Study on Key Steps of Three-lane Weak Surrounding Rock Tunnel Construction

Chao Wang $^{1,2}$, Hongyan Guo$^3*$, Xiangyang Cui $^{3,4}$, Ke Li$^3$ and Hao Ding$^3$

$^1$Guangdong Road and Bridge Construction Development Co., Ltd., Guangzhou, 510000, China;
$^2$Guangdong Communication Planning & Design Institute Co., Ltd., Guangzhou, 510000, China;
$^3$China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd., Chongqing, 400000, China;
$^4$Chongqing Jiaotong University, Chongqing, 400000, China;

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

Abstract. For tunnel excavation with poor stability of surrounding rock, controlling the construction of key steps in each construction method is of great significance to tunnel construction. Taking Fengshuao and Daping tunnels as examples, this paper uses FLAC software to simulate three construction methods, i.e. double sides heading tunnel method, three-step method and CRD method. Through the analysis of displacement deformation in the numerical simulation results of three construction methods, it is concluded that the corresponding steps of maximum displacement deformation in different construction methods are the key steps in construction: the double sides heading method needs to strictly control the excavation of double-sided upper steps, the excavation of inverted arch and the dismantlement of middle-wall; the three-step method mainly controls the excavation of curved guide tunnel of upper steps, the excavation of inverted arch and the strike of locked bolts. The control steps of CRD method are the excavation of upper steps on the left wall, the excavation of upper steps on the right wall and the dismantlement of the middle wall. Therefore, strictly controlling the key steps of each construction method can improve the safety and efficiency of this kind of highway tunnel construction, and provide reference for future construction.

1. Introduction

Because of the poor stability and eccentric pressure of surrounding rock of highway tunnel, the selection of key steps in tunnel construction method is particularly important [1]. Defining the key steps in the construction method has played a significant role in speeding up the construction progress, ensuring the construction safety and saving funds. However, different construction methods correspond to different key steps in the process of tunnel excavation. Therefore, exploring the key steps of each construction method and taking precautions against them will play a guiding role in the construction of tunnels with similar construction methods [2].

The construction methods of tunnels with poor surrounding rock stability are studied by domestic and foreign scholars using theory and numerical simulation in tunnel excavation. Li P.Y. uses FLAC software to establish a tunnel deformation prediction model under soft surrounding rock conditions. The simulation results and field data monitoring show that the method of reserving core soil is correct.
[3]. Shu D.G. used the fluent-additional expansive force field coupling numerical simulation method, through the simulation analysis of different construction methods, concluded that the step method is most suitable for the construction of Hefei Metro tunnel, and the excavation size should be less than 1.5m [4]. Zhang Y.L. analyzed the application conditions and technical requirements of the two construction methods for the construction of large-span shallow buried soft surrounding rock, and obtained their respective characteristics and application [5]. Xu R.N. and others used Flac3d software to establish five construction methods for Xigeda Stratum. From the point of view of space-time effect characteristics of surrounding rock deformation, the corresponding construction methods satisfying each reserved deformation were obtained. Tian J. and others made a detailed analysis of the key working procedures of tunnel construction through practical experience, and obtained the corresponding solutions to the problems [7].

Although the above researches have been done on tunnel construction methods under different surrounding rock conditions, the key steps corresponding to each method have not been explored. For different construction methods adopted in tunnel construction process, protective measures cannot be effectively applied to the key steps, resulting in safety problems in construction. Starting with the TJ4 section of the Huizhou-Qingyuan section of Shantou-Zhanzhou Expressway, this paper analyses and compares three different construction methods. Through numerical simulation, the displacement and deformation during tunnel excavation under different working conditions are obtained. By comparing the displacement and deformation under each working condition, it is concluded that the corresponding steps of the maximum displacement and deformation are the key steps in construction, which should be strengthened and strengthened in the construction process. The important precautionary construction steps are given theoretical basis [9-10].

