Analysis of Deformation Characteristics of Surrounding Rock in Shallow Excavation Tunnel

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Abstract: This paper takes the section of the excavation section SK25+490 of Nanzhi Road Station of Harbin Metro Line 2 as the background. Through collecting field monitoring data, the diachronic variation curves of surface subsidence and vault subsidence are drawn. By using FLAC3D software, a 3d model is built based on the engineering profile of the tunnel. Through comprehensive comparison of numerical analysis results and field monitoring data, it is found that the deformation of tunnel surrounding rock can be divided into three stages: rapid deformation, slow growth and basic stability with the advance of palm face. The similarity between the field monitoring data and the numerical analysis of the surrounding rock deformation law is high, which is of guiding significance for the reasonable selection of construction methods and types of supporting lining.

1. Introduction
With the construction of subways in major cities in China, the shallow burying method is widely used in soft formations due to stratigraphic improvement, space-time effects and rapid construction. In this paper, the tunnel excavation section is constructed by PBA method, and the PBA method is a kind of shallow-buried excavation method. The main idea is to combine the cover digging and the step-by-step digging method to each other and give play to their respective advantages. Through the side pile, the middle column, the top bottom beam and the top arch, the initial force system is formed to withstand the load during the construction process. The permanent bearing system formed by the lining combination [1]. However, the problem of surface settlement and deformation of surrounding rock caused by tunnel construction is still a common concern of design, construction personnel and scientific research workers [2]. The dynamic monitoring and measurement of tunnel surrounding rock is an important means to judge whether the surrounding rock is safe and stable. This paper takes the underground excavation section of Nanzhi Road Station of Harbin Metro Line 2 as the background, and first analyzes the on-site monitoring data of the vault sinking and surface subsidence, summarizes the law of surrounding rock deformation during tunnel construction, then uses FLAC3D software to build a three-dimensional model and numerically simulate the tunnel excavation process. The variation of surface settlement and dome subsidence displacement in the section of tunnel SK25+490 is analyzed, and the on-site monitoring results are compared with the simulation results. The deformation law of tunnel surrounding rock is analyzed, which has certain reference value for tunnel construction [3].

2. Project Overview
2.1 Project Overview
Nanzhi Road Station is located at the intersection of Nanzhi Road and Zhujiang Road. The main
structure of the intersection of Nanzhi Road and Zhujiang Road is an underground double-story two-span arched straight wall structure, which is constructed by using the excavated PBA method. The structure adopts φ32 small conduit to advance the pre-grouting to strengthen the stratum. The large arch is advanced by the large pipe shed, and the φ32 small pipe is pre-grouted to reinforce the stratum, and the tunnel is excavated. The starting point of the station excavation section is SK25+455.845, the effective station center mileage is SK25+486.954, and the ending mileage is SK25+518.054. The width of the platform is 11m, and the elevation of the rail surface at the station center is 123.034, and the covering soil is about 5.5m.

2.2 Engineering Geology
The foundation soil of the site drilling depth range (50m) is mainly composed of artificial fill and general Quaternary sedimentary soil. According to its genetic origin, structural characteristics, soil properties and physical and mechanical properties, it can be divided into five large layers. The structure of each layer is as follows: New system of artificial accumulation (Q₄mⅠ，Miscellaneous fill ①)，Uplifting Harbin Group's alluvial deposit (Q₃hⅠml，Silty clay (①) ，Silty clay (②)，Silty clay (②-1))，Middle-Updatedry and Upper Lushan Group Lake (Q₂hⅠ，Silty clay (①)，Silty clay (②)，Silty clay (②-2))，The alluvial layer of the Badan Formation in the Middle (Q₁hⅠml，Silty clay (①)，Silty clay (①-1)，Fine sand (②)，Coarse sand (③)，Coarse sand (④))，Lower update of the ice water accumulation layer of the Tongdong deep well group (Q₁hⅡml，Silty clay (①) ，Coarse sand (①-1))，

3. On-site monitoring and data analysis
On-site monitoring is an important means to study the deformation of tunnel surrounding rock. It can obtain real and effective monitoring data in the first time. Through on-site monitoring, it can grasp the dynamics and information of surrounding rock stability and support deformation and deformation, and pass the surrounding rock and the change of support, stress measurement, modification of the support system design, and guidance of construction operations [4]. In the past, the design of the tunnel relied entirely on experience, but with the rapid development of theoretical analysis methods, its analysis results have been paid more and more attention. Therefore, on-site monitoring and measurement to study the deformation law and stability of rock mass can provide good experience for other similar projects, which is of great significance for the development of tunnel theory [5].

