

Experimental Validation and Design Review of Wave Loads on Large-Diameter Monopiles

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Introduction & Thesis Scope

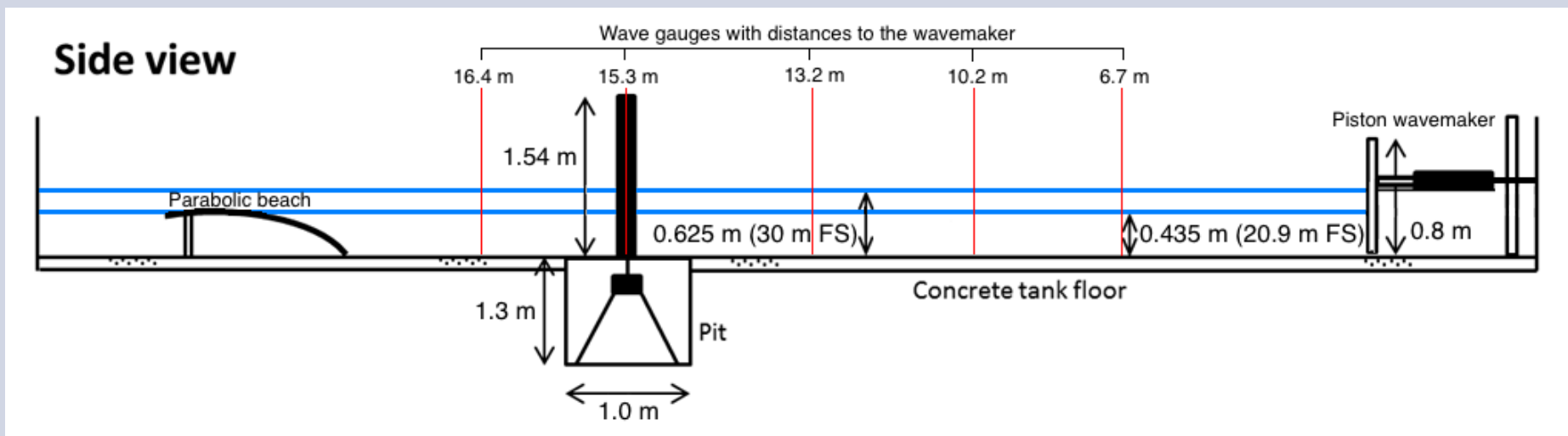
Statkraft’s involvement in the proposed wind farm at Dogger Bank acts as the backdrop of this thesis work. The site boasts great wind conditions and shallow water depths, making it a well-suited location for a wind farm of monopile-foundation turbines.

In order to avoid over-conservatism in turbine design, and thus reduce project costs, understanding the physical mechanisms inducing the largest loads is vital. Shallow water depths and strong winds introduce complex wave kinematics, of which models to accurately estimate forces are not well established. As turbine dimensions increase it is important to document the effect on loads and responses in order to maintain structural integrity and safety in turbine operation.

The main objective of the thesis work has been to perform experimental studies of wave loads in extreme sea states, to investigate how the largest response loads on an idling wind turbine develop. Deterministic and stochastic validation of theoretical higher-order wave load models has also been a central part of the thesis scope.

Experimental Setup

The model testing took place in the small towing tank at MARINTEK. The tank facility is a 28 m long and 2.5 m wide wave flume, with a piston-type wavemaker, a perforated parabolic beach and 13 installed wave gauges. All the tests were videotaped with front-view and rear-view cameras. The 6.9-m full-scale diameter pile structure is rigid and is scaled with a factor of 48. A top mass corresponding to 557 tonnes full scale is placed alongside the accelerometers on top of the pile and a flexible rotational spring is fit at the base.



The objective was to determine the responding forces and moments from wave loads, including slamming, in irregular sea states corresponding to 10, 50 and 1000-year return periods at a Creyke Beck B location in the Dogger Bank region. Eight sea states were tested at two water depths, 20.9 m and 30 m, corresponding to full-scale significant wave heights H_s of 6.71 m, 7.69 m, 8.22 m, 9.04 m, and spectral peak periods T_p of 11.25 s and 15 s. For each sea state, 20 seeds were run.

