

## **Study of Nonlinear Wave Scattering by A Submerged Step in a Fully Nonlinear DBIEM Numerical Wave Tank**

*Chunrong Liu*

Maritime Research Center, School of Civil and Environmental Engineering, Nanyang Technological University  
Singapore

*Zhenhua Huang*

School of Civil and Environmental Engineering, Nanyang Technological University  
Singapore

*Soon Keat Tan*

DHI-NTU center, School of Civil and Environmental Engineering, Nanyang Technological University  
Singapore

### **ABSTRACT**

To study the nonlinear wave interaction with large submerged, rectangular breakwaters, the writers developed a fully nonlinear numerical wave tank, which is based on the mixed Eulerian-Lagrangian (MEL) formulation. The desingularized boundary element method (DBIEM) is adopted here to circumvent the singular integration in the boundary element methods (BEM) that are based on Green's function formulations. After code verification, our nonlinear numerical wave tank is used to study the nonlinear wave scattering by a submerged rectangular step. In comparison with our experiments, we found that higher harmonic wave components generated by nonlinear wave processes in shallower water over the step are well predicted by our DBIEM numerical wave tank. The reflection coefficients and the transmission coefficients of the second harmonic waves are also modeled satisfactorily. The transmission coefficients of the first harmonic waves predicted by the DBIEM demonstrated improvement over those by linear theory.

**KEY WORDS:** Desingularized boundary integral equation method; numerical wave tank; breakwaters; wave scattering

### **INTRODUCTION**

Submerged breakwaters are frequently used to provide economic measure in shoreline erosion control. The purpose of a submerged breakwater is not to create completely calm water behind the breakwater, but to reduce the wave intensity behind the breakwater to an acceptable level. Early research on this subject focused on the linear interactions between waves and submerged objects. Following Newman (1965), who first studied the scattering of long waves by submerged obstacles, Mei and Black (1969) investigated the wave scattering by two-dimensional obstacles in waters of finite depth. Recent reviews of linear wave scattering by impermeable submerged steps can be found in Dingemans (2000) or Mei et al. (2005). Ocean waves nearshore are most likely nonlinear in nature and the interactions between waves and the submerged structures are strongly or at least weakly nonlinear as well. It is not always possible to obtain analytical

solutions for fully nonlinear problems. Most problems about nonlinear wave interactions with large submerged objects are studied preferably by either numerical modeling or physical modeling in wave tanks/basins. Compared with physical modeling in wave tanks/basins, numerical modeling has the advantage of being lower cost and without scale limitation.

For the past two decades, much work has been carried out on the numerical wave tank. These works can be categorized into two groups. One is based on N-S equations in which the viscous effects are considered, the other is based on the potential flow theory in which the viscous effects are ignored. Based on N-S equation, there are two main methods to obtain the position of the free-surface: marker-and-cell (MAC) method (Park, et al, 1999), and volume of fluid (VOF) method (Hirt and Nichols, 1981). These methods can solve the fully nonlinear problems with breaking waves and vortex shedding, but the cost of computation of these methods is huge. Based on the potential flow theory, boundary element methods (BEM), and later desingularized boundary integral equation methods (DBIEM) are developed. In order to simulate a fully nonlinear free surface problem by BEM (or DBIEM), many researchers adopted the mixed Eulerian-Lagrangian (MEL) formulation. The single largest advantage of the BEM/ DBIEM is that it can reduce the dimensions of the problem by one, thus the computational cost becomes lower.

Compared with BEM, DBIEM has the following advantages. Firstly, it does not require one to evaluate the singular integrals and it is easier to develop the program code. Secondly, for this method, the velocity and the derivatives of the velocity on the boundaries are continuous and smooth and can be easily calculated. This method has been suggested by Cao(1991), and followed by Beck(1994), Lalli(1997), Kim(1998), Celebi(1998, 2001), Zhu(2001), SchÖnberg(2002), Zhang et al (2006,2007), among others. In DBIEM, the singularities are placed on the integration boundaries which is offset a small distance outside the corresponding physical boundaries. As such, the integral kernels are no longer singular. The distance of the singularities away from the corresponding physical boundaries (desingularization distance) is very important to the simulation accuracy. Cao (1991) did some numerical