3.1 Monitoring content and detection frequency
According to the deformation of the surrounding rock of the tunnel, the subsidence of the vault and the surface settlement are mainly monitored. The dome sinking measurement is the basic method for judging the supporting effect, guiding the construction operation, confirming the stability of the surrounding rock, and ensuring the construction quality; for shallow tunnels, surface settlement is an important indicator for judging the stability of tunnel surrounding rock [6]. Shallow buried tunnels are usually located in weak surrounding rock with poor stability. If the construction method is improper, the surface will be harmful and sinking. If there is a building on the local surface, it will endanger its safety. Therefore, the measurement of surface settlement can provide a basis for the tunnel excavation speed and the strength parameters of the supporting structure to ensure the safety of the entire tunnel structure and surrounding environment [7]. The layout of the dome sinking and surface settlement monitoring section is shown in Figure 1.
Tunnel surface settlement point layout requirements: a row of measuring points is arranged directly above each guiding hole and the buckle arch, and two rows of measuring points are arranged outside the excavation line of the station structure, and the spacing between the measuring points is 5 m. Layout requirements for vault sinking measurement points: a section every 5m in the longitudinal direction corresponds to the surface settlement monitoring section.

When the settlement or convergence rate is greater than 2mm/day (or $L \leq B$), 1~2 times/day; 0.5~2mm/day (or $B < L \leq 2B$), 1 time/day; 0.1~0.5mm/day (or $2B < L \leq 5B$), 1 time/2days; less than 0.1mm/day (or $L > 5B$), 1 time/week; After basically stable, 1 time/month.

### 3.2 Arch settlement analysis

The displacement of the dome can directly reflect the deformation of the surrounding rock and is also the focus of monitoring and measurement. In this paper, the monitoring points on the SK25+490 section of the No. 3 guide hole are selected as the research objects, and the obtained monitoring data are analyzed and sorted. The obtained settlement rule curve is shown in Fig. 2 and Fig. 3.

According to the analysis of the sedimentation results of Figure 2 and Figure 3, it can be seen that:

- The relationship between the dome displacement and time is mainly as follows: In the early stage of tunnel excavation, the displacement increases rapidly with time. When the time reaches a certain time, the displacement growth rate shows a slow trend and finally stabilizes. The deformation of the surrounding rock can be summarized into the following three stages: rapid

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**Fig. 1 Monitoring point layout**

**Fig. 2 Vault settlement time curve**

**Fig. 3 Cumulative settlement time curve**
deformation stage (8.23~9.3) The initial deformation rate of surrounding rock after tunnel excavation is very large, and the cumulative convergence displacement accounts for about 80% of the final observed convergence displacement. Slow growth phase (9.4~9.11) The deformation rate begins to slow down, and this part of the cumulative convergence displacement accounts for about 20% of the final observed convergence displacement. Basic stabilization phase (9.12~9.19) The deformation amount is basically no longer increased, the deformation rate approaches zero, and the surrounding rock of the tunnel tends to be stable.

- Judging from the curve of the settlement of the dome, the amount of collapse of the section during the inspection is small, the maximum value is 1.5mm, and the sinking and convergence speeds are converging, indicating that the tunnel surrounding rock is in time after the excavation. The deformation of the protection system is small.
- When the excavation face is within the range of twice the diameter of the measuring point, the settlement value is larger, and the settlement value is significantly smaller than the double hole diameter. This is due to the favorable influence of the timely support of the tunnel after excavation.

3.3 Surface settlement analysis

The monitoring of surface subsidence is an important part of on-site monitoring and measurement. Through the monitoring measurement during tunnel excavation, the information of surface settlement can be grasped in time. Taking the monitoring points on the section of the No. 3 guide hole SK25+465 as the research object, the change process of the settlement amount can be obtained by monitoring the data, and the obtained settlement curve is shown in Fig. 4 and Fig. 5.

![Fig. 4 Surface subsidence change curve](image1)

![Fig. 5 Surface cumulative settlement time](image2)

According to the analysis of the sedimentation results of Figures 4 and 5, it can be known that:
- Because the distance between the left and right lines of the same section is relatively close, the settlement values and settlement laws of the left and right lines on the same section are similar. The closer the distance from the centerline of the tunnel, the larger the surface settlement.
- The settlement value above the left line of the section is larger than the settlement value above the right line. This is because the left upper guide hole is first excavated, and the soil around the upper left guide hole is disturbed when the upper right guide hole is excavated, so when the left line is excavated a large settling is produced.
- The cumulative settlement value of the section is relatively flat, and no abnormal phenomenon
occurs, that is, the sinking deformation of the tunnel is in a normal deformation state.

