Analysis of Excavation Impact on Urban Shallow-Buried Super-large Cross-Section Tunnel with CD and CRD Method

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Abstract

The construction of high-grade highways leads to the emergence of large-section tunnels. At present, the study on the super-large cross-section tunnel is not mature, and there is no specific requirement in the construction and design specification. This paper is based on the constructing Longding Tunnel on the connecting line between Jinan and Beijing-Shanghai High-Speed Highway, and the ABAQUS finite element method is used to conduct finite element simulation of the excavation of the super-large cross-section tunnel, in order to reveal the deformation and stress distribution of the tunnel surrounding rock under the CD method and the CRD method, thus providing theoretical basis for the design and construction of the super-large cross-section tunnel, as well as verification through field monitoring. Besides, this paper helps to guide the design and construction of the super-large cross-section tunnel by revealing the deformation mechanism of the super-large cross-section tunnel and optimizing the construction technology.

Keywords

Super-Large Cross-Section Tunnel, CD Method, CRD Method, Excavation, Deformation Control.

1. Introduction

With the development of the national economy, higher requirements have been put forward for traffic infrastructure. Besides, high-quality road network continues to extend to the suburbs and mountain areas, accompanied by an increasing number of super-large cross-section tunnels, making more demanding requirements for the tunnel construction technology. According to the standards proposed by the International Tunnel Association, the classification of the tunnel section is conducted according to the area of the tunnel excavation or the area of the horizontal section, and the section with area of more than 100 m2 is the super-large cross section. Due to the large span of the super-large cross-section tunnel and relatively narrow span to height, the deformation law and load release law of the surrounding rock are different from those of the general tunnel [1-2]. Therefore, the mechanism of the previous supporting structure cannot be fully applied, which makes the design and the actual construction more difficult, especially for shallow-buried soft broken rock, the construction of which is much more demanding.

At present, according to the statistical analysis of existing engineering projects, common construction methods used in shallow-buried super-large cross-section tunnel construction are two side-wall pilot tunnel method, CD method, CRD method, bench method, hole pile method and so on [3]. The purpose of the design is to minimize the project as much as possible with the aid of various methods, so as to seal the project into a ring as soon as possible, thus reducing deformation of the surrounding rock to protect its stability [4-5].

It is very necessary to analyze the mechanical properties and deformation characteristics of the surrounding rock in the construction process of the urban shallow-buried super-large cross-section tunnel in poor stratum, for they are of great significance to the design of the tunnel, the process adjustment and the timing of support during the construction. Based on the project of super-large cross-section Longding Tunnel on the connecting line between Jinan and Beijing-Shanghai High-Speed Highway, the paper adopts ABAQUS finite element analysis and actual monitoring to study the excavation process with CD method and CRD method, so as to reveal deformation mechanism of super-large cross-section tunnel, and then offers feedback to the construction design and guidance to actual construction.

2. Project Profile

2.1 Section Headings.

The second section of Project of connecting line between Jinan and Beijing-Shanghai High-Speed Highway is 6.632Km long in total. It is a Class I highway with the function of city expressway. The speed is set to be 80 km/h and it has two-way eight lanes. There are 2 long tunnels in the section, namely, Longding Tunnel and Ganggou Tunnel. Longding Tunnel is located in west of Taiping Village, Lixia District, Jinan, with the entrance at 520m east of Longding Avenue and the exit at 350m northwest of Taiping Village. The left line begins with the station number of K6 +490 and ends with K8 +675, with the total length of 2183.439m. The right line begins with the station number of YK6 + 492.7 and ends with YK8 +677.3, including 988.496m of Class III tunnel. The spacing between left and right of the tunnel trunk is 13 ~ 36m. The exposed strata in the tunnel area are Ordovician and Cambrian limestone, dolomitic limestone and bioclastic limestone, and some gully areas are covered with the Ordovician silty clay. The lining structure of the tunnel is shown in Fig. 1.

