Ⅲ-A160 Liquefaction analysis of soil deposits composed of sands and clays using a viscoelastic-viscoplastic constitutive model

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1. Introduction

Most of liquifaction studies have only focused on the liquefaction of sand deposits. However natural ground has a layerd structure composed of sand and clay layers. When we consider the earthquake response of ground composed of sand and clay layers, it's important to evaluate the effect of clay layer on the ground motion. Up to now, elastic or elasto-viscoplastic models have been used for clay behavior in the dynamic analysis. It is, however, preferable to use a viscoelastic-viscoplastic constitutive model for clay because of the rate sensitivity of clayey materials in wide range of strain rate(frequency).. This study is carried out the FE analysis of liquefaction phenomena of ground composed of clays and sands using the viscoelastic-viscoplastic constitutive model based on the non-linear kinematic hardening rule for clay layers.

2. Constitutive Model for clay

The three parameter model with Voigt element and elastic spring, called the linear spring Voigt model is adopted for the total viscoelastic deviatoric strain rate tensor $\dot{e}_{ij}^{tve}$ as

$$\dot{e}_{ij}^{tve} = \dot{e}_{ij}^{e} + \dot{e}_{ij}^{ve} = \frac{1}{2G_1}\dot{s}_{ij} + \frac{1}{\mu}(S_{ij} - 2G_2 \cdot e_{ij}{}^{ve}) \tag{1}$$

where, $\dot{e}_{ij}^{e}$ and $\dot{e}_{ij}^{ve}$ denotes the elastic deviatoric strain rate component tensor. G_1 and G_2 are the first and second elastic shear modulus respectively, μ is the coefficient of viscosity, and S_{ij} is the deviatoric stress tensor. The total deviatoric strain rate component tensor included the viscoplastic deviatoric strain rate component tensor is expressed as $\dot{e}_{ij} = \dot{e}_{ij}^{tve} + \dot{e}_{ij}^{vp}$.

Based on the the previous work(Oka, et al. 1999), we obtain general description of the cyclic viscoelastic-viscoplastic constitutive equation for overconsolidated clay as follows;

$$\begin{aligned}\dot{\varepsilon}_{ij} &= \frac{1}{2G_1}\dot{S}_{ij} + \frac{1}{\mu}\left(S_{ij} - 2G_2 \cdot e_{ij}{}^{ve}\right) + \frac{\kappa}{3(1+e)}\frac{\dot{\sigma}_m^{'}}{\sigma_m^{'}}\delta_{ij} \\ &+ C_{01}\frac{< \Phi_1^{'}(F) > \Phi_2(\xi)}{\sigma_m^{'}}\frac{\left(\eta_{ij}^{*} - \chi_{ij}^{*}\right)}{\bar{\eta}_x^{*}} \\ &+ C_{02}\frac{< \Phi_1^{'}(F) > \Phi_2(\xi)}{\sigma_m^{'}}\left\{\tilde{M}^{*} - \frac{\eta_{mn}^{*}\left(\eta_{mn}^{*} - \chi_{mn}^{*}\right)}{\bar{\eta}_x^{*}}\right\}\frac{1}{3}\delta_{ij}\end{aligned} \tag{2}$$

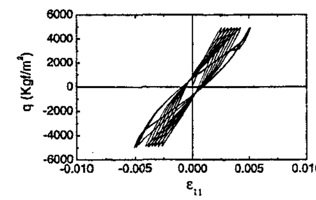

Fig. 1. Elastic-viscoplastic model

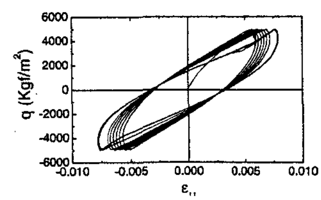

Fig. 2. Viscoelastic-viscoplastic model

Fig.1 shows the relationship between deviatoric stress-strain relation by elastic-viscoplastic model, while Fig.2 appears that of viscoelastic-viscoplastic model and these two model has different damping characteristics respectively. Material parameters used in this analysis are shown in table 1. In the following analysis, cyclic elasto-plastic model(Oka et. al.) is used sand.

Table 1. Material parameters

σ_m'=0.95(kgf/cm²), σ_{mb}'=0.8(kgf/cm²)
$1/\mu$=2.8E-09, Time=100,000sec
e_0=1.922, κ = 0.0477, λ=0.355,
G_1=8.0E+01(kgf/cm²)
G_2=2.66667E+01(kgf/cm²)
qmax=0.5(kgf/cm²), qmin=-0.5(kgf/cm²)
Deviatoric stress rate (4.8E-04(kgf/cm²/sec))
Viscoplastic parameters (m_0=12.8, C_{01}=9.0E-09, C_{02}=1.5E-08)
Stress ratio at failure Mf=1.45 at maximum compression Mm=1.2
Hardening parameters (B_0=57, Bs=15, Bt=1, H=500, G_3=408)

