

A 2D fully nonlinear wave-current numerical wave tank based on BEM

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ABSTRACT

A 2D fully nonlinear wave-current numerical wave tank (NWT) based on BEM is investigated. In this paper, a new approach, a total velocity potential function is adopted to solve a wave-current interaction problem; meanwhile, the fully nonlinear free surface boundary condition is treated by using Mixed Eulerian-Lagrangian method (MEL). A linear and a high order wave-current theories are used as a feeding function separately to generate waves from input boundary, and assume the uniform current has existed in the wave tank before waves are generated. To dissipate the wave energy at the end of wall, a numerical damping zone is modified and deployed at the tank-end. A boundary element method with linear element scheme and the Runge-Kutta 4th order method are used to predict the water surface elevation varied with time. The simulated results show well agreement with other solutions in deep water as well as in intermediate water depths.

KEY WORDS: fully nonlinear, wave-current, numerical wave tank, damping zone, Mixed Eulerian-Lagrangian method, BEM.

INTRODUCTION

It is one of interesting topics of ocean engineering to precisely comprehend the nonlinear properties of wave-current interaction due to the fact that waves always propagate with currents in the real open sea. Moreover, the interactions of wave-current are hard to study in hydrodynamic laboratory due to difficulty generating fully uniform steady current with waves in the tank. Therefore, developing a fully nonlinear wave-current NWT to investigate the properties of wave-current interaction is an important issue.

Over the last two decades, numerical solution of the exact nonlinear equations for the inviscid water waves using a boundary integral equation description has become an extremely successful scheme (Coite, 1990; Grilli and Svendsen, 1990; Kim et al., 1999; Tanizawa, 2000). Although there are many papers dealing with fully nonlinear waves by NWT, researches on fully nonlinear wave-current interactions are still rare.

In the past, the study of wave-current interactions is mostly based on linear numerical method and experimental data (Thomas, 1981; Baddour and Song, 1990) or perturbation expansion method (Peregrine, 1976; Brevik, 1979). Analytic solutions based on Stokes expansion are developed for intermediate and deep water wave regions. However, it may not suitable to describe the wave shape while waves propagating

into shallower water, the relative depth (h/λ) less than 1/10. Because shallow water waves has asymmetric wave form i.e. sharp wave crest and flat wave trough, Stokes expansion method based on sine/cosine functions can not correctly describe these phenomena. Therefore, the K-dV function (Cnoidal wave theory) is applied for investigating the shallow waves.

Generally, the treatment of the nonlinear free surface elevation (particle trajectory) by Lagrangian frame is more reasonable than Eulerian scheme because the wave shape may change sharply when traveling downstream. Ryu et al. (2003) developed a fully nonlinear wave-current NWT method based on a potential theory to predict the wave elevation and fluid particle velocity in the time domain and showed good agreement with the multi-layer Boussinesq model in the intermediate water depth. Therefore, numerical models may be more effective and suitable to study the nonlinear wave-current interaction for the shallow water region. In this paper, a new concept, a total velocity potential function (a combining form of a regular wave and a uniform current potential function), is adopted to solve this wave-current interaction problem; whereas other papers (e.g. Kim et al., 1998; Celebi, 2001; Ryu et al. 2003) used a pure wave potential function to solve this kind of problem first and then applied superposition principle adding the uniform current potential function to gain the final results.

This paper is structured as follows: A mathematical formulation is described in the beginning, then investigates the interactions of wave and current in deep water region as well as in intermediate water region, and then the effects of different feeding functions are briefly discussed. Finally, conclusions are made.

MATHEMATICAL FORMULATION

Governing equation

Figure 1 is a standard setting for an NWT. The total velocity potential of regular wave and uniform current is described in Eq. (1), where U_0 denotes the uniform current speed and ϕ denotes the pure wave potential function. Substitute Eq. (2) into the continuity equation in fluid domain $\Omega(t)$, then it becomes a Laplace equation for Φ , Eq. (3).

$$\Phi(x, z, t) = U_0 x + \phi(x, z, t) \quad (1)$$

$$\mathbf{V} = \nabla\Phi = (u, w) \quad (2)$$

$$\nabla^2\Phi = 0 \quad \text{in } \Omega(t) \quad (3)$$