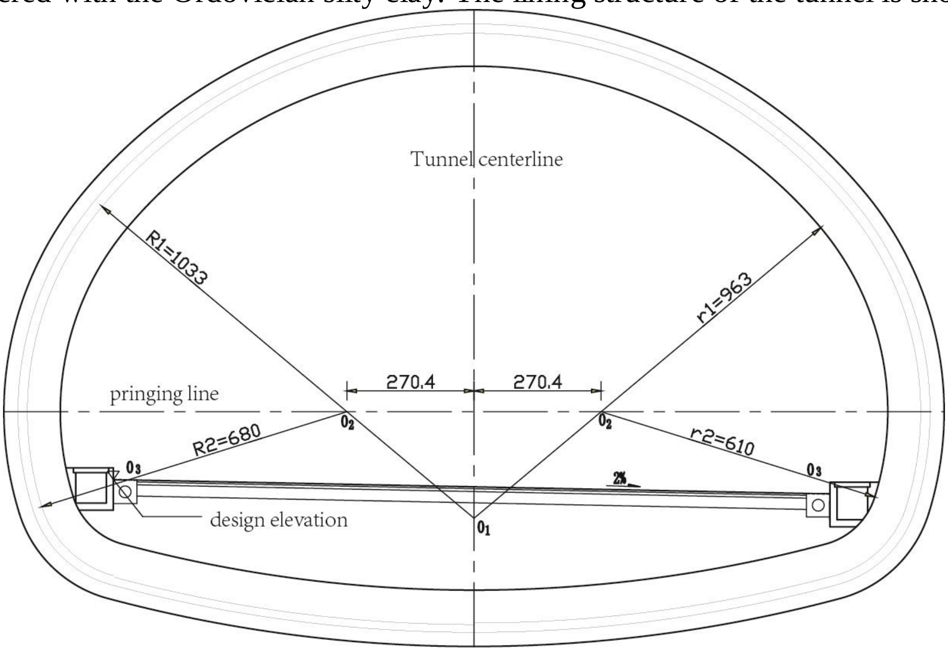

Fig. 1 Two or more references

3. Literature References

3.1 Modeling.

The excavation width of V-level surrounding rock of Longding tunnel has reached 20 meters. Due to serious difficulty in construction and complicated process, it is of great significance to select correct construction methods and steps, which help to reduce the deformation of surrounding rock, maintain its stability and ensure the safety of construction.

CD method, also known as the mid-partition method, is mainly applied for underground engineering construction with poor stratum and unstable rock, and strict requirements of ground subsidence. When the requirements cannot be met with CD method, temporary inverted arch can be set on the basis of CD method, contributing to CRD method (also known as cross mid-partition method). Based on bench method, CD method and CRD method divide the tunnel section into 4 to 6 parts from the middle, making two to three parts on the left and right of the step. Independent closed units have been formed for each part after excavation and support.

Calculation model is established according to the actual geological conditions to simulate CD method and CRD method, so as to reveal the deformation law and stress distribution characteristics of tunnel surrounding rock under different excavation modes. Analysis is conducted by ABAQUS, the large-scale commercial numerical simulation software, to establish two-dimensional plane simulation under single-hole excavation. The model is 110m wide with simulated burial depth of 54m. The parameters used in the calculation are shown in Table 1. The calculation model is shown in Fig. 2.

Table 1. Calculation Parameters of Surrounding Rock and Lining

Material type	E(GPa)	*M*	γ（KN/m3）	C(MPa)	φ
Rock（V）	1.8	0.35	18	0.1	23
Primary support	30	0.21	25		
3	32	0.19	25		

