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Model validation through scaled tests comparisons of a semi-submersible 10MW floating wind turbine with active ballast

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Semi-submersible model test campaign

In the EU H2020 project LIFES50+, a 1:36 scaled model test campaign was carried out for the NAUTILUS-DTU10, a semi-submersible 10MW floating offshore wind turbine (FOWT) with active ballast in 130m water depth [1]. The platform has 4 columns connected underwater by a square shaped ring pontoon (pon). They system has a design draft of 14.95 with empty water ballast [2]. The test included the use of a Real-Time Hybrid (ReaTHM) robot to simulate the aerodynamic loads in a wave basin. The turbine modeled was the DTU 10MW reference wind turbine, while the mooring system is based on 4 steel chain catenary lines. The wave basin testing was done by performing a variety of decay, pull out, regular wave, pink wave spectrum and extreme irregular wave spectrum tests, with and without simulated wind loads.

Fig 1: considered system

Modelling of Hydrodynamics

The research presented concentrates on the hydrodynamic modelling of state of the art simulation software FAST8 for FOWT. Its purpose is to compare the scaled model to the simulations, specifically looking at modelling the drift forces through second-order difference-frequency wave forces either through Newman's approximation or with the full quadratic transfer functions (QTFs).

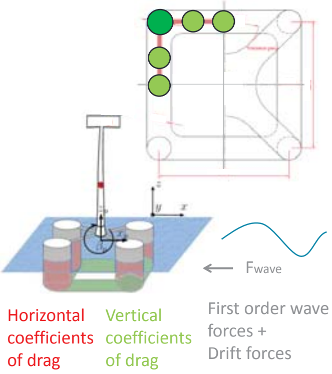

Fig 2: hydrodynamic drag and wave forcing on model

For the time domain simulation, the FAST8 model uses input from the panel code software WAMIT. Through use of potential flow theory it calculates the first order frequency dependent radiation damping, potential added mass and the wave excitation forces.

The mooring lines are modelled through the quasi-static solver MAP++.

Viscous forces are included through Morison elements. In FAST8 the coefficients of drag can only provide forces on cylindrical or circular areas. Thus, the underwater pontoon that connect the columns have been modelled as 4 cylinders in the horizontal direction and a set of 12 circles in the vertical direction (light green area). The columns have a coefficient of drag (Cd) in the horizontal and vertical direction (red and dark green areas respectively).

The hydrodynamic forces used on the platform model can be summarized as follows:

$$F_{hydrodynamics} = F_{wave} + F_{hydrostatic} + F_{linear\ radiation} + F_{drag}$$

Decay test tuning of model

The Morison element model is first calibrated to the free decay tests in the wave basin. Tuning of the drag coefficients to the experimental data can lead to an approximation of the free decay tests. When the moored decay tests were compared, tuning of the mooring model was needed to be able to better match the Eigen-frequencies of the yaw and surge DOFs.

The following decay frequencies were obtained:

	Surge	Heave	Pitch	Yaw
Mooored Tests (Hz)	0.0082	0.0511	0.0322	0.010
Model (Hz)	0.0079	0.0527	0.0314	0.011

Acknowledgements and References

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[2] M. Thys, V. Chabaud, T. Sauder, L. Eliassen, L. O. Sæther, Ø. B. Magnussen, "Real-time hybrid model testing of a semi-submersible 10MW floating wind turbine and advances in the test method", Proceedings of the IOWTC 2018 1st International Offshore Wind Technical Conference, November 4-7, 2018, San Francisco, CA

Validation of wave tests

The results are presented in terms of power spectral density of the 3 hour simulation results with an additional 1000s run in time not taken into consideration. Comparison with a pink wave test with significant wave height of 2m and wave period range from 4.5-18.2s were performed.

The decay tuned models for Newman`s approximation and Full QTFs shows a good agreement in the wave frequency range. Below these frequencies the models yields a good match in the slow-drift response in surge and sway, and tuning of the vertical coefficients of drag was necessary to obtain good agreement for the roll, pitch and heave. The low frequency yaw response was not reproduced properly.

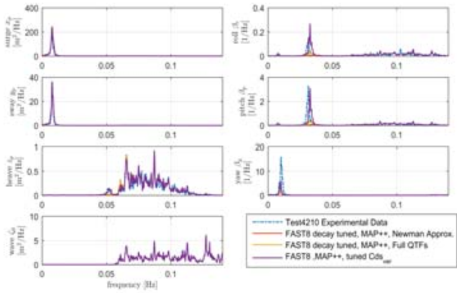
Fig 3: Pink noise spectrum test comparison

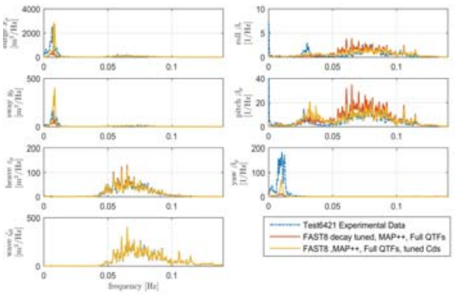
Fig 4: PM Extreme irregular wave spectrum test comparison

The extreme irregular wave test was carried out with a Pierson-Moskowitz (PM) spectrum with significant wave height of 10.9m and peak wave period of 15s. For the decay tuned model, the drift response is generally under-predicted. In the wave excitation frequency range, the pitch and roll are over-predicted.

By changing both the vertical and horizontal drag coefficients a better agreement is seen, yet significant discrepancies can be found in the yaw excitation as well as from trying to either match the pitch and roll, or the surge and sway responses.

Model	$Cd_{ver\ col}$	$Cd_{ver\ pon}$	$Cd_{hor\ col}$	$Cd_{hor\ pon}$
Decay tuned	78.05	12.95	0.715	2.05
Pink noise tuned Cds.	23.415	3.885	Unchanged	Unchanged
PM extreme tuned Cds	31.22	5.18	0.5125	0.1787

Conclusions and Outlook

Regarding the use of second order wave forces (with Morison elements for viscous effects) for modelling the motions of the NAUTILUS-DTU10 FOWT when compared to wave tank tests:

- For the Morison element model with decay tuned coefficients of drag, the use of difference frequency full QTF increased the response of the platform for the low frequency region (below the wave excitation region), mostly for pitch and roll , when compared to Newman's approximation. However, the decay tuned model was not able to reproduce all 6 degrees of freedom for the pink wave and JONSWAP irregular extreme wave spectrum tests.
- **Sea state dependant coefficients of drag were necessary for the model.** The pink noise tests with the full QTF model showed that through changes in the drag coefficients, the numerical model could approximate the test response well for all degrees of freedom except the yaw. The reason why the model cannot capture this is not clear. The extreme irregular wave showed larger discrepancies.

Further analysis on the modelling approach could include:

- Load case dependant coefficients of drag were necessary for the tests yet changing the coefficients for different sea states as well as dependency of the coefficients of drag on the Reynolds number, possible marine growth, and incoming wave direction necessitate more comprehensive studies.
- Scaling effects of the platform response and loads will also be of interest for the future development of the platform concept.