The numerical analysis on the distribution of wave-induced pore pressure around a breakwater

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1. Introduction

The interaction between wave, seabed and marine structure is an important issue in coastal engineering, as well as geotechnical engineering. Most previous numerical studies on the wave-induced pore pressure are based on homogeneous seabed. The real seabed is not homogeneous, but the geotechnical properties of seabed soils vary with the distance. An inhomogeneous seabed is approximated by many layers of homogeneous soils each of which has different values of geotechnical properties and thickness. [2)] In this study, the wave-induced pore pressure in inhomogeneous seabed around a breakwater is analytically examined.

2. Governing Equation

Biot's consolidation equation is used as the governing equation;

$$\frac{k}{r_w}\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial z^2}\right)=\frac{\partial \varepsilon_V}{\partial t}+nC_w^{'}\frac{\partial p}{\partial t} \tag{1}$$

where, p is the wave-induced pore pressure, k is the permeability, γ_w is the unit weight of pore fluid, ε_v is the volumetric strain, n is the porosity, and $C_w^{'}$ is the compressibility of pore fluid including air, which is defined by

$$C_w^{'}=S_rC_w+\frac{1-S_r}{P_{wo}}, \tag{2}$$

where, C_w is the compressibility of pore fluid, S_r is the degree of saturation and P_{wo} is the absolute static wave pressure.

Under the condition of plane strain, the equation of equilibrium [1)] can be expressed as

$$\begin{cases} G\nabla^2 u+\dfrac{G}{1-2\nu}\dfrac{\partial \varepsilon_V}{\partial x}=-\zeta\dfrac{\partial p}{\partial x} \\ G\nabla^2 w+\dfrac{G}{1-2\nu}\dfrac{\partial \varepsilon_V}{\partial z}=-\zeta\dfrac{\partial p}{\partial z} \end{cases} \tag{3}$$

where, u and w are the soil displacement in the $x-$ and $z-$ directions, respectively, G is the shear modulus, and ν is the Poisson's ratio.

3. Boundary conditions

At the seabed surface, $p=p_o\cos kx\cos\omega t$, $\sigma_z^{'}=0$, and $\tau=0$, where, $p_o=\gamma_w 2H_i/(2\cosh\kappa d)$, H_i is the wave height of the incident wave, κ is the wave number, ω is the angular frequency of the wave, and d is the water depth.

At the interfaces between the sub-layers, the soil stresses, the pore pressure, the pore-water flow, and the soil displacement are continuous. At the lowest layer,

$$u=0, w=0, \partial p/\partial z=0 \tag{4}$$

4. Numerical results and discussions

The mesh and input data used in this model are given in Fig. 1 and Table 1.

