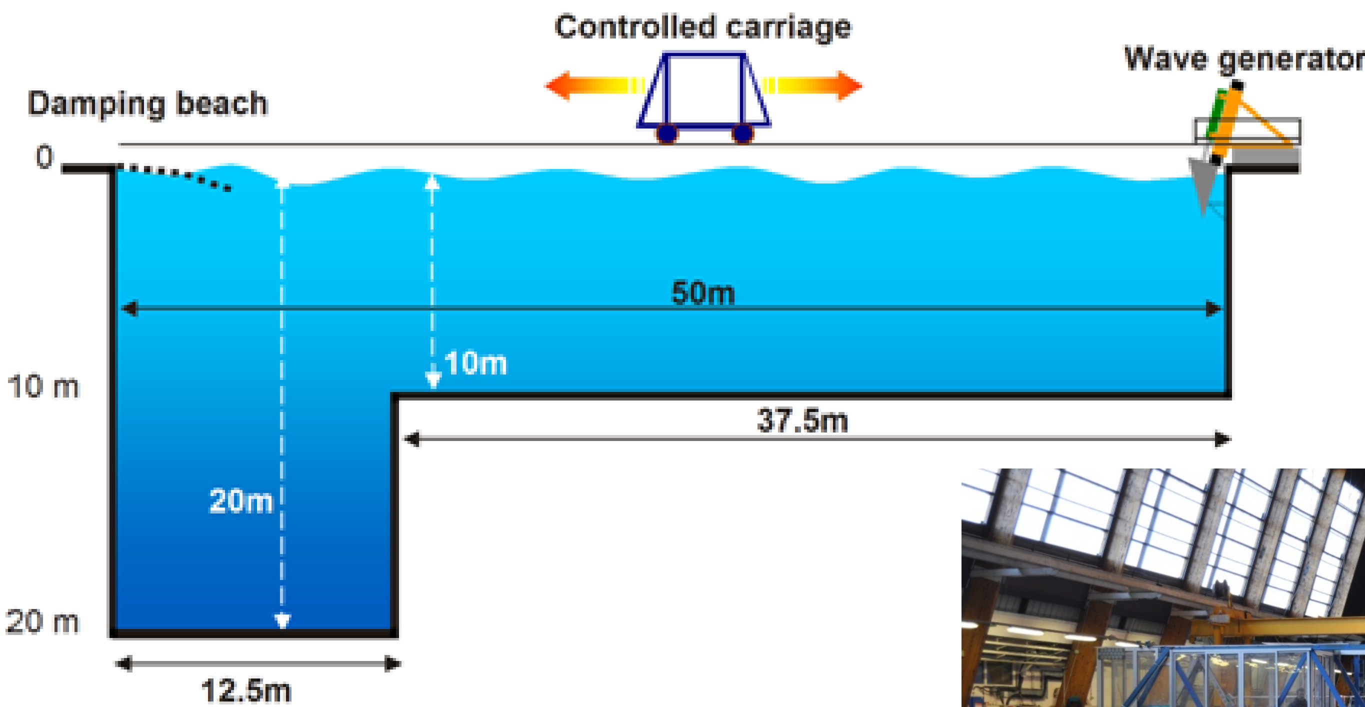
MARINET: Marine Renewables Infrastructure Network for Emerging Energy Technologies

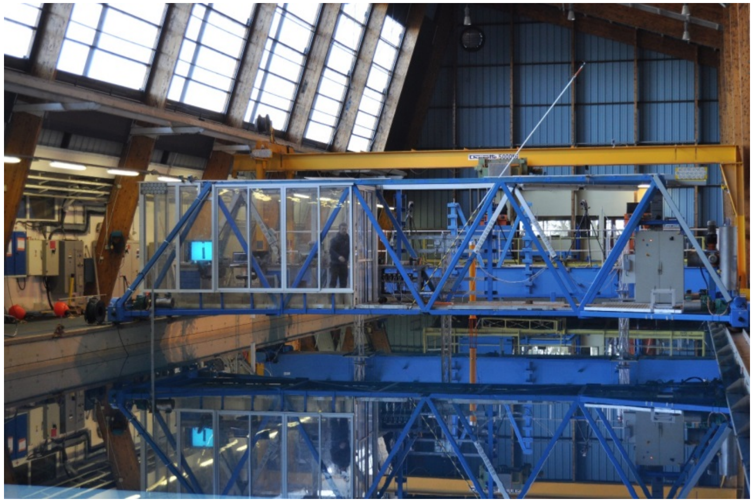
http://www.fp7-marinet.eu/



- Co-financed by the EC, MARINET offers periods of free-of-charge access to world-class R&D facilities and conducts joint activities in parallel to standardise testing, improve testing capabilities and enhance training and networking.

