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Propagation of Solitary Waves over Permeable Rippled Beds

Chih-Hsin Chen, Hsing-Han Chang, and Ching-Jer Huang
Department of Hydraulic and Ocean Engineering, National Cheng Kung University
Tainan, TAIWAN, China

ABSTRACT

The unsteady two-dimensional Navier-Stokes equations and Navier-Stokes type model equations for porous flow were solved numerically to simulate the propagation of solitary waves over a permeable rippled bed. The free surface boundary conditions and the interfacial boundary conditions between the water and the porous bed are in complete form. A boundary-fitted coordinate system was used in this model. The accuracy of the numerical scheme was verified by comparing the numerical results for the spatial distribution of wave amplitudes on the impermeable and permeable rippled bed at resonant conditions with the analytical solutions. Our numerical results showed that when the crest of a solitary wave propagates into the ripple section, flow separation with reattachment was formed at the lee side of each ripple crest. The flow separation develops gradually into a clockwise vortex with a dimension that covers the whole region between two successive ripple crests. The trajectories of fluid particles above the permeable rippled bed are similar to those on the impermeable rippled bed. Although all of the fluid particles on the impermeable rippled bed move eventually in the opposite direction of wave, some particles on the porous rippled bed do shift in the wave direction.

KEY WORDS: solitary waves; permeable; porous; ripples; numerical wave tank; finite-Analytic Method; vortex.

INTRODUCTION

Flow fields on the rippled bed induced by water waves have frequently been studied in an oscillatory flow field. A considerable amount of laboratory works has been performed to investigate the flow near the ripples (Sawamoto et al., 1982; Sato et al., 1987; Ranasoma and Sleath, 1992; among many others). Based on the measurements two stationary cells were found to exist between the ripple crests. The fluid motion under waves is different from that in an oscillatory flow. Toue (1996) simulated the flow above ripples under both an oscillatory flow and progressive waves and found that the boundary layer flow under the oscillatory flow was symmetrical and that under progressive waves was asymmetrical. Recently, Huang and Dong (2002) studied the propagation of water waves over impermeable rippled beds by solving the unsteady two-dimensional Navier-Stokes equations and the exact free-surface boundary conditions. Their results showed that as a solitary wave passes over rigid impermeable ripples, the fluid particles near the bed are lifted by the primary vortices induced at the lee side of the ripple crest and are transported in the opposite direction from the wave, while in the case of periodic waves the fluid particles are transported in the direction of waves.

The rippled seabed is often permeable. However, propagation of water waves over permeable rippled beds has been rarely investigated. Mase et al. (1995) derived a time-dependant wave equation for waves propagating over permeable rippled beds taking account of the effects of porous medium. They found that the transmitted waves become small due to the permeability of rippled bed. The reflection and transmission coefficients were influenced by the friction factor, the thickness of porous layer, and the porosity. In this study the unsteady two-dimensional Navier-Stokes equations and Navier-Stokes type model equations for pore flows proposed by Huang et al. (2003) were solved to investigate the flow behavior near the permeable rippled beds induced by solitary waves. The analytical solutions of Mase et al. (1995) for wave amplitude under the resonant condition are used herein to confirm the accuracy of the present numerical model. Following the verification of the numerical scheme, the flow fields and trajectories of the fluid particles near the permeable and impermeable rippled beds are compared and discussed.

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

This study investigates the propagation of solitary waves over rigid permeable rippled beds. A schematic diagram of the permeable rippled beds located at the bottom of a two-dimensional numerical wave tank is shown in Fig. 1. A piston-type wavemaker with stroke S_o is located at $x = 0$ and generates the incident waves. The still water depth is h_o.

The flow outside the permeable rippled beds was assumed to be laminar and obtained by solving the unsteady two-dimensional Navier-Stokes equations in a boundary-fitted coordinate system. The complete boundary conditions at the free surface and at the interface between water and the permeable rippled bed are satisfied. For details of the