Hydrodynamic comparison of 1:40 and 1:100 Froude-scale models of a lightly moored WINDMOOR semi-submersible

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Background

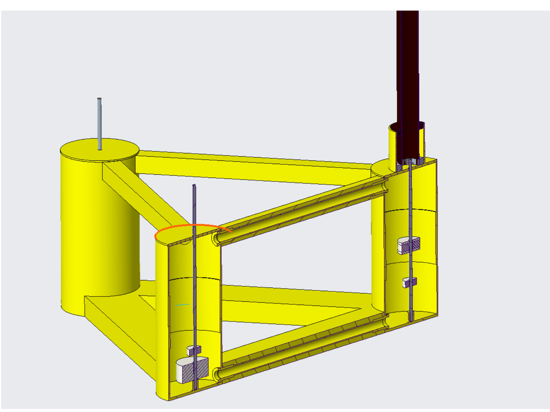
- Hydrodynamic tests on floating substructures is an essential part of floating wind turbine development.
- Most physical tests are conducted at small scale (typically 1:20 or smaller) and observing Froude-similitude. However, the applicability of such scaling, particularly with regards to drag effects, as well as for the test facility to reconstruct a particular wave climate, needs evaluating.

Aims

1. Verify the response of a 1:100 Froude-scaled model of the INO WINDMOOR substructure by comparing to measurements of a 1:40 scale model [1].
2. Evaluate the accuracy of using a 1:100 scale model within a narrow towing-tank for representing the hydrodynamic loads.

1:100 Model Manufacture

- The 1:100 scale model is built using a welded aluminium chassis for the vertical cylinders and pontoons, upon which CNC-machined isoporous foam is added to give the final geometry.
- Centre of gravity (CG) is targeted to be the same as SINTEF, with a brass top-head mass representing the rotor-nacelle assembly (RNA).

