Research on the effects of the excavation of cross passage for the displacement of tunnel and the surface of earth

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Abstract. In the construction of urban subway, the excavation of the cross passage is usually carried out after the completion of the main tunnel.At the same time, it is necessary to ensure the safety of the cross passage itself and the stability of the main tunnel and the normal access of the ground is also indispensable.Therefore, it is of great significance for the whole project to accurately grasp the scope of influence and the rule of change of the construction of cross passage.Based on the cross passage of subway in Xuzhou,the influence of the excavation of cross passage on vertical, horizontal displacement of tunnel and the settlement of ground is studied through the finite element software called MIDAS GTS/NX.The following conclusions are drawn:the curve of the settlement of the upper part of the tube, the uplift of the lower segment and the convergence of tunnel caused by the excavation of the cross passage are "U", half pentagonal, and triangular and the influence of tunnel with hole side is obviously greater than that of the other side tunnel.Besides,the overall range of impact is within 30m of the longitudinal distance from the central line of the tunnel. The tunnel eventually moves upwards and it moves toward the direction of the cross passage.The settlement curve of the change of surface caused by excavation of cross passage is basically the shape of "U".The main influence area is 15m within the center line of cross passage and the settlement of the soil near the middle line of the connecting passage is the most obvious, 6.5mm.In addition, all values meet the requirements of the deformation of control,which confirms the effect of the reinforcement of grouting.

1. Introduction

The structure of the subway is surrounded by surrounding rock. Although the ability to defend against external disasters is better, the ability to resist internal disasters is poor. Subsequently, 《The code for Metro Design》 stipulates that when the length of tunnel exceeds 600m, a cross passage must be set up.From a security point of view, the setting of cross passage is bound to form a relatively unfavorable form of space crossing with the tunnel. And the tunnel ring at the junction with the cross passage is the lowest safety link in the ring structure of the whole tunnel.From the point of view of construction, although the excavation of the connecting passage is small, the stability of the main tunnel is greatly reduced because the change of the stress of the main tunnel after the steel tube is removed. So it is particularly important for the whole subway to design and construct the cross passage reasonably.

With the construction of subway coming to a climax, more and more attention has been paid to the construction of cross passage.In view of the situation of horizontal stage freezing, Xu Yanqing and others[1] studied the law of stress and deformation of tunnel lining during the freezing construction of long-distance cross passage; Lv Hu and others[4] set up the model of risk analysis of cross passage and put forward the control measures for its construction risk ;Through monitoring and analyzing the displacement of the tunnel during construction, Zhao Jianping and others[7] obtained the influence of the settlement and displacement of the main tunnel in the cross passage constructed by freezing method.The above research has played a good role in mastering the mechanical behavior of construction of cross passage, but the research on the vertical and horizontal deformation of the surface and tunnel caused by the construction of the cross passage is not sufficient.Based on the cross passage of a subway in Xuzhou ,the influence of excavation of the cross passage on the deformation of the surface and tunnel is studied by MIDAS software.And the key and difficult points in the construction and corresponding suggestions are also put forward.

2. The general situation of engineering

In order to meet the requirements of disaster prevention and drainage, the cross passage is set up at the lower level of the line. The cross passage is constructed by advanced support in the tunnel and mining method. The distance between the axis of the cross passage is 11.638 meters, the thickness of the structure covering is 18.1 to 19.8m, and the maximum depth is up to 19.7m.The cross passage passes through medium weathered limestone and the upper layer is geo clay. The thickness is 0.5 to 6.5. And the sandy silt is distributed throughout the field with a thickness of 0.5 to 11.80.To sum up, the content of water of the overlying soil is relatively high, and it is easy to produce adverse geological disasters such as quicksand if handled properly. Its rock mass is highly permeable and it has poor ability to resist deformation under external force.Therefore, the soil around the connecting passage before construction should be reinforced by grouting.The geology of the cross passage is shown in Figure 2-1.

