Research on influence of excavation parameters of shield tunnel based on ABAQUS

Yang Liu1,a, Xin Fu2, Minghu Yang3, Zhendong Tang4, Lu Chen5 and Yuancai Liu6*

1,2,3 Civil engineering college, Southwest Forestry University, Kunming, Yunnan, 650000, China
4 China railway construction bridge engineering bureau, Kunming, Yunnan, 650000, China
5 Jingzhou municipal government investment project construction management center, Jingzhou, Hubei, 434000, China
6 Civil engineering college, Southwest Forestry University, Kunming, Yunnan, 650000, China

axl@swfu.edu.cn
*Corresponding author’s e-mail: 1121702038@qq.com

Abstract. At present, the mainstream method of urban subway construction is shield construction. What cannot be avoided in shield construction is the settlement and displacement of the ground surface, and the tunneling pressure is closely related to the grouting pressure and the settlement of the soil. For the overlapping tunnel shield construction, this paper takes the shield construction of the overlapped tunnel section of Kunming Rail transit Line 6 as the research object. Using ABAQUS finite element software to simulate overlap shield tunnel construction, the research of shield tunneling parameters and the relationship between the surface displacement of soil. The results show that reasonable selection of excavation parameters can well control ground settlement.

1. Introduction
When digging overlapping tunnels in soft soil layers, the determination of shield tunneling parameters is very important for the entire tunnel construction. If the appropriate tunneling parameters cannot be selected, the surface soil layer may undergo a large settlement or uplift, thereby danger to the new tunnel and surrounding buildings. Therefore, scholars at home and abroad have done a lot of research work on this. At present, the main research method for the soil displacement caused by shield tunnel construction is finite element numerical simulation [1]–[5].

This article is aimed at the construction of the overlapped section of the shield tunnel between Chajie Station and Dongjiao Road Station in the second phase of the civil engineering of Kunming Rail Transit Line 6, using abaqus finite element software to simulate the construction of the overlap tunnel, and simulate and analyze the shield by changing the shield tunneling parameters. The relationship between excavation parameters and surface soil displacement is expected to be of reference significance for actual engineering.
2. Project Introduction
The section from Chajie Station to Dongjiao Road Station of the second phase civil works of Kunming Rail Transit Line 6 starts at Chajie Station and finally arrives at Dongjiao Road Station. Due to environmental constraints along the line, the ramp section of the line underneath the Juhua overpass is designed as an upper and lower overlap tunnel. The soil layers of the overlap section are mainly silty clay layer and silt sand layer. The tunnel buried depth is 10.38–28.67 m, and the overlap section is long 360 m, the minimum distance between upper and lower tunnels is only 2 m. The excavation diameter is 6.43 m, the inner diameter of the segment is 5.5 m, the thickness of the segment is 0.35 m, the outer diameter of the segment is 6.2 m, and the width of the segment is 1.2 m. Each ring segment is 6 pieces, which are assembled in staggered seams.

3. Establishment of 3D finite element numerical simulation model

3.1. Modeling situation
The overall size of the model is taken as 36 meters in the longitudinal direction of the fully overlapped section of the shield tunnel, with a width of 80 m and a height of 60 m. Because the actual construction process of the shield is relatively complicated, in the model calculation, it is assumed that the soil is isotropic and obeys the Mohr Coulomb yield criterion. The soil is selected from the Mohr-Coulomb constitutive model, which is easy to determine the material parameters. The slurry layers are all made of elastic materials.

According to the research results of Yun Zhang[6] and others, the shield tail grouting layer is generalized into homogeneous, uniform thickness, and elastic equal generation layers. During tunneling, the shield tunnel synchronous grouting is simulated by changing the physical parameters of the equal layer materials. The thickness of the equivalent layer is related to the shield tail gap and the excavated soil layer. In this paper, overlapping shield tunnels mainly pass through the soil layer as silty For the clay layer, take 0.9 times the shield tail gap. Shield tunneling pressure and grouting pressure are set as uniform loads in the simulation. The X direction of the model boundary restricts its displacement in the X direction, the Y direction restricts its displacement in the Y direction, the bottom boundary restricts its Z displacement, and the top surface does not impose any constraints.

However, the grid division method is closely related to the calculation accuracy and calculation speed. In order to ensure the accuracy and time-consuming of the modeling calculation, the soil, shield, segment, and other generation layers are all made of eight-node linear hexahedral three-dimensional entities Unit, the soil around the tunnel adopts grid densification, and the soil away from the tunnel is sparsely meshed. The overall model is meshed as shown in the figure below. The total number of model units is 112868 and the total number of nodes is 136224.

