Numerical analysis on liquefaction damage of embankment considering air bubble injection as a countermeasure

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1. INTRODUCTION

Soil liquefaction describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress. Although it is well known that soil resistance to liquefaction increases as the degree of saturation the soil decreases, it has been difficult to lower the saturation degree of ground homogeneously[1]. A technique using air bubbles[2], however, can be expected to solve the problem because the air bubbles can easily permeate into voids among sand particles and cause them to be desaturated, thereby reducing the likelihood for the occurrence of liquefaction effects. To test the effectiveness of this desaturation technique (air bubble injection), numerical analyses were conducted for the two embankment models, that is, with and without the countermeasure technique of air bubble injection.

2. NUMERICAL METHOD

The FEM analyses were carried out using a soil-water coupled liquefaction analysis program "LIQCA2D17[3]" taking into consideration the elastoplastic model (Oka et al., 1999[4]). The model can be applied to liquefiable soil layers which can potentially be liquefied, and can also be applied to soil layers, such as non-liquefiable layers near the ground surface and/or an embankment

In the resent study, the pore pressure dependency of the bulk modulus for pore fluid was introduced in the analysis program to consider desaturation of soil. The bulk modulus of air-water mixture, K^f is given by

$$\therefore K^f = \frac{1}{\dfrac{S_r}{K^w} + \dfrac{1-S_r}{K^a}} \cong \frac{1}{\dfrac{1-S_r}{K^a}} = \frac{K^a}{1-S_r} \qquad (1)$$

where K^w is the bulk modulus of water, K^a is the bulk modulus of air, and S_r is water saturation. Since the bulk modulus of air, K^a equals to the absolute value of pressure from the Boyle's law, Eq. (1) gives

$$\therefore K^f = \frac{p_{abs}}{1-S_r} \qquad (2)$$

where p_{abs} is the absolute pore fluid pressure. In the following simulation, the water saturation S_r of the desaturated area is assumed to 80%.

3. FEM MODEL AND PARAMETERS

The FEM mesh of the analyzed embankment is shown in Figure 1. The analysis is done to simulate the results of dynamic centrifuge tests (conducted by PWRI 2000[5]), and the model was depicted by prototype scale. Figure 2 shows the model with consideration for improvement in the shaded region by injecting air bubble.

The elastoplastic constitutive model was applied to Edosakisa layer and Keisa layer. The material parameters and the input acceleration shown in the reference[3] were used, in which the Edosakisa is assumed to have the lower liquefaction strength than Keisa. The input acceleration is shown in Figure 3.

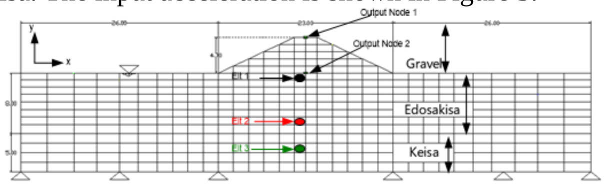

Figure 1. Analysis model and FEM mesh (Case I)

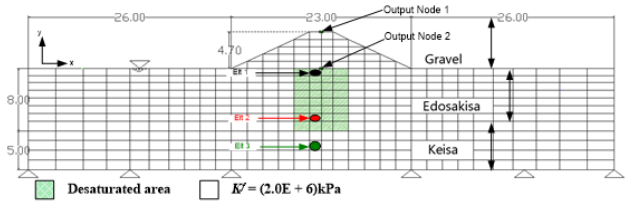

Figure 2. Analysis model and FEM mesh (Case II)

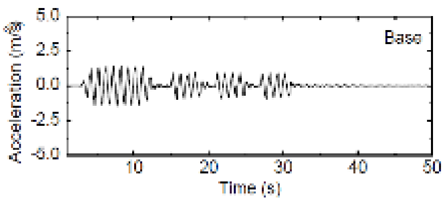

Figure 3. Input acceleration

4. RESULTS/DISCUSSION

After the earthquake motion, the embankment deforms as shown in Figure 4 and Figure 8. Case I has a top settlement of 2.6 m, while Case II has top settlement of 1.2 m respectively as shown in Figure 12. The excess pore water pressure builds up with time for the three different elements are shown in Figure 5. It is observed that element 2 for Case I which is located just beneath the embankment has the highest excess pore water pressure ratio of 1.0, while the excess pore pressure ratio does not reach up to 1.0 for the three elements for Case II as shown in Figure 9. The distributions of the excess pore fluid pressure ratio (= u/σ'_{v0}) and the effective stress decreasing ratio, ESDR

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($=1-\sigma'_m/\sigma'_{m0}$) are shown in Figures 6 and 7 for Case I and Figures 10 and 11 for Case II, respectively. The excess pore pressure ratio beneath the embankment is lower for Case II than that for Case I due to the higher compressibility of pore fluid. The value of ESDR is lower in the upper sand layer, while it is higher in the lower sand layer for Case II than those for Case I. This may come from the difference in the total stress in each case.

