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Wave Run-up and Response Spectrum for Wave Scattering from a Cylinder

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ABSTRACT

In this paper, we present both numerical and experimental studies on non-linear wave interaction with a circular cylinder in shallow water and examine the effect of non-linearity on the wave run-up on the structure. Second order wave diffraction theory has been included in the numerical simulation to steep waves. Both the wave run-up time history on the cylinder and the wave response spectrum derived from the diffracted wave time series are investigated and compared with the experiments conducted in a wave tank. Numerical predictions from the second order diffraction simulations agree very well with the experimental measurements for both wave run-up and response spectrum. This validation confirmed that the second order wave diffraction solution works well for steep waves in shallow water, while linear diffraction theory incorrectly predicts the peak water levels and response spectrum.

KEY WORDS: Wave-structure interaction; non-linear wave; circular cylinder; second order wave diffraction; focused waves; shallow water.

INTRODUCTION

Wave diffraction and scattering from coastal and offshore structures are of importance in understanding the impact of non-linear waves on structures, and resulting wave loadings for structural design. Over the past 20 years, research into non-linear wave interaction with deep-water offshore platforms and FPSOs (Kim & Yue (1989, 1990), Chau & Eatock Taylor (1992), Eatock Taylor & Huang (1997), Buldakov et al (2004), Zang et al (2003, 2005, 2006)), has indicated the importance of nonlinear wave theory for estimation and safe offshore design. Second-order wave diffraction theory has been successfully applied to predict non-linear wave forces and free surface elevations around deep water structures.

To achieve the target of 20% of the electricity generated from all sources coming from renewal energy by 2020, it is expected that large numbers of offshore wind turbines will be installed along the UK coast line in the coming decade. Deep water offshore technology, traditionally used for the development of offshore platforms and floating vessels for the oil and gas industry, is currently used for the development of offshore wind farms. Because the majority of offshore wind turbines are installed in intermediate and shallow waters, where strong non-linear wave interaction with structures cannot be ignored, there is a need to improve our understanding of the effects of wave non-linearity on wave-structure interactions in shallow water.

In this paper, physical experiments and numerical simulations are described for focused waves interacting with a vertical bottom mounted circular cylinder, a typical configuration for an offshore wind turbine foundation. Two test cases with different degrees of non-linearity are examined for both the time history of wave run-up on the structure and the resulting response spectrum. The experiments were conducted in a wave tank in the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, China. The numerical simulations were produced using DIFFRACT, a second order wave diffraction code, originally written by Chau & Eatock Taylor, and further extended by Zang. Detailed discussions of the effect of non-linearity on wave interaction with such structures in shallow water are given in the paper.

NUMERICAL METHODS

For modelling free surface run-up resulting from non-linear wave interaction with large offshore structures, the assumption of potential flow is reasonable, and the fluid may be taken as incompressible and inviscid, and the flow as irrotational. Then a velocity potential exists which satisfies the Laplace equation

$$\nabla^2\Phi = \frac{\partial^2\Phi}{\partial x^2} + \frac{\partial^2\Phi}{\partial y^2} + \frac{\partial^2\Phi}{\partial z^2} = 0 \quad (1)$$

Two approaches are currently taken for the numerical simulation of non-linear wave interaction with large offshore structures. These are: second order wave diffraction theory and fully non-linear wave diffraction theory. In principle, fully non-linear wave diffraction theory