Optimization design of pre-reinforcement scheme for large cross section shallow buried tunnel in Xi'an Metro

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Abstract. In order to control the deformation of the surrounding rock of the large section of the tunnel, the author analyzes the stratum displacement law caused by the tunnel excavation by means of on-site monitoring. And the optimized design of the existing tunnel pre-reinforcement scheme is carried out. The FLAC3D numerical simulation method is used to verify the feasibility of the pre-reinforcement optimization scheme. Field test showed that the tunnel surrounding rock deformation in the allowable range, and the deformation control measures of the surrounding rock are reasonable and effective. The research results have important guiding significance for future similar project.

1. Introduction
The surrounding soil disturbance and damage caused by tunnel excavation will cause the formation of different strata deformation [1-2].

Especially through the loess stratum, due to the stability of such soil vulnerable to the impact of water, dug construction process is easy to cause the collapse of the working face [3], which has brought great trouble to the tunnel construction, we must take reasonable and effective Pre-reinforcement measures to ensure project safety [4].

2. Project overview
Xi'an subway A section of the tunnel is located in the bustling area of the city. According to the on-site investigation, the surrounding area of the tunnel is very complicated and has 60m phase with the subway B station. It is designed to be larger than 100 m² due to the later transportation demand, the destination mileage is K19+851.632 - K19+905.653. The thickness of the soil above the tunnel dome is 8m. The CRD method [5] is used to construct the tunnel, and the depth of the groundwater level is between 8.70m and 9.80m in this section of the tunnel. This section is a type of diving [6].

The road traffic is very busy at the top of the tunnel, so the construction process must control the surface subsidence, to ensure that the road traffic is smooth during construction. Drilling revealed that the surface of the tunnel has a new distribution of plain fill \( Q_{4}^\text{vol} \). The distribution of the strata is down to the following: the new Pleistocene Aeolian \( Q_{3}^\text{eol} \), the residual soil, the old loess, the Silty clay, the silt, the coarse sand, the Silty clay and so on.

3. Strata displacement and deformation characteristics of tunnel surrounding rock under the original pre-reinforcement scheme

3.1 Tunnel pre-reinforcement parameters
(1) Pipe roof design parameters: Using Φ108mm hot-rolled seamless steel pipe, the thickness of pipe is
5mm, which arranged along the ring. The circumferential spacing is 0.5m, the external angle between 2° and 3°. The grouting liquid is made of 1:1 cement and water glass slurry, and the layout range for the arch is 120°.

(2) Advanced small duct parameters: Using Φ42 ordinary steel pipe, the length of pipe is 4.5m. The circumferential spacing of which is 0.25m and the longitudinal distance of which is 1.5m. The slurry is cement and water glass slurry. The layout range for the arch is 120°.

3.2 Vertical displacement of strata

Figure 1 The sedimentation Variation Curve of Deep Stratum over Tunnels vault

The point at the depth of 8m is the vertical measuring point of the vault in figure 1. As can be seen from Figure 1, the settlement of the strata increases with the increase of the buried depth, the reason is that part of the stratum appear relaxation area. When the measuring point is 6m ahead of the working face, the displacement value of the upper stratum of the tunnel is small, ranging from 1~4mm. When the measuring point is 12m behind the working face, the displacement of the upper strata of the tunnel grew more obvious, and the closer to the tunnel vault, the larger ground settlement is. The maximum settlement value is 30.18mm.

In the actual construction process, the maximum settlement of the ground reaches to 50-60mm, resulting in the upper road cracking, causing the pipeline rupture, and the wall of adjacent building cracking. The ground settlement caused by the CRD construction method increases with the increase of the excavation of the pilot tunnel. Although the construction method can effectively control the settlement of the ground. However, as a result of the research object is the loess large cross section tunnel, the ground settlement caused by CRD construction over allowable settlement value. So, we must take the ground settlement control measures in order to ensure the normal traffic on the ground.

