Analysis of Excavation Method and Transformation of Construction Method for Highway Tunnel

Yuwen Nie¹, Hongyan Guo²*, Xiangyang Cui³ ²³ Ke Li² and Hao Ding²
¹Guangdong Communication Planning & Design Institute 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. The geological conditions of tunnel entrance section are complex, and the hazards of landslide and collapse are easy to occur, which makes the selection of construction methods of tunnel entrance section particularly important before tunnel construction. Therefore, it is of great significance to study the transformation of construction methods between tunnel body section and tunnel entrance section for the safety construction of tunnel entrance section. Taking a tunnel of Meida Expressway as an example, the geological characteristics of the tunnel body and the tunnel entrance section of Meida Expressway are analyzed. Based on the comprehensive consideration of the construction period, safety and advantages and disadvantages of the construction method, the CD method is adopted to construct the tunnel outlet section. Through numerical simulation of tunnel body and outlet section, it is concluded that CD method is superior to bench method in tunnel body section, and can ensure construction safety; and the steps of conversion from bench method to CD method are summarized. Finally, through monitoring and measuring the surrounding rock and surface deformation near transition section, it is concluded that the maximum cumulative deformation at vault top is 78.6 mm, and the maximum cumulative deformation at surface is 94.6 mm, which meets the requirements of specifications and ensures the safety of the tunnel entrance. Therefore, reasonable transformation of tunnel construction method can ensure construction safety, at the same time, it can also speed up construction progress and save funds.

1. Introduction
The tunnel project occupies an important role in the whole highway construction process. The completion of the main structure of the tunnel is decisive for the overall completion of the entire expressway. Due to the huge investment in labor and machinery costs during the tunnel construction process, it is important to explore reasonable construction methods during the tunnel construction process to shorten the construction period and ensure construction safety [1]. Because the tunnel is underground and the geological conditions are complex, in the tunnel construction process, different construction methods can be selected for different geological conditions [2], which can guarantee the construction period and save money. Study the conversion of different construction methods in the tunnel construction process [3-4], which has a guiding role for such projects.

For the optimization and selection of tunnel construction methods under different surrounding rock conditions, domestic and foreign scholars have used the theoretical analysis and numerical simulation...
to do the following research on the tunnel construction method: Zang C.L. et al. to solve the problems of the traditional CD method in the construction process of large-span tunnels, which are low efficiency and so on, the traditional CD method is optimized to the upper bench CD method excavation, thus ensuring construction safety, ensuring the construction period, and saving costs [5]. Deng J.L. applied the strength reduction method to determine the change law of the safety factor when the intersection of the working face and the stratigraphic interface changed. The numerical calculation shows that when the thickness of the bedrock covered with the bedrock reaches 4m, the center separation wall method is converted to the bench method [6]. From the aspects of conversion process, temporary support cost, safety and quality, Jin B. summed up the intersection of the construction channel of the subway station and the main tunnel, when the local layer is better, the upper hole method is preferred [7]. Li H.B. et al. discussed the application of the bench method and the arc pilot tunnel with core-reserving method, and obtained the conversion of the construction method during the construction, which ensured the stability of the surrounding rock and improved the construction progress [8]. Although the above researches have been done on tunnel construction method optimization [9-11], there are few studies on the construction method conversion of two different construction methods, and rarely applied in actual engineering. This paper studies from a tunnel in Meizhou East Ring Extension of Meida Expressway. The tunnel body section of Meida Expressway is excavated by the bench method. The tunnel portal section is excavated by CD method, and through numerical simulation of the tunnel portal section. The rationality and feasibility of the CD method in tunnel portal section are obtained, finally verified the feasibility of the transformation of the construction method in the actual construction process by monitoring the measurement of the tunnel portal section.

