Numerical Estimation for Sliding of Gentle Slope on Saturated Fine Sand Subject to Sinusoidal Ground Motion

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1. INTRODUCTION

Although much attention has been paid to understanding the lateral flow of gentle slope involving liquefiable soil layers, relatively little effort has been devoted to improving our understanding of the dynamic response of gently sloped ground not reaching liquefaction during an earthquake. For investigating such deformation of a gentle slope, the authors have performed a series of centrifuge tests simulating sliding of the slope that appeared to be rarely associated with liquefaction. Again, a numerical model for estimation of the dynamic response of gentle slope has been constructed on the basis of the centrifuge model. This paper addresses the outline of numerical model and its validation through the comparison between the results from centrifuge and numerical models.

2. BREIF DESCRIPTION OF CENTRIFUGE TEST

A rigid container for the centrifuge model has been manufactured such that its central part sloped with a gradient of 15% to model a gentle slope as shown in **Fig. 1**. Its inside dimensions are 0.7m x 0.2m x 0.2m in length, height and width.

Two types of model grounds have been prepared as summarized in **Table 1**. The ground water level has been generated along the top of the lower soil layer with a help of water tanks installed at both sides of the container, which ensured formation of saturated soil. The sinusoidal input motion with a peak acceleration of 24.3G and a frequency of 2Hz has been employed to the bottom of the container under a centrifugal acceleration of 50G[1]. Accelerators and pressure meters were installed in the model ground to monitor the amplified acceleration and the excessive pore water pressure in the saturated fine sand during shaking as shown in **Fig. 1**.

Table 1 Testing conditions for centrifuge model

Soil	Thickness	Material	Dr	Saturation
Upper	8cm(4m)	Fine Sand	100%	14%
Lower	3cm(1.5m)	Silty Sand	80%	100%

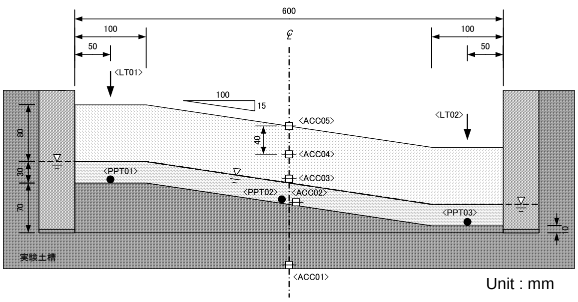

Fig.1 Longitudinal profile of sand container for centrifuge test

The observation of pore water pressure meters during the shaking identified a remarkable rise of pore water pressures at saturated silty sand layer, although they were far more below the threshold of liquefaction. At the same time, it appeared that irreversible shear deformation concentrated at the same soil layer resulting in a maximum value of approximately 25% for the maximum shear strains, $\gamma_{xy.}$ (See **Fig. 4**)

3. NUMERICAL ANALYSIS USING FDM

The finite difference code “FLAC” has been adopted for the numerical simulation with the combination of “FINN-BYRNE’s suggestion” that enables generation of excessive pore water pressure during a ground motion using Eqn. (1).[2]

$$\Delta\varepsilon_{vd}/\gamma = C_1 \exp(-C_2(\varepsilon_{vd}/\gamma)) \qquad \text{Eqn.(1)}$$

where, $\Delta\varepsilon_{vd}$=the increment of volume decrease, ε_{vd}=the accumulated irrecoverable volume strain, γ =the cyclic shear-strain amplitude, C_1, C_2=the constants

To evaluate the effect of excessive pore water pressure on the response of the slope, two dynamic simulations have been carried out according to the generation of pore water pressure or not by the switch to the activation of FINN-BYRNE model.

3.1 Numerical models and input parameters

To avoid the distortion of plane wave propagating upward at the boundary, the model for FLAC employs the free field boundary for both its sides. The acceleration histories monitored at ACC01 is set to the input waves for numerical analysis after being processed with a trapezoidal band pass filter for baseline correction. The Rayleigh damping has been joined to the fully nonlinear analysis based on the Mohr-coulomb failure criterion. The input parameters for both the cases have been chosen as **Table 2**.

