

Experiments on nonlinear wave scattering by a submerged rectangular step in the presence of a current

Zhenhua Huang

School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

M. S. Ghidaoui

Department of Civil Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong

ABSTRACT

Breakwaters in the form of submerged bars have the advantages of allowing the exchange of seawaters between harbors and open sea. In this paper, the scattering of monochromatic waves by a submerged rectangular step in the presence of an opposing current is examined experimentally. The wave blocking by opposing current is reported. The effects of the current on the transmitted fundamental and the second harmonic waves are investigated. It is found that the opposing current can greatly enhance the dissipation of wave energy, and thus reduce the energy of transmitted waves.

KEY WORDS: Wave scattering; breakwater; wave-current interaction; nonlinear waves.

INTRODUCTION

Breakwaters in the form of submerged bars have the advantages of allowing the exchange of seawater between harbors and open sea, and may be preferred in providing economical protection from waves in harbors or marinas. In coastal waters, both waves and various currents exist and understanding the influence of a steady current on the wave scattering by an impermeable rectangular step is of interest for design purposes.

Extensive research has been carried out on linear wave scattering by impermeable submerged steps (see Dingemans (2000) or Mei et al. (2005) for brief reviews). 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. Assuming that the length of a step is much larger than the step height, Devillard et al. (1988) applied the scattering matrix approach to wave scattering by a series of rectangular steps (see also O'Hare and Davies (1992) for scattering matrix approach). Belzons et al. (1988) showed experimentally the existence of the so-called localization of water waves over a series of irregular rectangular steps (so also Mei and Hancock (2003)).

For long waves scattered by a submerged rectangular step of finite length B in the absence steady current, explicit expressions are available for reflection coefficient R and transmission coefficient T (see Mei et al. (2005) for example). Both R and T show periodic variations with the relative step length $k_s B$ (k_s is the wave number over the step of length B). As dissipation of wave energy was not considered in linear theories, wave energy was conserved. For intermediate waves scattered by a submerged rectangular step, no explicit expressions are available for the reflection and transmission coefficients.

There are also some experimental and numerical studies on nonlinear wave scattering by a submerged step. Rey et al. (1992) studied experimentally the generation of higher harmonics due to wave scattering by a submerged bar. Ting and Kim (1994) experimentally investigated the formation of wave-induced vortex and showed the existence of the higher harmonic wave down-wave of the submerged rectangular step. On theoretical side, Massel (1983) proposed a potential wave theory for weakly nonlinear interaction between monochromatic waves and a submerged step. His model indicated that the second harmonic waves were generated in shallow water over the step and then transmitted into the deeper water as free waves. Recently, nonlinear wave scattering by submerged obstacles was revisited through numerical models by a number of authors (Huang and Dong (1999), Hsu et al. (2004), Shen et al. (2004), Sue et al. (2005), Yang et al. (2007), etc.). In all of the aforementioned studies, the effects of currents were not considered.

In coastal waters, there are tidal currents, wind driven-currents, wave-induced currents, etc., therefore waves and currents always co-exist. When waves propagate in a uniform current, both the wave height and wavelength will be modified by the current. For waves propagating on a co-linear current of depth-averaged velocity U , the wavenumber k can be determined by the following dispersion equation (see e.g., Mei et al. (2005))

$$(\omega - Uk)^2 = gk \tanh(kh), \quad (1)$$

where g is the gravitational acceleration. When waves propagate against the co-linear current, we have $U < 0$; otherwise, $U > 0$. Thomas