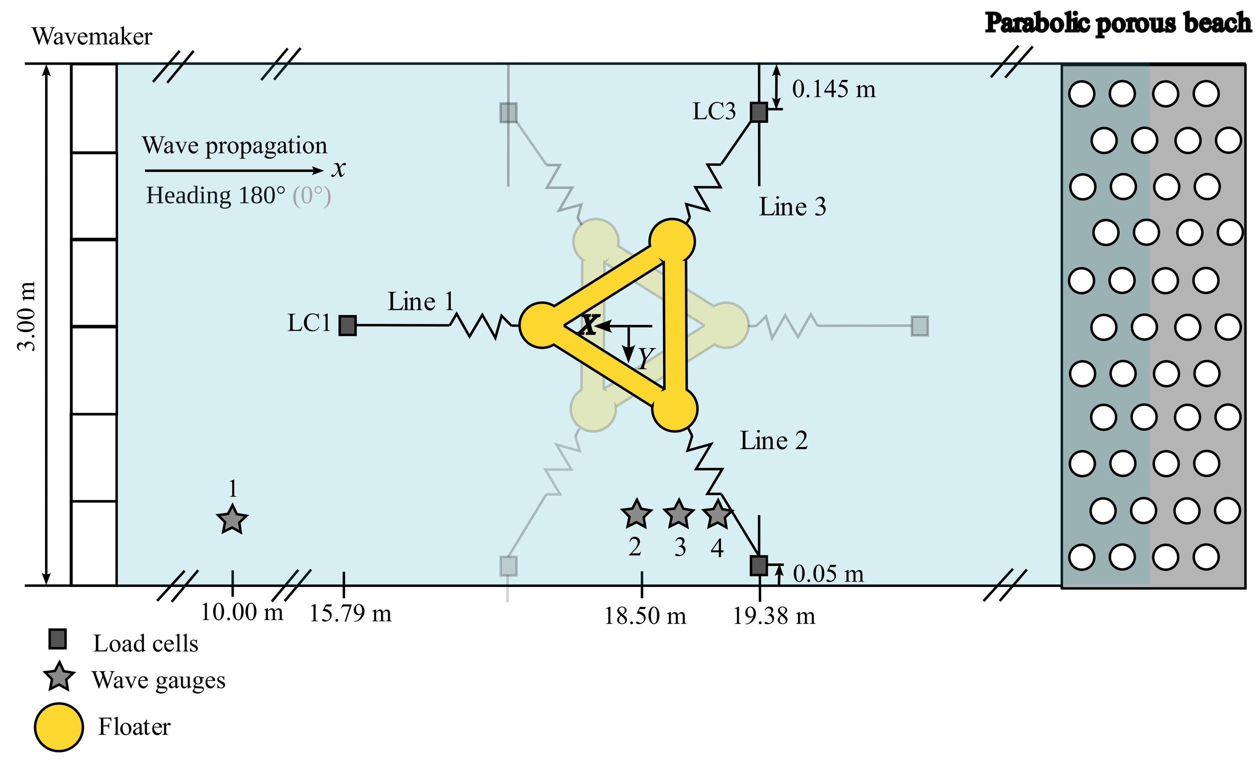


Experimental Setup - MarinLab

The following instrumentation is used, with time-synchronised recording into a NI-cDAQ 9174:

- Resistance wave gauges (128 Hz)
- Qualisys motion capture (100 Hz)
- One load cell per line (250 N capacity)
- RNA accelerometer

Mooring lines consist of 'inextensible' nylon rope, with 5 serial-connected linear springs attached at the fairlead positions, to give same horizontal stiffness as SINTEF tests.



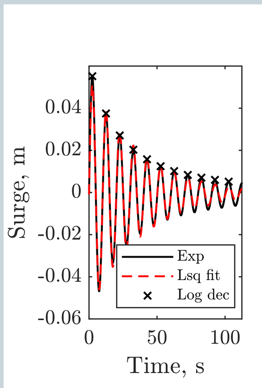
Dry Parameters

CG and gyration radii are obtained using the Bifilar suspension method. Results given in table:

Parameter	Units	SINTEF	MarinLab	Difference %
Floater mass	t	12129	12327	1.6
RNA & tower mass	t	1994	1497	-24.9
Total mass	t	14124	13824	-2.1
Total CG relative to origin	[m,m,m]	[0.01,0.00,3.94]	[0.00,0.00,4.20]	[-,-,6.6]
Total R_{XX}	m	43.62	40.42	-7.3
Total R_{YY}	m	44.01	38.65	-12.2
Total R_{ZZ}	m	29.87	32.91	10.2

Damping

Moored free-decay tests conducted in all 6 degrees-of-freedom (DOFs). Linear (p1) and quadratic (p2) damping coefficients are obtained by a least-squares approach. Results for 3DOFs are shown below:



	SINTEF			MarinLab		
	Natural period, [s]	p_1/M [1/s]	p_2/M [1/m or 1/rad]	Natural period, [s]	p_1/M [1/s]	p_2/M [1/m or 1/rad]
Surge	94.92	2.3E-3	1.6E-2	98.66	2.5E-3	1.6E-2
Heave	16.30	3.6E-3	1.7E-1	16.31	4.9E-3	-
Pitch	30.35	7.3E-3	7.5E-1	30.47	1.8E-2	2.5E-4

Response Amplitude Operators

JONSWAP irregular waves generated with random seeds. Water depth = 220m (full-scale).

Hs = 3.7 m	Hs = 6.2 m	Hs = 15 m
Tp = 7 s	Tp = 9 s	Tp = 14 s
γ = 4.9	γ = 4.9	γ = 4.9

