【 III －14 】

Numerical simulation of centrifuge test with considering dependency of bulk modulus of soil void on degree of saturation and confining pressure

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1. Introduction

To evaluate the effectiveness of “desaturation by air injection technique” as a liquefaction countermeasure for foundation soil layer, centrifuge test was carried out in the laboratory. The mechanical properties of the soil in the saturated and the desaturated zone was exactly the same with an exception of degree of saturation. Having been the mixture of water and air, the pore in the desaturated model had significantly lower bulk modulus as compared with that of the saturated. In this study, an attempt was made to numerically simulate the centrifuge model with effective stress analaysis (LIQCA-2D) by changing the bulk modulus of the pore fluid. Parameter listed in **Table1**, for saturated and desaturated conditions are same except bulk modulus of pore fluid K^f.

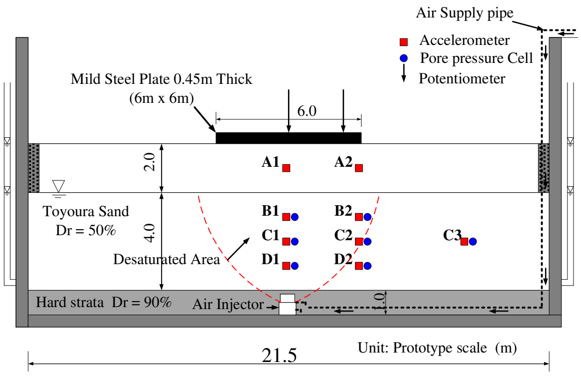

Figure 1: Centrifuge model

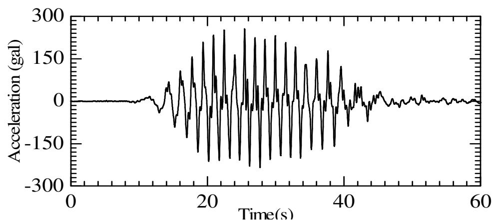

Figure 2: Input acceleration

2. Pore fluid bulk modulus and its pressure-level dependency

When the soil pores are filled with air and water mixture, the stiffness of the fluid depends on the amount of air present on it. The compressibility of the air-water mixture is mostly controlled by air compressibility, since, the water is very stiff compared with air (K^w = 2x106 kPa) and considered as uncompressible with constant stiffness. The stiffness of the air can be determined based on Boyle’s law. According to Fredlund and Rahardjo (1993), for unsaturated soil above 80% degree of saturation the air bubbles are exists in occluded form within the pore fluid.

So the bulk modulus of air-water mixture can be determined according to the pore fluid pressure and defined as;

$$K^f \cong \frac{\sigma' + P_0}{1 - S_r} < K^w \text{ ....(1)}$$

Where, S_r is degree of saturation, P_0 is absolute pore pressure, σ′ is effective stress, K^f is the bulk modulus of air water mixture and K^w is the bulk modulus of the water. **Eq. (1)** assumes that no air dissolution into water occurs as the air pressure changes.

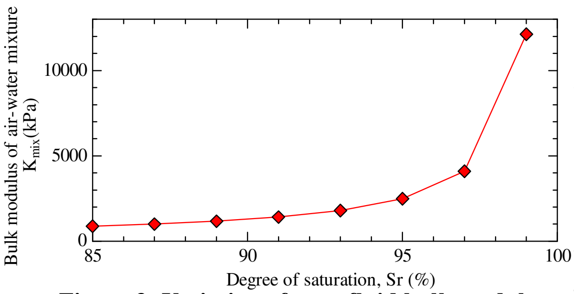

Figure 3: Variation of pore fluid bulk modulus with degree of saturation

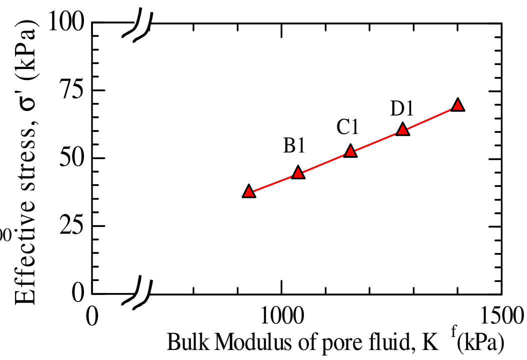

Figure 4: Variation of pore fluid bulk modulus with effective confining pressure

3. Analysis Method

The centrifuge models are simulated with the effective stress analysis (LIQCA-2D) based on the elasto-plastic finite element method (Oka et al., 1999). The centrifuge models consisted of a metal plate at the top (representing the structure weight) which is imparting the average contact pressure of 35kPa to the 6m (in prototype scale) deep loose (Dr = 50%)