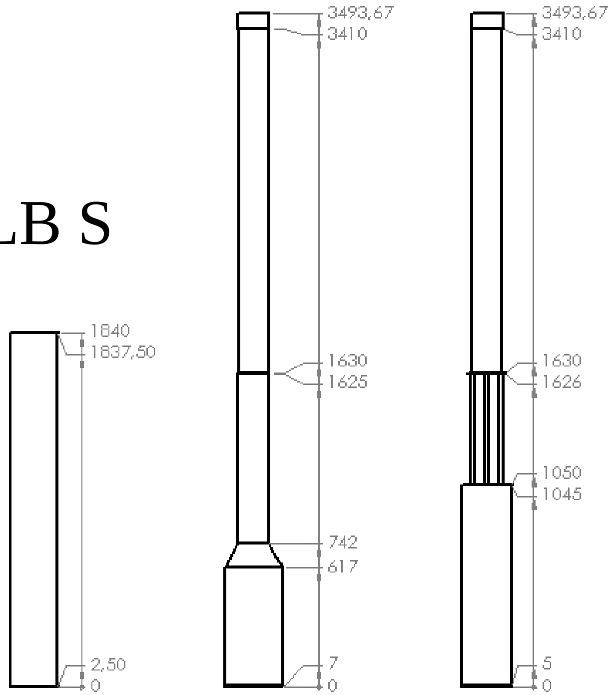
IFREMER Deep Sea Water Wave Tank, Brest, France



