Proceedings of the Seventeenth (2007) International Offshore and Polar Engineering Conference
Lisbon, Portugal, July 1-6, 2007

ISBN 978-1-880653-68-5; ISBN 1-880653-68-0(Set); ISSN 1098-6189 (Set)

Wave run-up on Vertical Cylinder by 3-Dimensional VOF Method

K.H. Lee*, D.S. Kim**, C.H. Kim**, S.K. Lee**, S.T. Kee***

*Department of Civil Engineering, Nagoya University, Nagoya, Japan
**Division of Construction and Environmental Engineering, Korea Maritime University, Busan, Korea
***Department of Civil Engineering, Seoul National University of Technology, Seoul, Korea

ABSTRACT

The wave run-up is vertical up-rush of water around the partially immersed body on when incident wave impinges. In this present study, the wave run-up is investigated on fixed single or dual vertical cylinders in fully nonlinear waves. The VOF method based on two-step projection has been developed to Navier-Stokes equation and validated by the comparison with published results. Using the developed numerical codes, the nonlinear interaction between structures and waves are discussed. It is found that complicated interactions between diffracted waves generated by physical circumstances of the varying size of the cylinders and gap distances dominate the complete wave run-up around structures.

KEY WORDS: Wave force; Wave transformation; Navier-Stokes equation; VOF method

INTRODUCTION

Investigation of the wave interactions on and around the large columns is very important in the design of the coastal structures, since the precise calculation and prediction of the physical phenomena can provide sufficient information for safe and economic design. MacCamy and Fuchs (1954) first developed a linear diffraction theory in finite depth water for calculating the wave forces on a vertical bottom mounted and fixed cylinder. However, evidences from experiments that the nature of water waves is, in general, inherently nonlinear and unsteady has been found through a variety study by many researchers.

Numerical modeling of nonlinear wave diffraction around large offshore structures are needs to obtain more accurate wave force and run-up predications than those of linear diffraction theory which is based on the assumption of infinitesimal wave heights.

The wave nonlinear problem is much more difficult to study in analytical form. For last decades, considerable efforts have been devoted to the analytical solution of the second order wave diffraction for single or multi-arrayed cylinders. A second order frequency domain solution based on the Stokes perturbation procedure (Molin, 1979, Kioka and Ishida, 1984, Eatock Tayor etc., 1989) has been developed to solve the wave diffraction around the fixed vertical circular cylinder. The perturbation expansion is generally used and yields separate linear boundary value problems to be solved for each term in the power series. The precise treatment of the second order free surface boundary conditions and a proper radiation condition for the second order diffracted waves are the principle difficulties so that the perturbation expansion is limited to smallness of the ratio of the wave height to the wave length. The most second-order solutions require numerical analysis of the problem since they are not completely analytic (Kriebel, 1990). Yang and Ertekin (1992) studied nonlinear wave diffraction by a fixed, vertical circular-cylinder that extends to the sea floor based on the 3-D BEM coupled with a time stepping procedure.

Isaacson and Cheung (1991) developed an integral equation method based on the Green's theorem to study a second order wave diffraction around two dimensional bodies and to study the nonlinear wave forces and run-up on a surface piercing body of arbitrary shape. A semi-analytic solution of the horizontal and vertical forces up to the second order is given by Huang and Eatock Tayor (1996), but this model is complicated and requires extra works to obtain the theoretical forces. A second order analytic solution of the velocity potential for the diffracted wave from the multiple cylinders without using Green function was derived by Sanada (1998) and was validated by laboratory experiments. The nonlinear potential analysis developed so far, although very useful, has been found to have limited applications because strong nonlinear waves generated by the interference between multilayered columns and wave impact forces by breaking waves can hardly be estimated.

In the present study, the finite difference method was employed to solve the three-dimensional Navier-Stokes equations. The prediction of the free surface is based on the volume tracking method VOF (Volume of Fluid). The pressure at the free surface has been directly evaluated through natural coordinate. This numerical method is developed to simulate highly nonlinear effects at the interface or complicated interference waves among structures, and has been validated through the comparisions with the published experimental results and second order analytical solutions of the velocity potential using without Green's function (Sanada, 1998).

THEORY AND NUMERICAL METHOD

Governing equations

In the present paper, the assumption of the incompressible viscous fluid flow is implemented to investigate the nonlinear wave diffraction and wave run-up by dual vertical circular-cylinder fixed