Optimized Selection of Construction Scheme for Huiqing Expressway Tunnel

Hua Kaikeng¹, Guo Hongyan²*, Li Ke², Cui Xiangyang³

¹Guangdong Provincial Road and Bridge Construction Development Co. Ltd, Guangzhou 510000, China
²China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd, Chongqing, 400000, China
³Chongqing Jiaotong University, Chongqing, 400000, China

*Corresponding author’s e-mail: guohongyan@cmhk.com

Abstract. In view of the complex construction environment of the mountain tunnel, the construction method conforming to each project is adopted, which is beneficial to avoid blind spots during the construction process. For poor surrounding rock conditions, the thickness of different soils will lead to the joint of the plastic zone of the excavation face, which will cause the overall settlement. Taking Maple Ridge, Daping and Fengshuao Tunnels as an example, comprehensive analysis of different surrounding rock thickness conditions, through the comparison of three construction methods of double side wall method, CD method and three step method, using FLAC finite element software results Analysis gives the most advantageous deformation control method. The results show that the larger the thickness of the overburden, the larger the displacement of the arch and the arch, the double-wall method does not extend to the slip zone in the plastic zone of different soil thickness, and the surrounding rock also maintains the self-stability, compared with the other two methods. Good stability. Therefore, it has a good guiding significance for the construction method in the same situation in the future.

1. Introduction

For mountain tunnels with poor stability of surrounding rock, the mechanical properties of surrounding rock are reduced and the self-stabilization ability is poor due to the different burial depth. Therefore, choosing appropriate construction methods can effectively control surrounding rock deformation, speed up construction progress and ensure construction safety. In the construction process, there is no clear stipulation on how to choose the two-sided wall method, three-step method and CD method. For the V-grade surrounding rock conditions, better construction methods than the selection, effective treatment measures and application of similar tunnels behind the construction of a greater guiding role [1-3].

The construction methods of tunnels with poor stability of surrounding rock are studied by domestic and foreign scholars using theory and numerical simulation as follows: Song Jiwu proposed an improved three-step and seven-step excavation method, and obtained that the improved construction method can effectively control the deformation of soil around the tunnels through numerical simulation [4]. Zhai Dongming et al. obtained the corresponding operating conditions of three methods through the application of three different construction methods in Large Cross-section Tunnels [5]. Chen Mingkui et al. numerically simulated the three-step method, the single-side-wall
method and the double-side-wall method, and found that the double-side-wall method is an effective scheme [6]. The field test and numerical analysis of Li Yacui, Yang Xin’an and other large cross-section soil tunnels show that the six-step CD method is the optimal construction method for this kind of soil surrounding rock.

The advantages of the improved construction method for controlling the deformation of surrounding rock are obtained by numerical simulation, and the application conditions of three construction methods are obtained. However, it is not pointed out which construction method should be adopted when considering different thickness of surrounding rock under poor surrounding rock conditions. On the basis of domestic and foreign researchers, starting from Huizhou to Qingyuan section of Shantou-Zhanjiang Expressway, this paper analyses the factors such as thickness of overlying soil and poor surrounding rock conditions, and concludes that the double-sided wall method is more suitable for application in this project [8-11].

2. Introduction to Engineering Background

2.1. Project Survey

Fengshuao Tunnel passes through hilly terrain area, which is a small net distance separated tunnel. The left tunnel has a starting and ending mileage of ZK68+024~ZK68+770, 746m in length. The entrance of the tunnel is end-wall type, the design elevation of the entrance is 302.88m, the exit of the tunnel is end-wall type, the design of the entrance is 319.60m, and the maximum buried depth of the tunnel is about 113.07m. The right tunnel has a starting distance of K68+020~K68+770 and a length of 750m. The entrance end-hole is end-wall type, the entrance is 302.88m, the exit end-hole is end-wall type, the entrance is 319.60m, and the maximum buried depth of the tunnel is about 116.30m.

Daping Tunnel passes through the low hilly terrain area, which is a small net distance separated tunnel. The left tunnel has a distance of ZK70+656~ZK71+385 with a length of 729 m. The entrance section of the tunnel is end-wall type. The entrance section of the tunnel is designed with an elevation of 361.85 m. The exit end-wall type is adopted, the entrance design is 367.83 m, and the maximum buried depth of the tunnel is about 98.68 m. The right tunnel has a starting distance of K70+655~K71+275 and a length of 620m. The entrance end-hole is end-wall type, the entrance is 361.85m, the exit end-hole is end-wall type, the entrance is 368.42m, and the maximum buried depth of the tunnel is about 108.33m.

