Optimizing and Monitoring Measurement of Single Tunneling Outlet Scheme for Three-lane Large Cross-section Tunnel

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Abstract. For a three-lane tunnel with large cross-section and one-way excavation, it is of great significance to select a reasonable scheme of entering and leaving the tunnel for the economy, safety and protection of the ecological environment of the tunnel construction. Taking Changshanpu No. 2 Tunnel as an example, the reasons for the optimization of the tunnel section are analyzed, the advantages of the optimization scheme are discussed, and the reasonable scheme is given. Through the numerical simulation of the outlet section, the monitoring data of the top of the tunnel and the analysis of the comprehensive index, it is concluded that the previous double-sided wall method is optimized to three-step temporary inverted arch method at 30m away from the outlet of the tunnel, which has the following advantages: (1) the construction space is large, the mechanical operation is convenient, the construction progress is accelerated, and the schedule requirements are met; (2) the construction of the temporary construction facilities and the large excavation in tunnel outlet section are avoided; (3) The method of three-step temporary inverted arch can be separately closed into rings, effectively restraining the deformation of surrounding rock, and the monitoring measurement meets the requirements. Therefore, the use of three-step temporary inverted arch method can improve the safety and efficiency of such highway tunnel construction, and provide a reference for future construction.

1. Introduction
In the construction of soft surrounding rock at the entrance section of three-lane and large-section expressway, the traditional construction methods include double-sided guide pit method, CD method, etc. Especially for medium and short tunnels with one-way exit, which are widely used. However, these construction methods are slow in progress, inefficient and have certain limitations. Therefore, drawing on the experience of large-section tunnel construction, we can avoid the limitations of traditional construction methods. It is particularly important to explore more reasonable construction methods [1]. Selection of reasonable construction methods can speed up tunnel construction progress, ensure construction safety, improve construction quality and reduce damage to the environment and water system. Therefore, the optimization of the one-way tunnelling and exit scheme of three-lane large cross-section tunnel and the preventive treatment will play a great guiding role in the construction of similar tunnels [2-3].
For the optimization of tunnel entry scheme, domestic and foreign scholars have done the following research in tunnel excavation by using theory and numerical simulation: Bai L.C. analyzed the stability of Beiyatou tunnel surrounding rock based on field monitoring data and established numerical model, which shows that the deformation of tunnel entrance section is small and consistent with the actual situation, so the optimization of construction scheme should be carried out [4]. Chen L.H. analyzed Shigu Tunnel in Yinpingshan Nature Reserve. Because of the pressure of environment and construction period, one-way tunnelling technology was adopted to ensure the construction quality and safety [5]. Shen J.J. et al. studied the mechanical properties of four-lane highway tunnel lining structure under different concrete strength grades and thickness by numerical calculation method, which showed that the thickness of the second lining had a reasonable range and was beneficial to structural safety [6]. Wei G. et al. measured the settlement of arch crown, convergence of arch waist and inverted arch uplift in shallow tunnel in soft soil area. It was concluded that rainfall and soil conditions would cause the settlement of arch crown. CRD method and four-step method had larger settlement in strong weathered rock [7].

Despite the above research, few tunneling schemes with such a large cross-section as three lanes have been optimized. At the same time, no numerical simulation and comprehensive index comparison have been made to verify the rationality of the scheme optimization [8]. Beginning with the sixth tender section of the expressway from Huizhou to Qingyuan, this paper analyses the reasons for the optimization of the one-way tunnel exit scheme of Changshanpu No. 2 tunnel and the characteristics of the related schemes. Through numerical simulation, monitoring and measurement analysis, it is concluded that the three-step inverted arch method after optimization can accelerate the construction progress, ensure the construction quality, and protect the ecological environment [8-10].