2. Project Overview

2.1 Project Introduction

A tunnel of Meida Expressway passes through the low-lying hilly landform area. It is a small spacing tunnel with a total length of 1367m. The main tunnel is set to two lanes. The main tunnel has a building boundary of 11.0m*5m. The main settings are shown in Table 1. The left-line tunnel starts from the pile number L1K6+645~L1K7+325, the tunnel length is 680m, the right-line tunnel starts from the pile number K6+630~K7+322, and the tunnel length is 692m. Both ends of the left and right lines are end-walled, and the east end of the gate is reversely-cut-bamboo-type. The slope of the left and right lines is 1.5%~0.5%, and the maximum depth of the tunnel is about 158.

| Tunnel Line | Line Speed (Km/h) | Arrange Form | Building Boundary Clearness (Width*Height) | Station Number | Length (m) | Hole Form | Lighting Mode | Ventilation in the Way |
|-------------|------------------|--------------|------------------------------------------|----------------|------------|-----------|---------------|-----------------------|
| Left Line   | 100              | Small Net    | L1K6+652~L1K7+330 | 678            |            | End-well  | cut-bamboo    | LED                   |
| Right Line  |                  | Distance     | K6+629~K7+318    | 689            |            | LED       | natural       |                       |

Table 1. List of a tunnel setting for Meida Expressway.

| Total Single Hole Length (m) | 1397 |

2
2.2 Engineering Geological Conditions

The tunnel passes through the low and gentle hilly landform area, the topographic relief is large, the ground elevation is 130-315 m, and the relative height difference is about 185 m. The mountains are densely vegetated. The slope shape at both ends of the tunnel is steep, and the maximum slope angle is about 30-40 degrees. According to the results of engineering geological mapping, fault f1 strikes northeast 35 degrees, dip angle is about 70 degrees, fault breakage bandwidth is about 1-2 m, and it is presumed that the route is near the vertical intersection of K6+920. In addition, K7+150~K7+350 section is affected by Fqx2 fracture, rock mass is very fractured, tunnel excavation should be strengthened in time to avoid collapse and roof fall. Faults do not affect the regional stability of the tunnel site. The tunnel site is a stable block, which is suitable for tunnel construction. According to the results of exploration and mapping, the stratum lithology of the tunnel site is Quaternary slope residual silty clay and gravel, and the basement is composed of Devonian sandstone, quartz sandstone, quartzite, gravel sandstone, cataclastic rock and structural breccia, etc. Surrounding rock grade is V.

2.3 Hydrogeology

Tunnel is located in low and gentle hilly area, the surface water is not developed, mainly for atmospheric rainfall to form surface water confluence along valleys, seasonal surface water. 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. Local fissure zones may be enriched. Groundwater is mainly recharged by atmospheric rainfall and lateral runoff, and evaporation and lateral runoff are the main discharge modes. Generally speaking, the groundwater in the tunnel site area is relatively poor.

3. Construction scheme

The tunnel in this section belongs to grade V surrounding rock with shallow burial depth, bias pressure and small distance between entrance and exit. Under the premise of ensuring construction and tunnel safety, the construction conditions of the tunnel entrance section should be improved as far as possible to ensure construction and tunnel safety, reduce land occupation and mountain excavation, and reduce damage to the environment. If the whole tunnel section is excavated by CD method, one-way tunnel entry is generally feasible, but considering the following factors, two different methods should be adopted for the tunnel section and entrance section: 1) the construction is difficult and the construction period is longer; 2) the strength of medium-differentiated sandstone in the tunnel section is much higher than that of medium-differentiated sandy mudstone in the entrance section; 3) CD method is superior to bench method in controlling the deformation of surrounding rock, and the construction of bench method is simple and simple. The progress is faster. The boundary of construction method for the left line of tunnel is shown in Figure 1.

![Figure 1. Tunnel left line construction method layout diagram.](image-url)
4. numerical simulation

4.1 Model Establishment

In this project, the bench method and CD method are used for tunnel excavation. The flac is used for numerical simulation analysis. In the process of simulation, Mohr-Coulomb model is used for surrounding rock and shell element is used for initial support. Among them, the total width of left and right is 90 m, the width of bottom is 50 m, the top is free boundary, and the bottom is fixed constraint. By analyzing the displacement deformation and plastic zone during tunnel excavation, the advantages and rationality of using bench method in tunnel entrance are obtained. The numerical analysis model diagram is shown in Figures 2 and 3.

