Numerical Modelling of Wave Motion and Seabed Response around a Submerged Porous Breakwater

J-S Zhang¹, B Wang¹, D-S Jeng¹, Y-K Guo²
¹ Division of Civil Engineering, University of Dundee, Dundee, UK
² School of Engineering, University of Aberdeen, Aberdeen, UK

ABSTRACT

In this study, a numerical model is developed to investigate the wave motion and seabed response around a submerged porous breakwater due to a surface solitary wave. The wave motion is simulated by numerically solving the extended Navier-Stokes (NS) equations, and the seabed response is gained from the numerical solutions of poroelastic theory. The existing wave model (COBRAS) and soil model (PORO-WSSI I) are combined to establish the new model--PORO-WSSI II. The numerical model is applied to investigate the effects of porosity and equivalent mean diameter of porous media on the wave propagation in the vicinity of porous structure. The results show that the porosity has more impact than equivalent mean diameter on the wave transformation and flow structure. The solitary wave-induced seabed responses such as pore pressure and vertical effective stress around the foundation of porous breakwater are presented as a case study.

KEY WORDS: Solitary wave; porous breakwater; seabed response; equivalent mean diameter; seabed response.

INTRODUCTION

Breakwaters, as one of the most important coastal structures, have been widely used for the near-shore protection, and, in composition, it could be an impermeable structure or a permeable structure. The main advantage of applying breakwaters is to dissipate and/or reflect the energy of the incident waves and consequently prevent beach erosion in near-shore region. Recently, permeable submerged breakwaters have become increasingly popular as additional wave energy can be dissipated due to the flow friction within the porous media. A porous breakwater is essentially different from that with impermeable solid surface. Ocean waves traveling through the porous media will significantly affect the dissipation rate of wave energy. To understand the functionality and stability of porous breakwater, the wave motion around such a structure and the seabed response around the structure foundation must be determined.

Many experimental researches have been carried out to investigate the interactions between ocean waves and porous structures. For example, Huang and Chao (1992) studied the reflection and transmission of a small-amplitude water wave by porous breakwater in an infinitely long channel. They found that the reflected wave is greater while the transmitted wave is less for waves of higher frequency with thicker and less porous breakwaters. Losada et al. (1997) carried out a series of experiments to investigate the monochromatic wave propagation over a submerged impermeable or porous step. Their study concluded that wave energy dissipation due to the porous material is the main mechanism controlling dissipation in the absence of wave breaking. For the breaking wave transmission over submerged porous breakwater, Kobayashi et al. (2007) found that the energy dissipation of wave train is mainly due to the wave breaking and the porous flow resistance inside the structure. All aforementioned laboratory measurements concluded that the degree of wave-structure interaction and its resulting energy dissipation highly depend on the incident wave conditions and structural parameters.

With the progress of computing technology and computational fluid dynamics (CFD), several mathematical models based on the extended NS equations have been developed to study this topic, such as the model applied by Liu et al. (1999), Hsu et al. (2002), and Karim et al. (2009). Among these, two main approaches have been used to consider the effect of porous media on wave motion in governing equations. One is to insert geometric properties and fluid resistance of porous media to the NS equations and the other is to use volume-averaging theory (applying a volume-averaging operator over a representative elementary volume to the NS equations). As discussed in Huang et al. (2003), the NS type models have shown great abilities in modelling the interaction of wave and porous structure, overcoming the drawbacks of the other models based on mild-slope equations (Mendez et al., 2001), finite-amplitude shallow-water wave equations (van Gent, 1994) or Boussinesq-type equations (Cruz et al., 1997).

Stability of structures is one of the main concerns in the design of coastal structure. The flow around the coastal structure does not only affect the wave force acting on the structure, but also induce sea floor instability (liquefaction). The excess pore pressure within the soil