2. General situation of Engineering
Fengshuao Tunnel passes through hilly geomorphic area. It is a small net distance tunnel. The left tunnel has a starting and ending mileage of ZK68+024-ZK68+770, a length of 746m, and the right tunnel has a starting and ending milege of K68+020-K68+770, a length of 750m. The entrance section is end-wall type with a design elevation of 302.88m. The intensity of neotectonic movement in Fengshuao Tunnel is weak and the structure is relatively stable, with a maximum buried depth of about 58.8m, a two-way six lanes, a net width of 14.75m and a net height of 7.74m. Weathering cracks in shallow rock mass are well developed, rock mass integrity is poor, and deep joint cracks are generally well developed, mainly developing three groups of joint cracks, which are not conducive to the stability of tunnel surrounding rock.

The Daping Tunnel passes through the low hilly terrain area, which is a small clear distance tunnel. The left tunnel has a distance of ZK70+656~ZK71+385, 729 m in length. The entrance section of the tunnel is end-wall type, the entrance design elevation is 361.85 m, the exit end-wall type, the entrance design elevation is 367.83 m, the maximum depth of the tunnel is 98.68 m, the two-way six lanes, the net width of the tunnel is 14.75 m, the net height is 7.74 m; the right tunnel is from the beginning to the end-wall type. Cheng K70+655~K71+275, 620m long. The partial pressure phenomenon exists in the ZK70+645~ZK70+850 section of Daping Tunnel. The local stress concentration of the tunnel may cause the tunnel structure to be destroyed by shearing. It should be monitored emphatically. The shallow partial pressure section of ZK70+660~ZK70+720 is located in the mountain gully, and the surrounding rock is silty clay, strongly weathered granite and moderately weathered granite from top to bottom. The overburden of the vault is about 2.0-12.0 m, and the topographic bias is serious.

3. numerical simulation analysis
3.1 Computing Scheme and Model Establishment
Three construction methods, namely, three-step method, CRD method and double-sided guide pit method, are selected in the construction section of this project, and the key steps of the three construction methods are analyzed. In this paper, Flac software is used to carry out numerical
simulation analysis, and the maximum deformation corresponding to the three construction methods is obtained respectively[11]. By controlling the maximum deformation corresponding to various construction methods, the important construction steps of various construction methods are obtained. The numerical analysis model is shown in Figure 1-3.

Figure 1 Calculation model of double sidewall guide pit method

Figure 2 Three-step calculation model

Figure 3 CRD method calculation model

3.2 Selection of Mechanical Parameters of Surrounding Rock and Support

According to the past experience, the elastic modulus E of the surrounding rock reinforcement circle will remain unchanged when the C and $\varphi$ value of the surrounding rock reinforcement circle are increased by 30%. The parameters such as equivalent stiffness of solid elements used in numerical simulation are shown in Table 1.
Table 1 Value table of surrounding rock mechanics parameters

| Name                  | density (g·cm\(^{-3}\)) | modulus of elasticity E/GPa | Poisson ratio/μ | friction \(\varphi/\circ\) | Cohesive c/MPa |
|-----------------------|--------------------------|-----------------------------|-----------------|-----------------------------|----------------|
| silt 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                      | 2.8×10\(^4\)                | 0.2             |                             |                |
| Secondary Lining      | 2.5                      | 3.15×10\(^4\)               | 0.2             |                             |                |

4. Analysis of calculation results

The displacement of tunnel vault under three working conditions, double-sided guide pit method, three-step method and CRD method is extracted, and the curves of vault displacement under three working conditions are drawn as shown in Figure 4, Figure 5 and Figure 6. The ratio of settlement to vault settlement during excavation is shown in Table 2, Table 3 and Table 4.

4.1 Result Analysis of Double-sided heading Method

Figure 4 shows the variation curve of the vault settlement of the left, middle and right guide pits with the excavation process of the tunnel. By analyzing and comparing the settlement of arch roof and horizontal displacement of arch foot under different construction methods, if the displacement deformation is large, it is the key step in the construction process, and should focus on protection and monitoring in the construction process.

