Wave induced seabed response in a vertical continuous non-homogeneous seabed

Musheng Yang1, Guangsheng Wang2, Chonghao Liu3, Tong Yu4, Titi Sui5, Jinhai Zheng1
1. Key Laboratory of Coastal Disaster and Protection (Hohai University), Ministry of Education
   Nanjing, Jiangsu, China
2. China Harbour Engineering Company Limited
   Beijing, China
   Jinan, Shandong, China

ABSTRACT

Wave-induced build-up of pore pressure may cause instability of seabed in the vicinity of marine structure foundations. Most previous investigations were limited to the oscillatory response or residual response of a homogeneous seabed, which ignores their coupling process and the non-uniform soil conditions. In the real environment, the seabed is often composed of non-homogeneous soil which affects the wave-induced seabed response. In this study, a coupled model for seabed response in a non-homogeneous seabed is developed, which retains the spatial derivative terms of eight soil parameters. Model validations are conducted by comparing the pore pressures between the existing numerical model, wave flume test and the present model. The validated model is applied to investigate the effect of soil non-homogeneity on the wave-induced coupled response (including oscillatory and residual response) and liquefaction in the silty seabed. This study indicates that the consideration of non-homogeneous soil properties in the numerical simulation will decrease the pore pressure induced by waves; the surface soil parameters also affect the seabed response, lower surface permeability and Young’s modulus leads to higher pore pressure and larger liquefaction depth.

KEY WORDS: build-up of pore pressure, non-homogeneous seabed, coupling effect, liquefaction

INTRODUCTION

An important issue in the design of foundations around marine structures is wave-induced seabed response and liquefaction. When waves pass by, cyclic pressure acts on the surface of the seabed and this will produce pore pressure and stress fields in the seabed, posing a threat to the safety of marine structures.

Two mechanisms have been proven to exist in wave-induced pore pressure by many previous studies: the oscillatory mechanism and the residual mechanism. The oscillatory response is always dominant in the coarse sand seabed due to its high permeability, and the residual response has been considered to be dominant in seabeds with low permeability. Many existing studies investigated these two mechanisms separately. For the oscillatory mechanism, Yamamoto et al. (1978) proposed the analytical solution for oscillatory pore pressures, effective stresses and displacements of seabeds of infinite thickness based on Biot’s theory (Biot 1941). Hsu and Jeng (1994) extended the solution to the seabeds with finite thickness. Sui et al. (2016) developed a three-dimensional numerical model to investigate the oscillatory seabed response around a mono-pile. For the residual mechanism, Seed and Rahman (1978) built a one-dimensional finite element model to simulate the buildup of seabed pore pressure under waves. Sumer et al. (2012) conducted a series of experiments to investigate wave-induced pore pressure accumulation and verify their mathematical model. Jeng and Zhao (2015) presented a two-dimensional numerical model using the time-phased shear stress obtained from the oscillatory response numerical model. Sui and Zhang et al. (2019) investigated the buildup of pore pressure and residual liquefaction in the vicinity of the monopile. The aforementioned models are known as the decoupled model. However, in the real seabed, these two mechanisms often coexist. Some studies have found that the oscillatory and residual responses may affect each other (Ye et al. 2015), which cannot be taken into account by decoupled models. To overcome the shortage of decoupled models, Liu et al. (2019) developed a coupled mathematical model which solves the oscillatory and residual responses simultaneously. However, the model proposed by Liu et al. (2019) confines to homogeneous seabeds, non-homogeneity of the soil cannot be taken into account. In reality, seabeds are always spatially inhomogeneous. Besides, it has been found by previous studies that the non-homogeneity would affect the pore pressure and soil stresses distribution in the seabed significantly. Hsu et al. (1995) proposed a semi-analytical solution to investigate the oscillatory response in layered seabeds under short-crested waves and standing waves. Jeng and Lin (1996) established a finite-element model to solve the oscillatory response of non-homogeneous seabeds under short-crested waves. Unlike layered seabed, the soil permeability and shear modulus was assumed to vary continuously over the seabed depth in their model. Zhang et al. (2016) investigated the effect of the horizontally non-homogeneous soil property and three-dimensional non-homogeneous seabed response