On the Numerical Simulation of a Piston-type Wavemaker

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ABSTRACT

The piston-type wavemaker is a very popular and important piece of equipment in coastal and ocean engineering physical wave model experiments so in this paper we use a numerical model to simulate the characteristics of the piston-type wavemaker. The numerical model is based on solving the Navier-Stokes equations, in which a two-fluid water and air system is adopted. The interface between the water and air is tracked by a particle level set method and the partial cell technique combined with the local relatively stationary method is used to simulate the motion of the wavemaker in the numerical model. Firstly, linear wave maker theory is implemented and tested for regular waves at various water depths, wave periods and wave heights, to see which wave making methods give reasonable results for short wave cases. The method is then extended to simulate irregular waves where the wave spectrum is specified and the individual wave components are superimposed. The output spectrum from a wave gauge in the numerical flume compared well with the target spectrum. Finally a focused wave is simulated by the numerical model and compared with published results. It is shown that the numerical flume can simulate an experimental flume with a piston-type wavemaker and thus physical tests can be accurately replicated by numerical modelling.

KEY WORDS: Wavemaker; regular wave; irregular wave; focused wave; level set; partial cell; local relatively stationary method.

INTRODUCTION

Wavemakers are important pieces of equipment in coastal and ocean engineering laboratory experiments to study wave interaction with structures such as wharves, breakwaters and any other near-shore or ocean structures. Generation of waves is one of the most significant tasks in this kind of laboratory.

The most common way in a physical experimental flume to generate waves is through the movement of a paddle, which is located at one end of the flume. Paddles used in flumes can be a flap, a piston or a wedge type, of which the piston-type is the most popular permitting simple generation of shallow water waves according to the velocity pattern near the paddle.

Havelock (1929) derived an analytical solution for waves generated by piston and flap wavemakers based on linear wave theory. Ursell et al. (1960) and Flick and Guza (1980) experimentally verified a piston wavemaker by using first order wavemaker theory. Ottesen-Hansen et al. (1980), Sand (1982) and Sand and Donslund (1985) discussed second-order effects such as long waves in experimental models. Schaffer (1996) derived a complete mathematical model for piston wavemakers to second order. The linear wavemaker theory has been extended to a 3D wave basin (Liu 1994, 1996; Newman 2010). In the implementation of wave making in the laboratory active absorption is often applied to avoid spurious reflection (Spinneken and Swan 2009a, 2009b).

Because the size of experimental models is limited by the size of wave tanks leading to scaling effect errors, numerical wave flumes began to be considered as a possible tool to support the design and regulation of costal, ocean and near shore structures. Numerical wave models based on nonlinear shallow water equations (SWE) can be found in Van Gent (1994), and Hu et al. (2000). Zhang (2005) built a numerical model based on the Boussinesq equations and compared numerically generated waves to physical results. As models based on the previous methods do not show the detailed information in the vertical direction advanced numerical wave flumes should be based on the Navier-Stokes equations (NSE).

The main challenge in solving NSE for wave generation is how to locate the free surface. There are two approaches for solving the NSE: mesh based methods and meshless methods. Meshless methods include the smoothed particle hydrodynamic (SPH) and moving particle semi-implicit (MPS) methods. Shao et al. (2006) presented an incompressible SPH model to investigate wave overtopping in coastal structures. Koshizuka et al. (1995) proposed the MPS method to solve the NSE used for the simulation of numerical wave flumes.

Mesh based methods include the volume of fluid (VOF) method (Hirt & Nichols 1981, Yong 1982, Ubink 1997), the level set method (Gu et al. 2009, 2010; Chen 2009) and the marker and cell method (MAC) (Harlow & Welch 1965) to capture or track the free surface together with a NSE solver such as the projection or SIMPLE method. Another