Tunnel Stability and Deformation Analysis under Excavation Load

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Abstract. Based on the finite element model of the tunnel influenced by approaching excavation of foundation pit, influence laws of excavation depth and distance on the tunnel stability are studied. The results show that the largest settlement occurs in the left lining, and the maximum uplift occurred in the right lining. The displacement values of the various monitoring section of tunnel structure on the left side are more closer, and the displacement values near the tunnel bus present obvious negative peak displacement. When the excavation distance is increasing, the settlement displacement of the tunnel increases obviously. Local uplift effect caused by unloading of soil gradually disappeared. With the increasing of the approaching distance, the bottom of the foundation pit bears all or part of the passive earth pressure, which makes the active area earth pressure and passive earth pressure area produce greater deformation.

1. Introduction
Tunnel and underground engineering under excavation conditions are susceptible to disturbance. When the excavated area and the tunnel are close, the approaching excavation will be harmful to both the tunnel structure, such as, subsidence intensify, bearing capacity of the tunnel decreasing and happening large deformation and damage. In the past, due to urban development speed is relatively slow, the research for the approaching excavation of tunnel is inadequate. However, the approaching excavation engineering problems as the new problems constantly emerges, and it is necessary to study the influence laws of the approaching excavation on the tunnel stability.

About the approaching excavation, Peck [1] recommended to use the relation between the subsidence degree and the distance from edge of foundation pit to estimate subsidence. Gong Xiaonan [2] performed a correction and improvement suggestion about the peck relationship curve and proposed a new empirical formula of ground settlement. He Wei [3] studied the ground subsidence which is behind the retain wall after the deep foundation pit excavation, and the results show that the maximum did not appear on the behind of the retain wall, however, it appeared a certain distance away from the foundation pit edge. Yang Min [4] performed the numerical simulation of foundation pit excavation based on the four basic deformation modes of retaining structures put forward by Goldberg [5], and found that the deformation of the maintenance structure has a linear relation with the maximum ground subsidence. However, most researches are focused on safety evaluation of approaching construction, and there is less research about the influence of approaching construction on mechanic behavior of surrounding building. Thus, based on the finite element model of the tunnel, the influence laws of the approaching excavation on the stability of the tunnel are studied.
2. Finite element model of tunnel.
Software Flac3d is used to simulate the excavation of foundation pit. The soil constitutive model used Mohr-Coulomb. The boundaries of the left and right sides are fixed the X displacement, and the bottom of the model are all fixed. The model has 198019 nodes and 18860 elements, as shown in Figure 1.

![Finite element model of the tunnel](image)

Figure 1. Finite element model of the tunnel

The soil layer physical parameters are shown in Table 1.

| Tier  | Soil                 | Weight (kN/m³) | Cohesion (kPa) | internal friction angle (°) | Elasticity modulus (MPa) | Poisson's ratio |
|-------|----------------------|----------------|---------------|-----------------------------|--------------------------|----------------|
| 1     | Fill earth           | 16.5           | 11            | 15                          | 14                       | 0.35           |
| 2     | Clayey silt          | 18.3           | 22            | 27                          | 20                       | 0.32           |
| 3     | Sandy soil           | 21.5           | 11            | 28                          | 23.6                     | 0.30           |
| 4     | Pebble               | 20             | 0             | 40                          | 29                       | 0.30           |
| 5     | Silty Clay           | 21.2           | 37            | 16                          | 34                       | 0.30           |
| 6     | Cobble and gravel strata | 22.5   | 12            | 32                          | 35                       | 0.28           |
| 7     | Basement             | 22             | 31            | 36                          | 41                       | 0.28           |
| 8     | Wall                 | 23             | 200           | 42                          | 44                       | 0.25           |
| 9     | Reinforced concrete  | 26             | 1000          | 45                          | 20000                    | 0.22           |
| 10    | Slop shield piles    | 26             | 600           | 45                          | 10000                    | 0.22           |
| 11    | Foundation of building | 25             | 100           | 45                          | 44                       | 0.25           |

3. Influence laws of the approaching excavation distance on the tunnel deformation.
The calculation results of approaching excavation distance 5m and 15m are researched when the excavation depth is 5m.