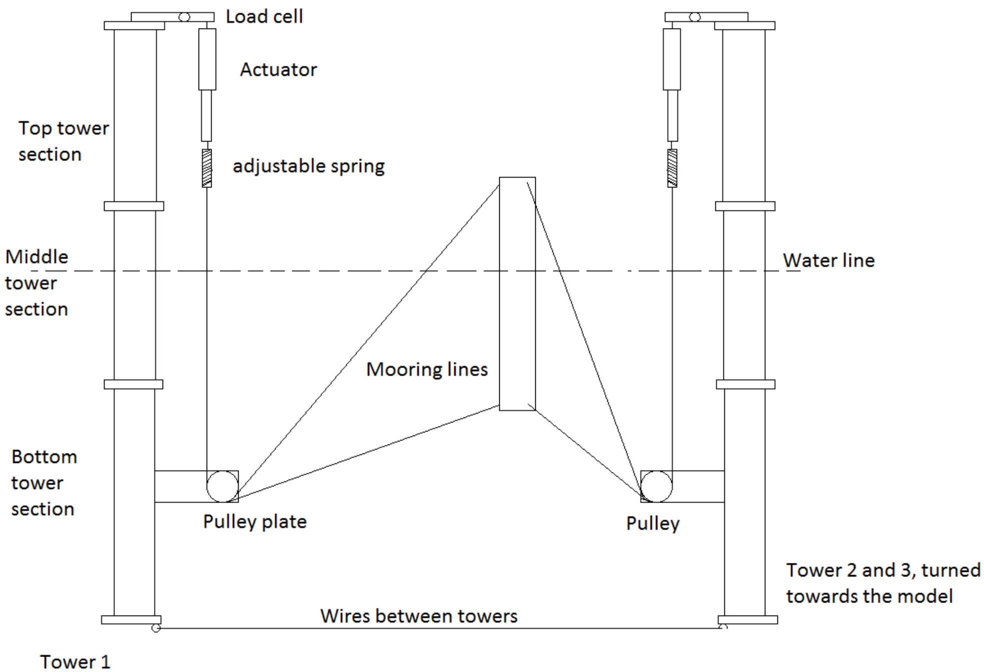


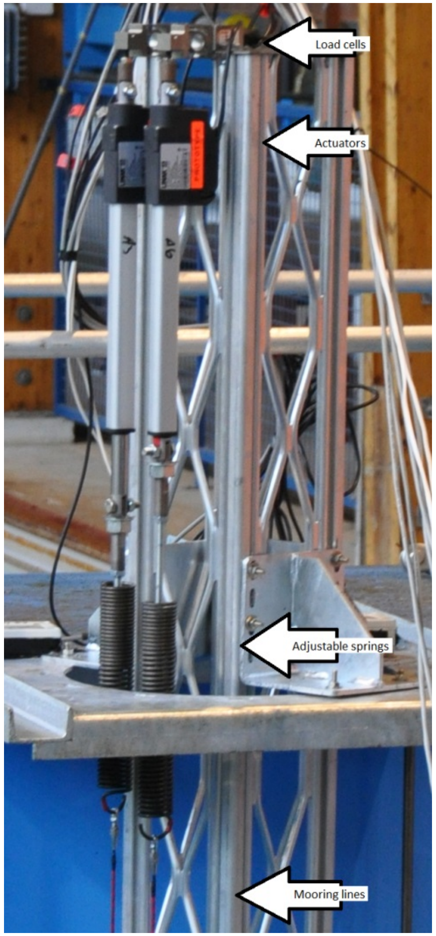
Platforms, scale 1:40

TLB S TLB B TLB X3



Mooring system



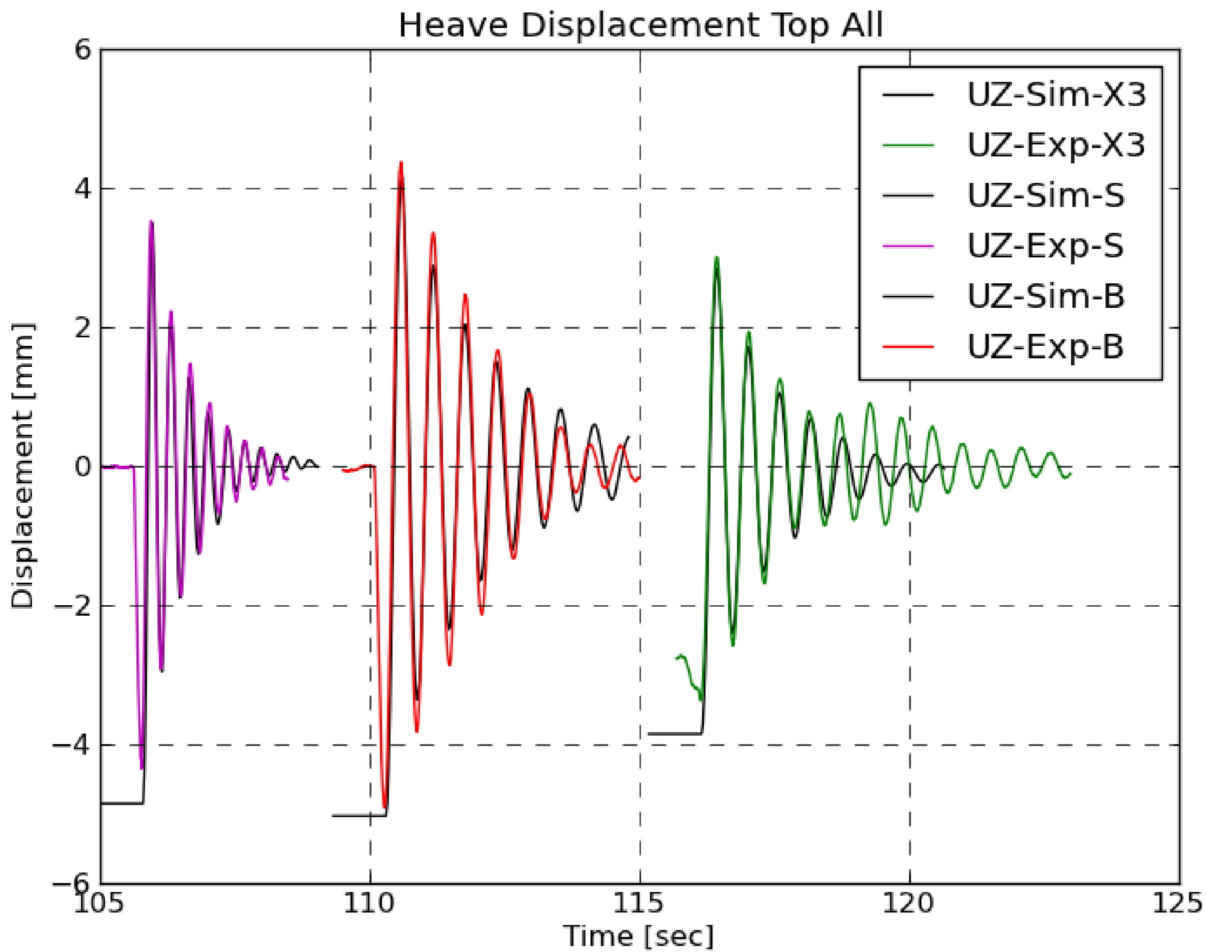


Load cases (presented in full scale)

- Decay tests: Heave,Surge/Pitch
- Regular waves: 10 cases
  1. Periods 6s – 16s
  2. Wave heights 6m – 20m
- Irregular waves: 3 cases

