Tunnel excavations considering building loads: 2D model tests and numerical analyses

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ABSTRACT
To investigate the effects of building loads in tunnel excavations, two-dimensional model tests and the corresponding numerical analyses are carried out. For this purpose, two values of initial dead load are applied adjacent to the tunnel. Two-dimensional numerical analyses are performed using an elastoplastic subloading t_{ij} model. It is found that the building loads control surface settlements such that the maximum surface settlement occurs not always above the centerline of the tunnel, but at the position of the existing building. The deformation mechanism during the tunnel excavation for the ground disturbed by the building loads varies with the magnitude of the building loads.

1. LAYOUT OF MODEL TESTS

The model tests were carried out with the trap door apparatus, whose schematic diagram is shown in Fig. 1. The reference [1] describes details of the apparatus. The apparatus consists of 10 brass blocks (blocks A to J) of 8cm in width each, and set along the centerline of an iron table. Block F is lowered to simulate tunnel excavation. For applying dead loads on the top of the ground in the trap door apparatus a plate of 8cm in width is placed at the surface of the ground adjacent to the lowering block F, and the load is applied at the middle of the plate before performing tunnel excavation. This load is kept fixed until completion of the tests. Model ground material consists of two kinds of aluminum rods having unit weight γ of 20.4kN/m^3. Model tests have been conducted for four values of soil covers, D/B equals 0.5, 1.0, 2.0 and 3.0, where D is the depth from the ground surface to the top of the tunnel and B (8cm) is the width of the tunnel. Two values of surface loads are applied to investigate the influence of load level. For surface load of 3.92kPa tests are conducted for all soil depths, and for surface load of 6.90kPa the test for D/B=2.0 is performed. Surface settlements are measured by using a laser type displacement transducer. Earth pressures are measured with load cells.

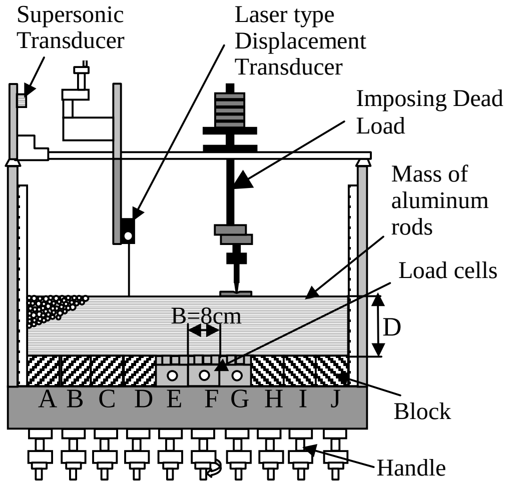

Fig. 1: Trap door apparatus with load plate

2. NUMERICAL ANALYSES

Two-dimensional finite element anlyses using elasto-plastic subloading t_{ij}-model have been carried out with the same scale of the model tests considering plane strain drained conditions. Fig.2 shows details of the mesh for D/B=2.0. To simulate the lowering of block F in the numerical analyses, vertical displacements are imposed at the nodal points, which correspond to the top of the lowering block in the model tests. The parameters for materials used in the numerical analyses are shown in Table 1, and with these parameters stress-strain relations under constant minor principal stress are shown in Fig. 3. These parameters reasonably characterize the properties of aluminum rod mass of the model ground. In the numerical analyses, the ground is initially formed under geostatic condition by using body forces (γ=20.4kN/m^3), then concentrated load is applied at the middle node of the plate as shown in Fig 2. The stresses, void ratios and density parameters of the constitutive model at all integration points are stored and then used as the initial ground before tunnel excavation.

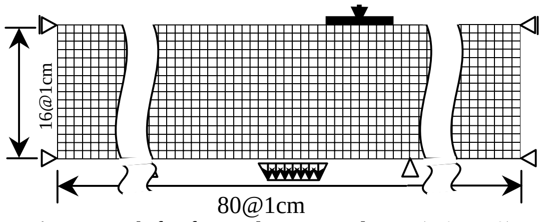

Fig. 2: Mesh for finite element analyses-(D/B=2.0)

Table 1. Parameter for FEA

λ	0.008
κ	0.004
N (e_{NC} at p=98kPa & q=0kPa)	0.30
$R_{CS}=(\sigma_1/\sigma_3)_{CS(comp.)}$	1.80
β	1.20
ν_e	0.20
a	1300

