An elasto-viscoplastic finite element analysis of excavation through thick soft clay deposit

Kyoto University	Student member	○ B. Siribumrungwong
Kyoto University	Fellow	F. Oka
Kyoto University	Member	T. Kodaka
Kyoto University	Student member	Y. Higo

1. Introduction

Modern techniques of excavation provide effective methods for minimizing deformations of the surrounding soil. However, it is difficult to fully control ground movements during excavations when the toe of wall is embedded in soft clay. Tanaka et al. (1989)[2] reported a case study of a large-scale braced excavation performed through thick soft clay deposit. The thickness of soft clay in the area is over 50m and thus the sheet pile was supported at the soft clay stratum. In the case study, large displacements of sheet pile below the excavation level and at its toe and significant heaving at the excavation surface were observed as the excavation approached the final state. The sheet piles continued to deform with time due to the effects of undrained creep. In this study, the mechanism of soil-structure interaction of the braced excavation through thick soft clay deposit is studied by the numerical simulation using an elasto-viscoplastic constitutive soil model. The numerical analysis is performed as a qualitative study of the data reported by Tanaka et al. (1989)[2].

2. Elasto-viscoplastic constitutive model for clay

An elasto-viscoplastic soil constitutive model for both normally consolidated clay and overconsolidated clay proposed by Oka, Higo, and Kimoto (2002) is adopted in the numerical analysis. The model of NC clay, which has been used in this study, is based on the Cam clay model and a Chaboche type of viscoplasticity theory. The model can describe the time dependent behavior, such as the acceleration creep failure and the dilatancy characteristics. In this model, the total strain rate can be decomposed into elastic and viscoplastic strain rates as:

$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{vp}$ (1), $\dot{\varepsilon}_{ij}$: Total strain rate tensor, $\dot{\varepsilon}_{ij}^{e}$: Elastic strain rate tensor, $\dot{\varepsilon}_{ij}^{vp}$: Viscoplastic strain rate tensor

$\dot{\varepsilon}_{ij}^{vp} = C_{ijkl} \left\langle \Phi_1(f_y) \right\rangle \Phi_2(\xi) \dfrac{\partial f_p}{\partial \sigma'_{kl}}$ (2), f_y: Static yield function, f_p: Plastic potential, Φ_1: First material function for indicating strain rate sensitivity, Φ_2: Second material function for controlling the failure states.

3. Numerical simulations

Numerical simulations under plane strain conditions have been carried out by the finite element method using the updated Lagrangian method with the objective Jaumann rate of Cauchy stress for a weak form of the equilibrium equation. Biot type of two-phase mixture theory (Biot, 1956) is used with a velocity-pore pressure formulation. An eight-noded quadrilateral element with a reduced Gaussian (2x2) integration is adopted. The pore water pressures are defined at four corner nodes. Figure 1 shows the ground conditions and the geometry of the excavation. The soil parameters of alluvial Osaka clay, which have been used in this analysis are shown in shown in Table 1. This study

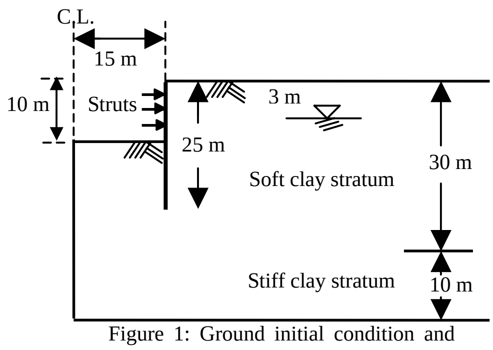

Figure 1: Ground initial condition and geometry of the excavation

Key word Excavation, Elasto-viscoplastic, Finite element analysis, Deformation
Contact address 606-8501 京都市左京区吉田本町 京都大学大学院工学研究科社会基盤工学専攻土質力学研究室 TEL 075-753-5086

focuses on idealized (symmetric) plane strain excavation with half width 15m and final depth of 10m. The sheet-pile and struts are used to support the ground during the excavation. The pile is installed to the depth of 25m. It should be noted that, the toes of the sheet pile wall are embedded in the soft clay stratum by this depth of the sheet pile installation. The geometry and the ground initial conditions described above are similar to those of the case study reported by Tanaka et al. (1989)[2].