3.2 Occurrence of excessive pore water pressure

Fig.2 through **3** show the calculated excessive pore water pressure histories at the central part of saturated silty sand for the model without/with the FINN-BYRNE model respectively during the excitement. Even though slight lifts of pore water pressures are seen even in **Fig. 2** (without FINN-BYRNE model) because of the dynamic volume changes induced by the sinusoidal excitement, they show little change after 4 seconds in the elapsed time. Besides, the model with FINN-BYRNE model exhibits the remarkable rises of pore water pressures up to approximately 50 KPa, equivalent to a pore water pressure ratio (u/σ) of 0.6, as being shaken which indicates a good match with the results from the centrifuge model. This implies that the significant increases of pore water pressures in the saturated silty sand lead to the reduction of effective stresses in the soil layer, which may result in yielding of the soil elements

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and thereby plastic flow at the soil layer.

3.3 Ground deformation induced by shaking

Fig.4 through **5** present the distribution of maximum shear strains at the elapsed time of 25 seconds for the centrifuge and numerical (with FINN-BYRNE model) model respectively. Both the models clearly demonstrate the concentrated shear deformation at the saturated silty sand, which brings about the sliding of entire area of unsaturated sand. The maximum value of the maximum shear strains appears as approximately 25% for either of them, which indicates that the current numerical model is able to reasonably simulate the behavior of gentle slope being shaken at the centrifuge model. By the way, **Fig.6** through **7** provide the comparison between the centrifuge and numerical model with respect to the calculated displacement according to the adoption of FINN-BYRNE model. As expected, the model with FINN-BYRNE model exhibits a reasonable match with the centrifuge models

4. CONCLUSIONS

The dynamic response of gentle slope subject to strong ground motion has been quantitatively investigated through a numerical model based on finite difference scheme in this study. The comparison between the centrifuge and numerical model has clearly shown that the fully nonlinear elasto-plastic model based on the Mohr-Coulomb failure criterion incorporated with FINN-BYRNE's suggestion has shown a reasonable match with the results from centrifuge model. A total stress analysis involving shear modulus reduction and hysteretic damping under cyclic loadings for the saturated silty sand will be successively conducted for further study.

5. REFERENCES

1) YOSHIZAKO K., OHBO N., IGARASHI H., YOSHIZAKI K., SAKANOUE T., Dynamic centrifuge test on estimate of slope deformation not caused by liquefaction(Part2), *Proceedings of the 40th National Conference of Geotechnical Engrg.. Hakodate*, JGS, pp. 2283-2284, 2005

2) ITASCA, FLAC Ver 5.0 Manual-Optional Features, 2005

Table 2 Input Parameters for fully nonlinear analysis using FLAC

Soil	Dry density (t/m^3)	Shear Modulus (KPa)	Bulk Modulus (KPa)	S-wave velocity (m/sec)	Damping ratio	Cohesion (KPa)	Friction angle (°)	Poisson's ratio	FINN-BYRNE coefficient C1	FINN-BYRNE coefficient C2
Unsaturated Sand (upper)	1.874	7.58E+04	1.85E+05	201		5.0	40.0	0.32	0.086	4.625
Saturated Sand (Lower)	1.512	4.22E+04	1.27E+05	167	10%	11.3	33.9	0.35	0.764	0.523
Foundation	2.700	1.00E+06	1.67E+06	609		-	-	0.25	-	-