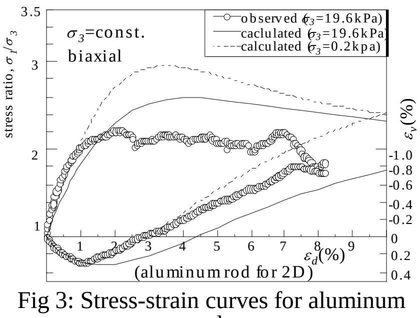

Fig 3: Stress-strain curves for aluminum rods

3. RESULTS AND DISCUSSIONS

Details of the results regarding surface settlements and earth pressures for dead load of 3.92 were discussed in the reference [3]. Hence, here only some results are discussed for this load level. Fig. 4 shows observed and computed surface settlements for applied displacements of 1mm and 4mm for different depths at dead load of 3.92kPa. This figure reveals that for D/B=0.5 the maximum settlement is observed almost at the crown of the tunnel, but as the ground depth increases the maximum surface settlement is seen at the position of the dead load. The plate of the dead load tilts towards the excavation except for D/B=3.0, where tilt is observed in opposite direction with a little inclination. Fig. 5 shows the movements of the ground for lowering block F. It is revealed in this figure that the deformation zone in case of D/B=1.0, 2.0 and 3.0 spreads towards the load plate from the top of the lowering block. Fig. 6 represents observed and computed earth pressure distributions of the model tests and numerical analyses at dead load of 3.92kPa. Irrespective of the ground depth, a significant amount of load transfer from the tunnel roof to each side is observed due to ground arching. This effect is more remarkable on the side where the building load is applied. Asymmetry in the earth pressure is observed at the place of excavation for lowering block F.

Key words: Tunnel excavation, Building loads, Surface settlement, Earth pressure, Finite element analyses
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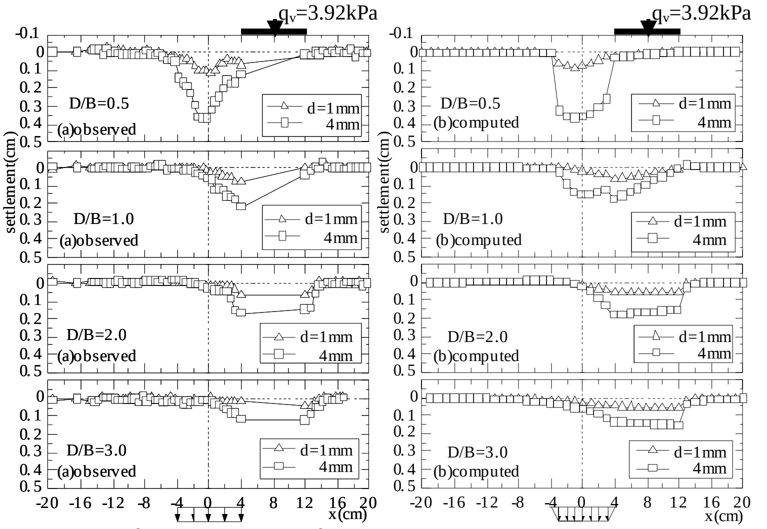
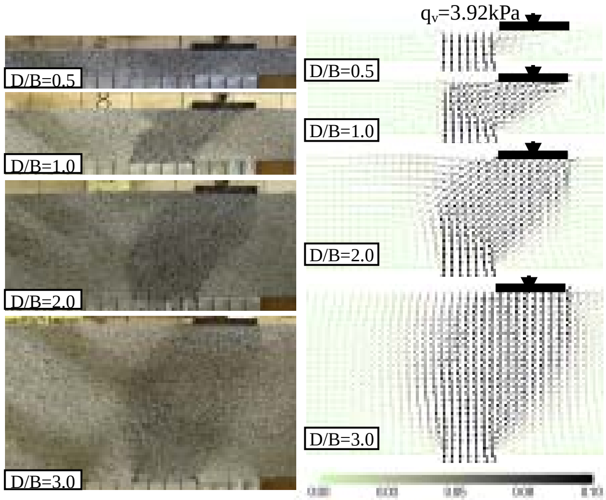


Fig. 4: Surface settlement profiles: (initial applied load=3.92kPa)



(a) Observed (b) Computed

Fig. 5: Ground movements: (initial applied load=3.92kPa)

