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Implementation and Validation of Nonlinear Wavemaker Models in a HOS Numerical Wave Tank

G. Ducrozet, F. Bonnefoy, D. Le Touzé and P. Ferrant
Laboratoire de Mécanique des Fluides/EHGO (UMR CNRS 6598)
Ecole Centrale de Nantes, Nantes, France

This study deals with the development of a novel, fully nonlinear, potential flow model for simulating the generation and propagation of 2-dimensional or 3-dimensional gravity waves in finite depth. This Numerical Wave Tank (NWT) relies on an original nonperiodic High-Order Spectral (HOS) model (Bonnefoy et al., 2004). In this new fully spectral formulation, propagation of waves is solved in a fully nonlinear manner, while generation can be modeled up to the 2nd order in wavemaker excursion. The resolution is made by means of only Fast Fourier Transforms (FFT), leading to a fast and accurate method. The efficiency and fast convergence of this spectral method enable modelization of the shortest wavelengths in a wave tank while keeping reasonable computational efforts. Several validation results are presented where numerical simulations are successfully compared to experiments on different 2-D and 3-D complex sea states.

INTRODUCTION

In recent decades, new experimental facilities have appeared with the capacity of reproducing complex 3-D sea states. The need for such experimental tools comes from the necessity to correctly estimate wave loads on floating body structures (ships, oil platforms and such) which often encounter critical sea conditions combining wave directional spreading and large amplitudes. These experimental facilities are then designed to reproduce all the characteristics of any complex sea pattern.

In parallel, some numerical tools have been developed for the simulation of gravity waves' propagation. Different levels of approximation exist, but up to now the potential theory approximation remains the best compromise for the numerical reproduction of severe sea conditions over longtime ranges. In this frame, some simulation tools based on Boundary Element Models (BEM) have been developed (e.g. Grilli et al., 2001, who presented an NWT able to simulate overturning waves). However, very fine grids are required for realistic sea patterns' modelization. This implies huge computational costs for large 3-D cases, which limits practical applicability. However, the application of Fast Multipole Algorithms may reduce this difficulty (e.g. Korsmeyer et al. 1993, Fochesato and Dias, 2006). Other types of fully nonlinear potential models based on spectral expansions have also been developed (e.g. Dommermuth and Yue, 1987; West et al., 1987; Fructus et al., 2004) which present specific and attractive fast-convergence, high-accuracy and fast-resolution properties. However, these models have not been able up to now to simulate a complete NWT (wavemaker, reflective walls, absorbing zone and such). Only the propagation of waves, with given initial conditions, was possible.

A new method, based on the High-Order Spectral (HOS) formulation of West et al., has been developed to extend this model's application field to bounded domains (Bonnefoy et al., 2004), and this results in a High-Order Spectral Tank (HOST) formulation. This new numerical tool is dedicated to modeling the ECN wave basin (50 m × 30 m × 5 m), including wave generation, as the physical wave tank is equipped with a 48-flap wavemaker on one of its 30-m sides. The initial method detailed in the previous paper included a linear wave generation (through a linearized inlet flux condition) with fully nonlinear wave propagation. It has been extensively validated, e.g. on the longtime evolution of irregular waves; see Bonnefoy (2005, in French) or Bonnefoy et al. (2005). In those validation examples, numerical simulations were successfully compared to experiments, and the method's accuracy was demonstrated. However, with highly nonlinear phenomena such as very steep waves, extreme focused waves, etc., it appears that wavemaker nonlinearities have to be taken into account. The present paper is thus devoted to the development of a nonlinear wavemaker model in the method. It is to be noted that wave propagation and generation are spectrally solved, which leads us to a very efficient tool.

The novel NWT formulation, based on coupling of the fully nonlinear HOST model with a 2nd-order spectral NWT model, is detailed as well as the efficient resolution approach. The resulting scheme solves the propagation of waves in a fully nonlinear manner, while the generation is modelized up to the 2nd order in wavemaker excursion. The model is then validated on a highly nonlinear phenomenon (2-D focused wave packet embedded in an irregular wave field), thanks to several experiments which will demonstrate the accuracy and efficiency of this new NWT. Finally, the model's abilities are pointed out with the generation of a complex 3-D wave field compared to experiments.

FORMULATION

We consider a 3-D wave tank L_x long, L_y wide and h deep, filled with a fluid which is assumed to be homogeneous, incompressible and inviscid (Fig. 1).

The section $x = 0$ corresponds to the wavemaker position which is treated later; side walls ($y = 0$ and $y = L_y$) and end wall ($x = L_x$) perfectly reflect waves and are modeled with no-flux conditions. The wave-induced motion of the fluid, initially at rest, is irrotational, and we assume that no wave-breaking occurs. Under these assumptions, the flow velocity derives from a velocity potential $\phi(x, y, z, t)$, satisfying the Laplace equation inside

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