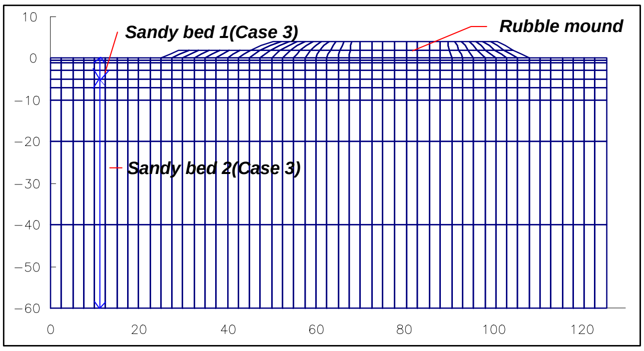

Fig. 1 Finite element mesh

Table 1 Input data for numerical examples

	Case 1	Case 2	Case3
Wave characteristic			
Wave period	10.2sec	10.2sec	10.2sec
Water depth	16.9m	16.9m	16.9m
Wave height	2m	2m	2m
Soil characteristic			
Seabed thickness	60m	60m	60m
Degree of saturation	0.99 (sandy bed) 0.99 (rubble mound)	0.99 (sandy bed) 0.99 (rubble mound)	0.99 (sandy bed) 0.99(rubble mound)
Porosity	0.35 (sandy bed) 0.45 (rubble mound)	0.35 (sandy bed) 0.45 (rubble mound)	0.35 (sandy bed) 0.45 (rubble mound)
Poisson ratio	0.45 (sandy bed) 0.3 (rubble mound)	0.45 (sandy bed) 0.3 (rubble mound)	0.45 (sandy bed) 0.3 (rubble mound)
Permeability	10^{-2} m/s (sandy bed) 10^{-1} m/s (rubble mound)	10^{-3} m/s (sandy bed) 10^{-1} m/s (rubble mound)	10^{-3} m/s (sandy bed 1) 10^{-2} m/s (sandy bed 2) 10^{-1} m/s (rubble mound)
Young modulus	3000 tf/m^2 (sandy bed) 40000 tf/m^2 (rubble mound)	3000 tf/m^2 (sandy bed) 40000 tf/m^2 (rubble mound)	3000 tf/m^2 (sandy bed 1) 3500 tf/m^2 (sandy bed 2) 40000 tf/m^2 (rubble mound)

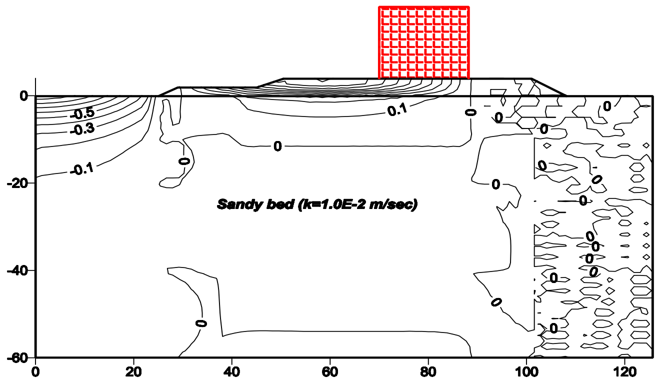

Fig. 2 Contour of the wave-induced pore pressure (Case 1, t/T=1/2)

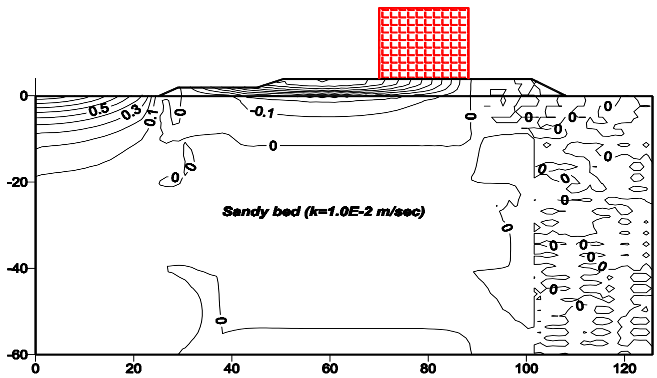

Fig. 3 Contour of the wave-induced pore pressure (Case 1, t/T=1)

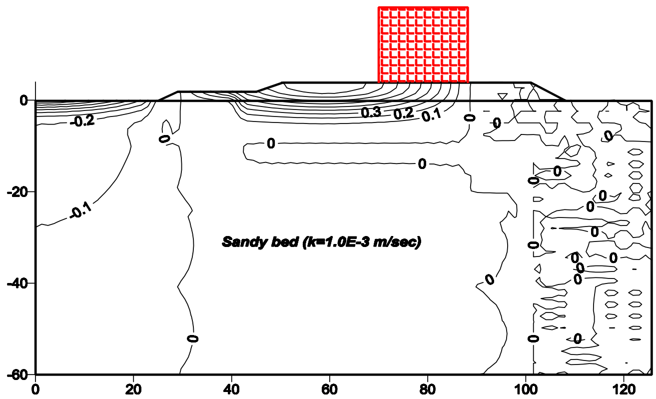

Fig. 4 Contour of the wave-induced pore pressure (Case 2, t/T=1/2)

