Numerical simulation study of overlapping tunnels in soft soil

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Abstract. In the process of urban subway shield construction, how to ensure the safety of the newly built tunnel and surrounding buildings is the key issue in the construction. Aiming at the overlapping shield tunneling in soft soil layer, this paper takes overlapped shield tunneling using the overlapping shield tunneling method in a subway section of Kunming Line 6 as the research object, and uses the finite element software ABAQUS to simulate the overlapping shield tunneling. The results are compared with the monitoring data of site construction. The results show that the construction sequence of constructing the lower tunnel first and then the upper tunnel and the condition of grouting and strengthening the soil around the overlapping tunnels can control the settlement of the ground to a large extent.

1. Introduction

During the excavation of overlapping tunnels in the soft soil layer, if effective measures are not taken, excessive surface settlement may be caused, which may cause danger to the new tunnel and surrounding buildings. Although the shield construction technology at home and abroad is becoming more and more mature, and there are more and more urban shield construction tunnels, the theoretical research is obviously behind the practice. Therefore, it is particularly important to strengthen the shield construction theory research. At present, the theoretical research of shield method mainly relies on empirical method (peck formula [1]) and finite element numerical simulation [2]–[3].

This article aims at the construction of shield tunnels in the overlapping section of the second phase civil engineering project of Kunming Rail Transit Line 6 from Chajie Station to Dongjiao Road Station. The abaqus finite element software is used to simulate the construction of overlapping tunnels, the different working conditions of the proposed construction method are analyzed and studied, and compared with the construction monitoring data analysis.
2. Project Introduction

2.1. Project Overview
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 10.38~28.67m, and the overlap section is long 360m, the minimum distance between upper and lower tunnels is only 2m. The excavation diameter is 6.43m, the inner diameter of the segment is 5.5m, the thickness of the segment is 0.35m, the outer diameter of the segment is 6.2m, and the width of the segment is 1.2m. Each ring segment is 6 pieces, which are assembled in staggered seams.

2.2. Construction plan to be adopted
The section between Chajie Station and Dongjiao Road Station in the second phase of Kunming Rail Transit Line 6 is a subsurface excavation section. The main soil layer through which the shield tunnels in the overlapped section passes is a silty clay layer, which has poor stability and is easy to deform, It is easy to collapse, so effective reinforcement design is often needed in actual engineering construction to ensure construction safety. In view of the actual engineering geological conditions of Line 6 and some accumulated construction experience, it is planned to carry out pre-grouting reinforcement for the soil around the overlapping section of the tunnel. In this paper, the ABAQUS finite element analysis software is used to analyze the soil displacement laws caused by the grouting reinforcement area in the surrounding soil layers of the overlapping tunnels, and to study the soil settlement and displacement laws of the overlapping tunnels passing through the silty clay layer, in order to make a difference in actual engineering construction. for your reference.

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 80m and a height of 60m. 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 shield and segment are all set It is an elastic material.

According to the research results of Yun Zhang[4] 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, the overlapped shield tunnels mainly pass through the silty clay layer, taking 0.9 times the shield tail gap. The 3m area outside the lining of the overlapping section of the tunnel is a grouting reinforcement zone. The tunneling pressure and grouting pressure of the tunnel are set as uniform loads in the simulation. The X direction of the model boundary restricts its X-direction displacement, and the Y direction restricts its Y-direction displacement. The bottom boundary constrains the Z-direction displacement, and no constraint is imposed on the top surface.

In order to ensure the accuracy of modeling and calculation and less time-consuming, the soil, shield, segment, and other generation layers use eight-node linear hexahedral three-dimensional solid elements. The soil around the tunnel is processed by mesh encryption, which is far away from the tunnel. The soil mesh is relatively sparse. 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.
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. Simulation of shield tunnel excavation process
In order to be more in line with the actual shield tunnel excavation and reduce the cost of finite element simulation, according to the research results of Sun Jun [5] and others, an excavation section can be calculated according to the width of the three-ring segment 3.6m, so the model is divided into 20 models in total. In the excavation section, shield tunneling is mainly borne by the shield body before the segment is assembled. At the beginning of tunneling, the soil unit of the first excavation section is removed first, and the shield unit and the tunneling pressure are activated at the same time. The tunneling of the first excavation section is completed, the shield unit and tunneling pressure are removed, and the shield is activated to enter the next excavation section for tunneling and excavation. At the same time, the segment is activated to escape the shield tail for synchronous grouting, and the grouting and other generations are activated. The grouting pressure is used to complete the upper tunnel excavation according to the above simulation process.

4. Analysis of numerical simulation results
As shown in Figure 2, after grouting and strengthening the soil around the overlapping tunnels, the maximum surface settlement value after the tunnel excavation is 4.82mm, and the maximum surface settlement value after the upper tunnel is 5.39mm. Under the condition of grouting and strengthening the soil around the tunnel, the maximum surface settlement value of the lower tunnel is 9.33mm, and the maximum settlement value of the upper tunnel surface is 9.83mm. Under the conditions of
comparative analysis with or without grouting reinforcement, it can be found that the soil around the tunnel reinforcement of the layer can greatly reduce the settlement of the surface soil layer.

As shown in Figure 3, under the condition of grouting reinforcement, the maximum ground settlement is 6.54mm at the vault after the tunnel excavation is completed, and the settlement value of the tunnel vault under the tunnel is 4.61mm after the tunnel excavation is completed. This value is 12.90mm and 8.85mm, respectively. The vault of the lower tunnel will rise after the upper tunnel is completed.

Combining the actual measurement values and numerical model data of the ground surface and the tunnel vault under the site construction monitoring, it can be found that under the condition of grouting and strengthening the soil, the settlement curve of the ground surface and the tunnel vault underneath is not much different from the actual monitoring value. It shows that the result of numerical analysis is reasonable.

At the same time, during the shield tunneling process, the soil layers all have subsidence and deformation, and the surface settlement will continue to sink after the tunnel excavation below, but the relative settlement is not large. However, after the upper tunnel excavation is completed, the simulation results and the actual monitoring results found that most of the lower tunnel vault has different degrees of soil rebound and rise. In the case of grouting reinforcement, the lower tunnel rises slightly, and the upper soil is excavated. After the effect of gravity is weakened, the elastic potential energy is released to cause the soil to float up and deform. This phenomenon is likely to cause the lower tunnel to float up due to the uplift of the lower tunnel vault after the upper tunnel excavation is completed during the excavation of the overlapping tunnel, which causes the segment to be wrong. Hidden quality hazards such as tunnels, water leakage, and tunnel overruns need to be paid attention to in the process of overlapping tunnels.
5. Conclusion
This paper is based on an example of the construction of an overlapped shield tunnel in the civil engineering section of Kunming Line 6, and uses the method of finite element numerical simulation and on-site monitoring to carry out the construction of the overlapped tunnel. Research and analysis, come to the following conclusions.

(1) Kunming Rail Transit Line 6 Phase II Civil Engineering Project of the overlap section of the shield tunnel between Chajie Station and Dongjiao Road Station is located in a silty clay layer. The stability of the soil layer is poor. Compared with grouting reinforcement without grouting reinforcement, the ground settlement value after the excavation of the reinforced soil layer can be reduced by about twice.

(2) Under the condition of grouting reinforcement, the maximum ground settlement is at the top of the tunnel after the tunnel excavation is completed. Combined with the monitoring data, it can be seen that the numerical simulation results are close to the measured values, indicating that the numerical simulation results can provide certain guidance for future projects.

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