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Study of mutual effect during the subway shield tunnel's overpassing the construction passage of inclined shaft

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Abstract: *Given the complexity of urban rail transit networks, it is inevitable to pass through existing or under construction projects during the design and construction of new underground projects. Based on a rail transit project in Chongqing, this study adopts the finite element method and combines with field monitoring to investigate the settlement and deformation rules of shield segments and inclined shafts during the construction process of the subway shield tunnel overpassing high-speed rail inclined passage. On this basis, the mutual effect between subway shield tunneling and construction passage of high-speed rail inclined shaft is revealed. The results show that during the construction of the shield tunnel's overpassing the inclined shaft passage, the settlement of the shield segments will increase due to the existence of the inclined shaft passage. Additionally, the inclined shaft passage will appear upward displacement and deformation, which is proportional to the distance between the shield tunnel construction intervals. The research results can provide certain technical references for the construction of similar projects.*

Keywords: *shield tunnel; finite element method; inclined shaft passage; field monitoring*

1. Introduction

Rapid development of urban underground space, the current subway tunneling construction process often need to cross the existing underground lines in close proximity, Yang Xin, Chu Xiuqiong, Ning Peng, et al.[1] used finite element software PLAXIS to establish a complex underground space under the shallow buried large cross-section top tube across the existing line tunnelling numerical model to analyze the amount of ground consolidation under the existing line of the uplift; Zhang Baogang, Xie Jiachong, Huang Xin[2] relying on the engineering Relying on engineering examples to establish numerical models to explore the interaction mechanism between existing double lines in the process of tunnel crossing double lines; Qu Tengfei[3] established a three-dimensional model through engineering examples, and systematically described the impact of shield construction technology on existing lines; Ruan Chengzhi, Shi Haibin, Yu Wanyou, et al.[4] analyzed the deformation value of existing tunnels after grouting and reinforcement, and proposed a tunnel reinforcement program to reduce displacement and deformation of the existing tunnels. This paper analyzes the deformation values of existing tunnels after grouting based on engineering examples, and proposes a tunnel reinforcement scheme to reduce displacement and deformation of existing tunnels. This paper introduces the interaction between shield construction and existing lines based on an example of a rail transit project spanning over an existing tunnel, in order to serve as a reference for similar projects in the future.

2. Engineering background

The project relies on a rail transit project in Chongqing, which is a two-lane shield tunnel, the shield tunnel is a left and right double-lane construction, the shield diameter of 6.9m, the installation of prefabricated concrete lining tube sheet outer diameter of 6.6m, inner diameter of 5.9m, the thickness of the tube sheet of 0.35m. Below the tunnel is a high-speed railroad slanting shaft construction channel, in which the left line of the tunnel shield from the nearest slanting shaft construction channel for the nearest 3.71m, the right line of shield tunnel from the nearest slanting shaft construction channel for the nearest 4.1m. The left shield tunnel is 3.71m away from the inclined shaft construction channel, and the right

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shield tunnel is 4.1m away from the inclined shaft construction channel, which makes the construction more difficult. Therefore, a three-dimensional numerical simulation model is set up to simulate the construction of this interval and analyze the mutual influence between the shield construction and the existing pipelines by using the interval of the shield tunnel construction crossing the existing inclined shaft channel. The schematic diagram of the project interval and the line of the existing inclined shaft channel is shown in Figure 1 below, and the geology of the project interval is mainly sandstone and sandpaper mudstone interbedded, and the physical and mechanical parameters of the strata are shown in Table 1 below.