![Figure 2. Bench calculation model.](image)

![Figure 3. CD calculation model.](image)

According to the measured data and related engineering cases [13-16], the surrounding rock and supporting mechanical parameters are simulated by using numerical simulation software (FLAC) as shown in Table 2.

| Geotechnical parameters          | Bulk density $\gamma$ (kN/m$^3$) | Modulus of elasticity $E$ (GPa) | Poisson ratio $\mu$ | Cohesive $c$ (kPa) | Friction $\phi$ ($^\circ$) | Resistance factor $K$ (MPa/m) |
|----------------------------------|-----------------------------------|---------------------------------|--------------------|-------------------|--------------------------|-----------------------------|
| Moderately weathered sandy mudstone | 25.8                              | 1.203                           | 0.37               | 350               | 26                       | 280MPa/m                    |
| Medium weathered sandstone       | 25.2                              | 2.223                           | 0.1                | 1260              | 34                       | 350MPa/m                    |
| C30 concrete                     | 25.0                              | 30.0                            | 0.2                |                   |                          |                             |
| C40 shotcrete steel              | 25.0                              | 30.0                            | 0.2                |                   |                          |                             |
| Steel                            | 78.0                              | 210.0                           | 0.3                |                   |                          |                             |

Table 2. Mechanical parameters of surrounding rock and retaining structure.
4.2 Analysis of Plastic Zone by Bench method and CD Method

Shallow burial of grade V surrounding rock should be excavated by side-wall pilot method, but there are some difficulties in the construction process and the construction period is longer. According to this project, the surrounding rock in the middle of the tunnel is weathered quartz sandstone, so CD method is used to construct the tunnel outlet section, and the change of the plastic zone of the surrounding rock in the tunnel outlet section is shown in Figure 4b; the rest of the fifth grade surrounding rock is still constructed by the bench method, and the change of the plastic zone of the surrounding rock in the tunnel body section is shown in Figure 4a).

![Comparison of the plastic zone between the bench method and the CD method.](image)

From the figure 4 above, it can be seen that the plastic zone mainly occurs at the shoulder and waist of the arch when the bench method is used in the construction of the cave section, and the plastic zone changes obviously relative to the top and bottom of the arch. When the CD method is used in the tunnel outlet section, the location of plastic zone is similar to that of the bench method, but the change of plastic zone at the arch shoulder and arch foot decreases obviously. The main reason is that the time of closure of each part of the CD method is short, the structure is uniformly loaded, the deformation is small, the support stiffness is large, the subsidence of the tunnel is weak during construction and the settlement of the stratum is small.

4.3 Bench Method and CD Method for Displacement Analysis

The results of deformation analysis by bench method and CD method are shown in tables 3 and 4.

| Excavation stage | Horizontal displacement /mm | Vertical displacement /mm |
|------------------|-----------------------------|---------------------------|
|                  | upper bench | middle bench | Lower bench | Crown | Left spring | Right spring |
| Bench method     | 1.9         | 5.2          | 5.4        | 8.1   | 7.5         | 7.3          |

| Excavation stage | Horizontal displacement /mm | Vertical displacement /mm |
|------------------|-----------------------------|---------------------------|
|                  | Upper left wall | Upper right wall | Left lower wall | Right lower wall | Left vault | Right vault |
| CD method        | 1.3              | 2.5               | 2.1             | 3.1             | 5.8       | 6.2         |
Table 3 shows that the maximum horizontal displacement of the surrounding rock of the upper bench is 1.9 mm and the maximum horizontal displacement of the lower bench is 5.4 mm. The maximum vertical displacement of the vault is 8.1 mm and the maximum vertical displacement of the surrounding rock at the arch foot is 7.5 mm. The maximum vertical displacement of the vault of CD method is 6.2 mm, the maximum horizontal displacement of the left wall is 2.1 mm and the maximum horizontal displacement of the right wall is 7.5 mm. The displacement is 3.1 mm. It can be seen that the vertical displacement and horizontal displacement of the CD method are smaller than those of the bench method because of the vertical support in the construction process and the timely closure in the construction process. Therefore, CD method is more suitable for excavation at the entrance of tunnel.