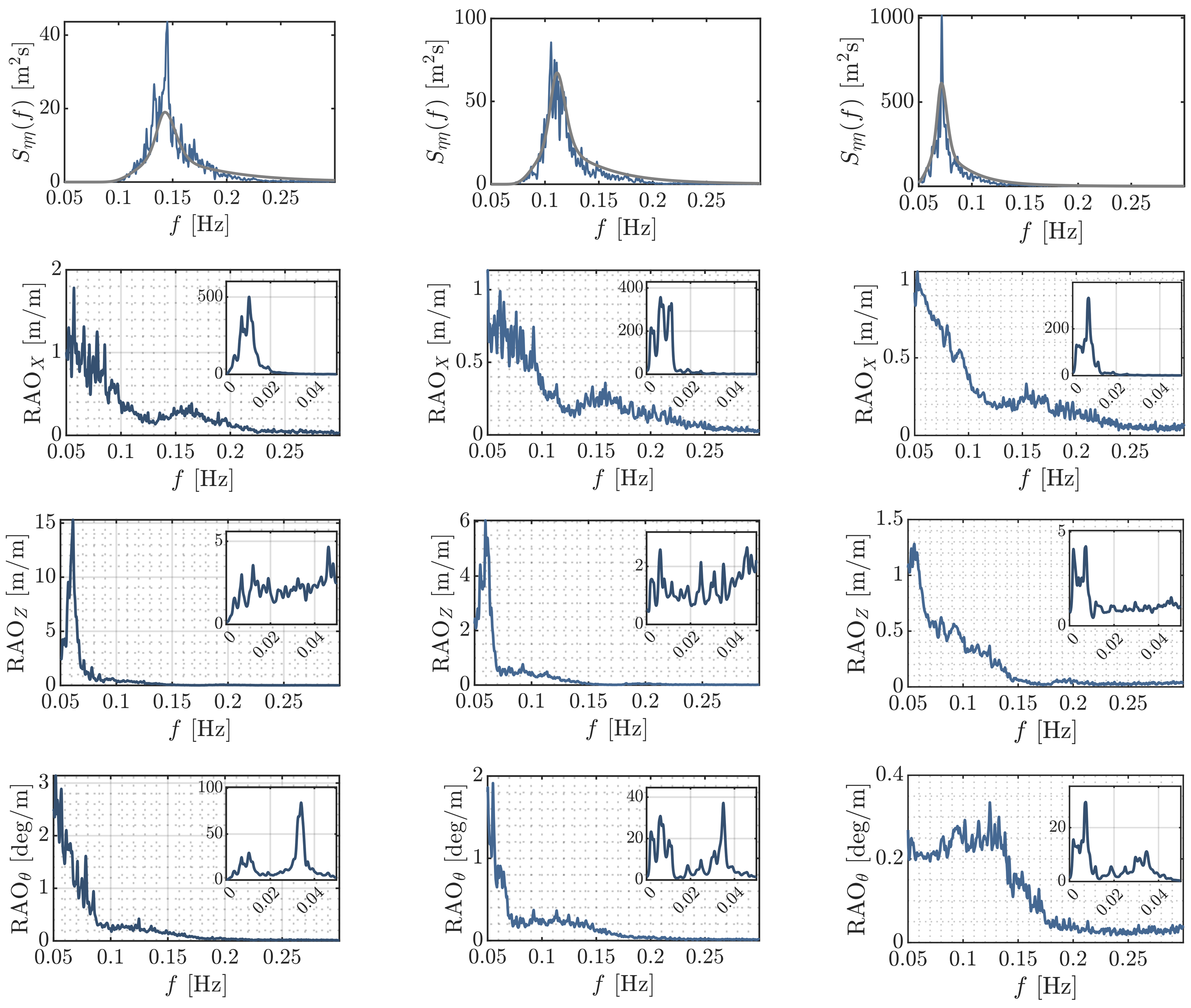
- RMSE to theoretical wave spectra: 3.5% and 1.8% and 1.7%, for Hs = 3.7 m, 6.2 m and 15 m respectively.
- Negligible transverse wall reflections for predominant degrees of freedom.
- Large heave response due to natural frequency inside the low-frequency wave cut-off of 0.05 Hz.
- Inset-axes show RAOs for the low-frequency region (<0.05 Hz), highlighting the slow varying drift response.

