Field data derived from Offshore Wind Energy Converters – Assessment and correlation of dynamic wave loads

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ABSTRACT

This paper presents the main objectives of the research project "GIGAWIND alpha ventus" in regard to the assessment of wind- and wave loads for supporting structures of offshore wind energy converters. The multiple sensor-equipped tripod structure for the acquisition of test field data in approximately 30 m water depths is presented here. Preliminary results from laboratory experiments with the objective to determine wave slamming and non-breaking wave forces on foundation structures are given exemplarily. Three dimensional numerical models combined with laboratory experiments and field data will be used. Temporal and spatial highly-resolved modelling of design loads are developed and validated to provide calculation methods for an efficient mass production of offshore wind turbines.

1   MOTIVATION

For the development of a sustainable environment political ambitions in Europe and in many other countries all over the world support the research and the construction of wind power plants. Due to the fact that the wind is blowing stronger and steadier on the ocean surface, offshore power wind farms with thousands of wind turbines are planned in coastal areas. The North Sea as a continental shelf provides wide areas with a relatively shallow water depth of 20-40m outside the coastal range of vision. Beside other European countries Germany has projected nearly 4700 wind turbines

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in the North Sea with an overall rated power of 23 GW. Within the framework of the research initiative RAVE ("Research at Alpha Ventus") field investigations are carried out in the context of the construction of the offshore wind energy converters (OWEC) in the test site alpha ventus, which are being installed in 30 meter water depth in the North Sea. Due to high follow-up and maintenance costs in case of tentative structure failure and due to uncertainties of dynamic loadings, the design of the offshore structure is overestimated in most cases. Therefore, mass production of OWEC requires an efficient design concept for the foundation type and supporting components based on the analysis of reliable wind and wave data. While slamming coefficients of breaking waves are decisive for the prediction of extreme loads, non-breaking wave loads set up the design parameters for fatigue limit state analysis. The project aims presented here focus on the optimization of OWEC supporting and foundation structures by investigating dynamic loads of breaking and non-breaking waves.

2 RESEARCH AIMS AND PREVIOUS STUDIES

Non-breaking wave loads on structural elements of an OWEC are generally calculated by the Morison formula (Morison 1952), which requires empirically determined load coefficients for the inertia term and the drag term (C_M,C_D). Existing load coefficients were often received from 2-D wave flume experiments and the application to natural conditions with a three-dimensional sea state is not optimized to the full extent. Therefore the affecting loads are often overestimated, which is safe for unique constructions but inefficient for the mass production of OWECs. Conventional load coefficients have partly been determined by investigation of regular waves based on the linear wave theory. Within this project, a comparison is drawn between the field measurements and the current methods of calculation with linear as well as non-linear wave theories. The first aim of the project is to provide efficient C_D and C_M coefficients for the fatigue problem analysis of OWECs.

The correlation analysis of wind and sea state loads is the second objective of the project. Concurrently recorded wind and sea state measurements offer the possibility to enhance and validate existing models. In previous studies statistical models for the determination of extreme directional sea states with high probability have been developed by Mittendorf (2005). The extreme sea states were hereby described through short term statistical parameters as wave height and period.

Local wave load effects are needed for detailed investigations of the supporting structure, e.g. for investigations of buckling or for the verification of shear stresses in welding nodes. In addition, nacelle acceleration induced by wave load impacts on the structure should be investigated as it is crucial to the overall wind turbine operation and for future maintenance purposes. For the dynamic response analysis as well as

for the other mentioned designing purposes a spatially and temporarily resolved pressure distribution due to breaking waves is needed. A common method to estimate the load of breaking waves on piles is the approach to substitute the drag coefficient C_D with a slamming factor C_S in the drag term of the Morison formula. The slamming coefficient has been empirically derived in several laboratory studies and proposed values for C_S scatter from 0.5π up to 1.7π (Sarpkaya 1978). The amplification of the drag term has been debated in literature since it is characterising a rough approximation of the impact process, especially of the rise time. However, the method has been successfully applied for design purposes of none mass production structures. Goda (1966) developed an approach based on the momentum of the virtual mass by introducing a linear time history of the impact and by assuming a constant velocity during the impact. Goda's approach is given in equation (1) with ρ = fluid density, C = celerity, D = cylinder diameter, τ = impact duration, t = time $< \tau$, η = water surface elevation and the curling factor λ for the description of the vertical slamming water front.

$$F(t) = \frac{1}{2} \cdot \pi \cdot \rho \cdot C^2 \cdot D \cdot (1 - t/\tau) \cdot \lambda \cdot \eta \qquad (1)$$

Sawaragi and Nochino (1984) extended Goda's method by introducing the so-called rise time of the impact load and they investigated the influence of the wave profile. Wienke (2005) developed an additional term for the Morison formula and describes the impact force over time and takes the rise-time, immerged structure, and the pile up effect at the cylinder front into account. The third goal of the GIGAWIND alpha ventus project focuses on the investigation of local pressure distributions and the validation and development of presently used approaches for wave slamming.