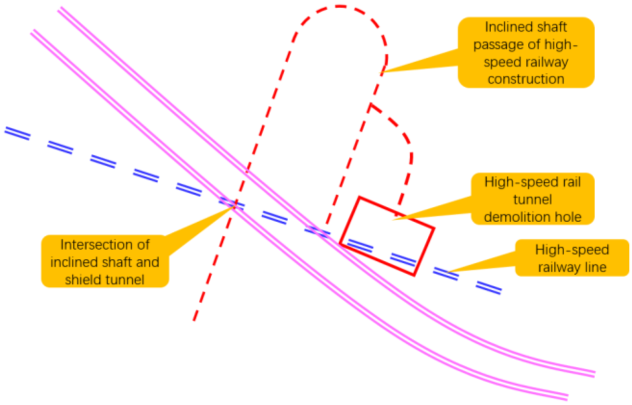

Fig. 1 Shield interval and high speed rail construction inclined shaft access plan

Table 1 Physical and mechanical parameters of the main soil layers

name	elastic modulus (MPa)	poisson ratio	volumetric weight	force of cohesion	angle of friction
sandy mudstone	1050	0.38	25.6	600	32.5
sandstone	3200	0.14	25	1700	39.3

3. Finite element analysis of settlement of shield segment and inclined shaft

3.1 Model establishment

Stratum model body using numerical model scale for the stratum depth of 100 m, high speed rail inclined shaft construction channel reinforcement range for shield interval left and right each 20 m, in order to simplify the calculation of the establishment of the stratum length of 50 m, the subway shield every 2 m assembled a ring of pipe pieces to 50 m width as the excavation interval to analyze the shield construction and the interaction of the existing construction pipeline. The top of the shield interval is located at a depth of 34 m underground, and the upper 30 m of the construction interval is sandstone, the middle and upper layer is 8 m sandy mudstone, the middle and lower layer is 10 m sandstone, and the lower layer is 52 m sandy mudstone, and its simplified model is shown in Figure 2 below. Inclined shaft construction channel support for the first time using 200 mm thick C25 shotcrete research, the second time using 300 mm thick C30 concrete to analyze and compare, the existing inclined shaft construction channel analysis of the 2D plate unit and give its attributes, the effect is shown in Figure 3 below.

3.2 Settlement analysis of shield segments

During the shield construction process, in order to facilitate excavation and tube sheet assembly, the tube sheet lining circle is generally slightly smaller than the shield construction excavation interval, so the shield tube sheet will produce a certain settlement in the construction process. As the shield construction is in close proximity to the inclined shaft construction channel, it is necessary to carry out left and right double lines to cross the inclined shaft channel separately. Figure 4 below shows the change curve of settlement of left and right double lines during shield construction.

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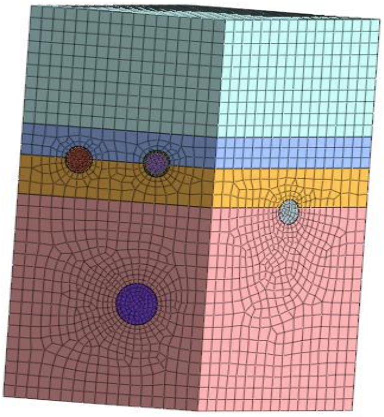


Fig. 2 Simplified calculation model

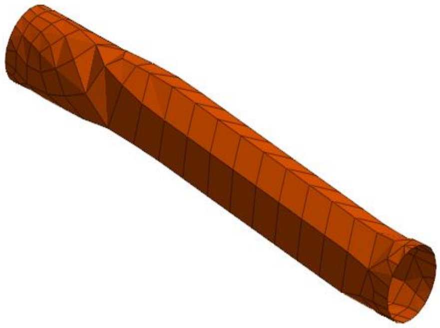
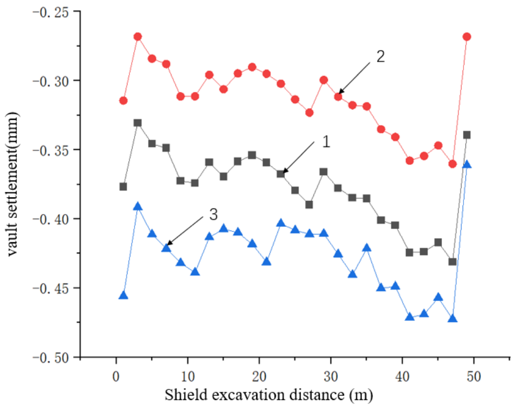