	Hs	Tp	Gamma
1	11.2	19.2	1.05
2	5.2	10	2.87
3	11.2	16	2.9

Heave Decay Test Results, Model Scale

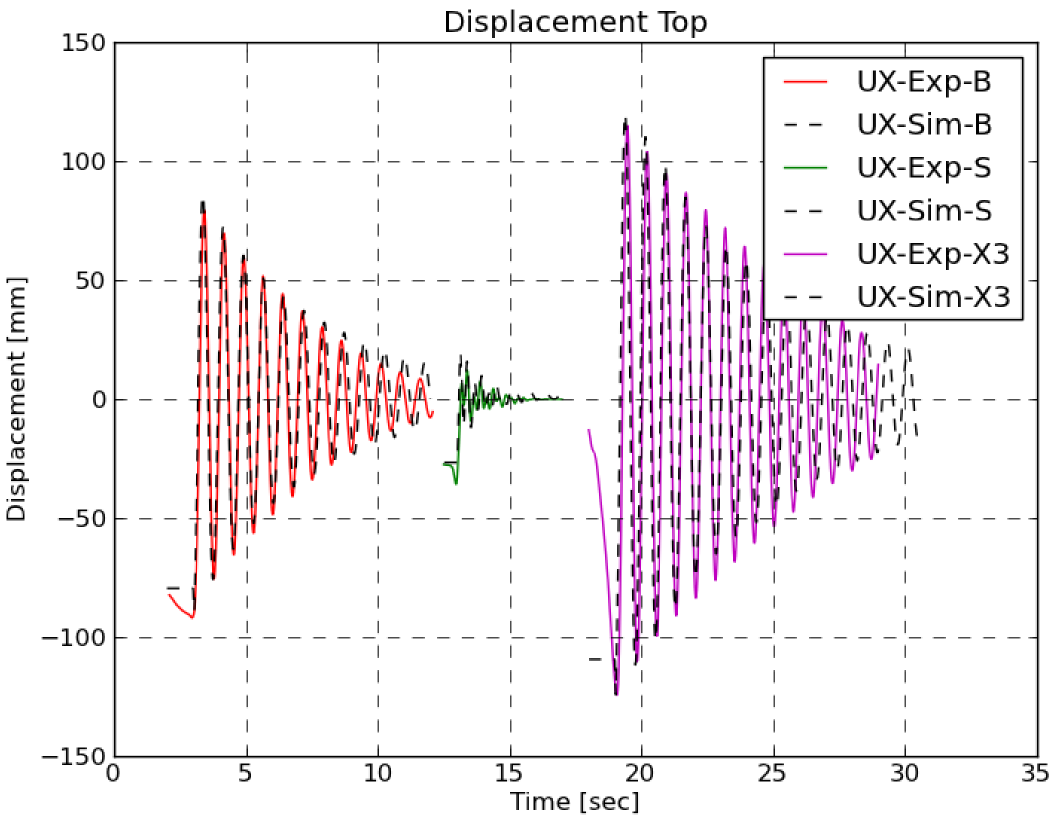


Matches first part of decay well

X3 experiment disturbed by other mode

Heave eigen frequencies are 2.9, 1.7 and 1.7 Hz for S, B and X3 respectively

Pitch/Surge Decay Test, Model Scale



Period of S and B are OK

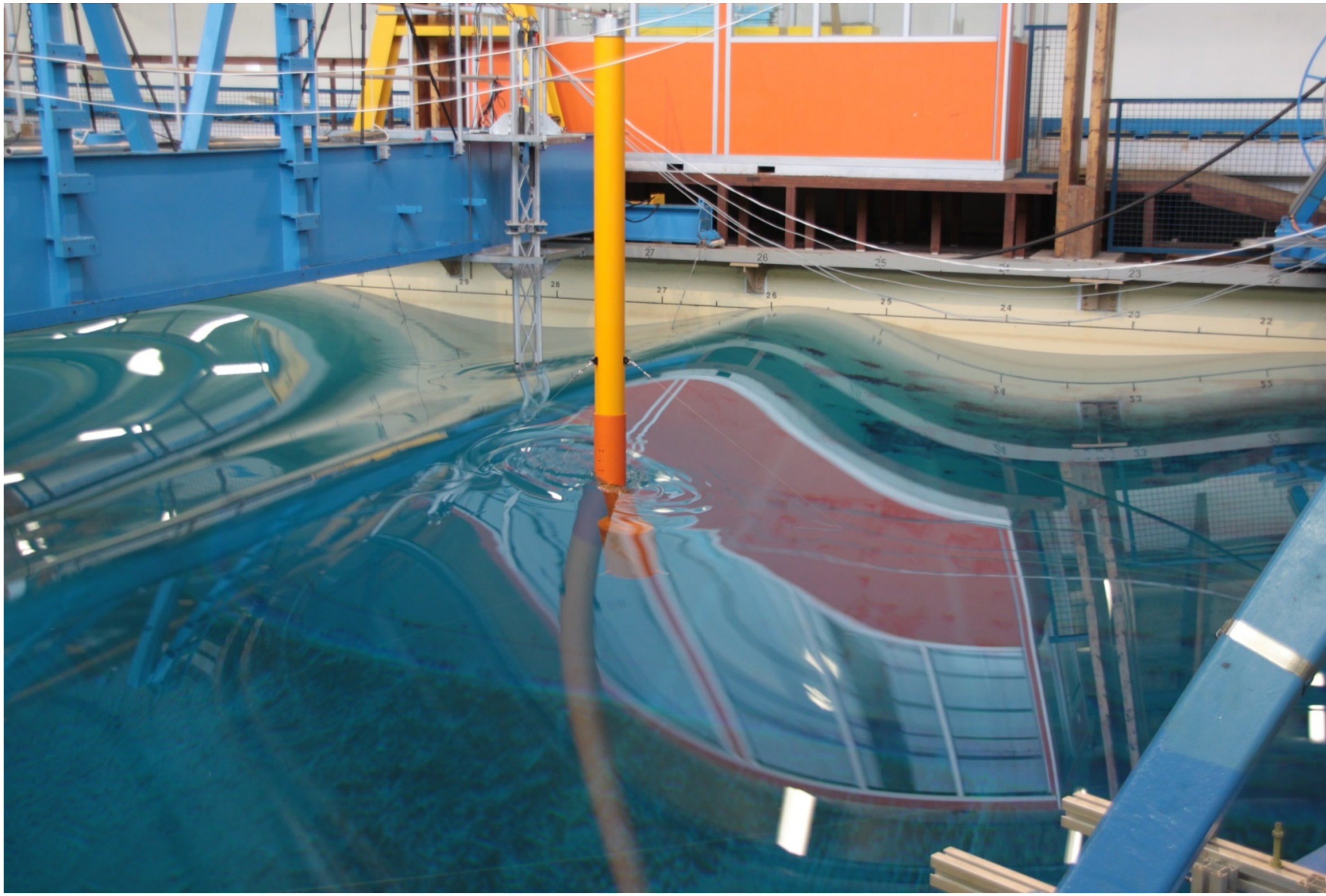
X3 period 3% longer in computation

Damping matches well
For B and X3.

