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Overturning of a solitary wave on a continental shelf

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ABSTRACT

In this study numerical model was developed to solve the unsteady two-dimensional Reynolds Averaged Navier-Stokes (RANS) equations and the turbulent $k-\varepsilon$ equations for simulating the evolution of a breaking solitary wave above a continental shelf. A hybrid particle level set method was adopted to capture the complex free surface evolution, beginning from the steepening of the wave profile to the wave breaking, which was accompanied by the air entrainment, then followed by the successive splash-ups. The governing equations were discretized by the finite-analytic method and the SIMPLER algorithm was used to calculate the coupled velocity and pressure fields. Accuracy of the advection scheme of the level set method was confirmed by solving the Zalesak problem. Before we proceed to investigate the evolution of breaking solitary wave on a continental shelf, our numerical results were compared with the experimental data. After having verified the accuracy of the present numerical scheme, both the evolution and kinematic properties of the overturning waves on the shelf have been revealed to details. Furthermore, our numerical simulation shows that during the overturning of the solitary wave, the maximum velocity of the fluid particles occurs at the region near the second reattachment point with a high speed of $1.84\sqrt{gh}$.

KEY WORDS: RANS; level set method; solitary wave; continental shelf; overturning.

INTRODUCTION

Wave breaking is one of the most commonly observed features of water waves in the coastal areas. When waves break, the momentum of waves is transformed to the ocean surface layer. Breaking waves are also important in the generation of near surface turbulence and mixing and in the generation of bubble clouds. Many experiments were conducted to explore the physical phenomena associated with wave breaking. In the ocean engineering, effects of breaking waves play an important role in the design of offshore structures. A numerical wave tank was developed in present study to simulate the evolution of water waves from the initial generation stage to the breaking stage and eventually to the splash-up of the water, in which the air has been entrained into the water due to the breaking waves. Among the afore-mentioned phenomena associated with the wave breaking, present study focused on the simulation of solitary wave overturning over a submerged structure and attended to clarify the mechanism of the energy translation.

The marker and cell method (MAC) presented by Harlow and Welch (1965) was the first attempt to simulate the time-dependent, viscous, incompressible fluid flow with a free surface. A finite difference technique was used to discrete incompressible, two-dimensional Navier-Stokes equations on a uniform Cartesian staggered grid system, and the velocity boundary conditions at free surface are based upon the requirement of mass conservation. Essential principle concept of advancement of free surface in MAC is that the coordinates of marker particles laid out everywhere in computational domain are assumed to be known at the beginning and moved according to the velocity components in their vicinities. After that, improved versions have been reported subsequently, e.g., SMAC (Amsden and Harlow, 1970), SM (Chen et al., 1991) and GENSMAC (Tome. and McKee, 1994) etc.

Opposite to the Lagrangian technique mentioned above, the Volume-of-Fluid method (VOF) originally proposed by (Hirt and Nichols, 1981) was developed based on the Eulerian manner. This method can simulate complex free surfaces, including fluid merging and reconnection. Location of the free surface is identified using a specific function defined as the fractional volume ratio of the cell occupied by fluid. The modified versions of VOF method have been widely used to track the interfaces between different fluids. Youngs et al, (1982), Ashgriz and Poo (1991) and Kim and No (1998) applied the so-called first-order linear approach or the second-order linear curve to reconstruct the free surface.

Recently, a novel technique presented by Sussman et al. (1994) was derived for computing the motion of two-phase flow which allows for large density ratios, surface tension, and jumps in viscosity. A level set method (Osher and Sethian, 1988) is proposed for capturing the interface between two fluids, and can be generalized to three-dimensional problems easily. This new treatment of the level set method provides another way to compute the interface separation and combination, such as the motion of air bubbles in water or falling water drops in air. However, numerical diffusion may arise during the time advancing. Numerous researchers consecrated to modify the traditional level set method, such as Sussman et al. (1998), Peng et al. (1999), Sethian (2001) and Enright et al., (2002) were attempted to develop a more accurate and efficiently solution algorism to reduce the computational effort.