Study on the Technology of Middle Column in Li-Jia-Ping Station of Chongqing Metro Line No.9

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Abstract. In order to study the construction technology of the underground excavation station of Chongqing where the geological conditions of the surrounding rock are better, Li-jia-ping Station of Chongqing rail transit line 9 is selected as the engineering background. On the basis of the traditional double sidewall tunnel method, the middle column method is proposed. Through the numerical simulation analysis of the variation of the tunnel dome subsidence, the horizontal displacement of the surrounding rock, and the plasticity of the surrounding rock under the construction of the spacer column method, the result shows that the construction of the middle pillar can satisfy the vault of Li-jia-ping station according to the field monitoring measurement data. Subsidence and surface subsidence control requirements. The research results can provide references for the design and construction of subway stations with large cross-section excavation under similar conditions.

Keywords: Extra-large section, Septal column method, Bearing capacity, Monitoring measurement, Numerical simulation

1. Introduction
The subway line is mainly arranged under the main traffic arteries of the city. At present, the most commonly used excavation method for underground subway station construction is double sidewall tunnel method [1-5]. However, there are some defects in the construction of underground subway station with double sidewall tunnel [6-10]. For example, the cumbersome process handover and small operation are not conducive to the construction of large mechanical equipment. The initial support of the station cannot be closed in time. In the later stage of the core pillar lifting, the safety risk is very high. The double sidewall tunnel method has many construction steps, slow speed and high cost.

Chongqing rail transit line 9 is a key project of Chongqing’s rail transit planning. It spans 32.276 km. Some subway stations of Chongqing Railway Line 9 are in rock strata, and the strength index of surrounding rock is high and the integrity is good. In view of the fact that the double sidewall tunnel method has its advantages under the poor conditions of surrounding rock of class V and class IV, this paper carries out the research on the construction technology of large-span subway station by using the middle column method in combination with the condition of favorable surrounding rock of Chongqing. As for the method of medium partition wall and reserved rock column [11-12], previous studies have been carried out. In this paper, related studies have been carried out for the middle partition column method to provide reference and help for the construction of underground station in mountainous cities.

2. Project Profile
Li-jia-ping station is the ninth station of Chongqing rail transit line 9, with a total length of 257.5m. The station is an island subway station with two floors below. The station is about 18~37m deep, and
the medium-weathered bedrock on the roof is 12.35~35m thick. Underground drilling and blasting are adopted in the main tunnel of the station. The mechanical parameters of rock are shown in table 1. The design recommends the construction of double sidewall tunnel.

In the actual excavation process, the ratio of rock strength is much higher in the geological investigation report, and the results are shown in table 2.

| Rock type Parameters | backfill | sandstone | sandy mudstone |
|----------------------|----------|-----------|----------------|
|                      | mixed soil | land | intense weathering | middling weathering | intense weathering | middling weathering |
| thickness(m)         | 1.1~3.8 | 0.5~3.2 | 3.0~5.7 | 4.3~12.9 | 0.9~3.6 | 3.5~11.7 |
| Heavy (KN/m3)        | 20.5* | 23.5* | 23.0* | 25 | 24.0* | 25.6 |
| Natural water content | 3.17 | 2.79 |
| Natural compressive strength standard value (Mpa) | 35.2 | 10.4 |
| Standard values of saturated compressive strength (Mpa) | 25.6 | 6.3 |
| Basic foundation bearing capacity (Kpa) | 500* | 400* | 2000* | 300* | 1000* |
| Internal friction angle(°) | 30* | 41 | 29* | 32 |
| Cohesion (Kpa) | 150* | 1707 | 80* | 447 |
| Tensile strength test (Kpa) | 492 | 126 |
| Elasticity modulus (Mpa) | 4301 | 1362 |
| Deformation modulus (Mpa) | 3614 | 1036 |
| Poisson ratio | 0.45* | 0.45* | 0.40* | 0.12 | 0.45* | 0.38 |
| Elastic reaction coefficient of surrounding rock(Mpa/m) | 150* | 480* | 100* | 250* |
| Horizontal resistance coefficient of rock mass(MN/m3) | 60* | 360* | 40* | 60* |
| Coefficient of subgrade reaction(Mpa/m) | Horizontal | 30* | 40* | 200* | 400* | 140* | 200* |
|                      | Vertical | 30* | 40* | 200* | 450* | 160* | 230* |

| Number | Mileage | Sandstone(MPa) | Sandy mudstone(MPa) |
|--------|---------|----------------|---------------------|
| 1      | YDK10+740 | 41/27          | /                   |
| 2      | YDK10+600 | /              | 19/13               |
| 3      | ZDK10+631 | /              | 17/13               |