2. **General situation of Engineering**
Changshanpu No. 2 Tunnel passes through the structure eroded low mountain topographic area. It is a small net distance separated tunnel. The left tunnel has a starting and ending mileage of K88+369-K88+865 and a length of 496m. The inlet section of the tunnel is bamboo-cutting type. The entrance of the tunnel is designed with a height of 250 m. The outlet section of the tunnel is designed with an end wall type as shown in Figure 1. The entrance of the tunnel is designed with a height of 240m, a slope of -1.7%, and the maximum buried depth of the tunnel is One-way tunnelling at the entrance (Shantou end) is planned for the tunnel. The length of the Left-Line third-grade wall rock is 195 m, accounting for 40.88%; the fourth-grade wall rock is 186 m, accounting for 38.99%; and the fifth-grade wall rock is 96 m, accounting for 20.13%. The right tunnel has a starting and ending mileage of K88+385-K88+875, a length of 490m, a bamboo-cutting gate at the entrance, a design elevation of 250m at the entrance, an end wall at the exit, a design elevation of 248m at the entrance, a slope of -1.7%, and a maximum buried depth of about 97m.

**Figure 1 Landform at the exit of Changshanpu No. 2 tunnel**
2.1 Engineering Geological Conditions

The tunnel site belongs to the low mountain topographic area of tectonic denudation. The whole mountain body is nearly north-south, and the surface elevation is 220-410m. The overall inclination of the slope of the tunnel body section is about 200 degrees. Along the slope, many gullies are formed. The cutting depth varies from 3 to 10 m, and the width varies. The highest elevation of the tunnel section is at K88+600, the elevation is about 340m, the lowest point is at the exit of the tunnel, the elevation is about 240m, and the relative elevation difference is 100m. The entrance of the cave is a valley slope with a slope of about 90 degrees, steep slope and gentle slope. The upper part is about 35 degrees, the lower part is about 25 degrees, and the valley and slope are sporadically distributed with granite orphans, ranging in diameter from 0.5 to 5 meters, with thick overburden and dense vegetation. The slope of the exit is about 260 degrees, with a slope of about 35 degrees, with a rock wall on the left side, a north-south trending gully at the bottom, and a depth of 3-5 meters wide downward cutting. At the bottom of the ditch, there are streams with a depth of about 100 m, and there are many hillside stones.

There are still 30 meters away from the entrance of the tunnel. The surrounding rock of the face of the tunnel is mainly weathered granite. The surrounding rock cracks are well developed. The rock mass is fragmented and fragmented, mostly with fractured block-mosaic fractured structure. The local cracks of the excavation face are densely developed or strong weathered and weak fractured interlayers are developed. During rainy season, the surrounding rock is partially rainy-linear flowing out of water, and the surrounding rock grade is V.

The natural slope at the tunnel exit is steep, vegetation is well developed, the cover is thin, the exposed rock is granite, the rock is hard, and the excavation depth is strong to moderately weathered rock mass. At present, the slope is stable as a whole. There are two sets of joints in the lower middle weathered rock mass. Joints intersect with the slope at a large angle or are reversed slopes, which have little effect on the stability of the slope. Structural plane combination which has no effect on slope stability has not been formed.

2.2 Hydrogeology

The groundwater in the tunnel site is pore water and bedrock fissure water of Quaternary loose strata, which are respectively hosted in slope residual strata and bedrock strata. The depth of water level varies with seasons, and the amount of water is affected by the development of bedrock fissures, and may be enriched locally. Groundwater is mainly recharged by atmospheric rainfall and lateral flow, and evaporation and lateral runoff are the main discharge modes. Generally speaking, the groundwater quantity in the tunnel site area is general.

2.3 Previous design scheme

ZK88+831-ZK88+861 is a class V surrounding rock with a length of 30m and a shallow buried section at the entrance of the tunnel. The surrounding rock is mainly composed of residual silty clay and strongly weathered granite on the slope. It is partly weathered rock with low strength and easy to soften and disintegrate in water. The previous design excavation method is double-sided guide pit method. The advance support of the entrance section uses the super-long pipe shed of φ108, the advance support of the tunnel body uses small pipe of φ50.