3 FIELD MEASUREMENT SETUP AND PRESENT INVESTIGATIONS

3.1 Tripod monitoring setup and installation

The GIGAWIND alpha ventus project focuses on both the jacket type foundation and the tripod, whereas the present paper concentrates on the tripod. Besides the external measurements of current, wind and waves, the data of strain gauges, acceleration meters, and water pressure probes is of special interest for the dynamic response. Among other sensors, the strain gauges and acceleration meters were installed by the Federal Maritime and Hydrographic Agency (BSH). The water pressure probes have been installed by the Franzius-Institut in July 2008 (Figures 1 and 2). By means of the applied pressure sensors the water level fluctuation will be observed around the cylinder's circumference, which are assumed to provide information about strong local pressure changes occurring in vortex separation areas (Sumer 2006).

Figure 1. Tripod with 3 equipped belts
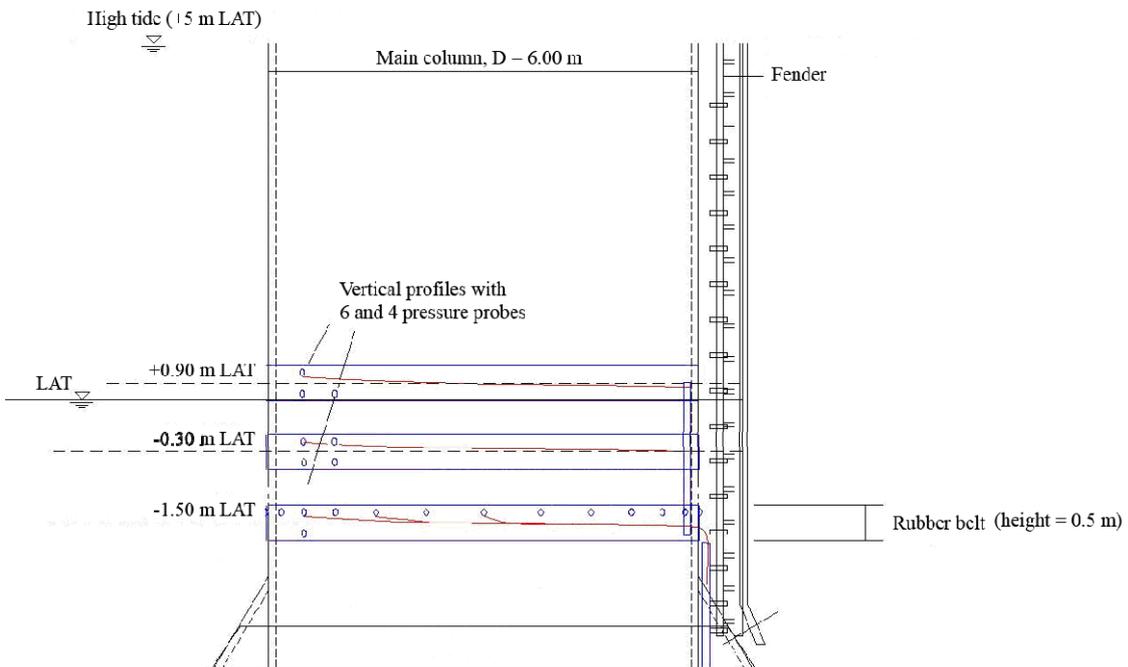

Figure 2. Fixed pressure sensor

Figure 3. Positions of 3 horizontally aligned belts and 32 pressure sensors

32 pressure probes on 3 horizontally aligned rubber sleeves are arranged around the main column (Figure 3). Two vertical measuring profiles are pointing North-west with six and four pressure probes, respectively. In regard to the three centerline positions of the rubber belts -1.5m, -0.3m, and +0.9m above Lowest Astronomical Tide (LAT) the vertical clearance of the pressure sensors to the centerline is 0,25m (Figure 3). The uppermost ring is equipped with three sensors, the middle ring with four sensors, and the lower belt with 25 sensors. The circumference profile consists of 24 probes on the sleeve -1.5m LAT and the heads of the probes are located -1.25 m LAT. On the North-west side a pressure probe is provided at the lower edge, which forms the vertical measuring profile of 6 sensors including the sleeves situated above. In addition the local wave run-up is captured by a CCD camera installed on a level with +21m LAT on the North-west side where the two vertical measuring profiles are situated.

