Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 137 (2017) 246–254

Energy Procedia

www.elsevier.com/locate/procedia

14th Deep Sea Offshore Wind RD Conference, EERA DeepWind'2017, 18-20 January 2017, Trondheim, Norway

Numerical study of irregular breaking wave forces on a monopile for offshore wind turbines

Ankit Aggarwal[a,*], Mayilvahanan Alagan Chella[a], Hans Bihs[a], Øivind Asgeir Arntsen[a]

[a]*Department of Civil and Environmental Engineering*
Norwegian University of Science and Technology
Trondheim 7491, Norway

Abstract

The substructures of offshore wind turbines are subjected to different types of hydrodynamic loads from sea states. The wave forces exerted by irregular breaking waves are one of the serious concerns because of the uncertainties involved in defining the breaking wave and the resulting force calculations. In the present study, irregular breaking wave forces on a vertical pile structure are investigated using an open-source Computational Fluid Dynamics (CFD) model REEF3D. The Level Set Method (LSM) is used for modelling the free surface. The Bretschneider spectrum is used for the irregular wave generation. This is validated in the numerical wave tank by comparing the numerical wave spectrum with the experimental wave spectrum. The wave free surface is calculated at three wave gauge locations and compared with experiments. It is observed that the peak of spectral wave density is higher for the wave gauge located besides the cylinder due to shoaling, wave run up and reflections from the cylinder and the peak of spectral wave density is lower for the wave gauge located behind the cylinder due to wave breaking. Further, simulations are performed to study the wave forces on a monopile due to the depth-limited breaking waves. A good match is observed with the experimental and numerical results. Numerical wave energy spectra at different locations along the tank are compared to study the changes in the wave surface elevations due to the interaction of irregular breaking waves with a monopile. The statistical parameters for free surface elevation and wave forces are further investigated. The free surface features around the monopile during its interaction with waves are also studied.

Peer-review under responsibility of SINTEF Energi AS.

Keywords: Irregular waves ; CFD ; vertical cylinder; wave force; wave spectrum

1. Introduction

The focus on offshore wind energy has considerably increased. Offshore wind energy is more clean and environmental friendly. Offshore wind turbines are exposed to different types of hydrodynamic loading and sea states. Breaking waves and hydrodynamics loads from them on wind turbine substructures are very important parameters in the design of offshore wind turbines. The study of irregular breaking waves is challenging due to their random

*Corresponding author:
E-mail address: ankit.aggarwal@ntnu.no

Peer-review under responsibility of SINTEF Energi AS.
10.1016/j.egypro.2017.10.347

characteristics. An irregular sea state can be defined in terms of wave spectrum, which describes the distribution of wave energy over a frequency range.
Many laboratory investigations have been performed to study irregular breaking waves and breaking wave forces. Kyle and Tørum[1] carried out an experimental investigation to study the wave forces from breaking regular and irregular waves on a vertical cylinder on a shoal. They measured the local and total forces and compared their results with theoretical values. Tanimoto et al.[2] conducted an experimental study to measure the impulsive breaking forces on an inclined pile due to random waves. They compared their experimental results with the theoretical results predicted by both Wagner and Karman theories. They developed a new simplified method to calculate the wave impact forces. Stansberg et al.[3] performed an experimental investigation to measure wave forces on fixed vertical truncated cylinders under irregular waves with a model scale of about 1:50. They carried out the test with a single as well as an array of cylinders and measured the contribution of high-frequency force components generated by the steep waves. Ochi and Tsai[4] developed a method to statistically predict the magnitude of impact pressure (including extreme values) produced by deep water waves breaking on a vertical cylinder as a pile of an ocean structure. They derived the probability density function of wave period associated with breaking waves for a specified wave spectrum, and then converted to the probability density function of impact pressure. Chakrabarti et al.[5] measured breaking wave forces on a single pile caisson in breaking waves for both regular and irregular waves.
Computational Fluid Dynamics (CFD) can be used effectively to study wave breaking in detail. CFD can reveal detailed information about the flow features. Many CFD based single and double phase investigations have been carried out in the past to study the breaking characteristics of waves [6] [7] [8] [9]. Some attempts have been made in the past to study the wave forces on cylinder. Bredmose et al. [10] investigated breaking wave impacts on offshore wind turbine foundations for the focused wave groups using CFD. They compared the numerical and theoretical free surface and wave forces in time- domain by using the linear reconstruction of waves. Aggarwal et al. studied the non-breaking irregular wave forces on a large vertical cylinder and compared their numerical results with the theory using CFD model REEF3D [11]. The numerical model REEF3D is used in the past to study regular and focused wave breaking. Alagan Chella et al. [12] and Kamath et al. [13] studied breaking waves and breaking wave forces on a vertical slender cylinder over an impermeable sloping seabed and they observed a good match with experiments. Bihs et al. [14] investigated the interaction of breaking waves with tandem cylinders under different impact scenarios. However, there is limited literature present on the numerical modelling of irregular breaking wave forces on a vertical cylinder.
The goal of the present study is to investigate the irregular breaking wave forces on a vertical cylinder using the open-source CFD model REEF3D [15]. The irregular waves are generated using the Bretschneider spectrum. The wave generation and wave propagation in the numerical wave tank (NWT) are validated by comparing the numerical wave spectrum with the experimental wave spectrum at three different wave gauge locations along the tank. Further, a numerical investigation is conducted to study irregular breaking wave forces with a vertical cylinder mounted on a slope. The numerical results are compared with the experimental force [5]. The changes in the free surface profiles due to the interaction of breaking waves with the cylinder are also presented and discussed.

2. Numerical Model

The present numerical model is based on the Reynolds Averaged Navier-Stokes equations (RANS) with the assumption of an incompressible fluid given as:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + g_i \tag{2}$$

where, u is the velocity averaged over time t, ρ is the fluid density, P is the pressure, ν is the kinematic viscosity, ν_t is the eddy viscosity, i and j denote the indices in x and y direction, respectively and g_i is the acceleration due to gravity.

The numerical model uses a fifth-order finite difference Weighted Essentially Non-Oscillatory (WENO) scheme for the spatial discretization [16]. The third-order TVD Runge Kutta scheme is used for the time discretization [17].