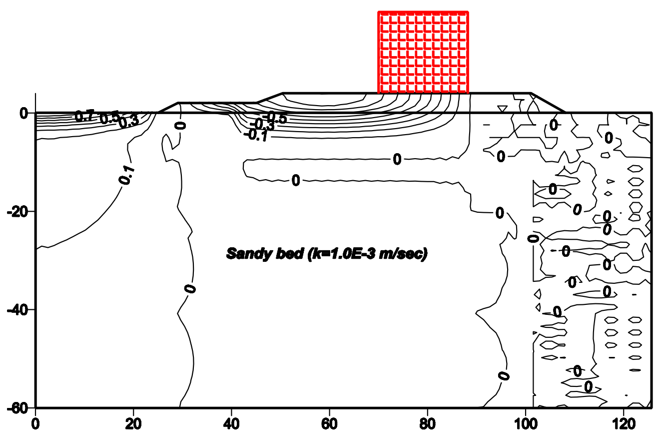

Fig. 5 Contour of the wave-induced pore pressure (Case 2, t/T=1)

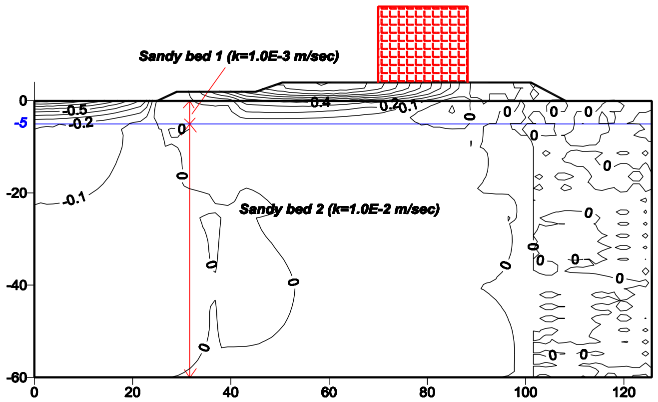

Fig. 6 Contour of the wave-induced pore pressure (Case 3, t/T=1/2)

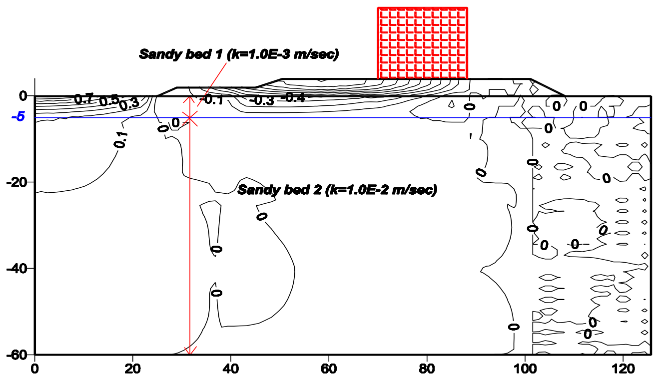

Fig. 7 Contour of the wave-induced pore pressure (Case 3, t/T=1)

Each of the contours in Figs. 2 to 7 indicate the ratio of wave-induced pore pressure, p/p_o, of the numerical cases, respectively. In the case of Fig. 6 and 7, soil properties fall into sandy bed 1 and sandy bed 2 at the depth $-5m$. The conditions of both sandy bed 1 and sandy bed 2 are given in Table 1. As seen in Fig 6 and 7, the wave-induced pore pressure change drastically at the depth $-5m$. In addition, it can be observed that there is a high ratio of wave-induced pore pressure p/p_o under both the rubble mound and the free seabed surface on the offshore side of the breakwater through Fig.4, 5 and 7. On the other hand, the ratio of wave-induced pore pressure p/p_o on the onshore side of the breakwater is small and goes to zero after some distance.

Reference

1) Kouki ZEN : Study on the wave-induced liquefaction in seabed, The port and harbor research institute ministry of transport, Japan, No. 755, 1993 (in Japanese).

2) Tokuo YAMAMOTO : Wave-induced pore pressure and effective stresses in inhomogeneous seabed foundation, Ocean Engineering, Vol. 8, pp. 1-16, 1981.