4. Numerical Simulation Analysis of Surrounding Rock Deformation

4.1 Calculation model
The FLAC3D finite difference software is used to establish a three-dimensional model based on the actual excavation of the tunnel, and the tunnel excavation-support process is simulated. Since the influence of stress redistribution caused by tunnel excavation is 6 times the whole diameter, the simulation range is 6 times the hole diameter, the simulated tunnel excavation length is 60m, the left and right boundaries of the model are 25m away from the tunnel boundary, and the length of the upper and lower boundaries is taken 45m. The cross-sectional shape of the numerical model is shown in Figure 6 [9].

The mechanical model of the surrounding rock adopts the Mohr-Coulomb elastoplastic model; Initial support (shotcrete) using solid element simulation, the constitutive model is an elastic model. The left and right boundaries and the bottom of the model are both one-way constrained displacement boundary conditions. Stress boundary conditions are applied to the top of the model. The initial stress of the surrounding rock is the self-weight stress of the overlying soil [10].

4.2 Simulation result analysis
Figure 7 is a displacement cloud diagram of the surrounding rock of the tunnel in the vertical direction. It can be seen from the figure that the maximum settlement value of the dome is directly above the centerline of the pilot hole, and the maximum settlement is 12.5 mm, which is larger than the on-site monitoring data, but the difference is small.

Figure 8 is a displacement cloud diagram of surface subsidence. It can be seen from the numerical simulation results that the surface settlement caused by excavation of the tunnel under the condition of initial support is the largest at the center of the tunnel center line, which is 11 mm. From the figure, the
surface settlement trough formed by tunnel excavation can be clearly seen. In the same section, the settlement value is the largest above the tunnel axis. The farther away from the tunnel axis, the smaller the settlement, the more stable. And the cumulative settlement of the surface decreases with the increase of the buried depth.

![Fig. 8 Surface settlement displacement cloud](image1)

![Fig. 9 Vault sinking with excavation curve](image2)

Taking the section of 20m in the longitudinal direction as the research object, the settlement data of the dome changing with the excavation surface is arranged, and the curve is drawn as shown in Fig. 9. From the analysis of the settlement curve, it can be seen that with the advancement of the excavation face, the deformation of the surrounding rock mainly undergoes a sharp deformation to a gradual easing, and finally reaches three states of stability. It provides a theoretical basis for the construction time of the initial support system and the prediction of surrounding rock deformation.

5 Conclusion

This article combines Harbin Metro Line 2 Nanzhi Road Station dark excavate the section and conduct specific analysis for the relevant data of the typical section. The excavation process of the tunnel under initial support conditions was simulated by FLAC3D software. The comparison between the displacement cloud map of the surrounding rock and the measured data of the field deformation was carried out. The following conclusions were obtained.

- Through the analysis of the monitoring data and numerical simulation results, the ground settlement of the tunnel is the largest deformation directly above the centerline of the section, the farther the distance from the axis is, the smaller the settlement is, and the settlement rate of the tunnel excavation surface is within the range of twice the diameter of the observation point. When the diameter of the cave is twice larger, the sedimentation rate slows down and gradually stabilizes.

- It can be seen from the curve of the subsidence of the vault and the surface subsidence that the two are mutually influential, the arch is too large, and the corresponding surface settlement will show a similar trend.

- From the displacement-time curve of the tunnel, the deformation of the tunnel surrounding rock can be divided into the following three stages: In the rapid deformation stage, the displacement increases rapidly with the increase of time in the early stage of tunnel excavation; During the slow growth phase, the deformation rate begins to decrease; In the basic stabilization phase, the deformation rate approaches zero and the surrounding rock is basically stable.

- According to the on-site monitoring data and simulation results, it is found that the settlement value of surrounding rock is small and within the scope of subsidence control standard. It is due to the timely support of the tunnel during the excavation process. After a period of stress adjustment, the branch is supported. The force of the protection system tends to be stable.

The similarity of the surrounding rock deformation law of the on-site monitoring data and numerical analysis is high, which proves the rationality of the numerical model and the obtained law, which provides reference for the safe construction of similar tunnel engineering.
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