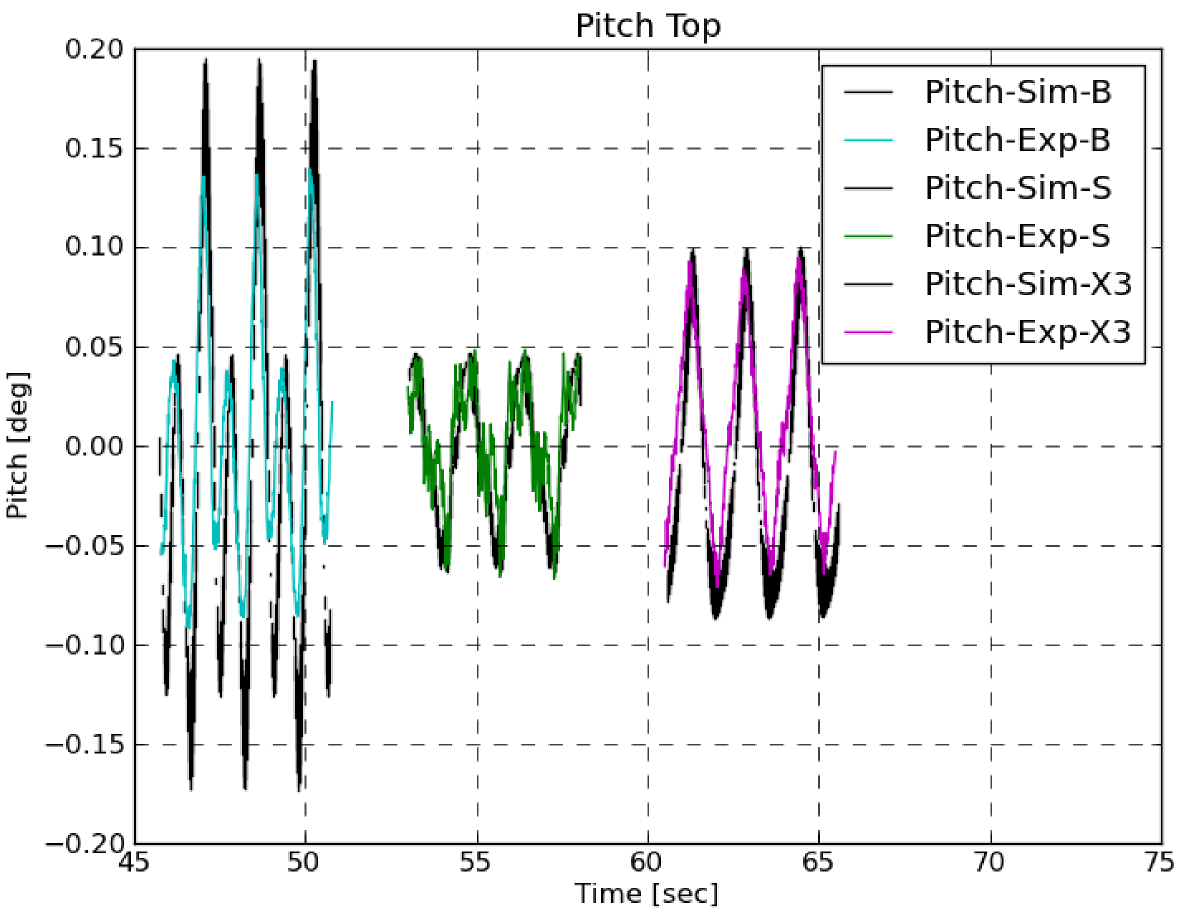
Damping in experiment for S is erratic and difficult to interpret

Pitch/Surge eigen frequencies are 2.34, 1.35 and 1.35 Hz for S, B and X3 respectively

LC9, Regular Waves: H = 5.2m, T = 10s in Full Scale
Sensitivity Study on Added Mass, Cm = 1.6 – 2.0

