HYDRODYNAMIC LOADS ON OFFSHORE WIND TURBINES

Drag, inertia and cross-flow forces on offshore foundations including secondary structures

DONG Energy wanted to gain a better understanding of the effects of wave loads on offshore wind turbine foundations. To help them do this, we performed physical model tests and used OpenFOAM® to conduct numerical simulations to analyse wave-structure interaction. DONG Energy will use the information to adjust their design tools for more accurate predictions.

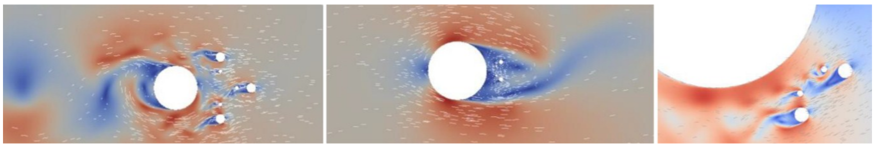
EVALUATING HYDRODYNAMIC LOADS ON FOUNDATION STRUCTURES

The high cost of offshore wind turbines compared to land-based wind turbines is a major barrier for the offshore wind industry. The cost difference is mainly due to the foundation principle as well as operation and maintenance. As such, a careful consideration and evaluation of hydrodynamic loads on foundation structures is very important. DONG Energy has built more than a third of the total offshore wind capacity in the world. As European Union (EU) countries strive to meet the EU's 2020 renewable energy targets, DONG Energy wanted to:

- gain a better understanding of the hydrodynamic loading on wind turbine foundations with secondary structures attached
- improve the present conservative design approaches and reduce the material consumption of steel in the foundations

In close collaboration with DONG Energy, we:

- established design diagrams of force response on the foundations with secondary structures from physical model testing
- built a Computational Fluid Dynamics (CFD) model using OpenFOAM® that was capable of simulating similar hydrodynamic forcing – we validated the numerical model simulations using results obtained in the experimental campaign
- delivered the CFD model and provided a short-course to the DONG Energy, enabling them to execute and analyse the CFD simulations in order to obtain in-line and cross-flow force coefficients for future design applications



Simulation of acceleration and deviation of the flow around the tested WTG foundations in various wave regimes: jacket leg with secondary structures (left), close-up of the monopile with secondary structures (middle), and close-up of secondary structure on the monopile (right). © DHI

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DONG Energy Wind Power A/S

CHALLENGE

- Determining (with improved accuracy) the wave loads on wind turbine foundations, including boat landing structures
- Reducing steel consumption to lower costs
- Improving the design of the fatigue life of the foundation structure

SOLUTION

A comprehensive physical model test campaign in a towing tank facility coupled with advanced numerical simulations in OpenFOAM® to study the wave-structure interaction in various sea states

VALUE

- Improved understanding of the wave-structure interaction in relation to the stroke of the wave motion and the propagating wave direction
- Established design diagrams for drag, inertia, and lift coefficients for cylinders with secondary structures
- Provided tailor-made short-course to DONG Energy on the Computational Fluid Dynamics (CFD) code OpenFOAM® simulation, model prediction of wave-structure interaction, and the force response on the structures
- DONG Energy gained in-house competences for setting up, executing and analysing model simulations to obtain in-line and cross-flow force coefficients for future design

LOCATION / COUNTRY

Denmark

PHYSICAL MODEL TESTING OF WAVE LOADS ON WIND TURBINE GENERATOR (WTG) FOUNDATIONS

This project required the establishment of a robust, consistent, and validated experimental physical model setup. The process of establishing and validating the data basis and analyses methodologies was followed by a certifying company.

We achieved this by testing the physical models with plain cylinders and varying surface roughness. The results obtained from our physical model setup and procedure agreed well with existing datasets reported in literature.

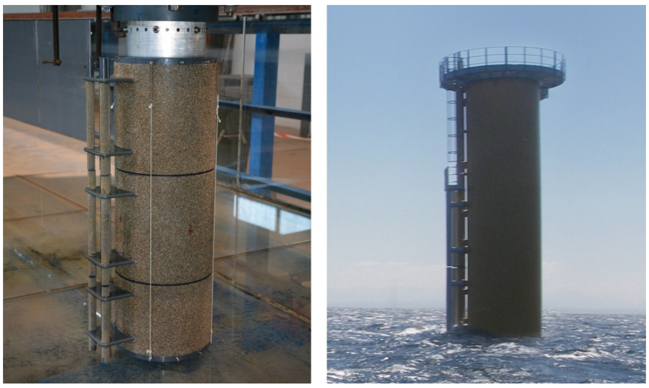
We executed an extensive experimental campaign that comprised wave loads on the model cylinders with secondary structures for several foundation types including:

- monopile with and without secondary boat landing structures
- jacket with and without boat landing structures

The experimental programme encompassed various environmental conditions that:

- matched the sea states experienced in practice
- took into consideration the orientation of the WTG foundation structures relative to the stroke of the wave motion and the main wave direction

The focus of the experimental part was maintained on the in-line and cross-flow force responses on the structure by a typical Morison approach. The integrated time series of wave loads on the structure are expressed in terms of force coefficients representing drag and inertia terms.

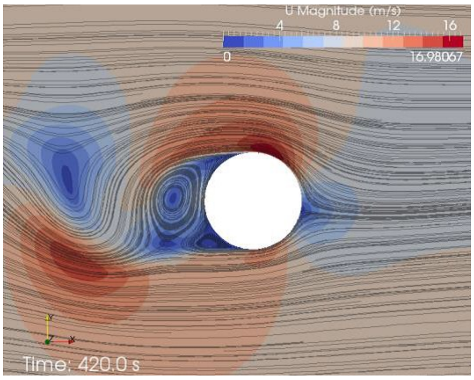


Monopile foundation with the secondary boat landing structures in the lab (left) and monopile foundation with the secondary boat landing structures in the field (right). © DHI

NUMERICAL SIMULATIONS OF WAVE LOADS ON WTG FOUNDATIONS

For the second part of the project, we utilised the knowledge and results obtained from the experimental programme and put them into a numerical framework. A CFD model in OpenFOAM® was setup to accurately simulate the oscillating flow around the structural elements and consecutively produce the integrated time series of force responses on the WTG foundation structures.

In conjunction with the time series analysis obtained from the physical model testing, the force time series were expressed in terms of drag and inertia coefficients. The results from the numerical CFD simulation agreed well with the results from the physical model setup. This enabled us to validate the numerical model, which could be used to broaden the range of results from the parametric experimental programme and in the future design of offshore WTG foundations.



Example of velocity contour and streamlines for the monopile structure in oscillating flow. © DHI

IN-HOUSE CFD MODEL TO SIMULATE WAVE LOADS

The analyses of more than 300 tests detailing the flow around and the accompanying forces on WTG foundation structures were made available to DONG Energy. We also conducted a CFD simulation short-course and provided model predictions of wave-structure interaction. This ensured that DONG Energy secured in-house competences for setting up, executing, and analysing model simulations.

The experimental tests, CFD simulations, and the short-course enabled DONG Energy to investigate flow under well-defined conditions. This information helped them understand how present design tools should be adjusted or replaced in order to more accurately predict in-situ loads and support the evaluation of the fatigue design life of foundation structures.

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> *Comprehensive physical and numerical modelling enabled detailed analyses, providing a solid basis for selecting the relevant wave loads for optimising material consumption in the foundation structures.*
>
> *Dr. Finn Rüdinger — Senior Load Engineer, Loads, Aerodynamics, and Control — DONG Energy*

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