An elasto-viscoplastic consolidation analysis of the soil-structure interaction during an excavation in soft clay stratum

Kyoto University	Student member	B. Siribumrungwong
Kyoto University	Fellow	F. Oka
Kyoto University	Member	T. Kodaka
Kyoto University	Member	S. Kimoto

1. Introduction

Tanaka et al. (1989) reported a case study of a large-scale brace excavation performed through a thick soft clay deposit. The depth of the excavation was about 11 m. The thickness of the soft clay in the area is over 50 m, and thus, the sheet piles were supported by a soft clay stratum. As the results, large displacements of the sheet piles and a significant heave were observed. The sheet piles continued to deform with time due to the undrained creep and the plastic flow of soil. This points out how important it is to consider the rate sensitivity of clay in the analysis of this problem. In the present study, the case study mentioned previously is studied by performing the numerical analysis. The constitutive model adopted is an elasto-viscoplastic constitutive model considering the degradation of soil strength from the change of soil microstructures developed by Kimoto et al. (2004).

2. Elasto-viscoplastic constitutive model for clay considering microstructure change

The model is based on the Cam clay model and Perzyna type of viscoplasticity theory. The model can describe the rate dependent behavior, such as the acceleration creep failure and the dilatancy characteristics. Furthermore, the degradation of soil strength, namely volumetric and shear strain softening due to the changes of microstructure can be reproduced in the model. In this model, total strain rate can be obtained from Equation (1) and viscopalstic strain rate is given by Equation (2).

$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{vp} \tag{1}$$

$$\dot{\varepsilon}_{ij}^{vp} = \gamma \left\langle \phi_1(f_y) \right\rangle \frac{\partial f_p}{\partial \sigma'_{ij}} \tag{2}$$

where $\dot{\varepsilon}_{ij}$: Total strain rate sensor, $\dot{\varepsilon}_{ij}^{e}$: Elastic strain rate tensor, $\dot{\varepsilon}_{ij}^{e}$: Viscoplastic strain rate tensor, f_y: Static yield function, f_p: Plastic potential, ϕ_1: Material function indicating the strain rate sensitivity. In order to describe the degradation of material caused by the structural changes, diminution in size of f_y and f_p with the viscoplastic strain is incorporated by introducing two independent parameters, β and σ'_{maf} into the constitutive equation. β is a parameter which denotes the degradation rate of the material strength and σ'_{maf} provides the degree for a possible collapse of the structural at the initial state.

3. Numerical simulation

Soil conditions at the construction site and the typical cross section of the bracing method are shown in Figure 1.The soil parameters for the soft clay AC_2 layer are listed in Table 1. These parameters are determined from the undrained triaxial tests performed by Tsuchida (1990). As for the soil in stratums AC_1, BS, and AS, there is no experiment data available, therefore, the typical parameters for soft clay and loose sand are adopted for these materials while the Young's modulus of the soils in these stratums is determined from their N values.

The progress of the lateral displacement of the sheet pile wall measured during the construction is shown in Figure 1. The shade portion in the displacement of wall shown in this figure approximately corresponds to the undrained creep displacement. The maximum horizontal displacement was 300 mm after the 4th stage excavation (to 9.8 m depth) before

Key words: Excavation, Soil-structure interaction, Elasto-viscoplastic, Numerical analysis
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地盤力学分野 Tel. 075-753-5086