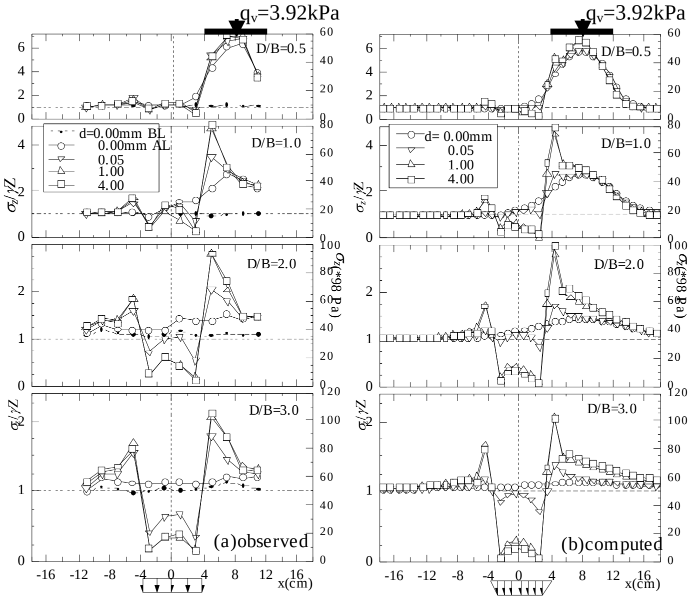


Fig. 6: Observed and computed earth pressure distributions

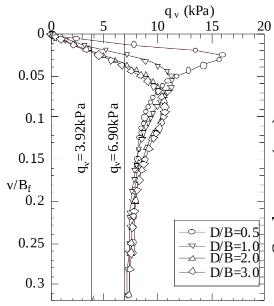


Fig. 7: Computed Load settlement curve

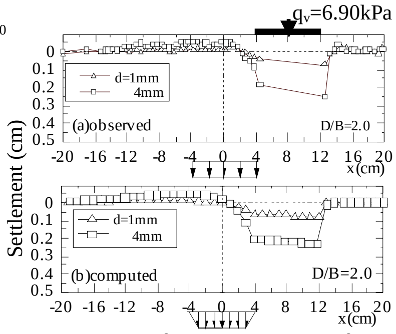
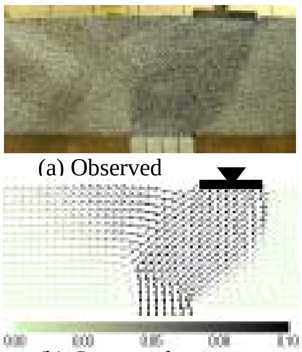


Fig. 8: Surface settlement profiles (initial applied load=6.90kPa)


(a) Observed

(b) Computed

Fig. 9: Ground movements: (initial applied load=6.90kPa)

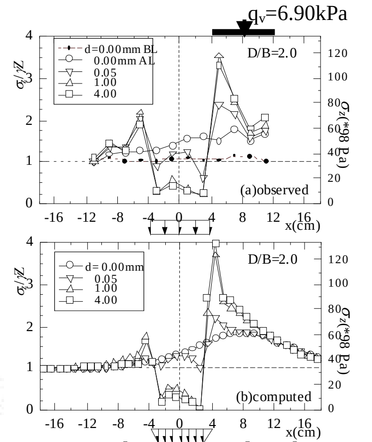


Fig. 10: Earth pressure distributions (initial applied load=6.90kPa)

Fig. 7 shows the normalized computed load-displacement (bearing capacity) curve of the ground of aluminum rod mass with different depths. Although the figure indicates that the bearing capacity is very high for *D/B*=0.5 because of the boundary effect, the load-settlement curves of *D/B*=2.0 and *D/B*=3.0 are almost same. The value of this second load (q_v=6.90kPa) is around 2/3 of the ultimate bearing capacity and slightly lower than the residual strength of the ground

Fig. 8 shows the observed and computed surface settlement profiles for second load level. The surface heaves above the tunnel and on the other side of the loaded plate. Fig. 9 represents the movement of the ground. Deformation zone of the ground spreads towards the loaded plate as before, but from this point a sliding rotational mechanism spreads towards the left at the excavation side. Due to the excessive shearing of the ground in the left side and beneath the loaded plate, it tills in the opposite direction of tunnel excavation. But, the direction of the tilting of the plate at q_v=3.92kPa is different as shown in figure 4. Fig. 10 illustrates the observed and computed earth pressure distributions for this load case. The tendency of the change of earth pressure for tunnel excavation for this load case is qualitatively similar to that observed when a load of 3.92kPa was applied. However, the effect for this value of dead load is more severe than that for the load of 3.92kPa. It is, therefore, clear that existing building load controls ground movement and earth pressure due to tunnel excavation. These also vary with the magnitude of the building loads. The numerical analyses can accurately predict the results of the model tests.

4.CONCLUSIONS

Building loads adjacent to tunnel control surface settlement and zone of deformation during tunnel excavation. Effect of building loads on surface settlement is greater for greater tunnel depths in shallow tunneling. For building loads, unsymmetrical earth pressure distribution is seen at the level of tunnel. Surface settlement and earth pressure vary with the magnitude of building loads. Finite element analyses showed excellent agreement with the results of model tests.

REFERENCES: 1) Nakai et al.: Proc. of the Int. Sym. on Modern Tunneling Science and Technology (IS- Kyoto), Kyoto, Japan, 2000, pp-153-158. 2) Nakai, T., Hinokio, M.: Proc. of 1st IWS on New Frontiers in Computational Geotechnics, Canada, 2002,pp-3-16. 3) Shahin et al.: Proc. of 38th National Conference of JGS, Akita, Japan, 2003.