Influence of existing building with different types of foundations on tunnel excavation—FEM analysis

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ABSTRACT

Two-dimensional finite element analyses, using the elasto-plastic subloading $t_{ij}$ model, are carried out to investigate the effects of the building loads in the tunnel excavation. This paper describes the simulations where the initial dead load is applied adjacent to the tunnel considering two kinds of foundations, shallow foundation and pile foundation. Again two types of piles are considered, one is shorter pile, and another is longer pile. It is found in this research that the affects is more in case when the adjacent building is based on shallow foundation or on shorter pile. For these two cases the deformation mechanism is totally different from that for the green field condition.

1. INTRODUCTION

Building based on shallow foundation changes settlement trough and earth pressure distribution during shallow tunneling (reference [4]). However, building is built not only on footing but also on deep foundation such as pile foundation. In this research the effect of adjacent structure based on building is built not only on footing but also on deep foundation such as pile foundation. In this research the effect of adjacent structure based on building load is considered applying concentrated load as shown in Fig 1, where figure 1(a) corresponds to footing (series II(a)), figure 1(b) corresponds to pile foundation with short pile (series II(b)), and figure 1(c) corresponds to long pile (series II(c)). In series II(b) the pile (Dp) is shorter than the soil cover (D), and in series II(c) the pile (Dp) is longer than the soil cover (D). A constant value of dead load was applied, which was 3.92kPa. This amount of load is about 1/3 of the peak strength of load-displacement curve (Fig. 3), and is equivalent to the load of a twenty-stories building (stress of 392kPa at base level) assuming a similarity ratio of 1:100. The stresses, void ratios and density parameters of the constitutive model at all integration points are stored and then used as the initial conditions of the ground before tunnel excavation.

2. LAYOUT OF NUMERICAL ANALYSES

Two-dimensional finite element analyses using elasto-plastic subloading $t_{ij}$ model have been carried out with the same scale of the model tests (the model tests have been described in reference [3]) considering plane strain drained conditions. Fig.1 shows the details of the mesh for $D/B=2.0$. Here, the width of the tunnel $B=8cm$, and $D$ is the soil cover. To simulate the lowering of the block 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. 2. These parameters reasonably characterize the properties of aluminum rod mass of the model ground. The ground is initially formed under geostatic condition. The tests of green field (without building load) is considered as series I. Building load is considered applying concentrated load as shown in Fig 1, where figure 1(a) corresponds to footing (series II(a)), figure 1(b) corresponds to pile foundation with short pile (series II(b)), and figure 1(c) corresponds to long pile (series II(c)). In series II(b) the pile (Dp) is shorter than the soil cover (D), and in series II(c) the pile (Dp) is longer than the soil cover (D). A constant value of dead load was applied, which was 3.92kPa. This amount of load is about 1/3 of the peak strength of load-displacement curve (Fig. 3), and is equivalent to the load of a twenty-stories building (stress of 392kPa at base level) assuming a similarity ratio of 1:100. The stresses, void ratios and density parameters of the constitutive model at all integration points are stored and then used as the initial conditions of the ground before tunnel excavation.

3. RESULTS AND DISCUSSIONS

Fig. 4 shows the surface settlements profiles of series II(a) for applied displacements of 1mm and 4mm in case of $D/B=1.0$, 2.0 and 3.0. These figures also represent the results of series I (green field condition) for 4mm applied displacement, which is shown with black rectangular mark. The position of the applied dead load and excavation are depicted at the top and bottom in each figure, respectively. It is seen in these figures that the maximum surface settlement occurs at the position of the building load. In series I surface settlement at the place of building is not so significant for $D/B=2.0$ and 3.0. On the contrary, in series II(a) for these two soil covers surface settlement occurs at the place of building due to building load. Almost no surface settlement is seen at the center line of the tunnel for these two soil covers in series II(a). The plate of the load tilts towards the excavation except for $D/B=3.0$, where tilting is observed in opposite direction with a little inclination. Fig. 5 shows the displacement vector of the ground for $D/B=2.0$ in case of series II(a). It is revealed in this figure that the deformation zone spreads towards the load plate from the top of the lowering block. Fig. 6 shows the earth pressure distributions for series II(a). Keeping the same scale as for the actual value of earth pressure, figures for different ground depths are plotted. The left vertical axis represents normalized earth pressures and the right vertical axis represents the value of earth pressure in Pascal. Legends represent the amount of applied displacement. Here, with black rectangular marks represent earth pressure of series I for $d=4.0mm$. It is seen in these figures that even in case of induced load from building earth pressure decreases at the place of excavation, while it increases adjacent to the excavation due to ground arching. This effect is more remarkable on the side where the building load is applied. Unsymmetrical earth pressure distribution is seen for building loads.
Fig. 8. Surface settlement profiles of series II(b). The black rectangular marks heaves above the tunnel and on the other side of the load plate. From figure 8 it is seen slightly lower than the residual strength of the ground (Fig. 3). For this load, the surface for load type 2 of series II(a). The value of the load is 0.56(*9.8N/cm). This load is Fig. 7 and 8 show the surface settlement profiles and displacement vector of the ground. The deformation mechanism of this series is very close to that of series II(a) for D/B=1.0.

Fig. 9 shows the surface settlements profiles of series II(b). The black rectangular marks represent the results of series I (green field) for d=4.0mm. As the result in footing, the maximum surface settlement occurs at the place of building load. Fig. 10 represents the displacement vector of the ground. The deformation mechanism of this series is very much similar to series II(a), i.e., the deformation zone of the ground spreads towards the load plate as before, but a sliding rotational mechanism spreads towards the left at the excavation side. The tilting of the plate for this load is different from load type 1 of the same series.

Fig. 11 shows earth pressure distribution of series II(b). The distribution of earth pressure is very close to that of series II(a) for D/B=1.0.

Fig. 12 shows the surface settlement profiles of II(c) for D/B=1.0 and 2.0. Fig. 13 shows the displacement vector for this series. It is seen in figure 12 the maximum surface settlement occurs around the center line of the tunnel. Here, the lower part of the pile which crosses the level of the tunnel crown restricts the movements of the soil towards the pile group. Therefore, the ground is more distorted above the tunnel block due to excessive shearing, which finally increases the surface settlement above the place of tunnel excavation. It is also noted that the surface settlement trough is wider on the opposite of the pile group for series II(c) than that for series I (green field). Here, the pile acts as a wall beside the tunnel. Almost no significant affect of tunnel excavation is seen at the place of building in series II(c). This type of long pile is effective during tunnel excavation which restricts surface settlement at the position of the building.

4. CONCLUSIONS

Existing building loads control surface settlement and zone of deformation during tunnel excavation. Surface settlement trough for tunnel excavation in the ground disturbed by existing buildings based on shallow foundation and pile group shorter than soil cover does not follow the usual pattern of a Gaussian distribution curve. For building loads, unsymmetrical earth pressure distribution is seen at the level of tunnel, even after completion of tunnel excavation.