3. Study on Construction Technology of Middle Column Method

3.1. Introduction to Middle Column Construction Technique

In the document of original design, the main structure of Li-jia-ping station was constructed by double sidewall tunnel method, and the construction steps are shown in figure 1 below.

With the improvement of actual surrounding rock conditions, the construction process of Li-jia-ping station is optimized without changing the original support strength at the initial stage of
design and the safety reserve of the secondary lining structure. The middle column method is adopted for excavation in combination with the advantages of the double-sidewall tunnel method and the CD method. The sequence of construction steps is shown in figure 2 below.

Detailed excavation steps are as follows:

Step 1 and Step 2: the leading hole around the step of the station is excavated and the initial support of the station arch is closed into a ring. Clean up the scum on the surface of the steps in the station and cut out the holes. Lay steel mesh sheets in the holes and pour concrete. Then, the steel pipe with a diameter of 609mm was erected as the support, and the longitudinal spacing was 2m, and the support anchor was put into the concrete foundation with expansion screw. Finally, all the steel pipe supports are vertically connected by sleepers at the end of the steel pipe support;

Step 3, Step 4, Step 5 and Step 6: excavate and support the left and right guide holes of the station steps and the lower steps;

Step 7 and step 8: in Step 7, the soil in the middle of the tunnel is excavated; in Step 8, the soil in the lower part of the station is excavated.

Step 9: the inverted arch waterproof layer is laid and the inverted arch concrete is poured.

Step 10: a waterproof layer is laid, and the tunnel arch, the secondary lining of the wall and the internal structure are poured.

3.2. Stability Analysis of the Middle Column Method

The section width of the station is 23.24m, the height is 19.92m, and the overburden of the vault the arch overburden is about 20m thick. The surrounding rock of the tunnel is mainly sandy and mud. The calculation model is shown in figure 3 below.

3.2.1. Vertical Displacement of Surrounding Rock. The vertical displacement of surrounding rock is shown in figure 4 below. According to the above cloud map and the displacement of monitoring points,
the vertical settlement of the vault after the excavation of the upper tunnel is about 1.78mm, while the vault continues to subside during the excavation of the lower tunnel. The maximum vertical displacement of the vault reaches 7.90mm after the completion of the tunnel. The surface subsidence caused by the upper tunnel excavation is about 0.5mm, while the surface subsidence continues to increase during the lower tunnel excavation, and the maximum surface subsidence reaches 3mm after the completion of the tunnel excavation. The uplift of the bottom of the arch caused by the underground excavation is large, and the maximum uplift is located near the middle line of the tunnel, which is about 6.56mm. The vertical displacement of surrounding rock is small.

![Figure 4. Vertical displacement diagram of surrounding rock](image1)

3.2.2. Vertical Stress Distribution of Surrounding Rock. The vertical stress of surrounding rock is shown in figure 5 below. From the above vertical stress cloud diagram, it can be concluded that stress concentration appears at the arch foot during the excavation of the upper foundation pit, and the maximum vertical stress is about 3.46MPa. The tensile stress at the top of the vault is about 0.08MPa. The vertical stress ($s_{zz}$) of the right and left vertical walls continued to increase during the excavation of the lower diversion pit, with the maximum value reaching 4.65MPa and the natural compressive strength less than that of the medium-weathered sandy mudstone layer being 10.4 MPa. The tensile stress on both sides of the vault is about 0.11 MPa. The overall stress of surrounding rock is small and the stress state is good.