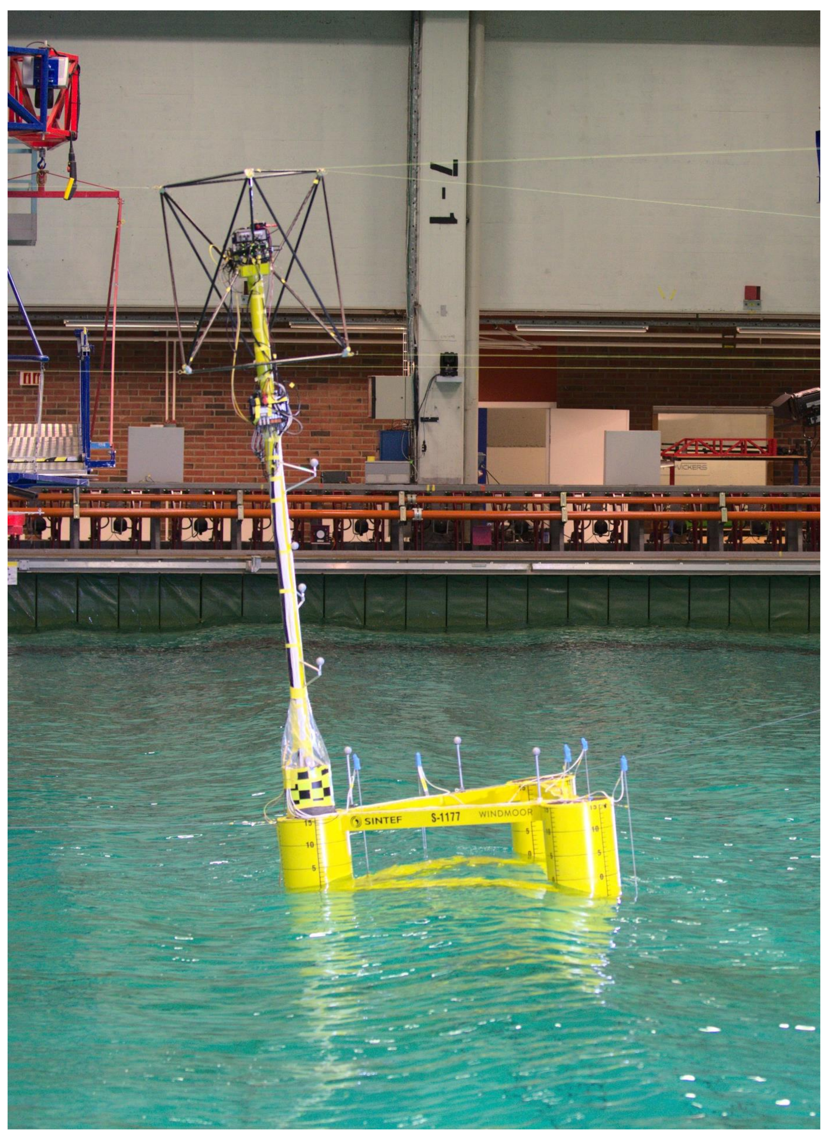
Input spectra

Surge

Heave

Pitch





Conclusions & Future Work

- 2% difference in dry mass, however 1:100 model has lower gyration radii about X- and Y-axes, due to difference in tower mass.
- Close agreement on natural frequencies from decay tests, though 1:100 model typically has more linear and less quadratic damping than 1:40.
- Tests are currently being re-run with wave heading 0° and lower-capacity load cells, to allow direct comparison to 1:40 model and improve mooring load accuracy.
- Future testing planned with aerodynamic loads using software-in-loop controlled ducted fan.

Acknowledgements

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SINTEF testing conducted as part of WINDMOOR project (No. 294573) Research Council of Norway, ENERGIX.

References

[1] Thys, M., et al. (2021) Experimental Investigation of a new 12MW semisubmersible floating wind turbine. https://doi.org/10.1115/omae2021-62980

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