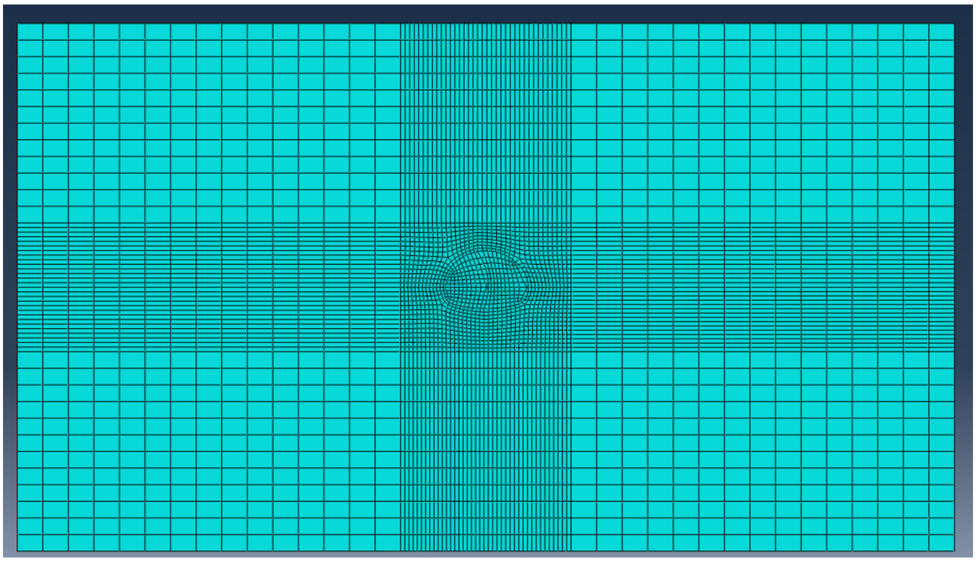

Fig. 2 Numerical Simulation

3.2 Analysis of Computing Results.

(1) Analysis of Displacement Field Results

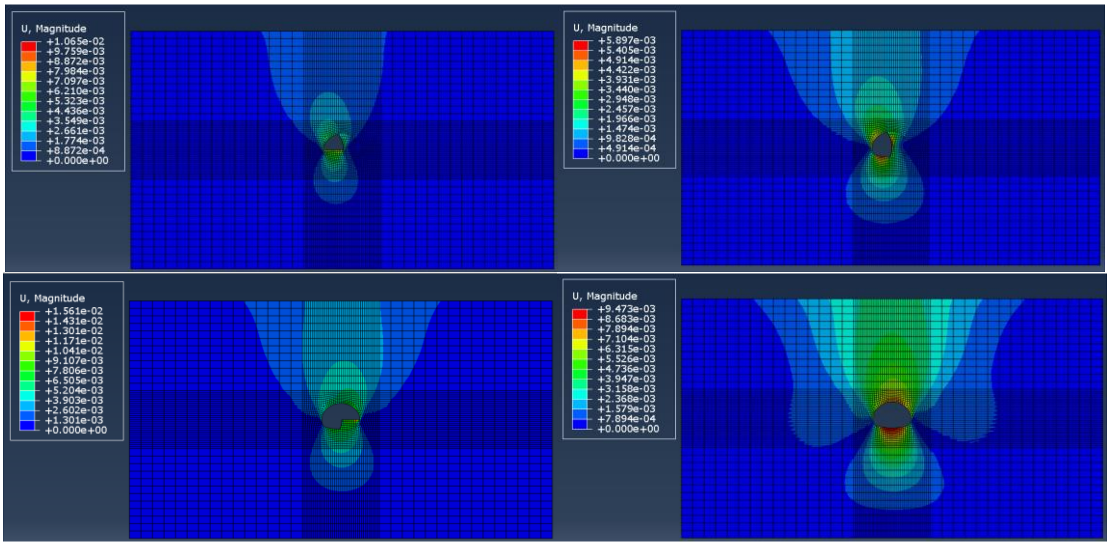

Fig. 3 Displacement Nephogram for Each Excavation Step with CD Method

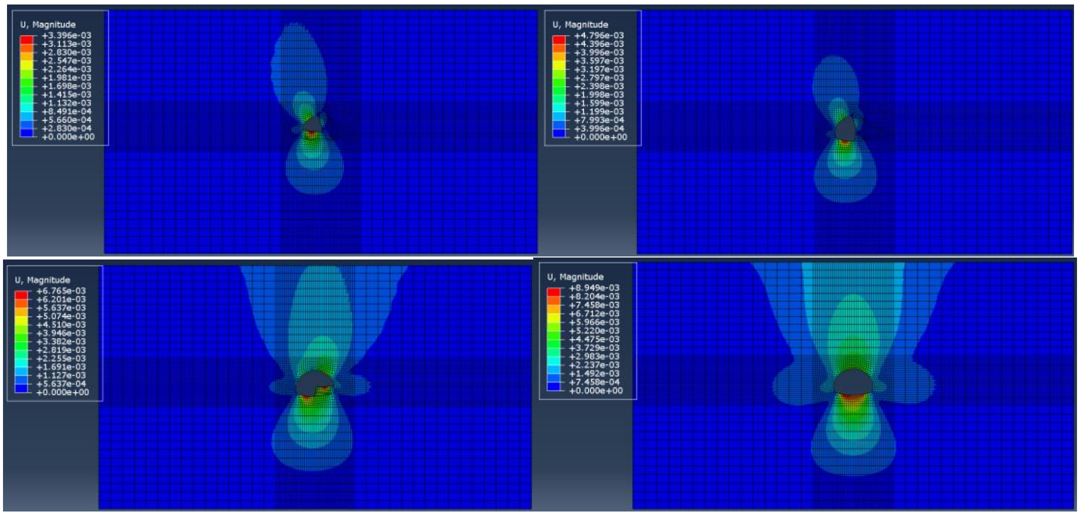

Fig. 4 Displacement Nephogram for Each Excavation Step with CRD Method

According to the analysis of Fig. 3 and Fig. 4, the influence range of the displacement field of the surrounding rock increases with more excavation steps. The displacement value and influence range of the displacement field of CRD method are greatly reduced compared with those of CD method.