![Figure 4 Settlement curve of the left, middle and right guide tunnels of the double-sided heading method](image)

It can be seen from Figure 4 that during the excavation of the tunnel, the settlement of the vault of the left, middle and right guide pits begins to increase rapidly, then increases slowly. The maximum settlement is 4.7 mm, 7.4 mm and 5.3 mm in turn. When the middle wall is demolished, the settlement increases suddenly, and the maximum settlement changes to 7.5 mm, 9.9 mm and 14.3 mm. After the implementation of the secondary liner, the settlement will not change. Because the excavation...
sequence is left pilot pit in front, right pilot pit in next, middle pilot pit in the end, left pilot pit in advance of right pilot pit 15 m, and settlement measurement point 10 m from the edge of the model. Therefore, when the face of the left pilot pit reaches the section of settlement measurement point, the right pilot pit and the middle pilot pit have not been excavated, so the settlement of the arch top of the left pilot pit is the largest at the beginning of Figure 4.

Based on the analysis of the data in Table 2, the excavation of the upper steps of the left and right guide pits by bilateral wall method has a large proportion of deformation and settlement, which is the key construction step. When the over-excavated of inverted arch at one time, the structure will be suspended and the full-ring will closure delay, and the whole deformation will be caused by the rheological action of soft rock, so the inverted arch excavation is the key process. The dismantling of the middle wall is at the node where the stress system of the integral support is transformed. The composite bearing of the initial support and the middle wall is transformed into the single bearing of the initial support, which causes the sudden increase of settlement and become the key construction step.

### Table 2 Proportion of stage settlement and stage crown settlement in bilateral wall method

| Measuring point position | Stage Settlement and Stage Settlement Ratio | Total settlement |
|-------------------------|-------------------------------------------|------------------|
|                         | Left hole excavation | Right hole excavation | Middle hole excavation | Before dismantling temporary shoring | After dismantling temporary shoring |
| 1 Left heading Vault    | 4.7 | 1.3 | 0.7 | 6.7 | 7.5 |
| 4 Right heading Vault   | 0.9 | 7.4 | 0.9 | 9.2 | 9.9 |
| 7 Middle heading Vault  | 2.9 | 5.3 | 5.2 | 13.4 | 14.3 |

4.2 Analysis of the results of three-step method

Figure. 5 shows the settlement of tunnel vault, and the horizontal displacement curve of left and right monitoring points with the process of tunnel excavation. In order to facilitate comparative analysis, the horizontal displacement of the right monitoring point is taken as absolute value. Horizontal convergence represents the relative horizontal displacement of left and right measuring points.

On the whole, the maximum settlement of the vault is more than 14 mm, which is 5.9 mm larger than that of the double-side heading method. Before the excavation arrives at the monitoring point, the settlement of the arch roof does not occur. After the excavation, the settlement of the arch roof increases rapidly. After the second lining (the horizontal coordinate 60m position in the figure) is applied, the increase rate of the settlement of the arch roof decreases immediately, and the settlement value does not change at the later stage. When the middle step is excavated to 20 m away from the monitoring point of the tunnel face, the horizontal convergence of the side wall increases sharply, reaching a maximum of 7.1 mm.
By analyzing the data in Table 3 below, it can be concluded that the excavation of the upper step arc guide pit is the key construction step for settlement control. In this stage, the settlement of the vault accounts for 47% and the settlement of the arch foot accounts for 33%. The excavation of the middle step will cause the settlement control of the vault and the horizontal convergence of the side wall, and the excavation of the middle step is the key construction step. The inverted arch is too long in the longitudinal excavation of the tunnel, which causes the steel frame at the foot of the wall to be suspended, and the closure time is too long, which will cause the overall settlement of the structure. The inverted arch closure should be taken as a key process to control.