Table 1: Soil parameters

m’	21.5
C_2	$4.50\text{x}10^{-8}$ 1/s
M*	1.05
k_x	$1.54\text{x}10^{-8}$ m/s
k_y	$1.54\text{x}10^{-8}$ m/s
σ_v	$20.0+(\gamma_s-\gamma_w)*z$ kN/m^2
K_0	0.90
λ	0.172
κ	0.054
$G_0/\sigma'_{v0}{}^{1/2}$	277.8
e_0	0.72
G^*_2	100

4. Results and discussions

Figure 2 shows the lateral wall deflections and the backfill soil settlements with the progress of the excavation. After the excavation is performed to the final level, the position of maximum lateral displacement reaches below the excavation surface with large displacements of the toe of wall. The maximum lateral displacement of sheet pile is 20cm with maximum backfill settlement of 8.3cm located at distance 14.5m behind wall. After the end of the excavation, the displacement of wall under the lowest supporting struts to the toe of wall still continues to grow largely with time. The wall deforms further for around 2cm during 20 days with almost constant rate. Figure 3 shows the distributions of the accumulated viscoplastic volumetric strain of soil. Large increasing of the viscoplastic strain extends from the excavation surface to the level near the toe of wall in the excavation side. This causes the wall to deflect largely under the excavation level with large movement of the toe of wall. The viscoplastic strain also increases at the soil behind the wall under the excavation level and around the ground surface. Now consider the change of viscoplastic strain after the end of excavation and at final stage. The comparison shows the increasing of viscoplastic strain. This indicates that the viscoplastic flow can be considered as one of the sources that cause the further displacements of wall after the end of the excavation.

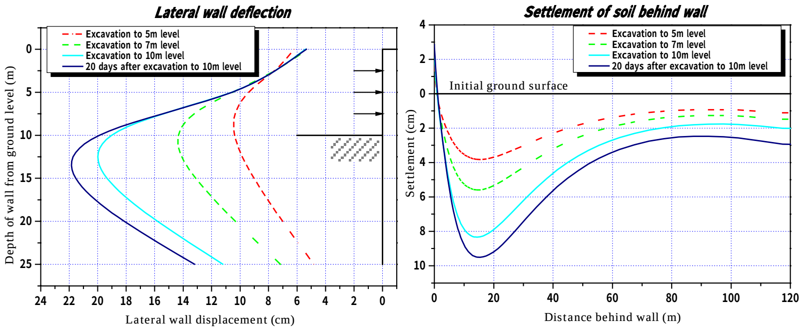

Figure 2: Lateral wall defection and settlement of soil behind wall

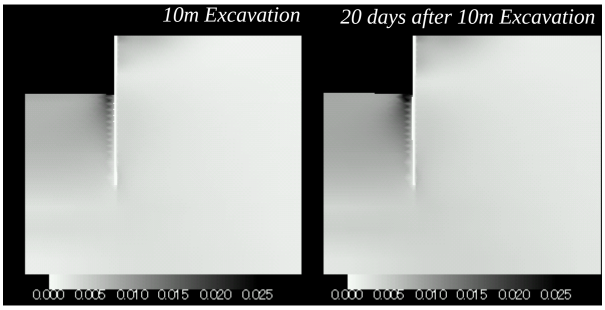

Figure 3: Contour of accumulated viscoplastic volumetric strain

5. Conclusions

In the excavation through thick soft clay deposits, in which the toe of wall does not reach the underlying firm stratum, the wall tends to deflect with the position of the maximum lateral deflection located under the excavation level with the large displacements of the toe of wall and the large amount of heaving. The lateral deflections of wall continue to grow largely with time even after the completing of the excavation by viscoplastic deformation of soil mass in the excavation side. Comparison shows good agreement of the wall and ground deformation patterns between the numerical results and the data from the case study and thus indicates that the present method can qualitatively reproduce the behaviors of the supported ground during excavation reported by Tanaka et al. (1989)[2].

6. References

1) Oka, F., Higo, Y. and Kimoto, S.: Effect of dilatancy on the strain localization of water-saturated elasto-viscoplastic soil, International Journal of Solids and Structures, Vol.39, pp.3625-3647, 2002. 2) Tanaka, H., Adachi, T and Toyoda, T : A case study on a braced excavation in soft soils, Report of the Port and Harbour Research Institute, Vol. 28, No.4, pp.25-54, 1989.