3. Performance of the numerical analysis

In the analysis of liquefaction, we have used FE program(LIQCA)(Oka et al.). Using u-p formulation, a numerical method for liquefaction analysis is prepared as follows;

1 . *Equuilibrium equation* $\qquad \rho\, \ddot{u}_i = \sigma ij,j + \rho\, b_i \qquad (3)$

2 . *Continuity equation* $\qquad \rho^f\, \ddot{u}_{i,i} - p_{,ii} - \frac{\gamma_w}{k}\dot{\varepsilon}_{ii} + \frac{n\gamma_w}{kK^f}\dot{p} = 0 \qquad (4)$

where ρ^f is the density of fluid, ρ is the density of the total phase, p is the pore water pressure, γ_w is the unit weight of the fluid, k is the coefficient of permeability, n is the porosity, b is the body force, and K^f is the bulk modulus of the fluid. The finite element method is used for the spatial discretization of the equilibrium equation, while the finite difference method is used for the spatial discretization of the continuity equation. Newmark's β-method is used for the time discretization of both equations.

In the numerical model the total depth is 100m, the width is 10m, and the whole area is divided into 13 rectangular elements as shown in the Fig. 1. Node 27 and 28 are fixed in vertical and horizontal directions. Drainage is only allowed at the surface. Figure 4 shows the input horizontal acceleration measured at Port Island NS component(Hyogoken-Nambu Earthquake). Fiures 5 and 6 are the results of liquefaction analysis by the viscoelastic-viscoplastic model and elastic-viscoplastic model. Fig.5 shows a time profile of pore water pressure compared with the results by two models for clay(elastic-viscoplastic, viscoelastic-viscoplastic), the developed pore water pressure in the case of viscoelastic-viscoplastic model in larger than that by elastic-viscoplastic model. However the influeces of the acceleration responses at the surface is very small for this particular case. In the case with larger viscosity($1/\mu$), relatively larger pore water pressure is developed in clay layers. The present study reveals that the development of pore water pressure strongly depends on the constitutive modeling of clay layers. This shows that the simplae viscoelastic terms should be reexamined considering the initial stress conditions.

4. Conclusion

In the present study, one-dimensional liquefaction analysis of soil deposits composed of clays and sands has been performed using the viscoelastic-viscoplastic constitutive equation and elasto-plastic constitutive equation. As a result, it is revealed that the modeling of clay layers are important for describing the dynamic behavior of ground composed of clay and sandthe existance of clay layers in the composite ground is influenced the earthquake motion and the application of the viscoelastic-viscoplastic approach for liquefaction analysis appears smaller value of liquefaction response in clay layers than that of the elastic-viscoplastic approach.

References

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3) Oka, et al(1994): FEM-FDM coupled liquefaction analysis of a porous soil using an elasto-plastic model, Applied Scientific Research. Vol. 52,pp.209

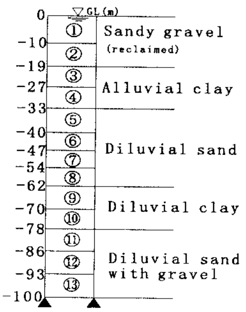


Fig 3. Analytical model

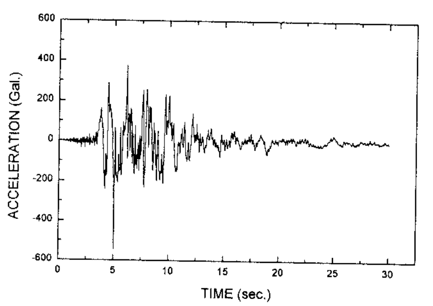


Fig. 4. Initial earthquake data

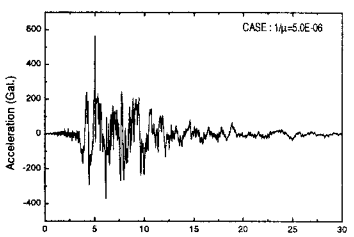
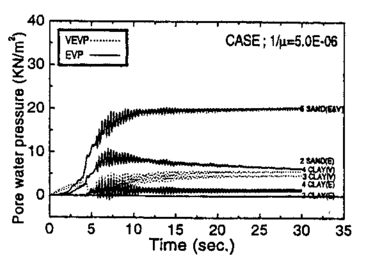


Fig. 5. The earthquake response in clay



Fig, 6. Pore water pressure.

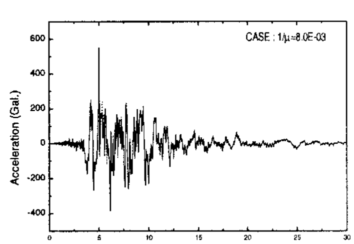
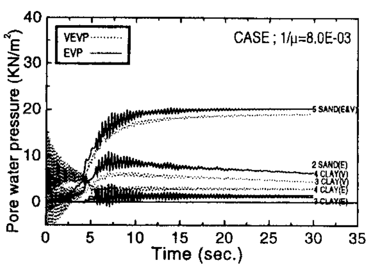


Fig. 7. The earthquake response in clay



Fig, 8. Pore water pressure