Analysis of the model experiment on the wave-induced pore pressure around a breakwater

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1. Introduction

The interaction among ocean wave, seabed and marine structure is an important issue in geotechnical engineering, as well as coastal engineering. The stability problem of breakwater at a typhoon season is such a typical example.

The wave-induced pore pressure has been considered to cause the liquefaction in seabed. The liquefaction may result in the serious problems such as the failure of seabed, floating of pipelines, and settlement of rubble mound, because once the liquefaction occurs, the liquefied seabed loses its shear strength.

A model experiment on a reduced scale of 1:100 $(T = 0.8\sec, H_i = 4.5cm)$ was conducted in the wave flume (Fig. 1 (a)). In the sandy bed beneath the caisson, the measuring devices such as pore water pressure transducers and pressure transducers on the bottom of caisson were installed (Fig. 1 (b)). The sand used in this experiment is Toyoura sand ($D_{50} = 0.18mm$, $\rho_s = 2.644g/cm^3$, $e_{\max} = 0.977$, $e_{\min} = 0.606$).

In this study, the oscillatory pore pressures observed in the model experiment were compared with the analysis results.

2. Governing Equation

The governing equation for the wave-soil interaction problem in a compressible porous seabed with compressible pore fluid is given by

$$\frac{K_x}{K_z}\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial z^2} - \frac{r_w n C_w'}{K_z}\frac{\partial p}{\partial t} = \frac{r_w}{K_z}\frac{\partial \varepsilon_v}{\partial t} \qquad (1)$$

where, p is the wave-induced pore pressure; K_x and K_z are the permeabilities of the soil in the $x-$ and $z-$ directions, respectively; r_w is the unit weight of pore fluid; n is the porosity; t is the time; ε_v is the volumetric strain; and C_w' is the compressibility of pore fluid including air, which is defined by

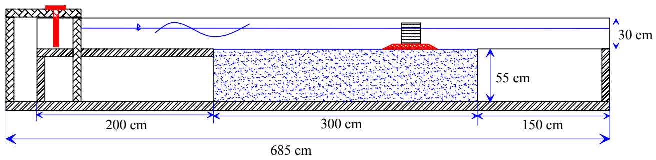
$$\varepsilon_v = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} \quad \text{and} \quad C_w' = S_r C_w + \frac{1-S_r}{P_{wo}} \qquad (2)$$

where, u and w are the soil displacements in the $x-$ and $z-$ directions, respectively; C_w is the compressibility of pore fluid, which is taken as $4.9 \times 10^{-10} m^2/N$; S_r is the degree of saturation; and P_{wo} is the absolute static wave pressure.

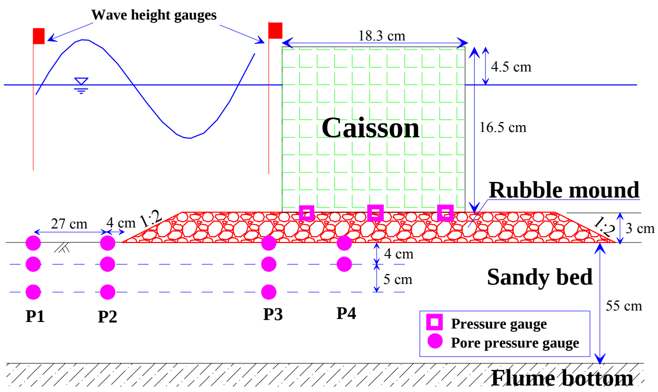
From the effective stress concept and Hook's law, force equilibrium within the soil skeleton relates the pore pressure gradient to soil displacements and volume strain (Biot, 1941). This provides

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

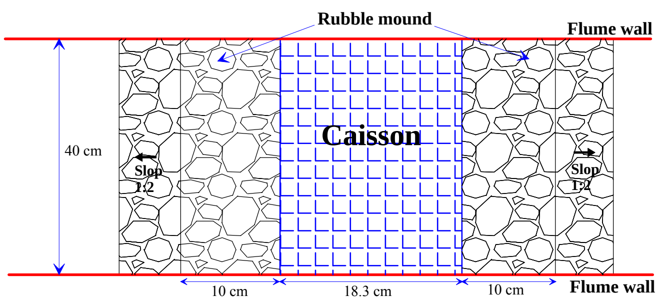
where, G is the shear modulus of the soil, which is related to Young's modulus E by the Poisson's ratio ν in the form of $E/(1+2\nu)$.