5. Conversion of bench method to CD method
When the upper bench of the bench method is excavated to the interface, continue to excavate, and excavate ahead according to the cross section shape of the upper and left bench of CD method. After the lower bench of upper and lower bench method is excavated to the interface, the left and lower bench section of CD method is formed by enlarging excavation, and then the right section of CD method is constructed to maintain the longitudinal consistency of the construction process. The specific construction conversion steps are shown in Figure 5.

Figure 5. Schematic diagram of the conversion of the upper and lower bench to the CD core soil method.

The bench method is adopted in the tunnel body section, and CD method is adopted in the tunnel outlet section; the step of conversion is step 1). First, when the upper bench procedure of the tunnel body section is excavated to the interface of surrounding rock, the excavation is continued according to step 1) of CD method; then step 2) when the upper bench procedure of the cave section is excavated to the interface of surrounding rock, the excavation is continued according to step 2) of CD method, in which step 2) lags behind step 1) 3-5 m; Step 3) Continue construction according to CD method, in which step 3) lags behind step 2) 3-5m; step 4) Continue construction according to CD method, in which step 4) lags behind step 3) 3-5m.

6. Monitoring measurement at interface
According to the geological factors and deformation characteristics of a tunnel in Meida Expressway, the following monitoring data are obtained at the interface between the tunnel body and the tunnel outlet. The rationality of adopting CD method in the tunnel outlet is verified by the changes of the vault and surface displacement. Four monitoring points are set at the vault top, the displacement is shown in Table 5 below; seven monitoring points are set at the surface, and the displacement is shown in Table 6 below.

| Monitoring section | vault | BC | AB | AC | DE |
|--------------------|-------|----|----|----|----|
| Vault cumulative deformation value (mm) | 78.6 | 46.1 | 9.8 | 6.8 | 5.4 |
| Average deformation rate of the vault | 0.1 | 0.1 | <0.1 | 0.1 | <0.1 |

| Monitoring section | 1-1 | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 | 1-7 |
|--------------------|-----|-----|-----|-----|-----|-----|-----|
| Total surface deformation value (mm) | 39.9 | 72.1 | 79.9 | 94.6 | 71.0 | 56.2 | 33.7 |
| Average deformation rate of the surface | 0.1 | 0.1 | 0.1 | 0.1 | <0.1 | 0.1 | 0.1 |
From Table 5 above, it can be seen that the four locations monitored by the left and right sides of the wall, the average change rate of vault settlement is less than 0.1 mm/d, the maximum displacement of vault is 78.6 mm, and the surrounding rock has reached basic stability. It is suggested that the second lining be applied in time to ensure construction safety. As shown in Table 6, The seven monitoring points of surface subsidence are monitored. The average change rate of each monitoring point is small. The average change rate is between 0.0 and 0.1 mm/d. The maximum cumulative deformation value of surface is 94.6 mm. The surface is in a stable stage. Continuous monitoring will be carried out. It can be concluded that CD method can better control the displacement and deformation of tunnel entrance section and meet the design and specification requirements.

7. Conclusion
Based on the numerical simulation of the bench method and CD method of a tunnel in Meida Expressway, the distribution of plastic zone of two different construction methods is obtained. Combined with the monitoring data of a tunnel in Meida Expressway, the feasibility of converting bench method into CD method is verified. The following conclusions are drawn.

(1) By comparing the two methods, it is concluded that CD method is more advantageous in controlling plastic zone. At the same time, by comparing the displacement of surrounding rock with the bench method and CD method, it is concluded that the maximum vertical displacement of the vault with CD method is reduced by 23.5% and the horizontal displacement by 53.7%. CD method is used to excavate the entrance section of a tunnel in Meida Expressway. The monitoring measurement shows that the average change rate of each monitoring point is less than 0.1 mm/d, which meets the design requirements.

(2) According to the actual situation, the bench method should be converted to CD method. The monitoring and measurement of the transfer section should be strengthened to ensure the stability of surrounding rock, and the second lining should be put into effect as early as possible to ensure the safety of tunnel construction.

(3) This paper only discusses the feasibility of using different construction methods in tunnel construction, ensures the safety and quality of construction, and shortens the construction period and saves funds. However, this paper does not solve the construction conditions and key steps that should be paid attention to in the conversion of different construction methods, so it needs to be supplemented in the future research.