3. Tunnel scheme optimization

3.1 Optimization reason

Previous designed for the construction of double-sided guide pit method, its construction method steps are more, construction progress is slow; and large-scale excavation is needed to ensure the stability of the slope at the entrance of the tunnel, which causes great damage to the local ecological environment; the latter stage of demolition of double-sided guide pit method is difficult, and the surrounding rock can be disturbed twice. Therefore, it has the following advantages to change the method of double-sided guide pit to the method of three-step temporary inverted arch.
(1) The left entrance of Changshanpu No. 2 Tunnel is located in a steep cliff with dense vegetation. The revised design scheme is three-step temporary inverted arch method and one-way entrance, which protects the ecological environment of the entrance to the greatest extent and implements the concept of "zero excavation" of the entrance.

(2) The left exit site of Changshanpu No. 2 Tunnel is too small to meet the construction schedule.

(3) In the previous design scheme, boreholes and grouting seriously damaged the surrounding atmosphere and water system during the support process of advanced large pipe shed. After the change, three-step temporary inverted arch construction method were used to reduce the damage to the surrounding environment, the construction progress was obviously accelerated, the disturbance to surrounding rock was reduced, and the stability of surrounding rock at the entrance of the tunnel was better guaranteed.

(4) The temporary support of double-sided guide pit method can be demolished only after the monitoring measurement proves that the surrounding rock is stable, which is difficult to demolish, and the second disturbance to the stabilized surrounding rock has potential safety hazards. The lower bench and the middle bench of the three-step temporary inverted arch method can be pulled open for 10 m, and the lower bench can play a core role in the middle bench; the middle bench and the upper bench can be pulled open for 10 m, and the middle bench plays a core role in the upper bench. Soil function is guaranteed in safety.

3.2 Optimization plan
In order to ensure the smooth and safe excavation of Changshanpu No. 2 tunnel, according to the topography and surrounding environment of the tunnel entrance, and in accordance with the principle of protecting the environment as far as possible and reducing the impact of construction on water quality and ecology, the specific scheme is to excavate the first step of Part Ⅰ, and to provide early support in time, i.e., spraying 4cm thick shotcrete, erecting steel frame, re-spraying concrete to the design thickness after drilling the bolt of the system, and temporary inverted arch at the bottom. Installation of temporary steel frame and shotcrete; excavation of Part Ⅱ after proper distance from upper step construction, joining long steel frame, timely implementation of initial support and temporary inverted arch steel frame and shotcrete; demolition of upper temporary steel frame and shotcrete, excavation of part Ⅲ, timely closure of initial support; pouring of part IV inverted arch; pouring of inverted arch filling of part V tunnel bottom; analysis based on monitoring measurement results, When the initial support converges, the VI part lining is poured with the lining formwork at one time as shown in Figure 2.

Figure 2 Construction process diagram of the excavation of the three-step temporary inverting arch of the V-class surrounding rock

4. numerical simulation
4.1 Model Establishment
In this paper, FLAC3D is used to carry out numerical simulation. In the simulation process, the surrounding rock adopts the Mohr-Coulomb model, the support structure adopts the elastic model, the shell element is used for the initial support, and the solid element is used for the second lining. The top of the numerical simulation model is free boundary, the bottom is fixed constraint, and the displacement constraint is applied around\[11-12\]. Surrounding rock and supporting parameters are shown in Table 1.

Table 1. Surrounding rock and support mechanical parameters.

| level | Bulk density (kN / m\(^3\)) | Modulus of elasticity (E(GPa)) | Poisson ratio | Friction angle (°) | Cohesion (c(MPa)) |
|-------|-----------------------------|-------------------------------|---------------|-------------------|------------------|
| V     | 20                          | 1.3                           | 0.35          | 22                | 0.12             |

4.2 Result analysis
According to the actual engineering geological conditions, the three-step construction method is adopted at 30m away from the entrance of the tunnel. For the three-step construction method, the variation of the plastic zone of the surrounding rock during the construction process is shown in Figure 3.

Figure 3. Variation diagram of plastic zone excavation by three-step method.