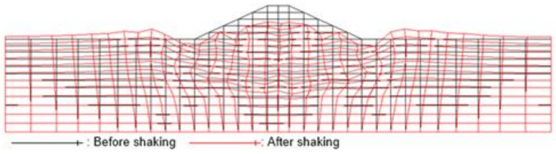


Figure 4. Deformation of the embankment (Case I)

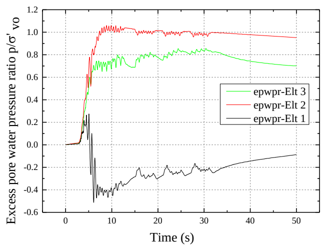


Figure 5. Excess pore pressure with time (Case I)

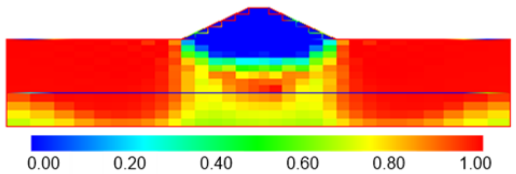


Figure 6. Excess pore fluid pressure ratio (Case I)

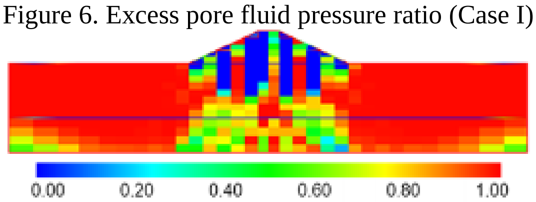


Figure 7. Effective stress decreasing ratio (Case I)

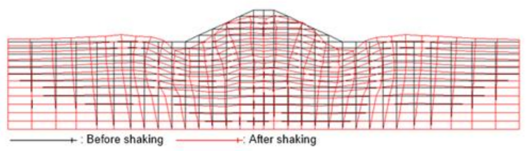


Figure 8. Deformation of the embankment (Case II)

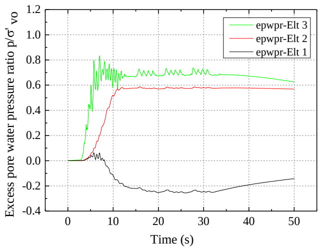


Figure 9. Excess pore pressure with time (Case II)

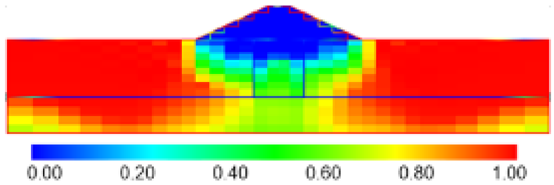


Figure 10. Excess pore fluid pressure ratio (Case II)

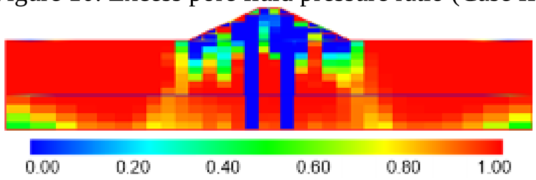
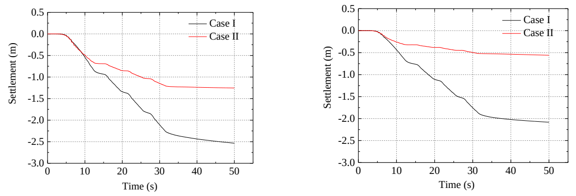


Figure 11. Effective stress decreasing ratio (Case II)



(a) at the top (Node 1) (b) at the bottom (Node 2)

Figure 12. Settlement – time relations (Case I, Case II)

5. CONCLUSION

From the deformation pattern and the settlement values, the embankment in Case II has a lower possibility to fail due to liquefaction during earthquake than the embankment in Case I because of the injection of air bubble. Therefore, we can conclude that, by injecting air bubble with a relatively lower value of the bulk modulus of the fluid under a given region beneath the embankment whose foundation soil has liquefiable properties, the possibility of the damages as a result of liquefaction can be significantly reduced.

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