3.3 Deformation characteristics of tunnel surrounding rock

(1) The level of groundwater is difficult to drop to the height of the design requirements. The moisture content of the surrounding rock is high, and the stability of the working face is poor. There have been two working faces collapse, but fortunately did not cause any casualties, causing the ground settlement above the tunnel obviously.

(2) The vault settlement is 375mm and the horizontal convergence is 294mm. Steel arch deformation distortion is serious; there is the risk of destabilizing damage.

(3) The deformation of the tunnel floor between 187mm and 226mm, which results in the mechanical operation is difficult.
4. Optimum design of pre-reinforcement scheme for underground excavation in shallow buried tunnel

4.1 Optimization of strata pre-consolidation scheme

In the original pre-reinforcement design scheme, the ground settlement caused by the excavation construction is too large. The deformation of the surrounding rock and the damage of the working face of the tunnel are rooted in the fact that the advanced small duct is not sufficient to maintain the stability of tunnel working face in this project. Combined with experience in the construction of Xi’an subway excavation construction, If we want to optimize the tunnel pre-reinforcement schemes, we should increase the number of pipe roof and the quantity of grouting liquid to sleeve valve pipe, and other supporting parameters of tunnels are kept unchanged.

(1) Pipe roof design parameters: Other parameters unchanged, the layout range for the arch is adjusted to 150°.

(2) Advanced small duct parameters: Using Φ42 ordinary steel pipe, the length of pipe is 3.5m. The circumferential spacing of which is 0.25m and the longitudinal distance of which is 1.5m. The slurry is cement and water glass slurry. The layout range for the arch is 150°.

(3) The sleeve valve tube grouting parameters: The grouting range is 180° for the arch and 3m in the periphery of the tunnel. The slurry is cement and Water glass.

4.2 Numerical simulation analysis of stratum pre-reinforcement optimization scheme

4.2.1 Model building. The soil on the vault of the tunnel is 8m, and the model area is 100 × 40 × 35 m. The calculation model is shown in Fig 2. The measures of pipe roof pre-grouting and small duct reinforcement, can be considered approximated that form a round reinforcement ring around the tunnel, which thickness is 0.5m. In the process of numerical simulation, this circular reinforcement ring is considered as the original strata; The cable unit is used to simulate the small duct and the pipe roof. The surface element is used to simulate the initial shotcrete and the steel grating. The thickness of shotcrete is 0.35m.

![Figure 2 FLAC3D calculation model(Unit: m)](image)

4.2.2 Calculation parameters. According to the report of geotechnical investigation and laboratory experiments, we can get the parameters related numerical calculation, as shown in Table 1.

| category       | Thickness (m) | Elastic modulus (MPa) | Poisson ratio | Density (kN/m³) | Angle of internal friction (°) | Cohesion (kPa) |
|----------------|---------------|-----------------------|---------------|-----------------|-------------------------------|----------------|
| Miscellaneous  fill | 2.51          | 2.54                  | 0.26          | 18.69           | 12.71                         | 11.21          |
| Plain fill     | 3.53          | 3.25                  | 0.26          | 17.91           | 19.14                         | 14.73          |
| New loess      | 8.05          | 6.43                  | 0.31          | 18.79           | 26.36                         | 17.86          |
| Old loess      | 12.16         | 9.27                  | 0.32          | 19.29           | 28.43                         | 16.32          |
| Silty clay     | 9.38          | 8.91                  | 0.32          | 20.08           | 28.97                         | 19.20          |
4.2.3 Analysis of numerical simulation results. The Mohr - Coulomb constitutive model is used to calculate the initial stress field, and then the excavation and support are carried out in strict accordance with the construction sequence. In the process of calculation, we should monitor the ground settlement and the deep deformation of overlying strata. At the same time, the earth pressure monitoring points are set in the dome and arch of the tunnel.