Fig. 3 Inclined shaft construction channel structure diagram



Note : 1-the right side settlement when excavating the right side ; 2 - the right side settlement when excavating the left side ; 3 - left side settlement when excavating left side

Fig. 4 Settlement of shield segment during excavation

As can be seen from the above figure, in the process of shield excavation, when only the right shield tunnel is excavated, the settlement of the right pipe sheet shows a gradual decrease with the increase of the excavation distance, but when the excavation distance is 50 m, and the scope of shield excavation exceeds the scope of the inclined shaft access reinforcement, the settlement decreases steeply; when the left shield tunnel excavation is started, the settlement of the pipe sheet of the right side of the completed shield interval decreases relative to that of the right shield tunnel only, comparing curve No. 1 and curve No. 2. When the left side of the tunnel is excavated, the settlement of the tube sheet on the right side of the tunnel is relatively larger, with an increase of 27.7% compared to the settlement of the tube sheet on the right side of the tunnel, and an increase of 43.7% compared to the settlement of the tube sheet on the completion of the double tunnel; curves 2 and 3 show the final settlement of the tube sheet of the final two-lane tunnel. The final settlement, in general, when the shield excavation interval passes through the inclined shaft passage, its tube sheet settlement gradually increases with the increase of excavation distance.

3.3 Settlement analysis of the inclined shaft

In order to analyze the impact of shield tunnel excavation on the inclined shaft construction channel under different reinforcement states, the first time 200mm thick C25 concrete is used to reinforce the inclined shaft channel and the second time 200mm thick C30 concrete is used to reinforce the inclined shaft channel under this model. Figure 5 and Figure 6 show the displacement clouds after the C25 concrete and C30 concrete were used to reinforce the inclined shaft channel, respectively.

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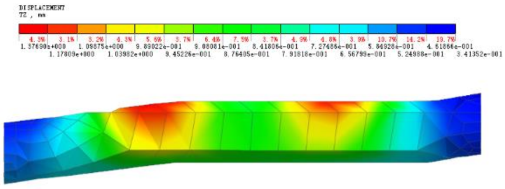


Fig.5 Settlement of inclined shaft channel reinforced by C25 concrete

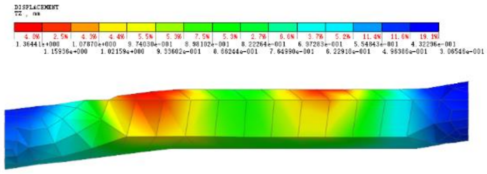
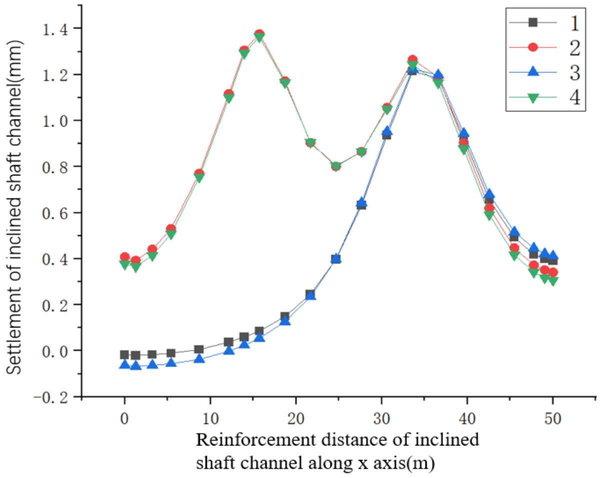


Fig.6 Settlement of inclined shaft channel reinforced by C30 concrete



Note: 1-C25 concrete reinforced inclined shaft only excavates the right side settlement; 2-C25 concrete reinforcement inclined shaft excavation to complete the settlement; 3-C30 concrete reinforced inclined shaft only excavates the right side of the settlement; the settlement amount of 4-C30 concrete reinforced inclined shaft excavation is completed