(2) Analysis of Stress Field Results

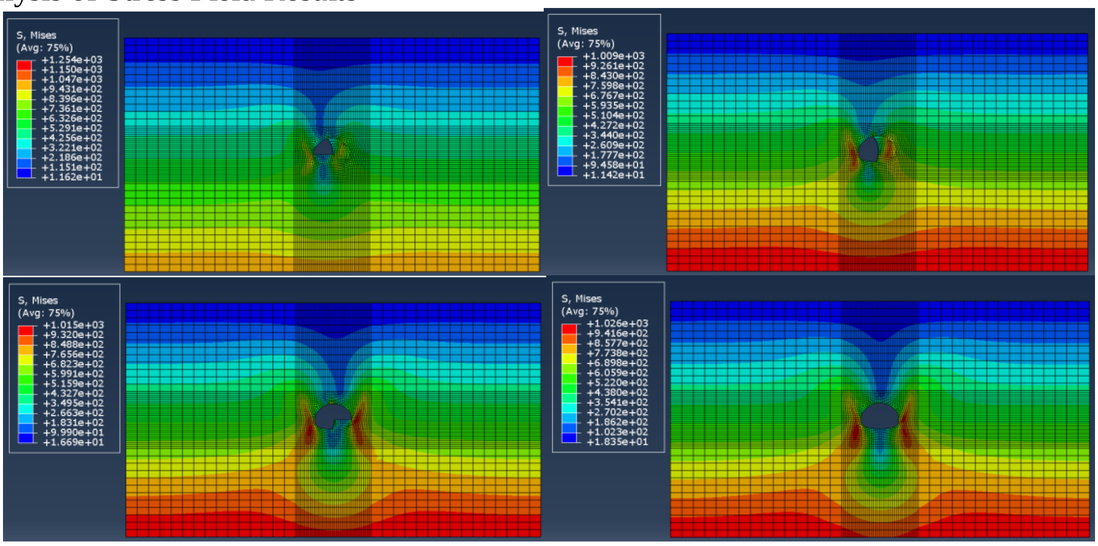

Fig. 5 Stress Nephogram with CD Method for Each Excavation Step

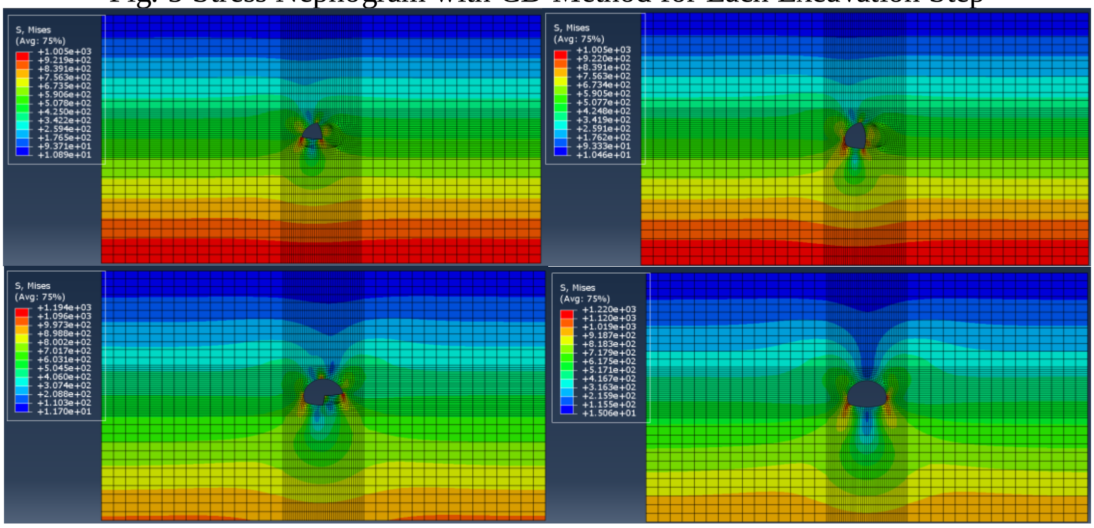

Fig. 6 Stress Nephogram with CD Method for Each Excavation Step

According to the analysis of Fig. 5 and Fig. 6, due to the smooth design of excavation section of tunnel, and timely preliminary bracing after excavation, the stress concentration problem around the tunnel is solved well. As a result, stress concentration is not obvious, and plastic zone only shows up in a small area around the tunnel and is obvious at the arch foot. Besides, most surrounding rock is within the elastic range. The stress field disturbance range and plastic zone distribution range of CRD method are greatly reduced compared with those of CD method.

4. Field Monitoring of Longding Tunnel

4.1 Field Monitoring Program and Implementation.

The field monitoring points of tunnel are arranged in strict accordance with the requirements of the Technical Code for Highway Tunnel Construction (JTG F60-2009) and the Technical Rules for Highway Tunnel Construction (JTG/T F60-2009), as shown in Fig. 7. Leica TS09 total station is used for contactless measurement, and corresponding vault crown settlement and the amount of horizontal convergence are measured by the position coordinates of the monitoring points.