liquefiable sand bed with ground water table at 2m from surface. **Fig. 1** shows the details of test centrifuge model with location of the transducers. A simulated sinusoidal wave with the dominant frequency of 40 Hz and acceleration amplitude of 9.5 g (190 gal in prototype) was imparted as depicted in **Fig. 2.**

Table 1: Input parameters

Parameters		Dr =50%	Dr = 90%
Density	ρ (t/m^3)	1.87	1.96
Initial void ratio	e_0	0.791	0.642
Coefficient of permeability	k (m/s)	2.0E-5	1.5E-5
Compression index	λ	0.0025	0.0091
Swelling index	κ	0.00030	0.00052
Initial shear modulus ratio	G_0/σ'_m	1150	2023
Failure stress ratio	M_f	0.99	0.99
Phase transformation stress ratio	M_m	0.707	0.707
Hardening parameter	B_0	3750	6000

Fig. 3 shows the variation in bulk modulus of pore (K^f) at C1 with degree of saturation. The bulk modulus decreases dramatically with the small reduction in degree of saturation from 100%. Similarly, **Fig. 4** depicts the bulk modulus on the center line of the centrifuge model (B1, C1, D1,). It clearly indicates that the bulk modulus increases with an increase in depth. Bulk modulus for saturated zone was 2.0 x 10^5 kPa and computed bulk modulus of desaturated zone are listed in **Table 2**.

4. Result and Discussion

Time histories of excess pore pressure ratio (EPPR) observed from dynamic centrifuge test and numerical simulation are depicted in **Fig. 5 and 6** respectively. The desaturated area by air injection in a model is enclosed by dotted redline (Bowl shape) as shown in **Fig. 1**

Table 2: Pore fluid bulk modulus (K^f) for desaturated area

Depth (m)	K^f (kPa)
0-2	1.88E+2
2-3	1.14E+3
3-4	1.22E+3
4-5	1.32E+3
5-6	1.42E+3

The EPPR at C3 (level ground) which is located in saturated zone, increased and reached to unity in a few cycle, indicating the soil liquefied in both centrifuge test and numerical simulation in a similar manner as depicted in **Fig. 5 and 6.** While in the desaturated zone on the structure centerline (D1, C1 & B1), EPPR was significantly lower than unity in both centrifuge test and simulation. At structure edge, C2 and D2 EPPR have much higher value (near unity) than structure centerline (D1, C1 and B1) in both centrifuge test and simulation results. This was probably due to C2 located at boundary of saturated and desaturated zone and D2 at saturated zone as dshown in **Fig. 1**.

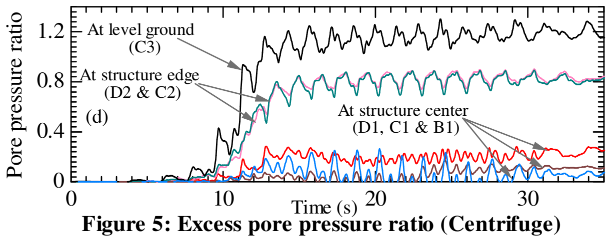

Figure 5: Excess pore pressure ratio (Centrifuge)

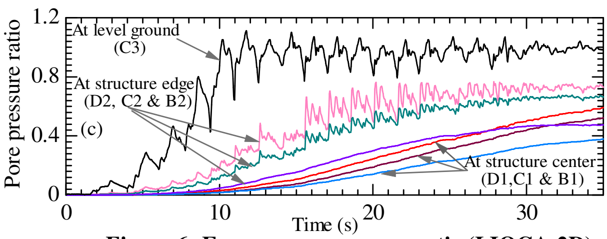

Figure 6: Excess pore pressure ratio (LIQCA-2D)

5. Conclusions

Numerical simulation results were quite comparable with the test results for both saturated and desaturated zone. This suggests that effects of soil desaturation can be successfully simulated by effective stress analysis by considering the dependency of the bulk modulus of void on degree of saturation and confining pressure.

References

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