Stability analysis of the middle wall in process of double-arch tunnel construction

Haidong Gao, Gang Li, Yanbing Guo and Peng Gao

China Railway 18th Bureau Group Company Limited, Tianjin, China

*Corresponding author e-mail: 961044814@qq.com, ghd740420@sina.com, 150029421@qq.com, 326182603@qq.com

Abstract. As the main bearing components of double-arch tunnels, the stability of the middle wall is related to the construction safety of double-arch tunnels during construction and operation. Different construction methods of double-arch tunnel have great influence on the stability of middle wall, especially when the excavation span is large and the buried depth is very shallow. Based on an ultra-shallowly buried double-arch tunnel with extra-large spans in Xiamen, China, the mechanical response and deformation law of the middle wall are obtained. Furthermore, the performance of the CRD method and the double-side-drift method for optimizing the deformation and stress state of the middle wall are compared. The results can serve as initial guidelines for the selection of double-arch tunnel construction schemes.

1. Introduction

In recent years, double-arch tunnel is often used in highway tunnel construction. Double-arch tunnel has the advantages of less land occupation and higher space utilization rate. However, the double-arch tunnel often has the characteristics of shallow buried depth and large span, so its structural form and excavation method are more complex than ordinary separated tunnel. Compared with the ordinary separated tunnel, the biggest feature of the double-arch tunnel is that the two tunnels are connected by the middle wall. As an important bearing components of double-arch tunnel, the stability of middle wall is related to the safety of the double-arch tunnel. Choosing a reasonable construction method to ensure the stability of the middle wall is the key to the design and construction of double-arch tunnels.

In double-arch tunnel construction, common construction methods mainly include two stages. Firstly, the excavation of the middle drift is carried out, and the middle wall is poured after the middle drift is supported. Second, after the partition wall reaches a certain strength, excavation of the left and right tunnels is carried out. Common excavation methods for the left and right tunnels mainly include full section method, bench method, centre diaphragm method (CD) and cross diaphragm method (CRD). Scholars and experts have conducted studies on the stability of tunnels and the mechanical behavior of partition walls for different construction methods. Gao et al. [1] simulated the bench method in the process of double-arch tunnel construction by finite element method. The mechanical response characteristics of the bench method on tunnel structure under different construction procedures were obtained. Liu et al. [2] investigated the displacement of tunnel, the stress of the surrounding rock and pressure arch distribution during the double-arch tunnel excavation in loess. Additionally, Wang et al. [3] analyzed the morphological evolution of the pressure arch induced by subsection excavation. Li et
al. [4] carried out an in-depth study on CRD method for the excavation of a shallow-buried double-arch tunnel. The stress distributions of the surrounding rock formations and the middle wall were obtained by a scaled physical model test and numerical simulations. Furthermore, Mao et al. [5] simulated the excavation of a middle pilot tunnel-bilateral pilot tunnel of a loess double-arch tunnel, accounting for fluid-solid coupling. The evolution law of seepage fields in loess multi-arch tunnels construction were obtained. Moreover, several scholars have also focused on the structural stability of the middle wall during double-arch tunnel excavation under asymmetrical pressure [6, 7]. However, the influence of different construction methods on the stability of the middle wall has been rarely studied, especially the double-side-drift method.

An ultra-shallowly buried double-arch tunnels with extra-large spans in Xiamen, China was used as the research background of this paper. The deformation law and stress characteristics of the middle wall between the CRD method and the double-side-drift method in the excavation of the double-arch tunnel were compared and analyzed. This study can provide guidance for the selection of double-arch tunnel construction schemes to ensure the stability of the middle wall.

2. Numerical simulation

2.1. Overview of the numerical model

The maximum double-line span of the double-arch tunnel is approximately 45 m, and the minimum burial depth of the tunnel is only 8.8 m. The compound middle wall with a thickness of about 3.8 m is adopted. The strata above the double-arch tunnel are mainly composed of silty clay and miscellaneous fill.

As shown in Fig. 1, two numerical simulation models of CRD method (Fig. 1b) and the double-side-drift method (Fig. 1c) are established, respectively. The disturbance range of the tunnel excavation is considered according to Saint-Venant’s principle. Therefore, the numerical model is 55 m high, 308 m wide and 20 m long. The top surface boundary of the numerical model is free, and the bottom surface boundary is pinned. Besides, the numerical model is fixed in the horizontal direction at each side. The Mohr-Coulomb model is adopted to simulate the mechanical behavior of surrounding rock, and the elastic model is adopted to describe the mechanical behavior of the lining structure and the middle wall. [8, 9]
2.2. Construction method simulation
As shown in Fig. 2, the double-side-drift method divides the tunnel section into 12 drifts. The CRD method divides the tunnel section into 8 drifts. In addition, it also includes the middle drift where the middle wall is located. The middle wall is poured after the excavation and support of the middle drift.

![Diagram of excavation section](image)

**Figure 2.** Diagram of excavation section

The excavation sequence of drifts by the double-side-drift method is as follows: 1 → 2 → The middle drift → 3 → 7 → 8 → 9 → 4 → 6 → 5 → 10 → 12 → 11. The excavation sequence of drifts by the CRD method is as follows: 1 → the middle drift → 2 → 3 → 4 → 5 → 6 → 7 → 8. When all sections of each tunnel have been excavated, the temporary supports are removed and the secondary lining is carried out.