Numerical Model

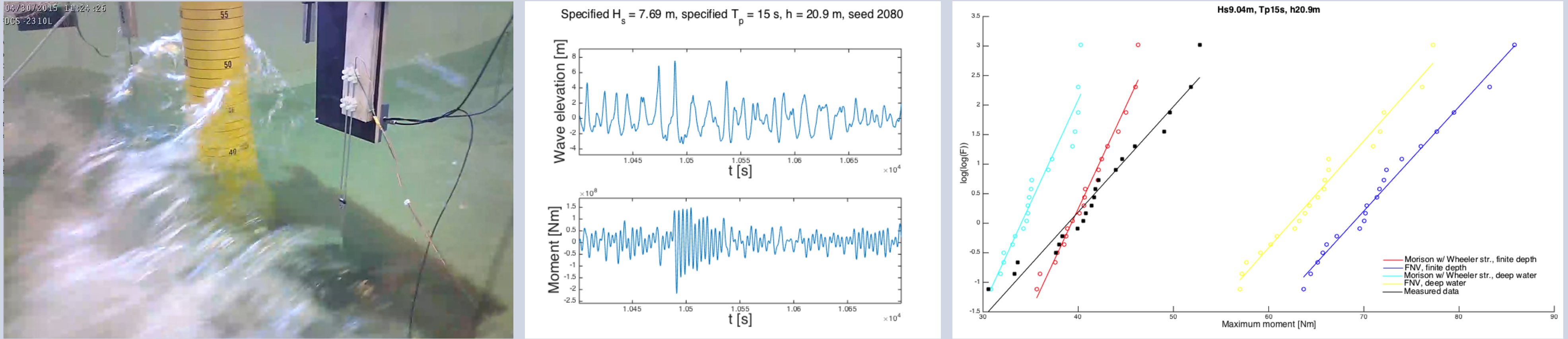
The numerical model is an idealized 1-DOF rotational system of a rigid cylinder with a rotational spring and a top mass. The structural damping is set to the decay-tested values of $\xi_c = 1.4\%$ and $\xi_c = 2.5\%$ for the two water depths, respectively. The load models included are deep-water and finite-depth versions of FNV and Morison with Wheeler stretching.

Results

The most important results of the thesis work follow:

- Repeated irregular wave runs with the model installed showed less than 1 % deviation in measured H_s . Similar correspondence was achieved for the wave calibration tests. However, larger discrepancy, between 2 % and 13 %, was found in measured response moments.
- At $h = 20.9\text{ m}$, the reduction in effective measured H_s relative to the input H_s , ranged from 1 %-12 % for the least to most rough sea states, respectively. The corresponding values for $h = 30\text{ m}$ were a 3 % increase to a 2 % reduction in H_s . All effective T_p values deviated less than 4 % off the nominal values.
- Frequent first-mode excitation was observed throughout the runs.
- The longer moment arm, i.e. the larger water depth, in general generated larger response loads. The relative difference was smaller for $T_p = 15\text{ s}$ than for $T_p = 11.25\text{ s}$.
- The largest response loads were due to impacts from breaking waves (left-hand figure).
- Compared with measured values, the finite-depth FNV model is the most conservative. The Morison model is generally unconservative for the larger sea states ($H_s = 9.04\text{ m}$ in the figure on the right).

A Gumbel plot showing a linear regression line for the measured maximum response moments in each seed, is exemplified for a large sea state in the right-hand figure.



Conclusions

Few ringing events from steep, but non-breaking waves, were observed. A possible cause might be the frequent, excessive first-mode excitation due to the conservative mode shape (resulting from the unrealistically stiff pile compared with the base rotational spring). A hypothesis was that a nonlinear phenomenon, such as ringing, would cause a rightward bend-off trend in the measured maximum moments of the Gumbel plots. This was tested in numerical simulations for a variety of damping levels, but no such tendency was observed for either sea state.

Due to the large amounts of breaking, the degree of realism of the resulting generated sea states are drawn into question. The breakers in question often propagate the length of the flume before breaking at structural impact. In the real Dogger Bank region, the relative distance between breaking zones and the wind parks are often much larger, so many of the large waves are prone to dissipate much energy before impacting a turbine. In addition, the metocean report for Creyke Beck B locations probably do not properly take shallow water effects into account, as pointed out by *Engebretsen, 2012*.

Since the greater water depth generally resulted in higher response loads, the effect of the larger moment arm can be said to exceed that of increased wave nonlinearity.

An FNV model that includes the intermediate-water dispersion relation and the vertical distribution of wave kinematics, was made. It is inconsistent with the conventional FNV load formulae, which are based on the assumption of deep water. The result is a more conservative model.

References & Acknowledgements

Central references in the thesis work include:

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- [5] Dean, R. G. and Dalrymple, R. A., *Water wave mechanics for engineers and scientists*, World Scientific (2nd printing with corrections), 1991.
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The testing facility setup figure (modified) is included by courtesy of T. Kristiansen (MARINTEK).

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