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Global slamming forces on jacket structures for offshore wind applications

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ABSTRACT

This study investigates the global slamming forces due to plunging breaking waves on a jacket structure, based on the statistical analysis of the experimental data from the WaveSlam project. Hammer tests and wave tests were conducted in the project, and the data are used to reconstruct the time series of the global slamming force by employing a method based on linear regression. The used wave test data were acquired under one wave condition. A total of 3910 force time series are reconstructed and analyzed statistically to reveal the characteristics of the slamming force. For each force time series, six parameters are introduced to describe it, including the peak force, duration, impulse and rising time, etc. The variability and correlation of these parameters are investigated. The distribution of these parameters is modeled with various probability distributions. The results show the high variability of the slamming force and the importance of statistical analyses. Based on these statistical analyses, the slamming coefficient is estimated from the peak force. For a curling factor of 0.4, the mean slamming coefficient is about 1.29. When considering one standard deviation around the mean, the slamming coefficient varies from 0.70 to 6.78 for a curling factor ranging from 0.1 to 0.5. A representative time series of wave slamming force is obtained by averaging the individual force time series. Accordingly, a 3-parameter triangular force model and a 5-parameter exponential force model are proposed to describe the development of the slamming force in time.

1. Introduction

Currently, the substructures supporting offshore wind turbines are usually bottom-fixed structures, such as monopiles, tripods, jackets, gravity based structures, etc. In certain sea environments, they are exposed to plunging breaking waves at some locations, which leads to slamming forces. Such kind of slamming forces have been identified based on the recorded sea state conditions and associated structural responses for a 2 MW wind turbine mounted on a monopile at the Blyth wind farm off the coast of England [1]. Slamming forces can affect the performance and fatigue life of the substructures for offshore wind turbines. They should therefore be considered in the design of offshore wind turbines, as recommended by various standards and guidelines [2–4].

Slamming is a strongly nonlinear phenomenon that usually causes an extremely high impact force within a very short time [5,6]. In the past decades, a large amount of efforts have been devoted to investigate slamming forces theoretically, numerically and experimentally. Theoretical analysis is usually based on the von Karman or the Wagner impact model together with several reasonable assumptions [5,7], and numerical studies on slamming forces use Computational Fluid Dynamics (CFD), considering either

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inviscid or viscid flows [6,8]. Due to the strong nonlinearities of slamming forces, small-scale experiments or full-scale field measurements seem to be the most reliable method to quantify them. To date, several experimental studies of slamming forces on vertical or inclined slender cylindrical structures have been carried out [9–11]. An on-site measurement regarding the slamming loads has also been conducted for a monopile wind turbine at the Blyth wind farm [1].

Most of the aforementioned studies on slamming forces are with respect to slender cylindrical structures, and the results can be used for the design of monopiles. Truss structures, such as jackets, are also a promising support structure concept for offshore wind turbines, especially in intermediate water. Because of the presence of several legs and braces, the waves approaching the hind legs and braces are affected by the front ones. This will result in a more complicated slamming scenario than that of the monopiles. Nevertheless, investigations of the slamming forces on jacket structures are still limited in number to date. The WaveSlam project[1] was initiated to bridge this knowledge gap. Using a 1:8 model of a jacket structure typical for offshore wind applications, the project is the first one at this scale and for this kind of structures.

Several other studies have been conducted to investigate the slamming forces on jacket structures based on the experimental data from the WaveSlam project. Rausa et al. [12] studied breaking wave forces on the front bracings of the jacket structure with a finite element model by assuming a triangular time history of wave slamming forces. A fitting procedure was then applied to match the result from the finite element model with the experimental data. Tu et al. [13] investigated the slamming loads on the bracings of the jacket structure based on local force data. An optimization-based deconvolution (ODC) method, which used the linearity of the structure, was proposed for the estimation. However, the methods used in these studies are only able to calculate the peak forces based on additional assumptions (e.g. assuming a triangular shape force model, which is not validated) or the impulses of the loads. The time series of the forces, which are necessary for the force analysis, were not resolved.

To obtain the time series of wave slamming forces, Jose et al. [14] applied Empirical Mode Decomposition (EMD) to analyze the total slamming force and the Frequency Response Function method to analyze the local slamming force on the jacket structure. Tu et al. [15] employed the regularization method, which is a classical inverse method, to develop two approaches for the reconstruction of the local slamming force time series. The method by Tu et al. [15] takes the structure property into consideration and can provide an easily applicable solution for the inverse estimation of slamming loads.

In this study, the slamming force estimation method proposed by Tu et al. [15] was further applied to reconstruct the global slamming force time series using the data set from the WaveSlam project. Six parameters were introduced to describe the global slamming force time series, such as the peak force, duration, total impulse, etc. The variation, correlation and distribution features of these parameters were investigated to reveal the characteristics of the global slamming force under one wave condition. A representative slamming force time history and the slamming coefficient were then estimated. Based on the representative time history, two slamming force models are proposed, which provide potential means to properly account for slamming forces in the future design of jacket structures.

2. Experiment and data

WaveSlam is a research project that aims to improve the method for calculating forces from plunging breaking waves on jacket structures through model tests on a large scale [16]. The project was conducted by a consortium headed by the University of Stavanger (UiS) and the Norwegian University of Science and Technology (NTNU) in 2012–2013. The jacket model used in the experiment was similar to the structure designed by Reinertsen AS for the Thornton Bank offshore wind farm [17]. Following the earlier small scale (1:50) model tests at NTNU [18], a 1:8 scale model of the jacket structure was constructed, and the experiment was carried out in summer 2013 using the Large Wave Flume facilities at the Coastal Research Centre (Forschungszentrum Küste, FZK)[2], Hannover, Germany. The data is now publicly available.

2.1. Experimental setup

The setup of the experiment is demonstrated in Fig. 1. The wave flume is approximately 300 m long, 5 m wide and 7 m deep. The waves were generated by the wave board at the left end of the flume, went over a 1:10 slope, then reached the jacket model on a 2.3 m high plateau. A water depth of 16 m was simulated, but the water depth at the jacket model was adjusted slightly to be 1.8 m (instead of 2.0 m) for some test cases. The legs and braces of the jacket model were both 0.14 m in diameter.

A global coordinate system is defined as following: The origin is at the center of the wave board and at the bottom of the wave flume. The x-axis is positive in the wave direction. The z-axis is positive upwards. The y-axis forms a right hand system with the other axes.

Wave gauges were installed at 15 different locations. Three Acoustic Doppler Velocity meters (ADVs) were installed in the plane of the legs. The motion of the wave paddle was also recorded. The jacket was equipped with four total force transducers, ten local force transducers on the legs, twelve XY force transducers on the braces, and four one-directional accelerometers.

The measurements taken by the total force transducers are essential in this study to investigate the global slamming forces. As shown in Fig. 2, there were two total force transducers installed at the top of the jacket model and two installed at the bottom of the jacket model. The structure was hung from the top and did not touch the ground during the tests. The measured forces are in global x

[1] http://hydralab.eu/research–results/ta-projects/project/19/; December 2016.
[2] https://www.fzk.uni-hannover.de/; December 2016.