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# A Numerical Wave Tank for Nonlinear Irregular Waves by 3-D Higher Order Boundary Element Method

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## ABSTRACT

**A nonlinear numerical wave tank has been developed using a three-dimensional higher order boundary element method (HOBEM). For this, simple (Rankine) sources are distributed on the free surface and other boundaries. The resulting boundary integral equation is repeatedly solved at each time step using a predictor-corrector time integration scheme. The instantaneous free surface points are calculated by the Eulerian scheme assuming that the free surface is single-valued. For the corners and edges of the wave tank, discontinuous boundary elements are employed, and at the open boundary a special form of Sommerfeld/Orlanski open boundary condition is used. Numerous numerically simulated linear and nonlinear waves are compared with theoretical input waves. In particular, very steep Stokes 3rd-order-like long-crested irregular waves are successfully simulated using our nonlinear numerical wave tank.**


## INTRODUCTION

Numerical simulation of steep ocean waves by the boundary integral equation method has been extensively studied during the past decade (e.g. Dommermuth and Yue, 1987; Sen and Pawlowski, 1988; Cao, 1991; Yang and Ertekin, 1992). In particular, the interaction of those waves with ocean structures is of great engineering interest. In this paper, we developed an efficient three-dimensional HOBEM to simulate a nonlinear numerical wave tank without a structure. The fully nonlinear wave-body interaction will be studied in the near future.

Three-dimensional numerical wave tanks have been developed using various numerical schemes. For instance, Romate (1989) employed a higher order panel method and absorbing open boundary condition to simulate nonlinear waves, whereas Xu (1992) numerically simulated secular breaking waves using a higher order boundary element method and double periodic boundary condition. Recently, Xu et al. (1993) used the Green-Naghdi theory for the numerical simulation of irregular nonlinear waves. Various numerical techniques have also been experimented for the proper treatment of the radiation condition at the open boundary, but the pros and cons of the existing numerical techniques have not been clearly defined yet.

The present numerical method assumes ideal fluid under uniform atmospheric pressure without surface tension. Thus the Laplace equation has to be satisfied in the fluid region. The boundary integral equation based on the Rankine source distribution is repeatedly solved at each time step. The input waves are predescribable theoretical waves and are continuously fed into the inflow boundary at uptank. At the downtank (outflow boundary), a special form of Sommerfeld/Orlanski open boundary condition is employed.

In the frequency domain, the higher order boundary element method (HOBEM) has been successfully applied to the linear and second order wave body interaction problems using the free-surface Green function (e.g. Liu et al., 1991, 1993). In this paper, we developed another simple-source-based HOBEM in order to simulate fully nonlinear irregular waves in the time domain. For accurate and robust computation, higher order boundary elements as well as continuous/discontinuous boundary elements are used. The discontinuous element is locally adopted in the neighborhood of corners and edges.

The input waves on the inflow boundary are gradually increased from zero to the actual value in order to reduce the transient disturbance. The free surface is updated at each time step by the fourth order Adams-Bashforth method (AB4) for the linear waves and fourth order Adams-Bashforth-Moulton method (ABM4) for the nonlinear waves. The free surface points are calculated by the Eulerian scheme assuming the wave elevations are single-valued. Therefore, the present scheme cannot be applied to the numerical simulation of plunging breaking waves. The input waves used in the present work are linear regular and irregular waves for the linear wave simulation, and the second order regular and third order irregular Stokian waves for the nonlinear wave simulation. The third order irregular waves are generated from the combination of two or four Airy waves (Pierson 1993).

Our nonlinear wave simulation satisfies the exact (or fully nonlinear) free surface boundary conditions. Using HOBEM, only a modest number of boundary elements is required even for steep and short wave simulation, which results in substantial saving in CPU time compared to conventional constant panel methods (CPM). In addition, the spatial derivatives of the velocity potential can efficiently and accurately be computed by HOBEM on the entire boundary surfaces.

Our predictor-corrector time integration of the free surface incorporated with intermittent smoothing technique functioned well in all the numerical examples shown in this paper. The major difficulty we have experienced, however, is the effective numerical implementation of the Sommerfeld/Orlanski open boundary condition, which influences the size of the numerical wave tank as well as simulation time period. The present study is focused on the effective and reliable computation of fully nonlinear waves within limited tank scale, so the long-time evolution of nonlinear waves cannot be clearly observed here. For such application, an efficient and robust scheme for a very long numerical wave tank has to be developed.

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