(1) Surrounding rock displacement

![Contour of Z-Displacement](image)

1) Vertical displacement nephogram

![Contour of Z-Displacement](image)

2) Horizontal displacement nephogram

Fig.3 Displacement and displacement of surrounding rock of loess tunnel after stratum reinforcement (Unit: m)

It can be seen from Fig. 3 that the maximum settlement of the tunnel dome is 9.90mm after the deformation control of the surrounding rock, and the maximum horizontal displacement is 5.15mm. The deformation of the surrounding rock is small, and the tunnel surrounding rock can be ensured, which indicates that the control measures of tunnel surrounding rock deformation proposed in this paper are feasible.

(2) Deep strata displacement
It can be seen from Figure 4 that the stratum above the tunnel vault under the disturbance from tunnel excavation, the closer from the dome, the greater the settlement value is; The greater influence from the construction disturbance. The maximum ground settlement above the tunnel vault is 4.51mm, and the settlement of ground near the vault is 7.42mm. The settlement of the surrounding strata above the dome is smaller than that of the top of the vault. With the increase of the depth, the ground settlement continuously reduce. Because the strata has a certain distance from the tunnel wall and less affected by the construction disturbance.

3) Ground settlement

It can be seen from Fig. 5 that after the reinforcement measures, the ground settlement caused by tunnel excavation is small, the width of settlement groove is 30m, and the maximum settlement above the vault is 4.53mm, which can meet the normal application of the road traffic above the tunnel.

Based on the above analysis, it can be seen that after the reinforcement measures, the deformation of the surrounding rock and the amount of ground settlement are small, which are within the allowable range. Therefore, the control measures proposed in the paper of tunnel surrounding rock deformation are feasible and can ensure that the surrounding rock stability and normal transport of urban roads in the process of tunnel construction.

4.3 Deformation Monitoring of Surrounding Rock Caused by Tunnel Excavation after Pre-reinforcement Scheme Optimization

4.3.1 Monitoring results of surrounding rock deformation. Taking the YCK19 + 290 monitoring section as the research object, the effect of the surrounding rock deformation control technique proposed in this paper was evaluated. The curves of the vault settlement and horizontal convergence with time are obtained, as shown in figure 6~7.
It can be seen from Fig. 6 to Fig. 7 that after the deformation control measures of the surrounding rock of the tunnel and its surrounding strata, the deformation of the surrounding rock increases rapidly with time, and until 15th, the growth trend of the deformation of surrounding rock tends to gentle and stabilized. The ultimate values of vault settlement and horizontal convergence are 11.93mm and 5.98mm respectively, and the deformation of surrounding rock is within the allowable deformation range, which indicates that the proposed deformation control measures are good.

### 4.3.2 Comparison of measured and calculated values of surrounding rock deformation in tunnel

In order to objectively evaluate the rationality of the deformation control measures proposed in this paper, quantitative analysis is used in this section to compare the measured values with the numerical simulation values, and verify the scientific of numerical simulation to predict the deformation of surrounding rock.

| Section number         | Monitoring value /mm | Calculated value /mm |
|------------------------|----------------------|----------------------|
| YCK19+290               |                      |                      |
| Vault settlement        | 11.93                | 9.90                 |
| Horizontal convergence  | 5.88                 | 5.15                 |

It can be seen from Table 2 that the field monitoring value is close to the finite element simulation results, the error is less than 5%, indicating that the research method used in this paper is reasonable, the research results are reliable, and further illustrate the rationality of the tunnel pre-reinforcement program, construction method and procedure.
5. Conclusion
(1) Analyzing the parameters of the deformation of strata and surrounding rock under original pre-reinforcement, we can obtain that the stability of the working face in tunnel is poor, which causing the deformation of tunnel surrounding rock and strata too large and affecting the normal traffic of the road above the tunnel. Combined with the deformation characteristics of tunnel surrounding rock, the pre - reinforcement scheme of tunnel is optimized.

(2) The feasibility of pre - reinforcement optimization scheme is verified by FLAC numerical simulation. The measured results show that the proposed deformation control measures are reasonable and effective, and it is possible to ensure that the surrounding rock deformation is within the allowable range.

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