2.2. Engineering Geological Characteristics

The intensity of neotectonic movement is weak and the structure is relatively stable in Fengshuao tunnel site area; the shallow rock differentiation fissures are well developed, the rock mass integrity is poor, and the deep joint fissures are generally well developed. There are mainly three groups of joint fissures, which are not conducive to the stability of tunnel surrounding rock.

The structural movement intensity of Daping Tunnel is weak and the structural stability is relatively good; the shallow rock weathering cracks are well developed, the rock stability is poor, and the deep joint cracks are generally well developed. There are mainly two groups of joint cracks, which are not conducive to the stability of the surrounding rock of the tunnel.

3. numerical analysis

In order to describe the quality of surrounding rock, strata are usually classified into several categories by grading method for engineering design and method selection. According to the numerical simulation of CD method, double-sided guide pit method and three-step seven-step excavation method adopted in the tunnel by FLAC software, the adaptability conditions of three construction methods in the upper stratum of Huiqing Expressway are obtained [12-16].
3.1. Computational Hypothesis
According to the plane strain model, the rock mass around the tunnel is discretized by the hexahedral finite element method. The following assumptions are made for the rock mass and supporting structure:

Mohr-Coulomb criterion applicable to geotechnical materials is adopted for plastic yield (failure) criterion. In order to consider the supporting effect of the construction method itself, the effect of system bolt and advance small pipe grouting is not considered for the time being.

The calculation models are about 50m in lateral direction. From the displacement field shown by the calculation results, the influence of boundary conditions on the calculation results can be neglected, and there is no boundary effect [17-18].

3.2. Selection of Surrounding Rock Parameters
The parameters such as equivalent stiffness of solid elements used in numerical simulation are shown in Table 1.

| Name                        | Natural density (g/cm³) | Modulus of elasticity E(MPa) | Poisson ratio μ | internal friction angle ψ (°) | Cohesion c/MPa |
|-----------------------------|-------------------------|------------------------------|-----------------|-------------------------------|----------------|
| Silty clay                  | 1.95                    | 20                           | 0.42            | 12                            | 16             |
| Strongly weathered sandstone| 1.99                    | 200                          | 0.33            | 22                            | 80             |
| Weak weathered siltstone    | 2.00                    | 500                          | 0.3             | 30                            | 220            |
| Initial support             | 2.4                     | 2.8×10⁴                      | 0.2             |                               |                |
| Secondary lining            | 2.5                     | 3.15×10⁴                     | 0.2             |                               |                |

3.3. numerical model
FLCD software is used to simulate the working conditions of different construction methods, and brick is used to simulate the initial support, which obeys the linear elastic stress-strain relationship. Taking the double-sided wall method as an example, this model considers the displacement of tunnel vault and arch foot in the case of 10/20/30m, respectively, as shown in Fig. 1 - Fig.3.

Fig 1 Double wall buried depth 10m model
4. Result analysis

4.1. Displacement Analysis by Bilateral Wall Method
The displacement of the vault top and the horizontal displacement of the vault bottom are shown in Table 2 when the buried depth is 10/20/40 m and the surrounding rock grade is V.

| Construction method | Burying depth (m) | Vault displacement (mm) | Horizontal displacement (mm) |
|---------------------|-------------------|-------------------------|-----------------------------|
| Bilateral wall method | 10                | 9                       | 3.4                         |
|                      | 20                | 17.5                    | 11.4                        |
|                      | 40                | 36.5                    | 30                          |

It can be seen from the table that the vault settlement of the left and right guide pits increases with the increase of buried depth. The vault settlement is 9 mm at 10 m depth and 36.3 mm at 40 m depth. The horizontal displacement of the upper and lower steps of the double-sided guide pit also increases with the increase of buried depth. The displacement of the side wall is only 3-4 mm at the depth of 10 m, nearly 30 mm at the depth of 40 m and between the two buried depths at the depth of 20 m. It can be seen that the vault displacement and horizontal displacement increase with the increase of burial depth.

