Numerical and Experimental Investigation of MIT/NREL TLP under regular waves

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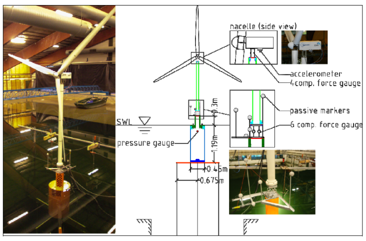
Introduction

In this study, numerical analysis of a tension leg platform (TLP) wind turbine is conducted and the responses are compared with available experimental test data. MIT / NREL TLP [1] design, supporting NREL 5 MW standard baseline turbine [2] is used for both numerical analyses and experimental tests. Numerical model is tuned according to free decay tests and regular wave tests. Responses are discussed in terms of natural periods, damping ratios and response amplitude operator(RAO) numbers. Numerical analyses with irregular waves are under development.

Experimental Data

Experimental data is gathered from the results of an experimental test campaign, conducted with a 1:40 Froude scaled model of the NREL 5 MW standard baseline wind turbine, within Hydralab IV Integrated Infrastructure Initiative [3]. Experimental tests were carried out in Danish Hydraulic Institute (DHI) Offshore Wave Basin in Hørsholm, Denmark, 2012. 4 mooring lines connected the structure to the wave basin by means of a serial connection of springs & load cells & high modulus synthetic fiber ropes. Springs were attached to the spokes. Spring forces were tracked by load cells. Rigid body displacements of the floater were monitored with a Qualisys Track System. 6DOF and 4DOF force gauges monitored the forces and moments below and above the tower, respectively. Wave gauges monitored wave heights before and after the structure. Tower and rotor blades were also Froude scaled in the model tests. Cases with the rotor stopped and rotating at rated wind speed (U=11.4 m / s) were tested. Rotation of the rotor was provided by an electric motor inside the nacelle. Additional thrust force was provided by means of a pulley to reach the target thrust force at rated wind speed.



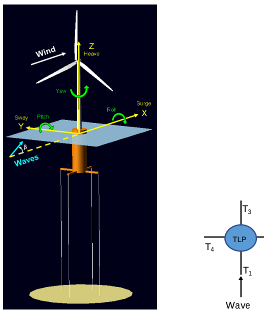
Wave Basin Test Model [3]

Platform Diameter	18.00	m
Draft	47.89	m
Radius to fairleads	27.00	m
Depth to fairleads	47.89	m
Unstretched line length	151.70	m
Water depth	200.00	m
Water displacement	12180	m^3
Platform mass including ballast	8600	tons

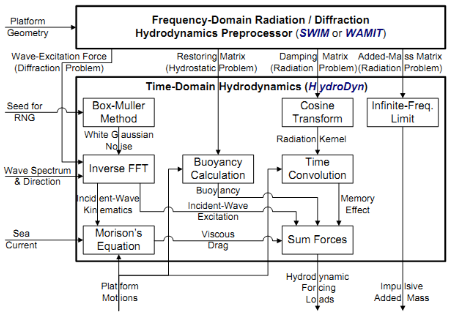
Platform properties in full scale [3]

Numerical Model

Numerical computations are conducted in Fatigue, Aerodynamics, Structures and Turbulence (FAST v8) code [4]. Aerodynamic loads are not considered in this study. Fluid inertia, added mass, and buoyancy terms of the hydrodynamic loading are calculated according to Potential Theory. Viscous drag forces on the platform and the pontoons are considered with Strip Theory. Second order wave loads have not been considered in this study. Mooring lines were implemented with the dynamic mooring module, MoorDyn. Linear waves are generated according to Airy wave theory.



Numerical Model [1]



Summary of the HydroDyn calculation procedure [5]

Results: Natural Frequencies

The only free decay test data, TEST #1271: Sway free decay test with y0= 7.91 m & z0= 0.19 m. Heave resonant motions are also excited in the sway free decay test. Time series are used to obtain the natural period and the damping ratios. Numerical model is tuned with additional linear damping according to the sway free decay test.

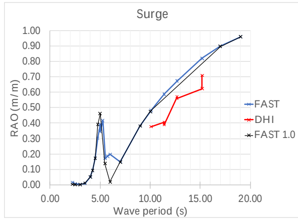
	Period (s)		Damping (%)	
	Analysis	Test	Analysis	Test
sway	63.9	56.3	5.1%	5.0%
heave	2.6	2.9	1.0%	1.1%
T2 high	2.6	2.9	1.1%	1.1%
T2 low	63.2	56.4	5.7%	7.1%
T1 high	2.6	2.9	1.1%	1.1%
pitch	4.9	NA	3.7%	NA

Natural period comparison of analysis and the Test #1271

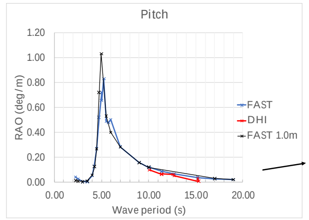
Results: Regular Waves

Wave only analyses with orthogonal wave propagation are presented. Wave basin tests wave loading period interval is between 10 &15 seconds. Results are given with Response Amplitude Operator(RAO). Additional numerical analyses with 6 m wave height are also conducted and represented with "FAST" data series. Sensitivity analysis with 1 m wave height is represented by "FAST 1.0" data series. Note that breaking wave height criteria is violated with analyses H= 6m and T<5.25 sec.
All the responses are filtered with wave frequency.

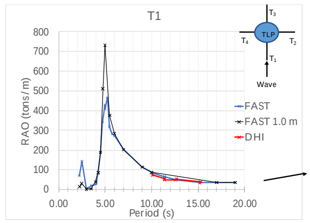
$$RAO = |H(\omega,\beta)| = \frac{\eta_a}{\zeta_a}$$



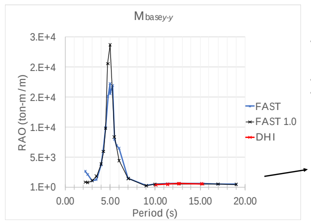
- Increasing response with increasing wave period.
- Analyses: Linear responses away from resonance freq.
- Test: Linear responses
- 20%-35% difference between analysis (FAST) and test (DHI)



- Resonance around the pitch natural period, 4.9 seconds
- Nonlinear responses with resonance.
- Model test response is linear.
- 7%- 35% difference between the analysis (FAST) and test (DHI)



- Nonlinear response around the pitch & heave natural period.
- Tendons are going slack with analyses H=6m & T= 4.75 sec to T= 6.0 sec
- Model test response is linear.
- 3% - 30% difference between analyses (FAST) and test (DHI)



- Nonlinear response around the pitch & heave natural period.
- Model test response is linear.
- 6% - 25% difference between analyses (FAST) and test (DHI)

Conclusions

Numerical model tuning with available test data resulted with relatively good accordance but also slight to moderate differences in the responses. These differences are credited for the uncertainties in the model testing, solution methodology of the numerical model. Numerical study is under development with irregular wave analyses and analyses including wind excitation.

References

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