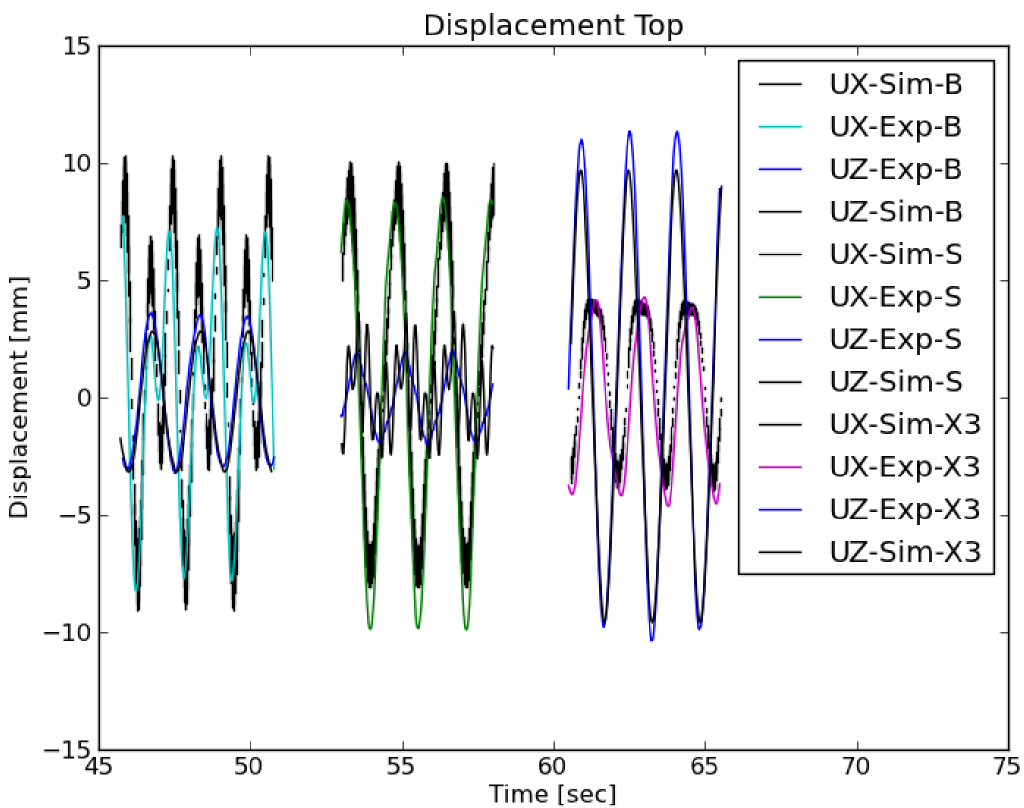


Tower Top Pitch Angle



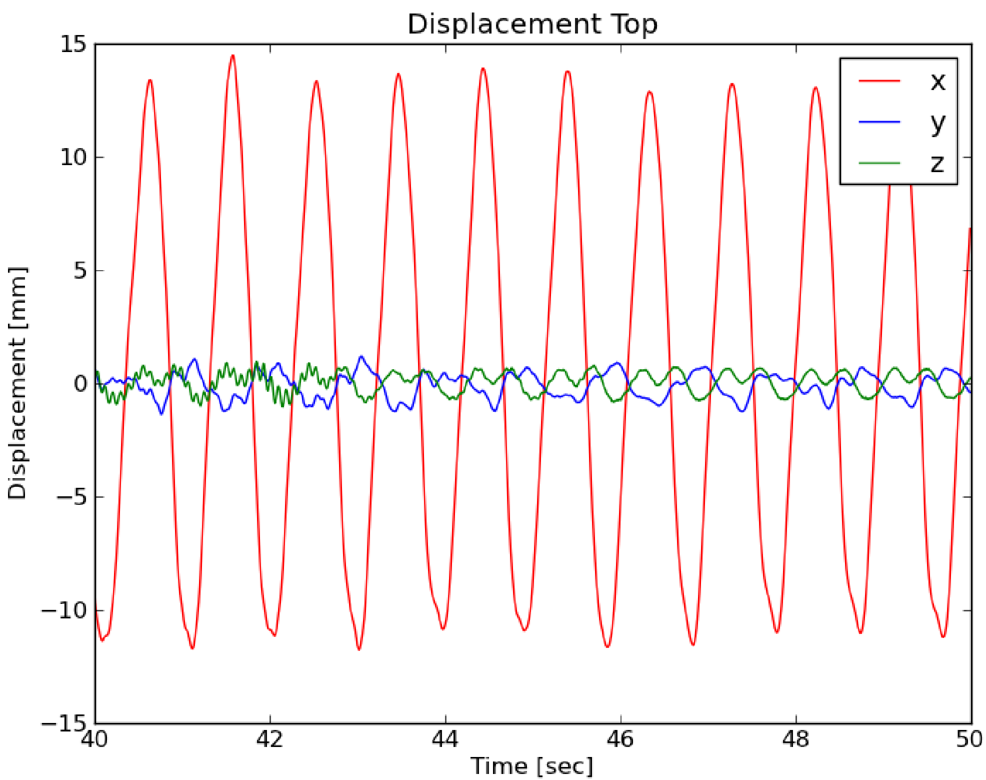
- Good agreement despite small angles
- TLB B (left) responds both at wave frequency, and twice the wave frequency (close to pitch/surge eigen frequency).

Tower Top Displacements



Good agreement, except for TLB S in heave (middle of figure):
Experiment (Blue): First order response.
Computations (Black): Also component 5x wave frequency, close to heave eigen frequency.