With the excavation of upper, middle and lower bench and inverted arch, the plastic zone of surrounding rock gradually enlarges and eventually expands into the shape of “butterfly”. After the inverted arch excavation, the plastic zone is further extended to the inverted arch foot, and the surrounding rock at the base of the arch foot develops downward shear yielding. The excavation of the upper, middle, lower bench and inverted arch under the three-step and inverted arch construction method can also better control the deformation of surrounding rock. The surrounding rock still has a certain bearing capacity, indicating that the surrounding rock is in a critical equilibrium state at this time. The surrounding rock of arch foot should be strengthened and the initial support should be made early so as to prevent excessive settlement of the tunnel as a whole.

After three-step excavation, the vertical displacement variation of surrounding rock in the tunnel is shown in Figure 5. When the upper and middle bench are excavated, the settlement of the vault is the largest, which is 7.6 mm, accounting for 89% of the total settlement. When the inverted arch is excavated, the total settlement of the left and right arch feet is equal to the settlement of the vault, which indicates that the whole settlement exists in the tunnel excavation, and the settlement of the left and right arch feet is mainly caused by the partial suspension of the arch feet. Therefore, it is necessary to implement shrinkage anchor and temporary groove steel cushion in time after step excavation to increase the bearing capacity of arch foot.
In summary, the plastic zone of tunnel excavation mainly concentrates on the tunnel vault and arch foot, and the construction of initial shotcrete and arch foot bolt should be strengthened as early as possible to ensure the safety of tunnel construction; the deformation of tunnel is small enough to meet the requirements of design specifications.

5. Construction Monitoring and Comprehensive Index Analysis

5.1 Monitoring and Measurement Analysis

Two settlement monitoring points are set up on the tunnel vault to monitor the size of vault settlement during tunnel opening excavation. The settlement of the vault at G1 and G2 points on the left and right lines is shown in Figure 5.

From Figure 5, it can be seen that in the process of tunnel excavation, the vault of the tunnel with three-step temporary inverted arch method increases rapidly at first, then the settlement decreases slowly until it is stable, and the settlement remains basically unchanged. Because the excavation sequence is to add temporary inverted arch to the upper bench, temporary inverted arch to the middle bench, temporary inverted arch to the lower bench. The middle bench and the upper bench are 10 meters apart, and the middle bench and the lower bench play the role of core soil to the upper bench. The inverted arch is no longer excavated and the lining structure is closed, so the settlement of the vault tends to be stable. The maximum settlement of the left tunnel is 11.8 mm, and the maximum settlement of the right tunnel is 6.7 mm. The above values all meet the design requirements of the code, so the three-step method can ensure the construction safety.
5.2 Comprehensive Index Analysis

Combined with the actual situation, the comprehensive progress index of three-step tunnel excavation is shown in Table 2.

| surrounding rock level | Construction method                     | loop Footage /m | Daily follow Ring number | Daily integration Ruler/m | Monthly integrated Ruler/m | Remarks                              |
|------------------------|-----------------------------------------|-----------------|--------------------------|----------------------------|----------------------------|--------------------------------------|
| Main hole V            | both side heading method                | 1               | 0.75                     | 0.75                       | 18.75                      | 24-hour uninterrupted operation and 25-day monthly effective construction. |
| V                      | Three-step temporary inverted arch method | 1               | 2                        | 2                          | 50                         |                                      |

From the above comparative analysis, it can be seen that the progress of the three-step and temporary inverted arch method is obviously better than that of the two-sided wall method.

In summary, it can be seen that the maximum settlement of the vault of the left and right tunnel is not more than 15mm when the three-lane large cross-section tunnel is excavated by the three-step method, and the monthly comprehensive construction progress of the three-step method is 50m, which is more than twice the construction progress of the previous design method. The construction progress is obviously accelerated and the local ecological environment is protected.

6. Conclusion

Based on the comprehensive analysis of Changshanpu No. 2 Tunnel, the optimization of one-way tunnelling construction scheme for three-lane large cross-section tunnel is studied. Through monitoring and measurement of excavation process, the following conclusions are drawn:

1) Changshanpu No. 2 Tunnel is 30m away from the entrance of the tunnel. The previous double-sided wall excavation method is optimized to three-step method temporary inverted arch method, which reduces the impact of ecological, environmental and water system, reduces the construction area, greatly speeds up the construction progress, reduces the disturbance to surrounding rock, simplifies the construction process and ensures the construction safety.

