

Wave Reflection and Vortex Evolution in Bragg Scattering of Water Waves

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ABSTRACT

The vortex generation and dissipation under Bragg scattering due to water wave propagation over a series of submerged rectangular breakwaters are investigated both numerically and experimentally. A Reynolds Averaged Navier-Stokes (RANS) model with a $k-\varepsilon$ turbulence closure is applied to simulate the vortical evolution process as water waves pass over a series of artificial rectangular bars. The Particle Image Velocimetry (PIV) is also used to measure the velocity field in the vicinity of the obstacles. The numerical model is thereby validated through comparisons of water elevations and velocity field with the measurements. Overall agreements between the calculated results and the measured data are quite fair. The corresponding wave reflection coefficients for both resonant and non-resonant cases are calculated and experimental results are compared with solutions obtained from the linear wave theory. Both experimental and numerical findings reveal a strong shift of the reflection peaks towards the lower value of $2S/L$, where S and L are spacing of dikes and the wavelength of the surface wave, respectively.

KEY WORDS: Bragg scattering; RANS; PIV

INTRODUCTION

Over the past decades, many researchers have studied the phenomenon of Bragg scattering, as water waves propagate over a patch of bottom ripples, by means of experimental, theoretical, or numerical methods. Their results indicate that the Bragg resonance occurs when the wavelength of the incident surface wave is twice that of the bottom undulation (Davies and Heathershaw, 1984; Mei, 1985). For a practical application on coastal engineering, Mei et al. (1988) proposed the concept of using breakwaters to protect the drilling platform from wave attack on the oil fields in the Ekofisk of the North Sea. Their researches revealed the potential effectiveness of breakwaters against approaching waves. Kirby and Anton (1990) and Bailard et al. (1992) also explored similar ideas. However, both the numerical and the theoretical studies are made based on the potential flow theory in which the viscosity and rotational effect of fluid is neglected (e.g., Dalrymple and Kirby, 1986; Kirby and Anton, 1990; Hsu et al., 2003).

In recent years, solution procedure of the Navier-Stokes equations with a turbulence $k-\varepsilon$ model in conjunction with VOF (Volume of Fluid) and HF (Height Function) methods for capturing the free surface have been developed in order to investigate the interaction between the periodic waves and the obstacles. Huang and Dong (2002) simulated the propagation of water waves over rigid ripples by solving Navier-Stokes equations directly. Nevertheless, only the case with considerably slight effect of Bragg scattering was studied, in which the wavelength of ripples was relatively smaller than that of incident waves. Later a two-dimensional RANS model was implemented by Hsu et al. (2004) and applied to investigate the interaction of periodic waves and impermeable submerged double breakwaters under non-breaking wave conditions. In their study, after a detailed verification of the numerical model with the existing analytical solutions and the laboratory data, they briefly address the flow physics and vortex evolution around the breakwaters.

On the other hand, in a experimental study Ting and Kim (1994) performed a two component Laser Doppler Anemometer (LDA) measurement on the flow separation induced by the propagation of water waves over a submerged rectangular obstacle. Petti et al. (1994) utilized the particle image velocimetry (PIV) to study the vortex behavior around a submerged obstacle. Hsu et al. (2000) used the Fiber Laser Doppler Velocimetry (FLDV) method to measure the flow field and the underwater effects around the submerged double breakwaters. Recently, Chang et al. (2005) used the particle image velocimetry technique to measure the instantaneous flow field around a submerged rectangular obstacle under a cnoidal wave. Moreover, Lin et al. (2006) experimentally studied the interaction between a solitary wave and rectangular dike by using the quantitative PIV technique and two qualitative flow visualization techniques, including the laser induced fluorescence technique and the particle tracing technique.

In the present study, the RANS model developed by Hsu et al. (2004) is utilized to simulate the propagation of water waves over a series of rectangular bars under Bragg scattering. The dynamics of the turbulence are described by introducing a $k-\varepsilon$ model with Boussinesq closure. The Height Function (HF) is implemented to treat the free-surface configuration. The significant benefit of the present study over the traditional way of analyzing wave propagation problems