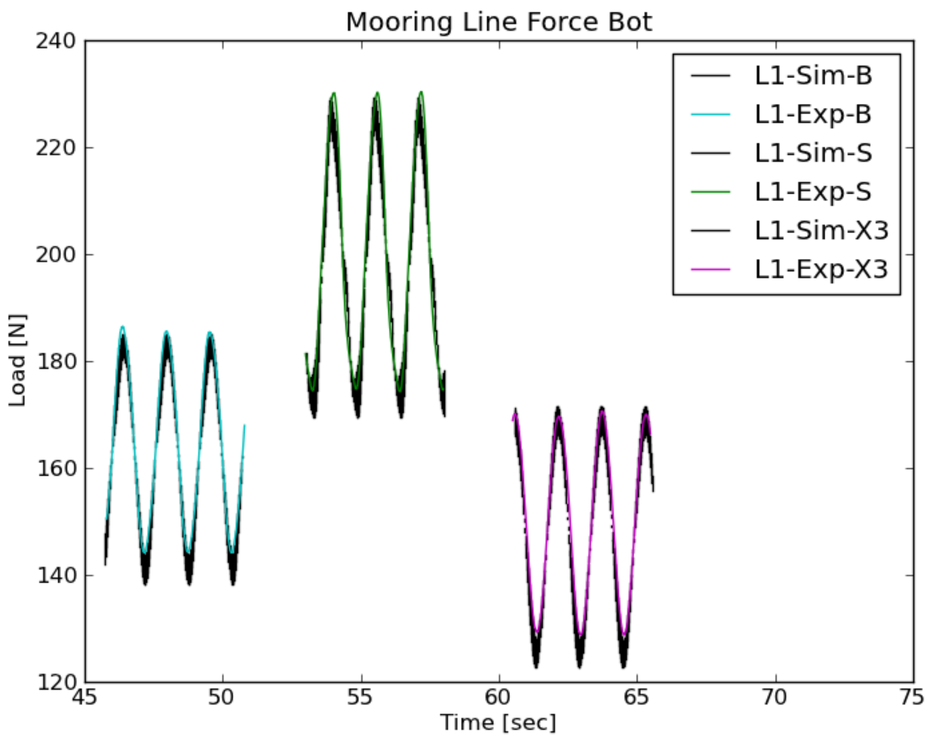
Heave resonant response found in the experiment, start of LC 26



Vertical component at heave eigen frequency is damped out.

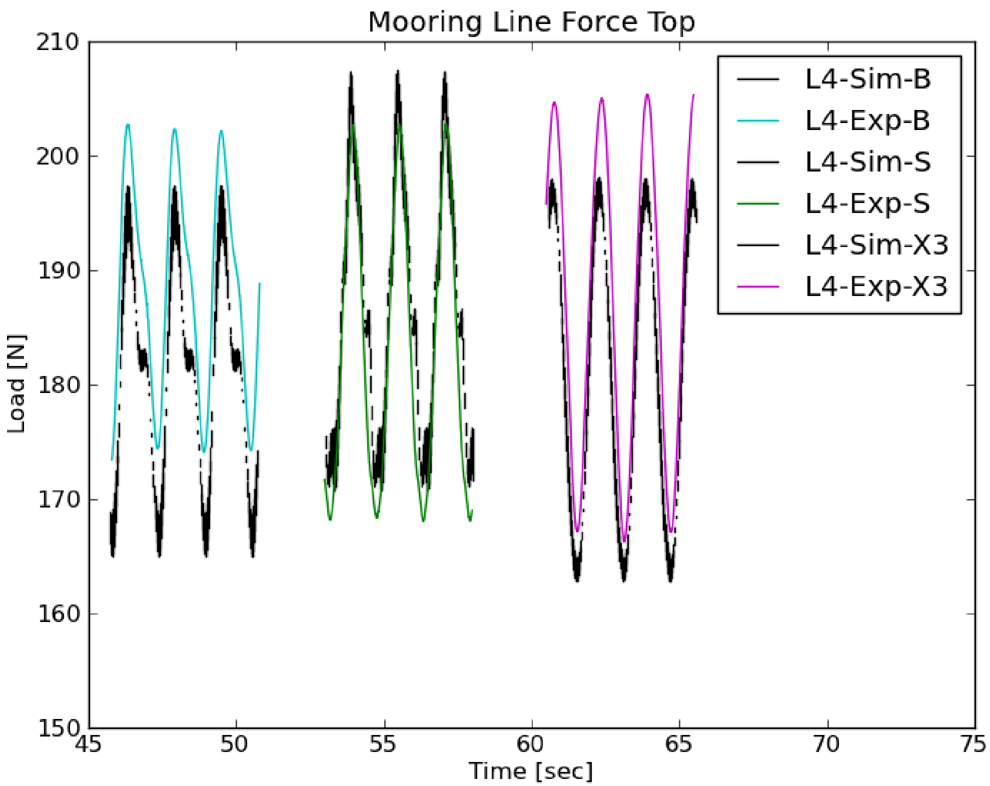
One possible explanation is the friction in the pulleys in the experiment. The friction hystereis in the mooring lines was measured to be 1N, at a mooring line tension of 200N