3.1. Approaching excavation distance 5m.
When the approaching excavation distance is 2m and 5m, the first excavation depth is 2m and the second excavation depth is 5m, shown in Figure 2 and Figure 3.
As shown in Figure 2 and Figure 3, when the displacement of excavation side edge is less, the friction of the soil could restrict the soil deformation, so the displacement near the edge of the excavation foundation is less. When the displacement of the excavation side edge is greater, the ground deformation is equal to the lining deformation. At this moment, the friction of the soil and the support structure of the tunnel has little restricting power, thus, the largest settlement occurs in the left lining, and the maximum uplift occurred in the right lining. The maximum negative displacement is -5.1mm, which appears at the monitoring point 8 of section 5. The maximum positive displacement is 10.9mm, which appears at the monitoring point 18 of section 15. The uplift trend of the tunnel is more remarkable.

3.2. Approaching excavation distance 15m.
When the approaching excavation distance is 15m, the first excavation depth is 10m and the second excavation depth is 15m, shown in Figure 4 and Figure 5.

![Figure 4. Displacement of the tunnel under excavation depth 10m](image1)

![Figure 5. Displacement of the tunnel under excavation depth 15m](image2)

As shown in Figure 4 and Figure 5, the displacement values of the various monitoring section of tunnel structure on the left side is more close, and the displacement values near the tunnel bus presents obvious negative peak displacement, and the vertical maximum displacement is -8.6mm, which appears at the monitoring point 15 of section 5. The average displacement of section 5 is -5.7mm, and the average displacement of section 35 is -3.7mm, and the average displacement of section 15 is 4.8mm, and the average displacement of section 25 is 4.0mm. The displacement is greater than that of excavation distance 10m, which shows that when the excavation distance increases, the settlement of tunnel increases obviously. Local uplift effect caused by unloading of soil gradually disappeared. When the excavation distance is 5m, the positive uplift of the tunnel is most obvious. When the excavation distances are 10m and 15m, subsidence of the tunnel is the main deformation characteristics.
4. Influence laws of excavation depth on ground subsidence deformation

When the approaching distance is 15m and the excavation depth is 2m, displacement nephograms of every section in the direction z are shown in Figure 6 and Figure 7.

![Figure 6](image1.png)

**Figure 6. The ground settlement displacement when the excavation depth is 2m**

![Figure 7](image2.png)

**Figure 7. The ground settlement displacement when the excavation depth is 5m**

As shown in Fig.4, the displacements of every monitoring section of the tunnel are close, and the tunnel bus has obvious negative peak displacement after the excavation. When the excavation increases, with the increasing of the approaching distance, inside of foundation pit discharges the original soil pressure, the bottom of the foundation pit bears all or part of the passive earth pressure, which makes the active area earth pressure and passive earth pressure area produce greater deformation. The influence of horizontal stress is gradually decreasing, and the influence of vertical stress is gradually increasing. Compared with the excavation depth 2m, the ground settlement displacement increases, and the maximum settlement displacement is -37.1mm, which increases 3 times than that excavation depth 2m.
5. Conclusions.
(1) The displacement values of the various monitoring section of tunnel structure on the left side is more close, and the displacement values near the tunnel bus presents obvious negative peak displacement. When the excavation distance increases, the settlement of tunnel increases obviously.

(2) When the excavation depth increases, with the increasing of the approaching distance, inside of foundation pit discharges the original soil pressure, the bottom of the foundation pit bears all or part of the passive earth pressure, which makes the active area earth pressure and passive earth pressure area produce greater deformation.

(3) The influence of horizontal stress is gradually decreasing, and the influence of vertical stress is gradually increasing. Compared with the excavation depth 2m, the ground settlement displacement increases.

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