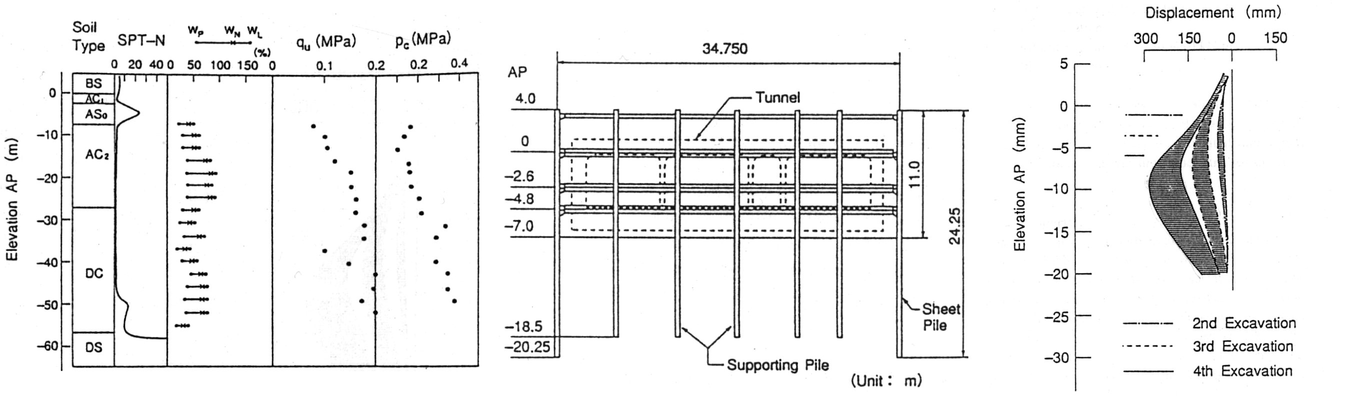

Figure 1　From left to right: Soil conditions at the construction site, typical cross section showing the bracing method, and measured horizontal displacement of the sheet pile wall (Tanaka et al. 1989)

the excavation was halted and the measures were taken.

Figure 2 shows the computed horizontal displacements of the sheet pile wall. The positions of the maximum lateral wall displacements are found to be located beneath the excavation level. The figure also shows the large displacements of the toe of the wall with the progress of the excavation. After the 4th stage excavation, the displacement of the wall, in particular beneath the lowest supporting struts, still continues to grow larger with time, while the further movement of the wall above the lowest supporting level is relatively small. The rate of the wall displacement after the end of the excavation remains almost constant at 2.7 mm/day (7.13 cm/26 days). This result is comparable to the measured results (2.8-4.0 mm/day) from measurement (Tanaka et al. 1989). This indicates that the analysis method and the constitutive model used in this study can effectively simulate the rate-dependent behavior of the clay ground in the problem, which can not be studied with a typical elasto-plastic soil constitutive model (Sekiguchi and Oka 1997). During the final stage of the excavation, the calculated maximum lateral displacement of the sheet piles is 24.5 cm. It is seen that the predicted maximum lateral deflection of the sheet pile wall (24.5 cm) at the final stage is lower than the measured value (30 cm). The predicted position of the maximum lateral displacement is lower than that of the measured results. However, it may be seen that generally, the agreements between the calculated and the measured results are generally fair to good.

Table 1　Soil parameters

Parameters	AC_1	AC_2
k_0 (m/s)	1.54×10^{-8}	1.54×10^{-8}
OCR	1.0	1.25
λ	0.172	0.326
κ	0.054	0.0326
e_0	2.50	1.994
K_0	0.90	0.90
M^*_m	1.05	1.557
m'	20.0	20.45
C_0 (1/s)	9.3×10^{-10}	9.3×10^{-10}
σ'_{maf} (kPa)	$1.0\times\sigma'_{mi}$	$0.8\times\sigma'_{mi}$
β	0.0	15.0

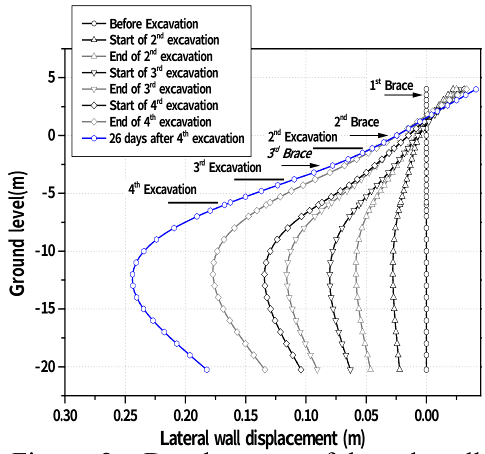

Figure 2　Development of lateral wall displacements with the progress of the excavation (analysis results)

4. Conclusions It was found that, the wall tends to deflect with the position of the maximum lateral deflection located beneath the excavation level. This shows the low-base stability of the excavation system. A comparison shows that the numerical method ad opted can quantitatively reproduce the behavior of the excavation system and the rate dependent of clayey soil observed in the case study.

5. Reference 1) Kimoto, S., Oka, F. and Higo, Y. (2004), Strain localization analysis of elasto-viscoplastic soil considering structural degradation, Computer Methods in Applied Mechanics & Engineering, 193, pp. 2845-2866. 2) Sekiguchi, K. and Oka, F. (1997), Ground deformation during a braced excavation in a thick soft clay deposit, Journal of Structural Engineering, 43A, pp. 1403-1410. 3) Tanaka, H., Adachi, T. and Toyoda, T. (1989), A case study on a braced excavation in soft soils, Report of the Port and Harbour Research Institute, 28, 4, pp. 25-54 198 (In Japanese). 4) Tsuchida, T. (1990), Study on determination of undrained strength of clayey ground by means of triaxial tests, Technical Note of the Port and Harbour Research Institute, 688, pp. 1-198 (In Japanese).