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

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In this paper, we present both numerical and experimental studies on wave interaction with a circular cylinder in shallow water and examine the effect of nonlinearity 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 2nd-order diffraction simulations agree very well with the experimental measurements for both wave run-up and response spectrum. This validation confirmed that the 2nd-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.

INTRODUCTION

Wave diffraction and scattering from coastal and offshore structures are of importance in understanding the impact of nonlinear waves on structures, and resulting wave loadings for structural design. Over the past 20 years, research into nonlinear wave interaction with deep-water offshore platforms and FPSO (Kim and Yue, 1989, 1990; Chau and Eatock Taylor, 1992; Eatock Taylor and Huang, 1997; Buldakov et al., 2004; Zang et al., 2003, 2005, 2006) has indicated the importance of wave theory for estimation and safe offshore design. Second-order wave diffraction theory has been successfully applied to predict nonlinear 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 renewable energy by 2020, it is expected that large numbers of offshore wind turbines will be installed along the UK coastline 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 nonlinear wave interaction with structures cannot be ignored, there is a need to improve our understanding of the effects of wave nonlinearity 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 nonlinearity 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 at the State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology (DUT), China. The numerical simulations were produced using DIFFRACT, a 2nd-order wave diffraction code, originally written by Chau and Eatock Taylor, and further extended by Zang (Chau, 1989; Chau and Eatock Taylor, 1992; Zang et al., 2003). The paper presents detailed discussions of the effect of nonlinearity on wave interaction with such structures in shallow water.

NUMERICAL METHODS

For modelling free-surface run-up resulting from nonlinear 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:

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

Two approaches are currently taken for the numerical simulation of nonlinear wave interaction with large offshore structures. These are 2nd-order wave diffraction theory, and fully nonlinear wave diffraction theory. In principle, fully nonlinear wave diffraction theory would account for much higher-order components in the solutions, seeming to be the best for simulating strongly nonlinear waves and their interaction with bodies, while the 2nd-order wave diffraction theory only includes the 1st- and 2nd-order terms in a Stokes-type expansion. However, in practice, most fully nonlinear wave simulation methods encounter severe numerical stability problems for the wave-structure interaction problem, and they cannot model large near-breaking wave interaction with structures. Such problems are still unsolved, even for regular waves. All these effects limit the applicability of fully nonlinear wave models to strongly nonlinear wave problems. In contrast, 2nd-order wave diffraction theory works well and demonstrates its robust ability to provide useful results for the engineering community.

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