3. Numerical results

3.1. Displacement characteristics of the middle wall
The displacement field diagram of middle wall after construction by CRD method and double-side-drift method is shown in Fig. 3. As a whole, the displacement fields in both the horizontal and vertical directions are basically symmetrical. The horizontal displacement mainly occurs at the waist and bottom of the partition wall. The displacement in the vertical direction is mainly concentrated on the top of the middle wall, mainly because it is in contact with the primary support of the double-arch tunnel.

![Displacement field of the middle wall](image)

**Figure 3.** Displacement field of the middle wall (a) The horizontal displacement of CRD method; (b) The vertical displacement of CRD method; (c) The horizontal displacement of double-side-drift method; (d) The vertical displacement of double-side-drift method

When using the CRD method, the maximum vertical displacement at the top of the middle wall is 14.1 mm, and the bulge at the bottom is 1.85 mm. However, the maximum vertical displacement of the top of the middle wall is only 7.5 mm, which is about 53.2% of the CRD method. Moreover, the
deformation area of the base of the middle wall with CRD method is much larger than that with double-side-drift method. It can be seen that the double-side-drift method is better than the CRD method in controlling the deformation of the middle wall.

3.2. Stress analysis of the middle wall
Due to the complex process of CRD method and double-side-drift method, the stress state of the middle all changes dynamically during the tunnel excavation. It is significant to analyze the stress state of the middle wall in each construction stage to guide double-arch tunnel construction.

A stress monitoring point is selected on the left and right sides of the waist of the middle wall, respectively, point L and point R. The stress change curves at two points of different construction methods are shown in Figure 4. Because the construction steps of the double-side-drift method are more than the CRD method, the number of fluctuations in the stress state is more than when the CRD method is used. No matter what kind of construction method, the middle wall has different degrees of eccentric compression state. During the construction of the CRD method, after the excavation of the 2 drift is completed, point L is subjected to a compressive stress of about 1.75 MPa, and point R is subjected to a tensile stress of about 0.4 MPa. The stress difference between the two points is 2.15 MPa. This value is 1.25 MPa when the double-side-drift method is used. Moreover, in the following construction procedures, the stress difference between R and L points when using double-side-drift method is also smaller than that using CRD method. According to the mechanical behavior of the middle wall, the double-side-drift method is better than the CRD method.

![Figure 4](image1.png)

**Figure 4.** The vertical stress change curve of the middle wall (a) CRD method; (b) Double-side-drift method

Fig. 5. Is the vertical stress contour of the middle wall by CRD method. It can be seen that the middle wall has obvious stress concentration where it overlaps with the temporary supporting. Attention should be paid to the lap joint methods between the middle wall and the tunnel supporting in the actual construction. The eccentric compression trend of the middle wall gradually disappears with the progress of construction. The stress state of the middle wall is changed most obviously by the excavation of the adjacent drifts.

![Figure 5](image2.png)

**Figure 5.** The vertical stress contour of the middle wall by CRD method
4. Conclusion
In this paper, the stability of the middle wall of an ultra-shallowly buried double-arch tunnels with extra-large spans under different construction methods is studied. The displacement in the vertical direction is mainly concentrated on the top of the middle wall. The maximum vertical displacement of the top of the middle wall is about 53.2% of the CRD method. The stress state of the middle wall changes dynamically with the tunnel excavation process. When the double-side-drift method is used, the eccentric compression trend of the middle wall is more obvious than that of the CRD method. The asymmetric construction method is the main reason of eccentric compression of the middle wall. In terms of controlling deformation and improving strained condition of the middle wall, the double-side-drift method is better than CRD method.

References
[1] Gao F. and Xue D. L. Double-Arch Tunnel Construction in Large Span Bias Weak Surrounding Rock. Journal of Chongqing Jiaotong University (Natural Science), 2014, 33 (02), 30 - 34.
[2] Liu X., Liu J., Huang L., Wang Z. J., Chen H. J. and Feng Y. Model test and pressure arch analysis for excavation of loess double arch tunnel. Journal of Zhejiang University (Engineering Science), 2018, 52 (6), 1140 - 1149.
[3] Wang S. R., Li C. L., Wang Y.G. and Zou Z.S. Evolution characteristics analysis of pressure-arch in a double-arch tunnel. Tehnicki vjesnik/Technical Gazette, 2016, 23 (1).
[4] Li S. C., Chao Y., Feng X. D. and Li S.C. Mechanical behaviour of a large-span double-arch tunnel. Ksce Journal of Civil Engineering, 2016, 20, 2737 - 2745.
[5] Mao Z. J., Wang X. K., An N., Li X. J. and Wei R. Y. Water disaster susceptible areas in loess multi-arch tunnel construction under the lateral recharge condition. KSCE Journal of Civil Engineering, 2019, 23 (10), 4564 - 4577.
[6] Zhang Y., Shi Y., Zhao Y., Fu L. and Yang J. Determining the cause of damages in a multiarch tunnel structure through field investigation and numerical analysis. Journal of Performance of Constructed Facilities, 2016, 31, 04016104.
[7] Wang S. Q., Qiao C.S., Xu G. C. and Zhu Z.G. Deformation and stress distribution of middle-wall for asymmetrically-loaded double-arch tunnel under complicated geological conditions. Rock and Soil Mechanics, 2007, 28 (S1), 449 - 454.
[8] Karakus M.and Fowell R. Effects of different tunnel face advance excavation on the settlement by FEM. Tunnelling and Underground Space Technology, 2003,18, 513 - 523.
[9] Li X., Xue Y. G., Qi D. H., Ma X. M., Qu C., Zhou B. H. and Kong F. M. Application of data mining to lagging deformation prediction of the underwater shield tunnel. Marine Georesources & Geotechnology, 2019, 1 - 13.