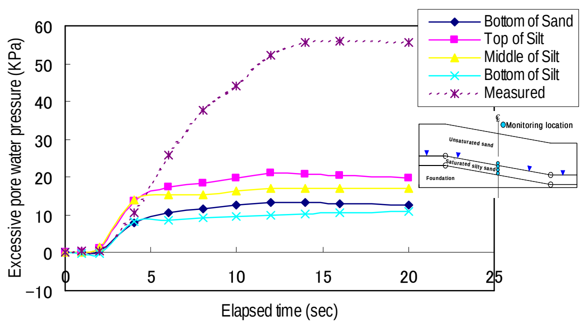

Fig.2 Histories of pore pressures at model w/o FINN-BYRNE model

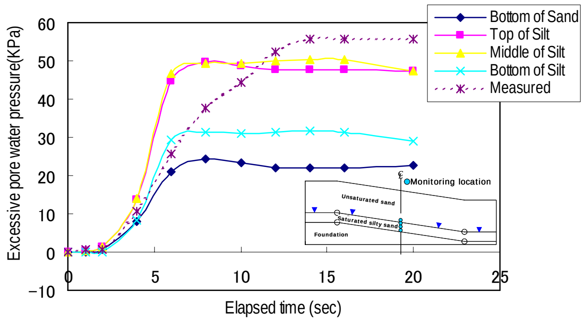

Fig.3 Histories of pore pressures at model with FINN-BYRNE

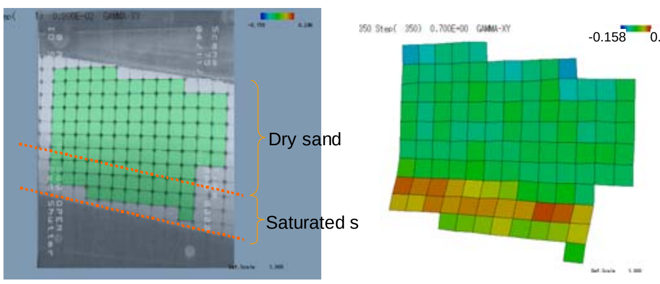

Fig.4 Maximum shear strains at the centrifuge model

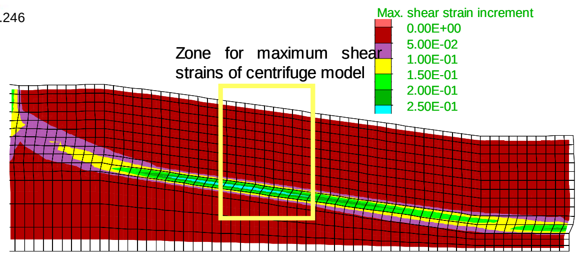

Fig.5 Maximum shear strains at the numerical model

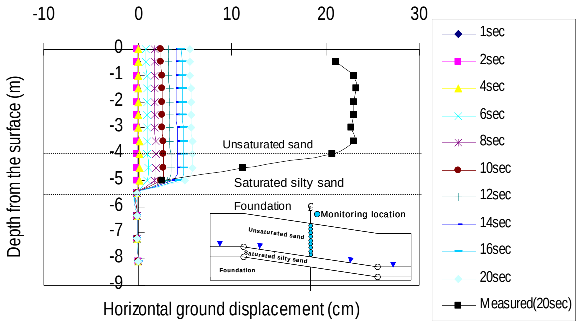

Fig.6 Horizontal disp. at model w/o FINN-BYRNE model

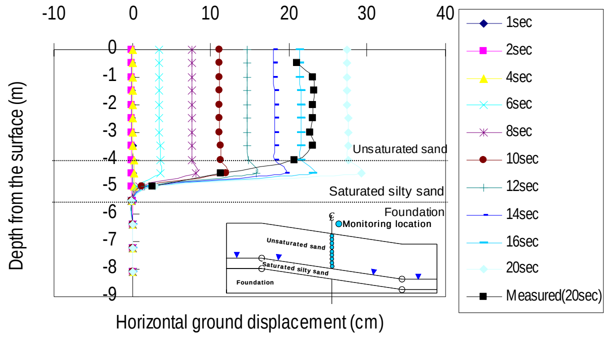

Fig.7 Horizontal disp. at model with FINN-BYRNE model