In summary, under the conditions that tunnel construction meets the design requirements, the quality of lining structure meets the requirements of specifications, shortens the construction period and saves funds, the simple and convenient construction method should be chosen in the case of better surrounding rock conditions, and the stable construction method should be chosen in the case of poor surrounding rock conditions. In order to ensure construction safety and meet schedule requirements, concrete analysis of specific problems is needed in practical projects.

Acknowledgments
The authors would like to express their appreciation to the National Natural Science Foundation of China (41601574), the Chongqing Basic and Frontier Research Project (cstc2015jcyjBX0118), the Chongqing Science and Technology Innovation Leading Talent Support Program (CSTCCXJRC201715), and the Chongqing Social Undertakings and Livelihood Security Science and Technology Innovation and Special Program (cstc2017shmsA30010) for providing funding for this research.

Reference
[1] Zhang Y., Yi X.S., L N. (2018) Study on Tunnel Construction Method and Causes of Collapse in Weak Expansive Soil Areas[J]. Journal of Highway and Transportation Technology, 35(10): 82-91.
[2] 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), 38(08): 1257-1270.
[3] Dan L.Z., Wang D.Y., Chen W., Guo Q.H. (2018) Research on the influence of construction method on the underpass road tunnel[J]. Journal of Water Resources and Architectural Engineering, 16(02): 60-65.
[4] Qing W.W., Gao Y., Zhu Y., Zhang H.J. (2018) Study on Construction Method of Super-span Four-line Deep-buried Tunnel——Taking Wumengshan No.2 Exit Station Tunnel as an Example[J]. Tunnel Construction (Chinese and English), 38 (01): 91-102.
[5] Yan C.L., Yu Y.Y. (2018) Discussion on the construction technology of the step CD method on the super-long span tunnel[J]. Highway Traffic Technology, 34(S1): 154-159.
[6] Deng J.L.(2016) Research on Conversion Timing of Soft and Hard Uneven Formation Tunnel Excavation Method Based on Strength Reduction Method[J]. Tunnel Construction, 36(06): 676-682.
[7] Jin B.(2010) Comparison of CRD Method and Upper Picking Method for Vertical Intersection of Small Section Passage into Large Section Main Hole[J]. Tunnel Construction, 30(06): 701-705.
[8] Li H.B., Li B, Li M.G.(2010) Analysing the Transformation of Tunnels in Soft Surrounding Rocks[J].Guangdong Highway Communications,(3):60-62.
[9] Zhai Z.H., Yan T., Tian M.J., Zhang J.X.(2017) Study on construction method and reasonable excavation process of shallow buried tunnel under adjacent roadbed slope[J].China Civil Engineering Journal,50(S2):203-208.
[10] Liu S.B., Fang Y.(2017) Comparison and Selection of Construction Methods for Excavation Stability of Underlying Pressure Vessels in Tunnel[J]. Construction Technology, 2017, 46(11): 71-76.
[11] Xu R.N., Wang Z.J.(2017) Analysis of Construction Method Comparison of Large Cross-section Tunnels in Xigeda Formation[J]. Highway,62(1): 231-236.
[12] Hong J., Guo H.M., Zhang J.R., Chen L.J.(2016) Study on Structural Selection and Construction Method of the Three-line Transition Section of the New Kaotang Tunnel Exit[J]. Tunnel Construction, 36(8): 953-959.
[13] Tian J., Li J.P.(2018) Application of Mechanized Construction Method for Large Section of Soft Surrounding Rock Stratum Tunnel[J]. Tunnel Construction (Chinese and English), 38(8): 1300-1360.
[14] Deng X.H., Yuan Y.Y., Yao J., Tang L.(2018) Study on the construction method of a super-shallow buried large-span tunnel under the existing highway[J].China Foreign Highway,38(4):201-207.
[15] Pan J.S., Yu C.J., Liu T.(2018) Research on construction method of shallow buried rock mass tunnel[J]. Coal Technology, 37(3): 16-18.
[16] Shu D.L., Qi F., Wang J.G., Yu L.(2017) Study on construction method of shallow buried tunnel of single-expansive soil in Hefei subway[J].Chinese Journal of Underground Space and Engineering,13(S2):726-731.