(a) Wave flume



(b) Cross section around the caisson



(c) Plan view around the caisson

Fig. 1 Model setup with the location of the measuring devices in the wave flume

3. Analysis results and discussions

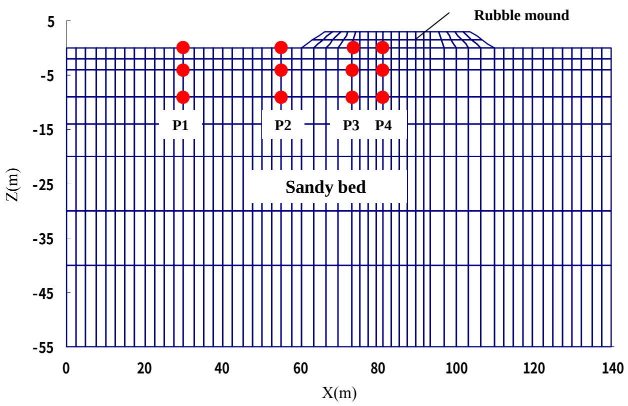


Fig. 2 Finite element mesh

Table 1 Soil parameters

	Rubble mound	Sandy bed
Soil characteristics		
K_x=K_z (m/s)	1×10^{-1}	1×10^{-5}
E (MN/m^2)	200.2	24.5
ν	0.3	0.35
n	0.45	0.46
S_r	1.0	0.997
ξ	0.75	1.0

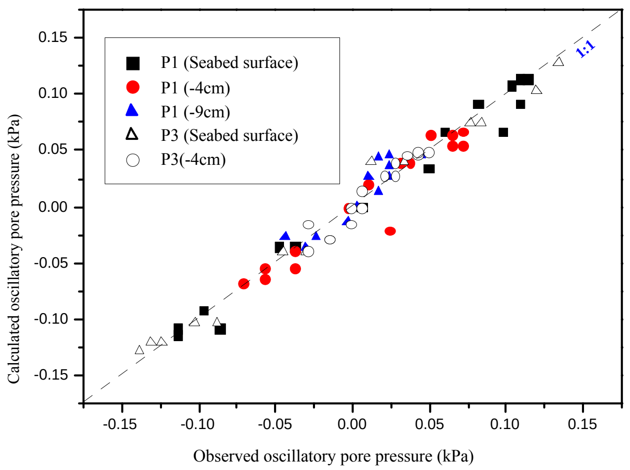
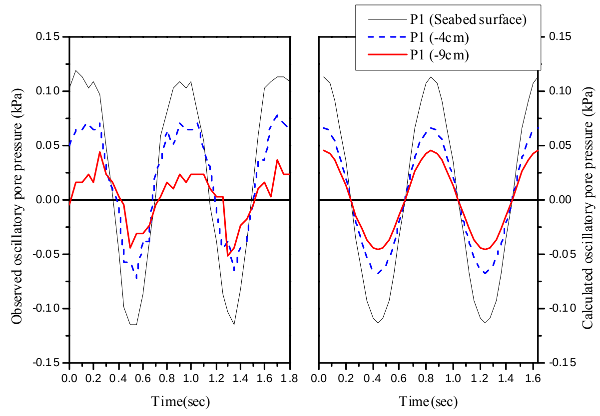


Fig. 3 Comparison between calculated and observed oscillatory pore pressures at the Point P1 and P3

The mesh and soil parameters used in this study are respectively given in Fig. 2 and Table 1.

Comparisons between calculated and observed oscillatory pore pressure are presented in Fig. 3 and 4. It is found that the calculated results agree fairly well with the observed values, and there is a phase delay in the observed oscillatory pore pressure which increase as the depth is increased. Fig. 5 indicates the distribution of the calculated oscillatory pore pressure ratio. It is found that the pore pressure attenuates rapidly around the depth $-3m$.



(a) Observed values (b) Calculated values

Fig. 4 Comparison between calculated and observed oscillatory pore pressures according to the time at the Point P1

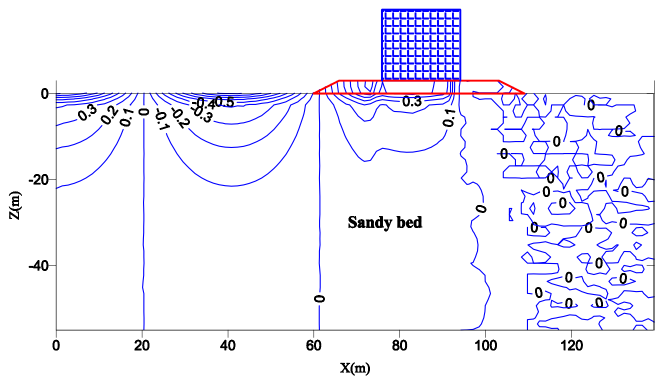


Fig. 5 The distribution of oscillatory pore pressure ratio $(t = 0.84s)$

4. Conclusions

Based on the results presented in this study, the following conclusions can be drawn;

(1) The calculated results agreed fairly well with the observed values.

(2) It is found that there is a phase delay in the observed pore pressure which increase as the depth is increased.

(3) It is found that the calculated pore pressure attenuates rapidly around the depth $-3m$.

Reference

1) Biot, M. A.: General theory of three-dimensional consolidation, J. Appl. Physics, Vol. 12, pp. 155-164, 1941.

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