Simulation of full scale tunnel excavations using TBM considering different excavation rates

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ABSTRACT

Finite element analyses are carried out for 3D tunnel excavation using Tunnel Boring Machine (TBM). In TBM, tunnel excavation is simulated considering soil-water coupled analysis. Two excavation rates are employed in the simulations to investigate the influence of excavation rate on ground movement in tunneling. It is found that surface settlement depends on the excavation rate that is employed during construction, and the ground settles continuously even after completion of the tunnel excavation due to the dissipation of pore water pressure.

1. LAYOUT OF ANALYSES

Three-dimensional finite element analyses with subloading t_{ij} model[1)] are carried out in large scale to investigate the real ground condition due to tunnel excavation using Tunnel Boring Machine (TBM). Fig. 1 shows the mesh used in these analyses. Assuming symmetry along the tunnel axis, half of the ground is analyzed. The diameter of the tunnel is 8m. Soil cover from the tunnel crown is 16m. The length of the tunnel is 48m. The tunnel is assumed as circular in shape. The length of the tunnel is divided into 6 tunnel blocks with 8m of width for excavating block by block. The bottom face is assumed as fixed boundary condition. The vertical faces are kept free in lateral directions. Isoparametric 8-noded elements are used as soil element. For tunnel lining (shield) 4-noded bilinear degenerated shell elements are used. The analyses are carried out considering soil-water coupled condition. The top surface of the ground is allowed to drain, and all other faces are assumed as impermeable boundaries. Therefore, water can not flow across the boundaries of the ground except the top surface. The water table is assumed at the top of the ground. To investigate the dependency of excavation rate on the surface settlement and earth pressure, tunnel is excavated considering two kinds of the excavation rates. In the first excavation rate, each block (8m in excavation direction) of the tunnel is excavated in 5 days. In case of the second excavation rate, each tunnel block is excavated in 50 days. Analyses are carried out for two types of the ground- (i) ground type 1 consists of a clay layer overlying a sand layer as shown in Fig. 2, and (ii) ground type 2 consists of normally consolidated clay for the whole domain of the ground. The coefficient of permeability for clayey soil is assumed as 10^{-7}m/min, and for sandy soil it is 10^{-4}m/min. Table 1 shows the parameters of clay, and Table 2 presents the parameters of sand used in the finite element analyses. Shin-Fujinomori clay is used as clayey soil, and Toyoura sand is used as sandy soil. Fig. 3 shows the stress-strain-dilatancy relation at triaxial condition for (a) Shin-Fujinomori clay and (b) Toyoura sand under constant cell pressure. The stress level chosen for the curve is equal to 294kPa which is the same vertical stress level at the middle of the tunnel considered in the finite element analyses. The figures confirm that clay show negative dilatancy, while sand exhibits positive dilatancy. The stiffness of lining is 2.45×10^{7}kPa and Poisson’s ratio is 0.20. Tunnel excavation is simulated by deactivating the soil elements inside the tunnel.

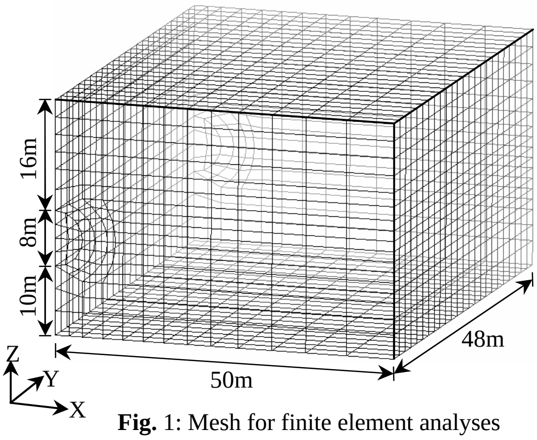

Fig. 1: Mesh for finite element analyses

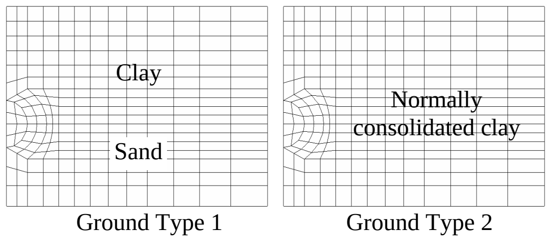

Fig. 2: Explanation of ground materials

Table 1. Parameter of Shin-Fujinomori Clay

λ	0.1039
k	0.0099
N (e_{NC} *at p=98kPa & q=0kPa*)	0.9220
$R_{CS}=(s_1/s_3)_{CS(comp.)}$	3.20
b	1.50
n_e	0.20
a	500

