Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference **www.isope.org**
Rhodes, Greece, June 17–22, 2012

ISBN 978-1-880653-94–4 (Set); ISSN 1098-6189 (Set)

Numerical Investigation of Extreme Wave Effects on Cylindrical Offshore Structures

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ABSTRACT

The interaction between extreme wave and a surface-piercing vertical cylinder is investigated numerically based on our recent naoe-Foam-SJTU solver, which is developed under the framework of the OpenFOAM, an open source code library writing with fully object-oriented C++ language. The governing equations are discretized by using the finite volume method. Two fluids are considered and the volume of fluids (VOF) technique is employed to capture water-air interface. The transient extreme water wave is generated by directional wave focusing just with two different regular waves. The model is validated by compare the extreme wave profile with the corresponding experimental data. Then the simulation of extreme wave-cylinder interactions is carried out. Extreme wave impact loading on the cylinder and wave run-up problems are studied and the results are analyzed and discussed. The presented results show the details of extreme wave effect on the cylinder. The present numerical method is validated to be efficiency for solving the problem of wave-structure interaction with large deformation of the free-surface.

KEY WORDS: Extreme wave; directional wave focusing; naoe-Foam-SJTU; wave run-up; impact.

INTRODUCTION

With the development of marine and offshore engineering, more and more offshore structures are being or will be constructed. Offshore structures may suffer serious damage due to rough sea climate especially when the extreme waves occur. Therefore, to ensure the stability and survivability of an offshore structure, it is of great importance to develop a reliable prediction method for investigating the extreme wave effects on offshore structures.

Extreme wave, also called freak wave, rogue wave, is a giant wave and may occur in both deep and narrow water. The extreme wave is highly transient and nonlinear. Due to the difficulty to predict when and where the extreme wave occurs, the extreme wave is considered as a real threat to human activities. Extreme wave has attracted great attention both in offshore engineering and academic research. Many efforts have been made to learn on the physical mechanisms of freak wave generation. In the experiments, the extreme waves are generated by the wave-maker. In order to obtain motion of wave-maker for generating freak waves, a number of laboratory experiments have been done. Baldock *et al.* (1996) produced a transient extreme wave by generating a larger number of waves which focus at one point in space and time in a wave flume. Kriebel (2000) superimposed a transient wave and a random wave train to generate a rogue wave. And Clauss (2002) generated a rogue waves in a wave flume by using a semi-empirical procedure to determine the control signal of wave-maker. Touboul & Giovanangeli (2006) investigated the freak wave experimentally without wind and in presence of wind and the freak wave formation is due to the dispersive focusing mechanism such as frequency and/or directional focusing of transient wave group.

With the development of CFD techniques, numerical modeling has been an alternative means to investigate the freak waves. Kharif & Pelinovsky (2003) gave a good review of physical mechanisms of the rogue wave phenomenon and summarized various numerical models for freak wave simulation such as the nonlinear Schrodinger equation, the KdV equations and the fully nonlinear potential equations. Furthermore, Brandini & Grilli (2001) carried out a 3D numerical study of spatial wave focusing using Boundary Element Model (BEM) with Eulerian-Lagrangian flow representation. The similar freak wave was also simulated by Fochesato *et al.* (2007) using the fast BEM method. Also high-order spectral method (HOS) was extended to study the freak wave appearance (Ducrozet *et al.*, 2007). Ma & Yan (2006) have invented a QALE-FEM which has been successfully applied to simulate 2D and 3D freak waves (Ma & Yan, 2007; Ma & Yan, 2008). Overall, current technology of physical model of rogue waves is mainly based on directional wave focusing of linear waves.

Extreme wave interaction with offshore structures has also been investigated in the last decade. For example, Cox & Ortega (2002) conducted a small-scale laboratory experiment to investigate green water problem in extreme transient wave. The same problem has also been studied using Smoothed Particle Method (SPH) by Gómez-Gesteira *et al.* (2005). Corte & Grilli (2006) studied the impact on cylindrical piles of extreme waves generated by directional wave focusing using Higher-order BEM. Yan & Ma (2010) studied the fully nonlinear interaction between freak waves and 2-D submerged cylinders using QALE-FEM method. Cao & Wan (2011) studied the extreme wave interaction with a fixed offshore platform by solving Navier-Stokes equations.

Despite the high computational cost, the Navier-Stokes model can deal with complex free surface such as overturning waves while the