![Figure 5. Vertical stress distribution of surrounding rock](image2)

3.2.3. Plastic Zone Distribution of Surrounding Rock. The distribution of plastic zone of surrounding rock is shown in figure 6. It can be seen from the development trend of the plastic zone that a small part of shear plastic zone appeared in the arch foot during the excavation of upper guide hole, so the support of the arch foot should be strengthened after the step excavation. After the excavation of the
lower tunnel, a large range of plastic areas appeared in the left and right straight walls, most of which are shear stresses, so it is necessary to strengthen the monitoring and initial support of straight walls.

![Figure 6. Plasticity distribution of surrounding rock](image)

### 4. Monitoring Measurement

The middle column method is well applied in Li-jia-ping station, as shown in figure 7. Totals of eighteen monitoring points were arranged in Li-jia-ping station cross section. The specific layout form are shown in figure 8. The monitoring results show that the cumulative settlement of the vault is -8.6mm, and the cumulative settlement of the surface is -4.7mm. There is a little deformation of the surrounding rock of the station and the land subsidence is within the permitted range.

![Figure 7. Field application](image)

![Figure 8. Settlement and convergence monitoring points](image)

### 5. Conclusions

In this paper, the construction technology of the middle column method is proposed for the Li-jia-ping station of Chongqing rail transit line 9 under favorable conditions of surrounding rock geology. The application of the middle column method in the Li-jia-ping station of Chongqing rail transit line 9 is feasible through numerical simulation analysis and field practice.

The middle column method has the following advantages. First, the construction process is simple and the construction speed is fast. Second, it can remove the rock column in the middle of the steps in advance and apply the initial support, so that the initial support of the station vault can be closed as soon as possible, and the stress concentration can be avoided and the bearing capacity of the initial support can be improved. Third, the middle column method uses steel pipe support instead of the middle rock column, which can greatly reduce the supporting materials of temporary invert and temporary connecting beam.
References

[1] Shi Lei, Hou Xiaojun, Wu Jinguang. Research on construction methods for large cross-section loess tunnels [J]. Tunnel Construction, 2013, 33(3):173.

[2] GAO Haihong. Application of double side drift method in construction of extra-large cross-section hard rock station tunnel located in busy urban area [J]. Tunnel Construction, 2008, 28 (2): 191.

[3] GAO Feng, TAN Xukai. Stability analysis on large section tunnel with double-side-drift method [J]. Journal of Chongqing Jiaotong University: Natural Science, 2010(3): 363.

[4] HUANG Haibin, ZHOU Ping, CHEN Peng. Theoretical research on different construction methods for double-line highway tunnel under-passing existing railway tunnel [J]. Railway standard design, 2016, 60(11):104.

[5] Li Kexian, Li Shucai, Zhao Jizeng. Study on optimizing excavation construction of large span sub-way station [J]. Chinese Journal of Underground Space and Engineering. 2017,10 (13):72.

[6] Guo Jie. Analysis on construction safety of optimized double side drift method [J]. Tunnel Construction, 2014, 34(6):525.

[7] Yang Yongbo, Liu Minggui, Zhang Guohua, et al. Analysis of construction parameter optimization for new large cross-section tunnel next to existing tunnels [J]. Rock & Soil Mechanics, 2010, 31(4):1217-1226.

[8] Wang Xing-bin. Study of Application of different construction methods to tunnel large deformation control in carbonaceous slate [J]. Tunnel Construction,2017, S1 : 121.

[9] XU Yong, LIU Zhongren, WANG Weigao, et al. Comparison and contrast among different construction methods for double-track railway tunnels in soft ground [J]. Tunnel Construction,2010,30(2): 134.

[10] Jiang Kun, Xia Caichu, Bian Yuewei. Optimal analysis of construction schemes of small space tunnel with bidirectional eight traffic lanes in jointed rock mass [J]. Rock & Soil Mechanics, 2012.

[11] Yu Haijun. Research about the critical technology for the construction of shallow buried large section of the subway station [D]. Chongqing Jiaotong University, 2014.

[12] Cui Zhendong. Stability analysis of excavation of intermediate diaphragm wall in large cross-section metro station constructed by double-side-drift method and its key technologies [J]. Tunnel Construction, 2017, 9: 1140.