Lower Mooring Lines Tension



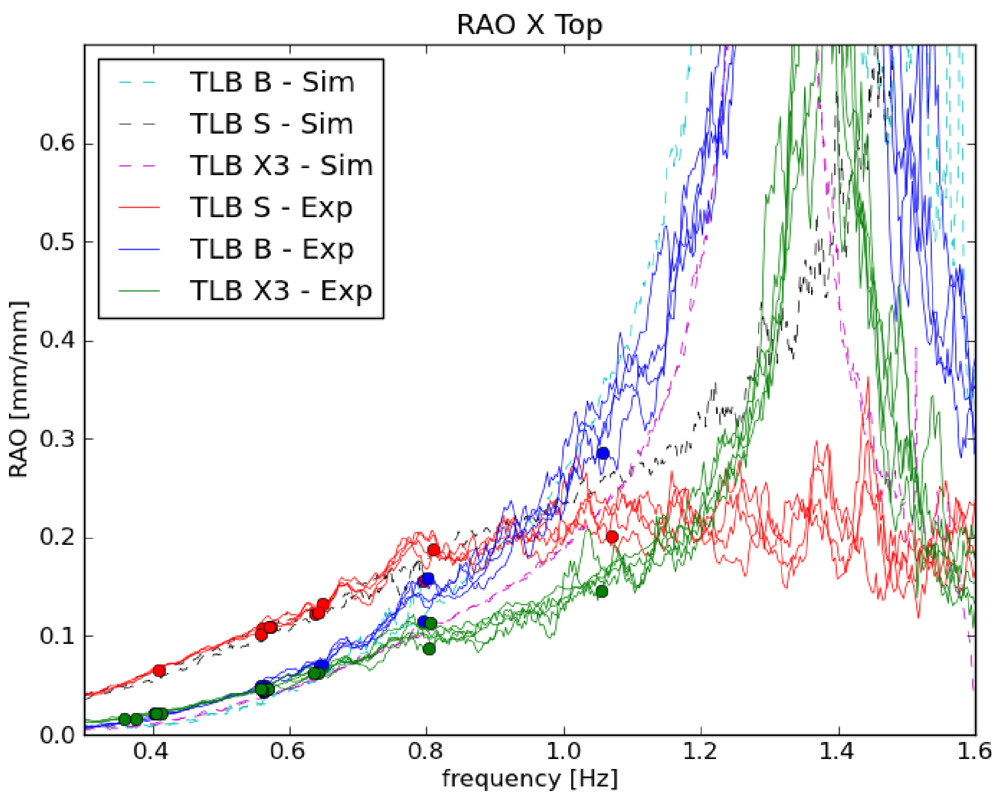
Good agreement

Upper Mooring Lines Tension



Mean tension offsets, but amplitudes match well

Irregular(lines) and regular (dots) Wave Cases, Tower Top Horizontal Displacement RAOs, Model Scale



Good agreement for B

Higher response towards resonance for S and X3 in computations

Results in region above 1 Hz are sensitive to friction

Conclusions, experiment

- Time series for decay tests, regular- and irregular wave cases have been measured for three different 1:40 scale models of Tension-Leg-Buoys.
- Preliminary computations show good agreements for the regular load cases, except heave resonant response for TLB S in the simulation.
- The irrgular wave cases show good agreement for low frequencies, and significant differences for frequencies around pitch/surge and heave resonance
- The differnces between experiment and simulation may be due to friction in the pulleys in the experiment
- The X3 space-frame reduced anchor loads 10 %, not enough to justify the increased complexity of this floater.

Conclusions, experiment, outlook

- Next step: We are currently implementing node hysteresis damping in 3DFloat, to take into account the friction in the pulleys in the experiment
- The data set should be of interest for validation of computational tools for offshore wind turbines. The raw time series will be open after our publication of the results.

Outlook for TLB

- Next step is better modeling of the anchors in different types of soil
- IFE and the Norwegian Geotechnical Institute (NGI) has just started discussions about implementation of anchor «super-elements» in 3DFloat
- The TLB is a candidate for filling the gap between bottom-fixed foundations (up to 50m depth) and the Spar-Buoy (100m and deeper), at sites with restrictions on footprint and adequate soil conditions

Acknowledgements

- EU FP7 MARINET funded wave tank time, on-site support and part of the travel costs
- NOWITECH/IFE funded direct costs for building the test equipment
- UMB funded parts of the test equipment
- Thanks to the staff at IFREMER for two interesting, intensive and fun weeks.

Thank you for your attention !

Extra slides

Summary, GHG emissions

- For the six conceptual design examples in the study, the resulting GHG emissions are in the range18 - 31g CO2-equivalents per kWh.
- To put this in perspective: Coal is around 1000g/kWh
- The Energy Payback Time is in the range 1.6 to 2.7 years
- Major drivers are substructure (steel) mass, installation/decommisioning and maintenance
- For a large-scale deployment of offshore wind turbines, substructures with low steel mass should be of interest

Tension-Leg-Buoy, IFREMER, Brest

- Platforms: (rotor represented by clump mass), 1:40, intended to support NREL 5MW rotor in full scale
  1. Simple straight tubular floater («Simple»)
  2. Baseline floater including conical section («TLB B»)
  3. Load reduction by transparent structure in the wave action zone («X3»)
- Load cases
  1. Decay tests
  2. Regular waves
  3. Irregular waves
- Sensors
  1. Wave elevation, front and side of model
  2. Mooring line tension
  3. Motion of platform

Coefficients for computations

1. Morison normal drag coefficient of 1.0 chosen from KC and Re (Sarpkaya experiments)
2. Morison axial drag coefficient set to 0.5 for bottom end cap, and 0.5 for top end cap (X3).
3. Morison axial and normal added mass chosen to match heave and pitch/surge eigen periods respectively
4. Structural damping in the mooring lines and horizontal and vertical linear damping chosen to match the decay in the free-decay tests

Documentation of results

- Design and fabrication of equipment: Master Thesis of Anders Spæren, UMB (in Norwegian).
- Experiment and model geometry: Journal article by PhD candidate Anders Myhr and Tor Anders Nygaard (supervisor). Ongoing internal review
- Experiment and comparisons with 3DFloat computations: Journal article by PhD candidate Anders Myhr and Tor Anders Nygaard. Ongoing internal review
- Time series of results will be available after publication of the articles