Fig.7 Settlement of inclined shaft channel caused by shield construction

In Figure. 7, Curve 1 and Curve 3 show the settlement of the inclined shaft passage in the right shield excavation only, where the positive value indicates that the passage rises upward. Comparing Curve 1 and Curve 3, i.e., the inclined shaft passage reinforced with C25 concrete and the inclined shaft passage reinforced with C30 concrete, it can be seen that, for the excavation of the right tunnel only, the amount of settlement occurred in the interval of 0-20m in the direction of the X-axis when the inclined shaft passage was reinforced with C25 concrete was smaller than that in the interval of 20-40m, i.e., below the shield excavation. It can be seen that only for the right tunnel, the settlement of the C25 concrete reinforced inclined shaft passage in the X-axis direction 0-20m is smaller than that of the C30 concrete reinforced inclined shaft passage, and in the 20-40m interval, i.e., underneath the shield excavation interval, the settlement of the two different reinforcement methods is basically the same, and then it gradually shows the trend of larger settlement with the C30 concrete, and in the direction nearest to the X-axis, the C30 concrete reinforced inclined shaft passage is larger than that with the C30 concrete. direction, the settlement of C30 concrete reinforcement is 263% higher than that of C25 concrete reinforcement, and 5.6% higher than that of C25 concrete reinforcement at 50m. Curves 2 and 4 show the settlement of the inclined shaft passage interval at the completion of excavation. The overall trend of the settlement curves of the inclined shaft passage reinforced with C25 and C30 concrete respectively is basically the same, but at the nearest and farthest points from the X-axis, the settlement generated by the curve reinforced with C30 concrete is less than that generated by the C25 concrete reinforcement, and its settlement is reduced by 7.5% year-on-year.

After the above analysis and comparison, the deformation displacement of the inclined shaft construction channel produced by C25 concrete is smaller when only one side is excavated, while the deformation displacement of the inclined shaft of the tunnel reinforced with C30 concrete in the shield excavation process is smaller only when both sides of the tunnel are excavated. In the final comparative analysis, the benefits of using C25 concrete reinforcement were maximized.

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4. Analysis of field monitoring

4.1 Layout of monitoring points

The construction of a project in Chongqing as a basis, after comparative analysis of numerical simulation, the site construction process of the inclined shaft tunnel reinforcement area using 200mm thick C25 concrete for reinforcement, and the reinforcement interval for the shield construction interval before and after the range of 50m, in the inclined shaft channel vault above the installation of precision level, the installation effect is shown in Figure 8 below. In order to ensure continuous monitoring data, a monitoring point is arranged in 5-10m of the inclined shaft passage, and data monitoring is carried out twice a day during the shield tunnel construction, and once every two days after the shield tunnel passes through the reinforcement range to ensure the safety of the inclined shaft passage.

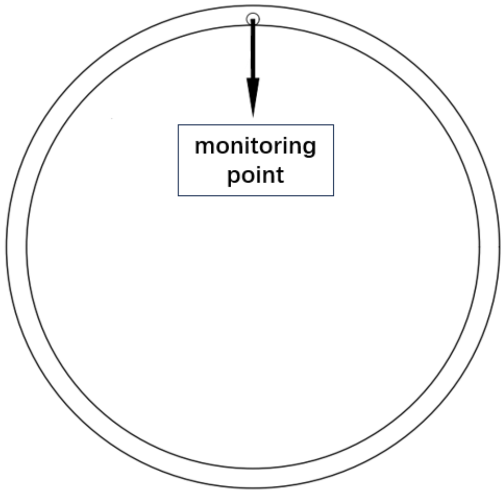
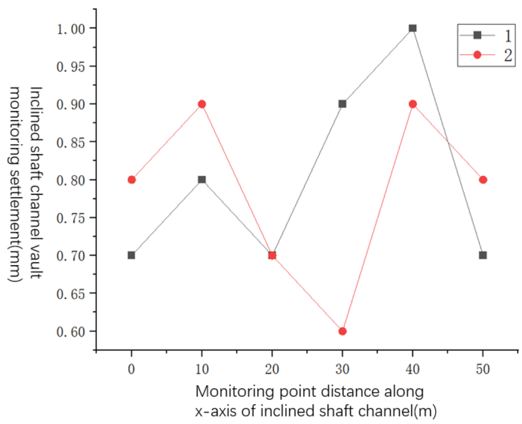


Fig 8 monitoring point of vault settlement of inclined shaft tunnel

4.2 Field monitoring data

According to the actual construction monitoring on site, the settlement data of the inclined shaft channel within 50m of shield excavation was obtained during the tunnel excavation as shown in Figure 9 below.



