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Estimation of slamming coefficients on local members of offshore wind turbine foundation (jacket type) under plunging breaker

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Abstract

In this paper, the slamming coefficients on local members of a jacket structure under plunging breaker are studied based on numerical simulations. A 3D numerical model is used to investigate breaking wave forces on the local members of the jacket structure. A wide range of breaking wave conditions is considered in order to get generalized slamming coefficients on the jacket structure. In order to make quantitative comparison between CFD model and experimental data, Empirical Mode Decomposition (EMD) is employed for obtaining net breaking wave forces from the measured response, and the filtered results are compared with the computed results in order to confirm the accuracy of the numerical model. Based on the validated results, the slamming coefficients on the local members (front and back vertical members, front and back inclined members, and side inclined members) are estimated. The distribution of the slamming coefficients on local members is also discussed.

Keywords: Navier Stokes; Numerical simulation; Wave breaking; Slamming coefficient; Jacket

1. Introduction

Due to the increased energy demand and thrive for clean energy, offshore wind energy has become popular these days. A large number of offshore wind turbines are been supported by fixed type substructures (e.g., monopile, gravity foundations, tripod, or jacket type). Among these, the monopile structures are generally used because of simplicity in the design and installation. However, the increase in the turbine capacity and feasibility of fixed type Offshore Wind Turbine (OWT) in deeper water depths made the industry to focus more on rigid type of substructures, such as jacket type structures.

Most of the existing offshore wind turbine substructures are installed in relatively shallow water in order to reduce the cost of fabrication, maintenance and grid connectivity. However, in case where the substructures are installed in shallow waters where wave breaking occurs (e.g., Thornton bank wind farm near Belgian coast), the breaking waves would give rise to serious damages to the substructure. Since the wave-breaking phenomenon is extremely complicated and involve strong non-linear effect, the breaking wave forces would be one of the major concerns in the design of these OWT substructures.

Till date, a semi-empirical formula has been used to calculate the breaking wave forces on monopile structures (Goda et al., 1966). The slamming coefficient used in the semi-empirical formula should be determined in advance, based on the previous researches. Many researches have been done in past to estimate the slamming coefficients (Goda et al., 1966; Sawaragi and Nochino, 1984; Wienke and Oumeraci, 2005) valid for monopile structures. However, it is revealed that there is a major uncertainty in the value of slamming

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coefficients, which is to be used for the calculation of breaking wave forces on monopile structures using the semi-empirical formula. For example, the slamming coefficients estimated by different researchers showed a considerable degree of scatter (from 3.14 to 6.28). The design guidelines (IEC 61400-3 (2009), ISO 21650 (2007), GL (2005), ABS (2010), DNV-RP-C205 (2010), API RP 2A-WSD (2007) and ISO 19902 (2007)), also shows no exact agreement on the slamming coefficient to be used for the design of such structures. The strong nonlinear wave–structure interactions during the wave breaking and difficulties in the accurate measurement of the breaking waves would make the exact physical representation of breaking waves a challenging task.

In the case of jacket type structures, there have been not many attempts in the past to estimate the breaking wave forces on the structures. In comparison with monopile, the jacket type structures are complex due to more members, joints and different member orientations. Hence, it is important to investigate the slamming coefficients on each local members (e.g., front and back vertical members, front and back inclined piles and lateral inclined member) of the jacket structure in the wave breaking zone. Moreover, the distribution of the slamming coefficients on the local members is important in the design of OWT substructure (e.g., base shear and bending moments). Nevertheless, in the design guidelines (and previous researches), there is limited information on the design of jacket structures against breaking waves.

The WaveSlam project (Arntsen and Gudmestad, 2014; Arntsen et al., 2013) was carried out in 2013, with the aim to investigate the wave forces from plunging breaking waves on a jacket structure in shallow waters. In the experiment, the jacket structure was tested for number of wave breaking cases and the response of the structure was measured. Jose et al. (2016b) performed initial studies on the experimental measurement data and proposed methods to obtain actual breaking wave forces on jacket members from the measured responses. However, the experimental studies have some limitation in terms of the instrumentation to measure the variation of local wave forces along the jacket members.

The development of a Navier Stokes solver to study the breaking wave forces have been an active field of research in recent past (Mo et al., 2013; Lee, 2006; Lee et al., 2011; Christensen et al., 2005; Alagan Chella et al., 2016; Choi et al., 2015). Mo et al. (2007) developed a Navier–Stokes solver to compute the wave–structure interaction on vertical slender pile. Christensen et al. (2005) studied the nonlinear run-up and the breaking wave forces on a cylindrical pile under spilling and plunging breakers using Navier Stokes solver. Kamath et al., 2016 studied breaking wave interactions on a vertical cylinder with respect to different wave breaking positions. They used open source CFD model REEF3D to simulate the breaking wave forces on the vertical cylinder. Choi (2014) and Choi et al. (2015) used a 3D numerical model based on finite difference method to calculate the breaking wave forces on monopile structures. The breaking wave forces on monopile structure at various orientations were simulated in those studies. The numerical results showed good agreement with the experimental measurements. However, most of these studies were limited to monopile structures. As there were limited experimental results available for jacket structures, there have been not many attempts to develop a numerical model to predict the breaking wave forces on the jacket structures.

Recently, Jose et al. (2016a) validated a 3D numerical model with the WaveSlam experimental data for the jacket structures. Based on the numerical simulations, slamming coefficients were estimated for the front and back vertical members of the jacket structure. The maximum slamming coefficient for the vertical members was found to be slightly smaller than the value suggested by Goda et al. (1966). A triangular distribution of wave slamming coefficients on the vertical members was obtained in contrast to the rectangular distribution proposed by Goda et al. (1966) and Wienke and Oumeraci (2005). However, in the research, the simulations were performed for a limited number of wave cases and final values of slamming coefficient could not be ascertained.

The objective of the present study is to estimate the slamming coefficients for the local members of a jacket structure. The present paper is an extension to Jose et al., 2016a. A wide range of breaking wave conditions (from short wave (4.6 s) to long wave (5.55 s)) are considered in order to get generalized slamming coefficients on local members of the jacket structure. In order to make quantitative comparison between experimental and CFD results, empirical mode decomposition (Huang et al., 1999; Choi et al., 2015) is used to filter out the dynamic amplification component in the measured response force time series data and the filtered results are compared with the computed results in order to confirm the accuracy of the numerical model. Based on the validated numerical results, the slamming coefficients on the local members (front and back vertical members, front and back inclined members, and side inclined members) are estimated. The distribution of slamming coefficients on the local members is studied. Moreover, the slamming coefficients obtained from the present study are compared with the values presented in previous studies by other researchers.

2. Model description

2.1. Experimental setup

The WaveSlam experiment was carried out in 2013 at the Large Wave Channel, Hannover, with the aim to study the breaking wave forces on a jacket structure. The truss structure of 1:8 scale was tested for large number of wave breaking conditions (Jose et al., 2016b). The experimental setup is shown in Fig. 1.

The large wave flume in Hannover is of 300 m long, 5 m wide and 7 m depth. The slope of the bottom of the tank is 1:10. The diameters of all the jacket members are 0.14 m. The jacket structure was located at a distance of approximately 200 m from the wave generator. The truss structure was equipped with total and local force transducers to measure the wave forces on the structure. There were wave gauges