![Figure 1. Shield body, segment and equivalent layer grid division](image-url)
3.2. Parameter value
According to the engineering geotechnical engineering exploration report, combined with local excavation and construction experience in similar soil layers, the physical parameters of the materials are determined as shown in Table 1.

| Structure name         | Elastic modulus (Mpa) | Poisson's ratio | Cohesion (kpa) | Internal Friction angle (°) | Density (kg/m³) |
|------------------------|-----------------------|-----------------|----------------|----------------------------|-----------------|
| Plain fill             | 11                    | 0.35            | 8              | 15                         | 1820            |
| Silty clay             | 14.8                  | 0.3             | 39.6           | 15.3                       | 1990            |
| Silt                   | 20.6                  | 0.3             | 0              | 28                         | 2000            |
| Tube piece             | 29750                 | 0.2             | ——             | ——                         | 2400            |
| Shield body            | 206000                | 0.28            | ——             | ——                         | 7850            |
| Generation level       | 1.2                   | 0.2             | ——             | ——                         | 2100            |
| Grouting reinforcement | 35                    | 0.35            | 38             | 18                         | 2100            |

3.3. Shield tunneling parameter simulation
During the shield tunneling process, the tunneling pressure is applied to the tunnel face when the shield tunneling machine is tunneling, which is used to balance the stress release of the tunnel face soil on the shield machine cutter head. During the tunneling process, the tunnel face soil pressure and the tunneling pressure are restricted by the complexity of the construction conditions, and it is difficult to maintain an absolute balance. Excessive tunneling pressure makes the cutterhead squeeze the soil to cause surface swelling, and too small tunneling pressure will cause surface settlement. Therefore, it is necessary to determine the appropriate tunneling pressure.

The simulation tunneling pressure is set to T=200kPa, T=400kPa and T=600kPa. Simultaneous grouting during shield tunneling has an extremely important influence on the settlement and deformation of the ground. Simultaneous grouting can fill in the building voids created by the tunneling cutter head in time. At the same time, it is also the first barrier for shield tunneling. This article simulates the effect of grouting pressure on surface settlement. When affected, take the grouting pressure P=200kN/m², P=350kN/m² and P=500kN/m² based on the actual situation.

4. Analysis of numerical simulation results

4.1. Analysis of the influence of tunneling pressure on ground settlement of shield tunneling
As shown in Figure 2, from the surface settlement displacement curves of different excavation pressures, it can be seen that the value of the excavation pressure during shield tunneling has a greater impact on the surface settlement displacement. When the tunneling pressure is T=200kPa, T=400kPa and T=600kPa, the maximum surface settlement is 16.6mm, 12.9mm and 6.2mm, respectively. It is found that the greater the tunneling pressure, the smaller the surface settlement. When the shield tunneling pressure is 600kPa, the surface subsidence is significantly reduced. Therefore, in terms of settlement, the greater the tunneling pressure, the better, but when the tunneling pressure is too high, it will cause the soil in front of the tunneling hole to swell, and the excessive thrust will also cause damage to the segment. Therefore, the value should be considered comprehensively in the actual project.
4.2. Analysis of the influence of grouting pressure on ground settlement

As shown in Figure 3, it can be seen from the grouting pressure and surface settlement curve that the value of grouting pressure has a greater impact on the value of surface settlement. The grouting pressure is $P=200\text{kN/m}^2$, $P=350\text{kN/m}^2$, $P=500\text{kN/m}^2$, the maximum surface settlement is 13.55mm, 10.67mm, 8.22mm, respectively. The greater the grouting pressure, the smaller the formation settlement deformation, but if the grouting pressure is too high, it is easy to cause shield tail sealing during shield tunneling leakage. Therefore, in the actual project, the value should be considered comprehensively according to the actual situation.

5. Conclusion

Based on the construction example of the shield overlapped tunnel section of Kunming Line 6, this paper uses finite element numerical simulation to study the relationship between the excavation parameters and ground settlement, and draws the following conclusions.

(1) In the construction of shield tunnels, the greater the shield tunneling pressure, the lower the surface settlement value, but if the tunneling pressure is too high, it is easy to cause the soil mass in front of the tunneling tunnel to swell, and at the same time it is easy to cause the segment to rupture. The tunneling pressure is not the bigger the better, but it needs comprehensive consideration.
(2) The greater the grouting pressure of the shield, the smaller the ground settlement value. However, if the grouting pressure is too large, it is easy to cause leakage of the shield tail seal during shield tunneling. Therefore, it is necessary to combine actual conditions in actual engineering. Consider.

References

[1] Ma, W.H., Peng, H., Yang, C.Y. (2018) The construction parameter control of the shield tunnel underneath the existing subway shield tunnel at a close distance [J], Journal of Southwest Jiaotong University, 53(1):119-127.

[2] Yu, N., Zhu, H.H. (2004) Shield construction simulation and numerical analysis of adjacent influence [J], Rock and soil mechanics, 25(2):292-296.

[3] Zhang, H.B., Man, X.L., Wang, J.L. (2015) Numerical simulation study of tunnel construction technology in silty clay layer [J], Journal of Qingdao Technological University, 36(2):25-29.

[4] Wu, F.B., Jin, H., Yang, Q.Y. (2020) Parameter analysis of ground surface lateral settlement trough in Beijing subway tunnel [J], Tunnel construction (Chinese and English), 40(5):660-671.

[5] Huang, J.L., Sun, X.L., Wang, G.J. (2008) Analysis of Lateral Settlement Troughs in Shield Tunnel Construction [J], Railway construction, (2):34-37.

[6] Zhang, Y., Yin, Z.Z., Xu, Y.F. (2002) Analysis of Ground Deformation Caused by Shield Tunneling [J], Chinese Journal of Rock Mechanics and Engineering, 21(3):388-392.