Note: 1-the settlement of the inclined shaft reinforcement area after the completion of the right line; the settlement of the reinforced area of the inclined shaft after the completion of the 2-double line tunnel

Fig 9 monitoring curve of settlement at the top of inclined shaft tunnel

Figure 9 above shows the actual monitoring curve of the inclined shaft passage during the actual construction process. Curve 1 shows the displacement curve after the shield right tunnel passes through the reinforced area of the inclined shaft passage, which shows that the curve is in the state of rising in the grouting from 0-40m, indicating that in this interval, due to the influence of the shield construction, the inclined shaft passage gradually produces an upward displacement, and it reaches its maximum value at 40m, i.e., below the right line of the shield, where the inclined shaft passage produces the maximum upward displacement, which is 1.02mm. The maximum upward displacement of the inclined shaft tunnel is 1.02mm, after that, due to the gradual increase of the distance between the inclined shaft tunnel and the right line of the shield, the curve of the upward displacement shows a decline; curve 2 shows the displacement curve of the top of the inclined shaft tunnel after all the construction of the shield double-lane tunnel passes, and it can be seen in the figure that the maximum upward displacement of the inclined shaft tunnel occurs at the positions of 10m and 40m, i.e., the inclined shaft tunnel below the right and left double-lines of the shield is at the position of 1.02mm. It can be seen from the figure that the maximum upward displacement occurs at 10m and 40m, i.e., the maximum upward displacement occurs at the position below the left and right double lines of the shield tunnel, and the maximum displacement is over 0.9mm, and the displacement at the position below the middle of the shield tunnel is the minimum value, which is only about 0.6mm.

4.3 Comparative analysis of field monitoring and numerical calculation

Comparing curve 1 in Figure 7 with curve 2 and Figure 9, after completing the excavation of the right-lane shield interval only, both curve 1 in Figure 7 and curve 1 in Figure 9 produced upward displacements that reached the maximum value at the position of about 40m, with the maximum results close to each other, and with the increase of the distance, i.e., the increase of the distance between the shield tunnel and the inclined shaft access, the displacement curves of the inclined shaft access all decreased; in the case of the double-lane shield interval excavation is completed, curve 2 in Figure 7 and curve 2 in Figure 9 both show an M-shaped trend, and the actual monitoring results are close to the numerical simulation results.

5. Conclusions

By conducting finite element analysis and combining with field monitoring, the mutual effect between shield segments and inclined shaft passage during the shield tunnel’s overpassing the inclined shaft passage. The following conclusions are mainly drawn.

(1) During the process of the shield tunnel’s overpassing the inclined shaft passage, the shield segment at one end of the shield tunnel’s first overpassing of the inclined shaft passage will reduce its displacement and settlement when it overpasses the inclined shaft passage for the second time. In other words, when the shield tunnel is excavated for the second time, the settlement in the interval where the shield excavation is completed for the first time will be reduced.

(2) For shield tunnels with large burial depths and stable soil properties, the impact of the concrete grade used in the reinforcement section on the displacement of the inclined shaft passage during the construction process of the shield tunnel’s overpassing the inclined shaft passage of high-speed railway is not significantly different.

(3) During the process of the shield tunnel’s overpassing the inclined shaft passage, the closer it is to the shield tunneling section, the greater the impact of shield tunneling on the inclined shaft passage. Moreover, the inclined shaft passage undergoes upward deformation, that is, deformation in the direction of the shield tunnel section.

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