Numerical Simulation of Focused Wave Generation Using CIP Method

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ABSTRACT

Freak wave (extreme wave, rogue wave, huge wave, water wall, et al) is extremely large water wave in ocean and may occur all over the sea area. Despite its low possibility of occurrence, such a wave may lead to damage of ships and offshore platforms. Until recently, there was no means to generate a realistic extreme wave appearing in a random wave train. A relatively easy way to generate freak waves is using wave focusing. Along with physical experiments, numerical simulations are useful tools for designing coastal structures as well as for understanding natural hydrodynamic processes in the field of ocean engineering. This work is motivated by the requirement of hydrodynamics laboratories to generate focused waves and to investigate the survivability of offshore wave energy converters due to focused waves. The purpose of this paper is to demonstrate a CFD approach applied to simulations of focused wave.

In this paper, a constrained interpolation profile (CIP)-based Cartesian grid method are proposed for the focused wave generation problems and validated by experiment. Focused waves are generated based on the mechanism of wave focusing in a 2D numerical wave tank. The numerical simulation is performed by the CIP-based Cartesian grid method, which is described in the paper. An improved THINC scheme (THINC, tangent of hyperbola for interface capturing), the WLIC/THINC scheme (WLIC: weighed line interface calculation), is applied as the interface capturing method. To validate the capability of the CIP-based model described in this paper, generation of regular waves is firstly computed and compared with the theory. By adjusting the phases of the linear harmonics components, focused waves are formed at a certain target time and target position. The numerical results are compared with experimental data. All the comparisons are in good agreement. It is concluded that the present model with the aid of the CIP technique can provide with acceptably accurate numerical results on the route to practical purposes.

KEY WORDS: CIP; wave focusing; WLIC/THINC; interface capturing; wave tank.

INTRODUCTION

Recent studies have shown that the occurrence of extreme wave may be related to wave energy focusing including a number of factors: wave-wave interaction, wave-current interaction, bathymetry, wind effect, self-focusing instabilities, directional effects, etc. These different mechanisms of formation of extreme waves are reviewed in details by Khari and Pelinovsky (2003) and Dysthe et al. (2008). Due to the limit of wave tank length, none of existing physical flumes has ever been long enough to achieve a full-scale extreme wave appearing with long-time evolutions (Ducomet and Bonnefoy, 2007; Wu and Liu, 2005). In laboratory a relatively easy way to generate extreme waves is using wave focusing. The concept of wave focusing in model test and simulations is not new and is for example applied in studies by Baldock et al., (1996); Yan and Ma, (2008); Westphalen et al., (2008); Sun et al. (2008). However, the experimental test can be time consuming and expensive. It is desirable to have analytic and/or computational tools to perform analyses in the early stage of design to reduce the number of different design alternatives that require wave tank testing. Development of new CFD simulation methods for the seakeeping researches is therefore necessary.

The major difficulty in the numerical simulation of violent flow is that the topology of free surface may be largely distorted or broken up, which makes it impossible to apply the conventional numerical method such as potential flow solver by BEM. Recently several challenging works have been reported by the finite difference method in which the free surface is tracked by VOF method, by the particle method (Sueyoshi and Naito, 2001) and the SPH method (Rudman and Cleary, 2009). In this paper, we use a CIP-based Cartesian grid method, which is recently named as RIAM-CMEN (Computation Method for Extremely Nonlinear hydrodynamic). This numerical model for predicting hydrodynamics loads associated with strongly nonlinear ship-wave interactions has been developed over a period of years in the Research Institute for Applied Mechanics (RIAM) at Kyushu University. The constrained interpolation profile (CIP) algorithm (Yabe, 2001) was adopted as the base scheme to obtain a robust flow solver for the Cartesian grid approach. The two- and three-dimensional development of the CFD code has been presented in previous papers (HU, 2004, 2006, 2008). It should be pointed out that in the problem associated with extreme waves the CIP-based models are not yet widely applied. The aim of this paper is to present the validation of proposed model for focused wave generation using the CIP-based finite difference method.