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Irregular Wave Forces on a Large Vertical Circular Cylinder

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Abstract

Substructures of offshore wind turbines are exposed to irregular sea states that are generally defined using wave spectra. The waves undergo transformations due to non-linear wave-wave interactions and due to interaction with the structures they are incident on. In the present study, simulations of regular and irregular wave interaction with a vertical cylinder are carried out using the open-source Computational Fluid Dynamics (CFD) model REEF3D. The model solves the Reynolds Averaged Navier-Stokes (RANS) equations over the entire domain and provides detailed information regarding the wave hydrodynamics including fluid pressure, velocities and the free surface. The non-linear wave-wave, wave-structure interactions and the turbulence in the flow are accounted for in the solution of the RANS equations. In this way, detailed flow features around the cylinders can be visualised and analysed. The numerical model is verified with the analytical equations for the loads on a cylinder under regular waves. Further, simulations are carried out for irregular waves generated using the JONSWAP wave spectrum and the wave force spectrum is calculated. The wave spectrum for the different wave gauges around the cylinder are compared. The free surface features around the cylinder are visualised and correlated to the wave forces on the cylinder. It is observed that the regular waves with higher steepness show a clear diffraction pattern around the cylinder. For the irregular waves, the diffraction pattern is less developed and irregular.

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

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1. Introduction

A pre-insight into the wave loads is very important in design and operation of the offshore structures. A real sea state is completely irregular, three-dimensional and unsteady, which makes the study of irregular waves and irregular wave forces crucial in offshore engineering applications. Irregular waves can be represented by the super-positioning of linear regular wave components. Fast fourier transformation (FFT) can be used to simplify the random sea surface into a summation of linear waves. There are various wave spectra available to define an irregular sea state depending on the sea conditions, e.g. Pierson-Moskowitz spectrum, JONSWAP spectrum, Bretschneider spectrum. A wave spec-

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trum describes the distribution of the wave energy over a frequency range. Most of the statistical wave parameters such as the significant wave height, maximum wave height, down- and up-crossing time period, can be calculated from the wave spectrum [1]

Many experiments have been performed to study irregular wave propagation. Tørum et al. [2] conducted an experimental study for long crested irregular waves to understand the irregular wave kinematics. Onorato et al. [3] studied the statistical properties of the surface elevation for long crested waves in deep water characterized by the JONSWAP spectra with random phases. Beji et al. [4] investigated irregular wave propagation over a submerged bar and examined the wave transformation processes such as wave breaking and wave shoaling. Goda et al. [5] employed the FFT in order to analyse the results from their random wave experiments. Ohl et al [6], studied the wave diffraction forces by irregular waves on an array of cylinders. They presented measurements for the variations of the wave heights in the vicinity of a multi-column structure. Linear diffraction theory for random seas was used to predict the wave spectral diffraction.

Several numerical studies are performed to model the irregular waves. Computational fluid dynamics (CFD) can be used to study wave hydrodynamics. CFD is widely used in the field of the marine and offshore engineering to model regular waves and regular wave forces. Westphalen et al. [7] and Hu et al. [8] simulated the wave forces on a partially submerged cylinder without using any turbulence model for wave energy convertors using CFD. They compared their numerical results with experimental data [9]. CFD results show good comparison with the experimental results. Alagan Chella et al. [10] used the two-phase CFD model REEF3D to investigate the characteristics and profile asymmetry properties of wave breaking over an impermeable submerged reef. Kamath et al. [11] investigated the wave interaction with a pair of large tandem cylinders. They presented the changes in diffraction pattern around the cylinder for different wave steepnesses. They also investigated the differences between the theory and numerical results for the waves with higher steepness. Kamath et al. [12] studied the upstream and downstream cylinder influence on the hydrodynamics of a four cylinder group using the CFD model REEF3D. A good agreement between the experimental and numerical values was observed.

In the present study, the open-source CFD model REEF3D is used to investigate irregular wave forces on a vertical large cylinder. First, the model is verified for the regular and irregular waves in a numerical wave tank without any structure including grid refinement study. Further, the numerical model is verified for the wave forces on a large cylinder under regular waves by comparing the numerical results with analytical solutions. Further, the irregular wave forces on a large cylinder are also investigated and compared with the results from Morison equation.. The free surface features around the cylinder are also presented and discussed.

2. Numerical Model

2.1. Governing equations

The CFD model REEF3D uses the incompressible Reynolds Averaged Navier-Stokes (RANS) equations. The momentum conservation equation together with the continuity equation defines the RANS equations :

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

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

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 is the acceleration due to gravity. The projection method given by Chorin [13] is used for solving the pressure in the Navier- Stokes equations. Bi-Conjugate Gradient Stabilized (BiCGstab) is employed in the numerical model for treating the Poisson pressure equation [14].

The numerical model uses the fifth-order finite difference weighted essentially non-oscillatory (WENO) scheme [15]. WENO schemes linearly combine or reconstruct the lower order fluxes to obtain a higher order approximation. The locally smoothest stencil is automatically chosen by employing a nonlinear adaptive procedure. This way, the crossing