Table 2. Parameter of Toyoura Sand

λ		0.070
k		0.0045
N (e_{NC} *at p=98kPa & q=0kPa*)		1.10
$R_{CS}=(s_1/s_3)_{CS(comp.)}$		3.20
b		2.0
n_e		0.20
a	$a_{(AF)}$	30
	$a_{(IC)}$	500

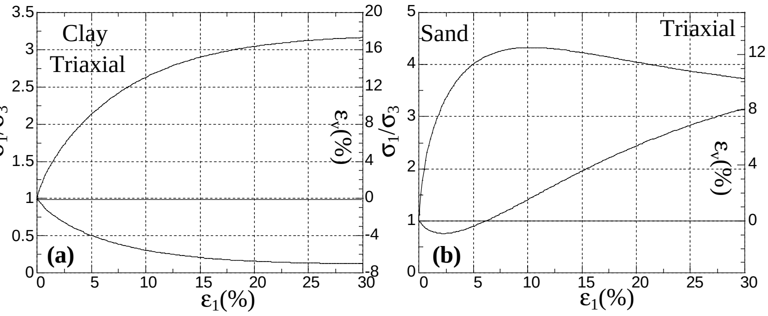

Fig 3: Stress-strain curves near middle of the ground: (a) Clay; (b) Sand

2. RESULTS AND DISCUSSIONS

Figs. 4(a) and 4(b) illustrate the profiles of surface settlement at the transverse cross section of the ground for ground type 1 at the excavation rates 8m/5day and 8m/50day, respectively. The legend indicates the position of the excavation front from the measuring section, where the solid black circular

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marks represent the result when excavation front is at the measuring section. It is revealed in these figures that the surface settlement after completion of the tunnel excavation at the excavation rate 8m/50day is larger than the result at the excavation rate 8m/5day. The maximum surface settlement at the center of the tunnel is around 4.5mm at the excavation rate 8m/50day. One should notice that excavation takes only 30 days at a rate of 8m/5day, against 300 days at a rate of 8m/50day. Therefore, it is obvious that the settlement at the end of construction is higher for the slower rate (8m/50day). Figs. 5(a) and 4(b) illustrate the profiles of surface settlement at the transverse cross section of the ground for ground type 2 (normally consolidated clay) at the excavation rates 8m/5day and 8m/50day, respectively. It is seen in this figure that the settlement at the end of construction is higher for the slower rate (8m/50day) the same as for ground type 1.

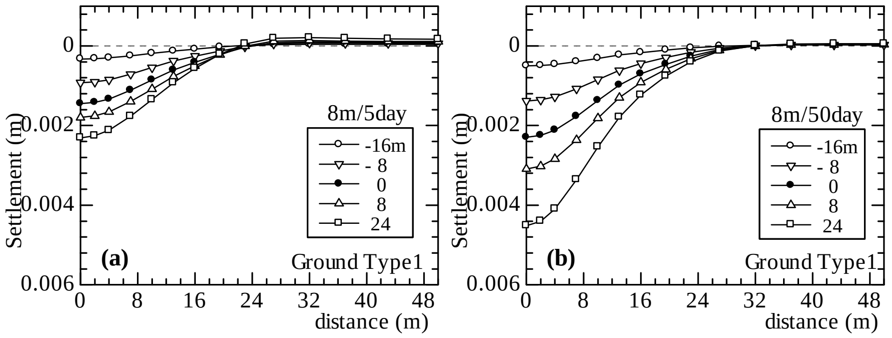

Fig. 4: Surface settlement profiles for ground type 1: (a) Pattern 1; (b) Pattern2

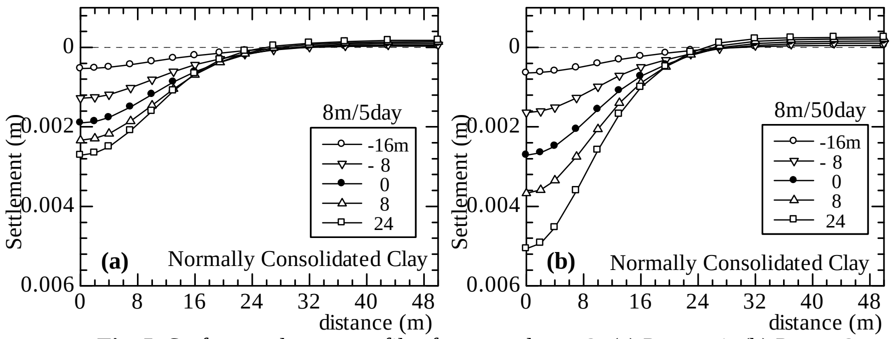

Fig. 5: Surface settlement profiles for ground type 2: (a) Pattern 1; (b) Pattern2