3.2 Physical and numerical modelling of wave loads

Figure 4. Breaking wave on cylinder

The dynamic pressure distributions around both the circumference and the height of the tripod structure are currently investigated by precedent laboratory experiments (Figure 4) in physical scale 1:20. Tests with breaking and non-breaking waves have been conducted with the same positioning of the pressure sensors at the physically scaled main column of the tripod. After having conducted these small-scale experiments, the main supporting structure of the tripod will be additionally assembled in large-scale (1:10) and erected and tested in the Large Wave Flume (GWK). With the help of laboratory experiments the influence of crucial factors concerning the wave slamming on cylinders and tripods will be investigated to determine the impact forces under idealized conditions.
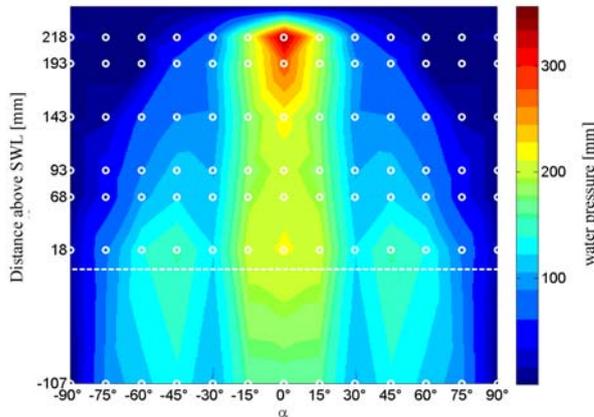
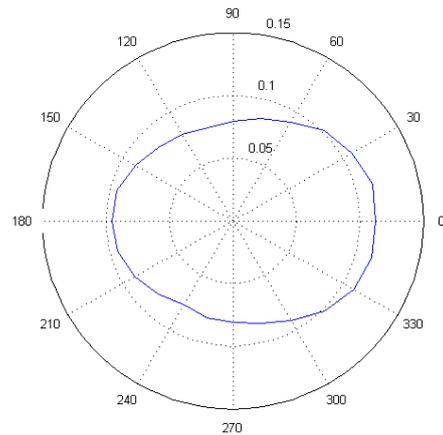Figure 5. Pressure distribution of breaking wave around the cylinder

Figure 6. Water pressure distribution of non-breaking wave [m]

While wave slamming events and vortex shedding in real sea conditions are superimposed by several phenomena, laboratory tests provide ample opportunities to thoroughly investigate the parameters of impact forces and shedding processes separately. Exemplary snapshots of the pressure distribution are given in figure 5 and 6 for breaking and regular non-breaking waves, respectively. Indicated by the white circles in figure 5 the positions of the pressure gauges above the still water line are illustrated, which were applied for the cylinder shown in figure 4. The breaking wave height from trough to crest is 0.35 m and the period is 1.5 seconds. In comparison to the nearly constant water pressure of 200 mm around the circumference of the structure, an apparent local pressure peak with over 300 mm is exposed in the upper section 218 mm above the still water level. In addition to the maximum magnitude the timely resolved and spatial extension of the impact is analysed and utilized for the calibration of CFD Models. A similar procedure is applied in case of non-breaking waves shown in figure 6 with a period of 2.5 seconds and a wave height of 0.2 m, for example. Various positions of the pressure sensors and wave parameters were tested. Characteristics of the vortex shedding processes were analysed around the cylinder's circumference for the comparison with real sea data from the offshore measurements and for calibration purposes.

4   SUMMARY AND PERSPECTIVE

The North Sea provides a large potential for offshore wind energy production with areas of strong and steady wind conditions at relatively shallow water depth, ranging from 20 to 40 m. To support the European efforts for reaching a sustainable development of the environment, the Federal Republic proposes to construct offshore wind energy farms with an overall rated power of 23 GW in the North Sea. Within the framework of the research initiative RAVE, field investigations are carried out on

the first offshore wind energy converters in the test site alpha ventus, which are being installed in 30 meter water depth in the North Sea. The main tasks of the research project with respect to wind and wave loads are described. Furthermore the equipped tripod structure is presented with strain gauges, acceleration meters, and water pressure sensors related to the investigation of wave loads and structural dynamic response. 32 pressure gauges have been mounted on three levels along the span of the main column to collect in-situ data of the water level fluctuation and local pressure variations due to vortex shedding processes around the tripod structure in summer 2008. Subsequently, by the help of laboratory experiments influencing parameters in regard to wave loads on cylinders and tripods are presently investigated. The experiments were conducted to estimate wave slamming effects and wave forces due to non-breaking waves under idealized conditions. Furthermore, the experimental results are used for the calibration of 3D numerical models. Calibrated numerical models provide a useful tool for a detailed analysis of the time and spatial resolved pressure distribution around the structures. By the combined use of numerical simulations and laboratory experiments in the large wave flume at the Coastal Research Center (FZK, Germany) hybrid models will be developed for the enhancement and validation of calculation methods. Finally, the field measurement data from the Alpha Ventus test field in the North Sea provides the validation of design load modeling and design concepts.

5   AKNOWLEDGEMENT

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