4.2. Displacement Analysis by Three Step Method
The displacement of vault top and horizontal displacement of vault bottom by three-step method under the condition that the buried depth is 10/20/40 m and the surrounding rock grade is V are shown in Table 3.
| Construction method | Burying depth (m) | Vault displacement (mm) | Horizontal displacement (mm) |
|---------------------|-------------------|-------------------------|-----------------------------|
|                     | 10                | 16.8                    | 5.9                         |
|                     | 20                | 34                      | 18.6                        |
|                     | 40                | 67.6                    | 54.6                        |

It can be seen from the table that the vault settlement increases with the increase of buried depth during the excavation of upper, middle and lower steps. The vault settlement is 16.8 mm at 10 m depth and 67.6 mm at 40 m depth. The horizontal displacement of the three-step excavation increases with the increase of buried depth. The displacement of the side wall is only 5.9 mm at 10 m depth and 54 at 40 m depth. The deformation value of 6 mm and 20 m buried depth is between the above two buried depth.

4.3. CD Displacement Analysis
Because of the disturbance of the left pilot tunnel excavated in advance, the settlement of the vault of the right pilot tunnel excavated later is larger than that of the left pilot tunnel, and the law has nothing to do with the burial depth. The displacement of vault and horizontal displacement of vault bottom under the condition of 10/20m depth are selected by three-step method as shown in Table 4.

| Construction method | Burying depth (m) | Vault displacement (mm) |
|---------------------|-------------------|-------------------------|
|                     | 10                | 8.3                     |
|                     | 20                | 16.2                    |

It can be seen from the table that the settlement of the arch roof by CD method increases with the increase of buried depth. The settlement of the arch roof is 8.3 mm at 10 m buried depth and 16.2 mm at 20 m buried depth. The horizontal displacement of the arch wall by CD method increases with the increase of buried depth. The displacement of the side wall by CD method is only 4.2 mm at 10 m buried depth and 9.5 mm at 20 m buried depth. CD method is affected by the disturbance of the left pilot tunnel excavated first, and the settlement of the vault of the right pilot tunnel excavated later is larger than that of the left pilot tunnel, and this law has nothing to do with the burial depth.

4.4. Comprehensive comparative analysis
In the case of V-grade surrounding rock with a depth of 10/20/40m, the displacement curves of vault top and arch foot are obtained by numerical simulation using double-sided wall method, three-step method and CD method as shown in Fig. 4 and Fig. 5 respectively.
With the increase of burial depth, the plastic zone around the tunnel increases with the increase of ground pressure. Under the condition of increasing burial depth, the displacement of vault top and arch foot is obviously smaller than that of three-step method. After excavation by the three-step method and CD method, the plastic zone runs directly from the arc arch foot to the surface until it is further extended to the arch foot, and the surrounding rock of the arch is in a critical equilibrium state. Because of the weakness of the base rock and the bearing capacity of the foundation, under the action of the upper load, the arch foot and the arch have the overall settlement together. Therefore, it is difficult to ensure the stability of surrounding rock during the excavation of each step because of the high safety risk of using the three-step method. The deformation control of CD method is better than that of three-step and seven-step excavation method. The deformation of tunnel under 20m depth is similar to that of double-sided excavation method, but the deformation of tunnel under 20m depth is larger than that of double-sided excavation method. Therefore, the application of bilateral wall method in this project is conducive to deformation control under different burial depth.

5. Conclusion
Through the above comprehensive analysis of the construction methods used in Daping and Fengshuao Tunnels, this paper studies the construction methods adopted in the case of poor surrounding rock conditions and different thickness of overburden soil, and draws the following conclusions:
(1) Summarize the above three construction methods of different thickness of overlying soil, double-sided wall method, three-step method and CD method. Combined with the results of numerical simulation analysis, when the tunnel is buried deep, with the increase of surrounding rock pressure above the arch top, due to poor surrounding rock conditions, tunnel excavation results in large displacement of the top and arch foot.

(2) The basis for better control of deformation by using bilateral wall method under the condition of V-grade surrounding rock is obtained. Under different burial depth conditions, the plastic zone does not extend to the surface to form a shear slip zone, and the surrounding rock has a certain self-supporting capacity, so the deformation of the tunnel is the smallest.

(3) In order to ensure safety, the reserved deformation and supporting parameters should be adjusted in time according to the monitoring results of surrounding rock. In the course of excavation, if the surrounding rock changes and does not conform to the requirements of the drawings, the excavation method shall be determined jointly by the owner organized by the Director General and the design parties.

(4) Although the numerical analysis method used in this paper has a good guidance for practical engineering, due to its less application, a large number of engineering cases are needed to verify the conclusions and enrich the application scope.