2) The length of the upper, middle and lower bench should be controlled to avoid instability due to the long excavation distance. In addition, the arch foot should be supported in time to prevent the overall subsidence of the tunnel due to the uncertain surrounding rock.

3) The three-step temporary inverted arch method is to divide the large cross-section into three small units from top to bottom for excavation and to reduce the excavation cross-section; the use of temporary inverted arch is to make each small unit closed in time to form a ring force, effectively exert the overall force effect of initial support, protect the natural bearing capacity of surrounding rock, effectively restrain the deformation of surrounding rock and prevent the deformation of supporting structure.

4) According to the monitoring data of tunnel excavation construction, the convergence of the vault of the left tunnel and the settlement around the left tunnel are the maximum values, which are 11.8 mm and 18.5 mm respectively, which are twice the corresponding monitoring values of the right tunnel. It can be seen that the right tunnel is excavated first, and then the left tunnel is excavated. During the excavation of the left tunnel, the disturbance to surrounding rock is increased, and the settlement of the vault is larger. Therefore, the monitoring and measurement of the left tunnel should be strengthened in the construction process.

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Reference

[1] Tunnel Construction, (2018). Key Techniques for Undercut Construction of Urban Shallow Tunnels with Ultra-Shallow Buried Extra Large Section Straight Wall Tunnel. http://202.202.244.12:80/rtw/CNKI/http/NNYHGLUDN3WXTLUPMW4A/kcms/detail/41.1448.U.20181203.1459.032.html.

[2] Wan J.F., Li D.S. (2017) Study on the Structure Design of Bridge Tunnel Connections under Complex Terrain Conditions [J]. Tunnel Construction (in Chinese and English), 37(S2): 169 - 174.

[3] Li K, Guo J. (2016) Study on ventilation of one-way tunneling construction of extra-large section highway tunnel[J]. Highway and Motor Transport, 2016(02):211-215.

[4] Bai L.C. (2018) Optimization of Construction Scheme for Large-section Highway Tunnels[J]. Journal of Highway and Transportation Technology (Apps & Technology Edition), 14(10): 209-212..

[5] Chen L.H. (2013) Research on Rapid Construction Technology of One-way Tunneling in Shigu Tunnel[J]. Journal of Highway and Transportation Technology, (1): 105-110.

[6] Shen J.J, Wan L, Liu C.L, Zhang C.A., Hu Y.Y. (2018) Study on thickness optimization of secondary lining of super-large section four-lane highway tunnel[J]. Highway Traffic Technology,34(S1):6-11.

[7] Wei G, Yao W.J., Xu B, Shi C.J., Fu Y., Wang Z. (2018) Analysis of the settlement of the vault of shallow-buried large-section tunnel in soft soil area[J]. Tunnel Construction (Chinese and English),38(7): 1123-1130.

[8] Ma G.Q. (2018) Analysis on Key Technology of Shield Tunneling Out of Weak Water and Weak Stratum in Complex Engineering Environment[J]. Construction Technology, 2018, 47(14): 39-43.

[9] Zhou W.C, Guo R.J., Qian H.J. (2018) Settlement Monitoring and Control Analysis of Large Cross-section Tunnel Underpassing Loose Stratum[J]. Journal of Highway and Transportati- on Technology , 14(08): 153-155.

[10] Journal of Shandong University. (2018) Analysis of the influence of large section and small clear distance highway tunnel construction.http://202.202.244.12:80/ Rwt/CNKI/http/NNYHGLUDN3WXTLUPMW4A/kcms/detail/37.1391.T.20180625.1152.002.html.

[11] Wang Z.J. (2018) Research on Key Technologies of Mechanized Construction of Large Section of Zhengwan High-speed Railway Tunnel[J]. Tunnel Construction (Chinese and English), 2018, 38(8): 1257-1270.

[12] Song C.J., Li K., Guo J., Lin Z. (2014) Study on ventilation organization of single head tunnel construction in special highway tunnel[J]. Journal of Highway and Transportation Technology, (2): 91-96