Numerical Simulation of Nonlinear Water Waves Propagating Over a Submerged Dike

C.J. Huang and C.M. Dong
National Cheng Kung University
Tainan, Taiwan, China

ABSTRACT

The Navier-Stokes equations along with the exact free surface boundary conditions are solved to simulate the deformation of water waves propagating over submerged dikes. The incident waves are generated by a piston-type wavemaker set up in the computation domain. Numerical results have been compared with experimental data to verify the accuracy. Transformations of waves of different Ursell numbers passing over trapezoidal dikes are studied and compared. The Fast Fourier Transform method was applied to decompose the transformed waves and the higher harmonics. The main characteristics of the flow fields are also briefly discussed.

KEY WORDS: Wave deformation, submerged dikes, high harmonics.

INTRODUCTION

The generation of higher harmonics as waves propagating over submerged dikes has long been known by direct field observations or by experiments (e.g., Johnson et al., 1951; Jolas, 1960). Since the deformation of water waves propagating over a submerged dike is important in the design of submerged breakwaters, this problem has attracted attention of many investigators. The phenomenon of harmonic generation can also be explained theoretically by the nonlinear shallow-water waves theory, usually the Boussinesq equations. The derivation of Boussinesq equations is based on the assumptions of both weak nonlinearity and weak dispersivity of waves, hence they may not be valid for the prediction on the trailing side of the dike, where higher harmonics may arise as deep-water waves. In order to overcome this defect, improvements on the Boussinesq equations have been developed. Peregrine (1967) developed equations of motion for long waves in water of varying depth. Madsen et al. (1991) improved the Boussinesq equation by adding a term to improve the dispersion characteristics. Battjes and Beji (1991) derived a new set of Boussinesq equations by combining the method used by Madsen et al. (1991) and the equation proposed by Peregrine (1967). Beji and Battjes (1994) employed these equations to study the deformation of water waves passing over a dike.

The boundary element method has also been applied to solve the Laplace equation and the nonlinear free surface boundary conditions to study the decomposition phenomena of waves passing over a rectangular submerged dike (Ohyama and Nadaoka, 1994). In Ohyama and Nadaoka the incident waves were generated by a numerical wave tank model developed by Ohyama (1991). This was similar to our method of setting up a piston-type wavemaker in the numerical domain to generate the incident waves.

To make the governing equations easier, the viscosity effect has been neglected in the above theories. However, the prediction of the flow fields without taking the viscosity effect into account may in some situations fail to provide useful knowledge about the real flow fields. In order to predict the flow fields more accurately, recently, the Navier-Stokes equations along with the exact free surface boundary conditions have been solved for the free surface problems. Huang et al. (1997) simulated the wavefields generated by a piston-type wavemaker by solving the Navier-Stokes equations. Huang et al. discretized the two-dimensional Navier-Stokes equations by means of a finite-analytical scheme. The SUMMAC method was used to determine the location of the free surface.

In the present study, the numerical wave tank model developed by Huang et al. was applied to simulate the deformation of water waves propagating over trapezoidal dikes. In order to verify the accuracy, numerical results have been compared with experimental data. Transformation of incident waves of different Ursell numbers passing over a trapezoidal dike was studied in detail. Grue’s method (1992) has been applied to decompose the transformed waves and the higher harmonics. The main characteristics of the flow fields were also briefly discussed.

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

A schematic diagram of a trapezoidal dike is shown in Fig. 1. A piston-type wavemaker is located at $x = 0$ to generate the incident