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Characterization of wave slamming forces for a truss structure within the framework of the WaveSlam project.

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Abstract

One increasingly popular type of foundations for offshore wind turbines in shallow water are truss structures. These are exposed to wave slamming forces from breaking wave events. These forces depend, among other parameters, on the slamming factor C_s that typically takes values between π -2π. So far, several studies about slamming forces have been done for monopile structures, but not much work has been done regarding truss structures such as offshore jackets. This paper is based on the WaveSlam project in which an instrumented multi-membered truss model has been subjected to regular and irregular waves in the large wave flume at FZK Hannover in 2013. The structure was built at scale 1:8 and equipped with force transducers along the bracings and columns that measured the structural response from the breaking waves. The goal of this study was to characterize the breaking wave forces acting on the front bracings of the structure, in order to estimate the respective slamming factors. The tested structure has been modelled and validated with a finite element model in ANSYS and a wave run test is analyzed. The wave loads have been defined as uniform loads with a triangular force time history acting along the bracings. Through a fitting procedure, the initial responses from ANSYS and from the data were matched with a relative error of 3% for one single wave test. From this, a slamming factor of 4.78 is found in the highest part of the front bracings. The characterization of more breaking wave loads is recommended in order to get an estimate of the largest slamming factor, which is relevant for design purposes.

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Keywords: Truss structures; Inverse problem; Transient finite element analysis; Slamming coefficient; Offshore wind energy.

1. Introduction

Offshore wind turbines are designed to withstand environmental loads for 20-30 years. Because offshore wind farms are not yet competitive with other solutions as fossil fuels, the costs have to come down by around 40% in the next decade. Det Norske Veritas GL, one of the largest technical energy consultancies in the world, has recently issued an "offshore wind cost reduction manifesto" (2013) [1] in order to reduce the costs by 25%, where the optimization of the substructure is a highlighted point for improving of the existing processes. The design of such structures in shallow water regions is predominantly subjected to loads from plunging breaking waves, which

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are usually larger than Morison forces. Thus, a better comprehension and reduction of the uncertainties in these slamming wave forces will imply a reduction of the wrong assessment risks for those loads, and therefore an optimization of the structure's design. That could mean for example lower requirements for some structure elements, such as smaller beams diameters, which could lead into a direct reduction of the energy cost.

This work is focused on truss substructures, which are used predominantly in shallow waters from 5 to 40 meters, typically called 'jackets'. The so called wave slamming forces caused by plunging breaking waves produce very rapid and high intense impacts, which govern the response of the structure. In recent works it has been found that the slamming forces (1) are proportional to the square wave celerity C_b, the impact area of the wave $\lambda_{\eta b}$, water density ρ_w, the radius of the element R, and a slamming coefficient C_s. This load factor has been intensively studied and most studies found values between π to 2π for a single vertical and inclined pile, Goda et al. (1966) [2], Wienke and Oumeraci (2005) [3]. Therefore, some of the most commonly used guidelines, such as DNV (2010 a, b) [4] and ISO 21650 (2007) [5], recommend a value of 5.15 to 2π for truss structures.

$$F_s = C_s \cdot \rho_w \cdot \lambda_{\eta b} \cdot {C_b}^2 \cdot R \tag{1}$$

The goal of this study is to characterize the slamming forces on truss structures and determine what values of the slamming coefficients C_s are associated to them. In 2013, a consortium headed by the University of Stavanger (UiS), Norway and the Norwegian University of Science and Technology (NTNU), Trondheim, Norway carried out the WaveSlam project (Arntsen and Gudmestad, 2014) [6]. In this project a prototype jacket (Fig. 1a) was built in a large scale 1:8 and subjected to thousands of wave impacts in the Large Wave Flume at FZK Hannover. The base of the channel was modified and set up with a slope of 1:10 in order to recreate plunging breaking waves in front of the structure. The structure was equipped with a total of 12 two-axis force transducers distributed along six bracings of the structure. Ten force transducers mounted in 40 mm high sections on the front legs provided information on the vertical distribution of the forces (Fig. 1b).

The starting point for characterizing the wave slamming forces on the bracings is to analyze the response recorded on the four transducers FTBF01 to FTBF04. For that purpose the structure was modelled using a multiple degree of freedom (MDOF) model in a finite element solver. Through a fitting procedure, the wave slamming loads were tuned until the response on the numerical model matched the response data.

a)

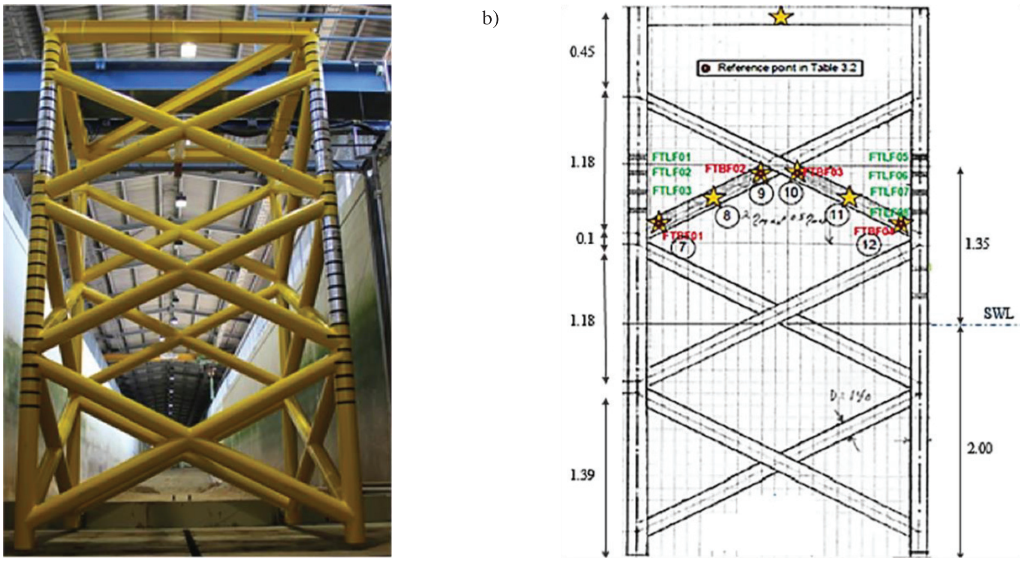

Figure 1. a) Tested structure in Hannover (reproduced with permission from the WaveSlam project). b) Location of bracing transducers FTBF01-02-03-04 and Impulse hammer tests, ★ . Units in [m].