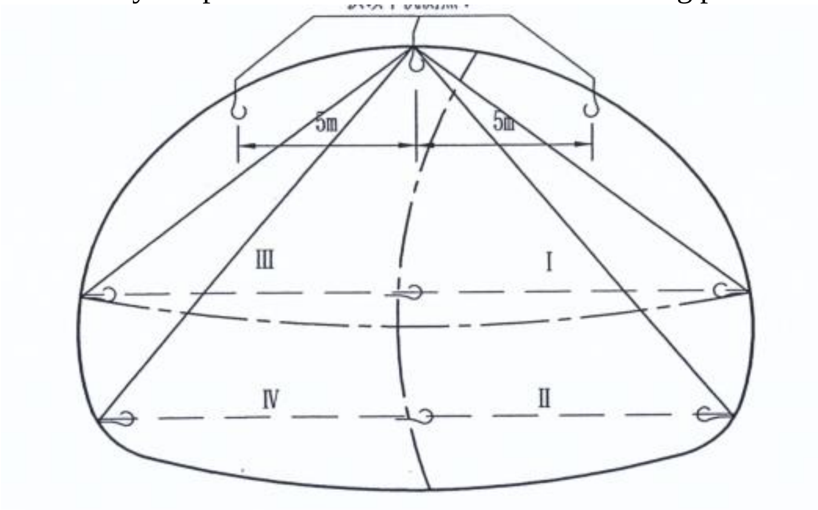

Fig. 7 Layout Diagram of Monitoring Points

4.2 Analysis of Monitoring Results

Monitoring sections are arranged in strict accordance with the relevant norms during field monitoring, and representative sections are selected for comparative analysis.

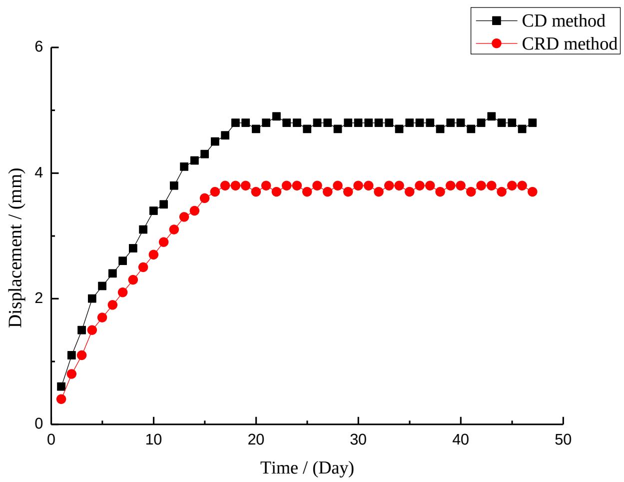

Fig. 8 Graph of Vault Crown Settlement of CD Method and CRD Method

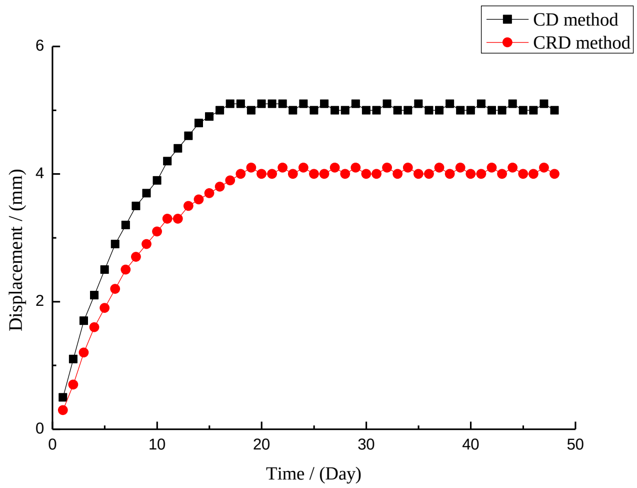

Fig. 9 Graph of Vault Crown Settlement of CD Method and CRD Method

The results show that the settlement value and the convergence value of CRD method are smaller than those of CD method, especially the vault settlement value, which is much smaller than that of CD method. It can be seen that temporary support of CRD method has a significant effect on vault settlement and horizontal convergence control.

5. Conclusion

In this paper, the influence of CD method and CRD method is studied based on actual project by using the method of numerical simulation and field monitoring. The main conclusions are as follows:

(1) Timely support is necessary after tunnel excavation to prevent the plastic zone expansion, and to enhance the self-stabilization of the surrounding rock. For excavation with CRD method, the tunnel vault settlement and horizontal convergence are much smaller than those with CD method. It can be seen that temporary support of the CRD method has a significant effect in controlling the vault settlement and horizontal convergence.

(2) During the excavation of the tunnel, tensile stress zones appear at the arch foot and bottom, because of the unloading effect on the arch bottom and stress concentration at the arch foot caused by resilience. Stress value and positional value of this point are relatively large. Therefore, support and monitoring of surrounding rock at the arch foot should be enhanced during design and actual construction to ensure safety.

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