Table 3 Proportion of stage settlement and stage arch settlement by three step method

| Measuring point position | Stage Settlement and Stage Settlement Ratio | Excavation stage | Total settlement /mm |
|-------------------------|--------------------------------------------|------------------|----------------------|
|                         | Stage Settlement and Stage Settlement Ratio | Upper step       | Middle step          | Lower step          | Core soil        | Inverted arch   |                      |
|                         |                                            | 5.94             | 5.41                | 1.43                | 0.03             | -0.17            | 12.64               |
| 1                       | Vault                                      | 47.0%            | 42.8%               | 11.3%               | 0.2%             | -1.3%            |                      |
| 2                       | Left arch                                  | 3.57             | 5.77                | 1.67                | 0.02             | -0.13            | 10.9                |
| 3                       | Right arch                                 | 3.53             | 5.68                | 1.59                | 0.05             | -0.17            | 10.68               |

4.3 Analysis of CRD results

As can be seen from Figure 6, before the removal of the middle wall, the settlement of the vault of the left and right guide pits increases first, and then remains basically unchanged. The maximum settlement of the vault is 6.1 mm and 8.3 mm. The settlement of right pilot arch is larger than that of left pilot arch. Because the excavation sequence is left pilot pit ahead, right pilot pit behind, left pilot pit ahead of right pilot pit 15m, and settlement measurement point is 10m away from the edge of the model. Therefore, when the settlement measurement point is reached at the face of the left pilot pit, the right pilot pit has not been excavated, so the settlement of the left pilot pit vault is larger than that of the right pilot pit vault at the beginning of the drawing. When the middle wall is demolished, the settlement increases suddenly, reaching the maximum of 6.7mm and 9.4mm. After the secondary lining is applied, the settlement will not change.
From the data in Table 4 below, it can be seen that the excavation of the upper step on the left side wall is the key construction step for settlement control. In this stage, 50.6% of the settlement of the left vault is affected, and 34% of the settlement of the right vault is affected. The excavation of the upper step on the right-side wall affects the settlement of the right vault, which accounts for 35.2%, and further leads to the connectivity and development of the plastic zone in the surrounding rock. Therefore, the excavation of the upper step on the right-side wall is the key construction step for settlement control. Removal of temporary support links accounts for 13% to 19% of the total settlement, which has a great impact and should be considered as a key process to control.

Table. 4 Proportion of stage settlement and stage arch settlement by CRD method

| Measuring point position | Stage Settlement and Stage Settlement Ratio | Total settlement /mm |
|------------------------|---------------------------------------------|----------------------|
|                         | Excavation stage                             |                      |
|                         | Left upper Steps | Left lower Steps | Right upper Steps | Right lower Steps | After dismantling temporary shoring |
| 1 Left heading Vault    | 6.92 | 1.39 | 2.06 | 0.7 | 2.61 | 13.68 |
| 2 Right heading Vault   | 5.37 | 1.64 | 5.56 | 1.18 | 2.04 | 15.79 |

5. Conclusion
Through the comprehensive analysis of Fengshuao and Daping tunnels, this paper studies the characteristics of different construction methods, explores the key steps of different construction methods, and draws the following conclusions:

1) For the upper step excavation in both sides heading method, it is necessary to control the single cycle footage of step excavation. It is necessary to follow up the support in time, shorten the footage of excavation, and control the settlement deformation and horizontal displacement of key processes. The inverted arch closure should be controlled as a key process because of the delay of suspension and full-ring closure caused by the large excavation of the inverted arch at one time. The dismantling of
the middle wall is at the point where the whole supporting system transforms. In order to prevent the sudden change of the supporting system, the temporary dismantling of the middle wall should be set as a key process to control.

2) In the three-step method, it is necessary to strictly control the length of the step and the single cycle footage. It is suggested that the anchor pipe of lock foot bolts and the groove steel cushion plate be set up to increase the vertical supporting capacity of the arch steel frame. The closure of inverted arch excavation causes the suspension of steel frame at the foot of the wall. The closure of inverted arch should be controlled as a key process. The key construction steps of CRD method are as follows: the excavation of the upper step on the left wall is the key construction step for settlement control, the excavation of the upper step on the right wall is the key construction step for settlement control, and the removal of the mid-partition wall should be regarded as the key process to control.

3) The key steps of three construction methods obtained by numerical simulation in this paper need to be tested in practical projects; the key steps listed in this paper do not mean that other construction processes are not important, and we should pay more attention to the key steps. Therefore, a large number of supplementary models for engineering demonstration are needed to better guide construction.

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