Fig. 6 shows the surface settlement at the center of the tunnel at the transverse cross section of the tunnel for normally consolidation clay at the faster excavation rate of 8m/5day. The vertical axis represents the settlement in meter, and the abscissa represents time in days. The solid part of the line shows the settlement during the excavation of the tunnel, and the dotted part represents the settlement with time. It is revealed in this figure that the settlement at the point increases continuously even after 12 years of the construction of the tunnel due to the dissipation of the pore water pressure. Fig. 7 shows the surface settlement at the center of the tunnel at the transverse cross section of the tunnel for normally consolidation clay at the slower excavation rate of 8m/50day. It is found that the settlement after 12 years is smaller in Fig. 7 than that in Fig. 6, although just after completion of the excavation the settlement for faster excavation rate is smaller than that for slower excavation rate. From these results it can be said that surface settlement depends on the excavation rate that is employed during excavation, and the ground settles continuously even after completion of the tunnel excavation due to the dissipation of the pore water pressure.

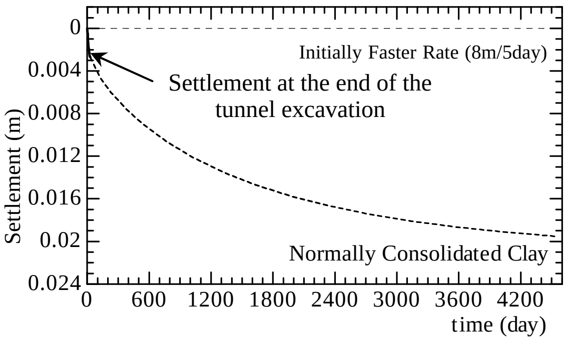

Fig. 6: Surface settlement at the center of the tunnel for ground type 2: Faster rate

The simulation for normally consolidated clay at slower rate (8m/50day) is performed up to 55 years. Fig. 8 shows the results for the simulation at the center of the transverse cross section of the tunnel. Here, the abscissa represents time in years. It is seen in the figure that the settlement at the point almost stabilizes after about 25 years of the tunnel construction.

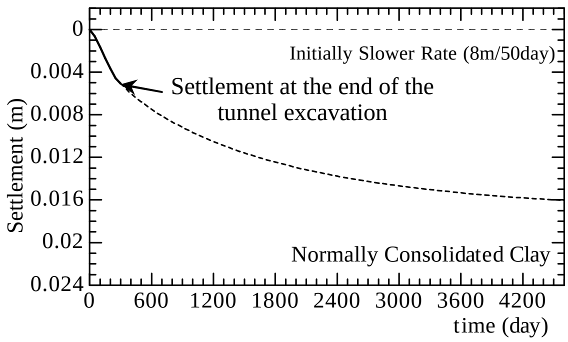

Fig. 7: Surface settlement at the center of the tunnel for ground type 2: Slower rate

3 CONCLUSIONS

Surface settlement depends on the excavation rate that is employed during excavation, and the ground settles continuously even after completion of the tunnel excavation due to the dissipation of pore water pressure. The faster the excavation rate the higher the generated internal pore pressures, thus producing higher values of surface settlements in the long term.

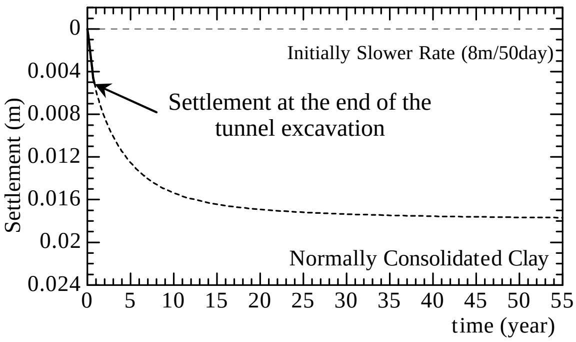

Fig. 8: Surface settlement at the center of the tunnel for ground type 2: Slower rate (up to 55 years)

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