Acknowledgments
The authors would like to express their appreciation to the special project of national key research and development plan (2017YFC0805305), the National Natural Science Foundation of China (41601574), the scientific research project of Tibet autonomous region (2016XZ01G31), the science and technology program of Tibet autonomous region (XZ201801-GB-07), and the Chongqing Science and Technology Innovation Leading Talent Support Program (CSTCCXLJRC201715) for providing funding for this research.

Reference
[1] Jiang K., Xia C.C., Yan Y.W. (2012) et al. Optimization analysis of two-way eight-lane small clear tunnel construction in jointed rock mass[J]. Rock and Soil Mechanics, (33)03:841-847.
[2] Shi X., Z. Jia., Liu B.Z. (2015) Study on the Construction Process of Large Section Shallow Buried Bias Tunnel by CRD Method[J]. Modern Tunnel Technology, 52(03):193-199.
[3] Chen S.Y., Zhu Y.P., Li Z., H. Li H., Zhang H.L. (2014) Analysis of the Influence of Lateral Slope Stability of Large Section Loess Bias Tunnel[J]. Modern Tunnel Technology, 51(01):82-89.
[4] Song J.W. (2017) Study on Optimization of Construction Method for Large Section Loess Tunnel[J]. Shan xi Architecture, 43(13):187-188.
[5] Zhai D.M., Hou M.Z., WuK.L., Zhang Y.L. (2015) Analysis and Comparison of Construction Schemes for Deep-buried Large-section Tunnel Excavation[J]. Journal of Highway and Transportation Technology, 11(11):206-209.
[6] Chen M.K., Shen Y.S., Hou R.B. et al. (2014) Comparison and selection of construction methods for large-span karst tunnels[J]. Journal of Highway Engineering. 39(2):031-036.
[7] Li Y.C., Yang X.A., Guo L. et al. (2014) Optimization analysis of construction method for large-section shallow buried soil tunnel[J]. Journal of East China Jiaotong University, 31(5):012-017.
[8] Xu C.B., Xia C.C., Zhu H.H. et al. (2009) Analysis of construction scheme of two-way eight-lane multi-arch tunnel[J]. Chinese Journal of Rock Mechanics and Engineering, 30(1):66-73.
[9] Gong J.W., Xia C.C., et al. (2009) Optimization analysis of construction scheme for large section and small clearance tunnel in Heshang[J]. Rock and Soil Mechanics, 30(1):236-240.
[10] Cheng X.S., Wang J.H., et al. (2013) Study on construction method of super large section loess tunnel based on displacement control of surrounding rock[J]. Rock and Soil Mechanics, 35(1):82-88.
[11] Zhang X.W. (2012) Elastoplastic analysis and construction optimization of tunnel surrounding rock under seepage effect[D]. Changsha: Central South University.

[12] Li Q.Q., Zhang D.L., Zhang C.P., Fang Q. (2013) Experimental Study on Surrounding Rock Failure of Metro Tunnels under Different Buried Depths[J]. Modern Tunnel Technology, 50(06):85-9

[13] Xu C. (2019) Control of Tunneling Parameters of Mud-Water Balance Shield Tunnel in Sandy Cobble Ground[J]. Railway Construction, 59(02):94-97.

[14] Wang Z.J. (2018) Study on Key Technologies of Mechanized Construction of Large Section of Zhengwan High-speed Railway Tunnel[J]. Tunnel Construction (Chinese and English), 38(08):1257-1270.

[15] Qin W. (2017) Optimization of Anchorage Parameters of Mountain Tunnel Construction Based on Harmony Search Algorithm[J]. Journal of Highway and Transportation Management Technology, 13(05):324-327.

[16] Liu J. (2017) Analysis of Forced Deformation of Tunnel Support in Fractured Rock Mass and Suggestions for Design of Bolt Parameters[J]. Journal of Highway and Transportation Research and Development, 13(01):104-106

[17] Zhang Z., W., JingZ,R. Zhihua. (2015) Optimization Model and Engineering Application of Combined Supporting Parameters of Anchored Steel Frame in Weak and Broken Surrounding Rock Tunnel[J]. Route Tunnel, 03):13-18.

[18] Wang D.Y., Yuan J.X., Li X.Z., Liu L.Y. (2015). Parameter Optimization of Construction Process of Underwater Double-line Shield Pipe Gallery[J]. Highway Engineering, 40(01):43-47.