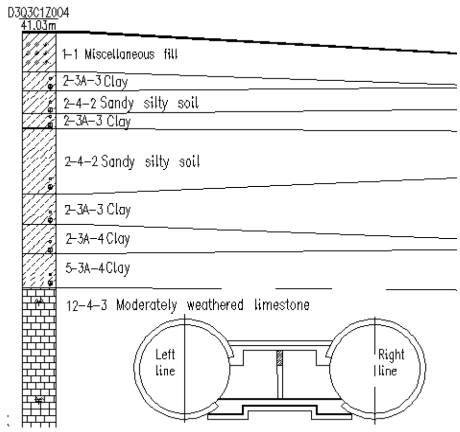


Figure 2-1. Geological section map of cross passage

3. The design of cross passage

The cross passage is designed according to the principle of "New Austrian Tunneling Method", and the structure of composite lining is adopted.The parameters and support of tunnel lining are mainly based on the factors such as the section of structure, the type of surrounding rock, the condition of hydrographic and geological , the characteristics of structural stress.And it is determined synthetically by calculation, analysis and optimization of the similar project.The initial support is mainly composed of steel mesh and concrete and secondary lining is made of waterproof reinforced concrete.In addition, a flexible waterproof isolation layer is provided between the initial support and secondary lining.The specific structure is shown in Figure 3-1.The length of reinforcement is the length of the cross passage, the height is the 3 meters of the vault and the outer floor of the connecting channel and the width is 3 meters outside the side wall.The specific scope of reinforcement is shown in Figure 3-2.

The design parameters of the cross passage are as follows:

The initial support: steel mesh of single storey + grid steel frame + sprayed concrete (280mm thick). The secondary lining:C35 waterproof reinforced concrete (300mm thick).

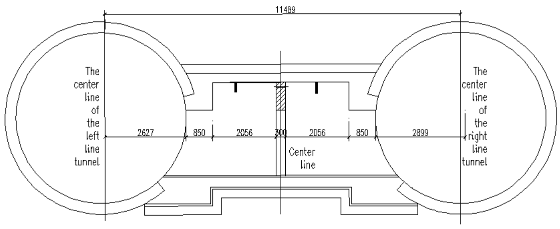


Figure 3-1. The plane diagram of a structure of cross passages.

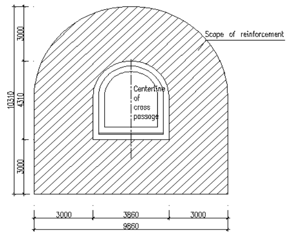


Figure 3-2. The map of the scope of reinforcement of cross passages.

4. Numerical simulation

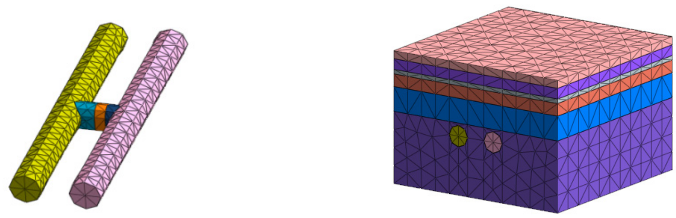
4.1. The model of calculation and the selection of parameters

In this paper, the Mohr-Coulomb criterion is used as the mechanical model, and the finite element software MIDAS GTS is used for numerical simulation.The upper boundary of the calculation model is taken to the ground, and the lower boundary is taken to three times as high as the height of tunnel.

And the horizontal of model is taken to three times as span as the span of tunnel.The model of calculation is shown in Figure 4-1.

The constraint of the bottom of it is fixed, and the lateral of the bottom of it is normal constraint.

And the boundary of the model is ground, which is set as a free surface. The area of reinforcement by grouting is simulated by improving the formation parameters. In the calculation model, it is assumed that the soil is an ideal elastic-plastic material. And its parameters are selected according to the report on geological exploration. The parameters of segment and initial support are elastic materials, which are selected according to the Code for Design of Concrete Structures (GB50010-2010). The specific parameters are shown in Table 4-1.



a. Model of tunnel and cross passage. b. Model of soil mass.

Fig. 4-1. The model diagram of the calculation..

Table1. The value of soil and parameters

Serial number	Project	γ(kN/m3)	Es (MPa)	υ	c(kPa)	φ(°)
1	Sandy silty soil（2-4-2）	19.26	6.5	0.25	7.4	16.5
2	Clay（2-3A-3）	18.96	5.4	0.25	13.2	7.1
3	Clay（2-3A-4）	19.57	12.13	0.3	34.1	3.0
4	Clay（5-3A-4）	19.17	13.01	0.25	71.9	4.4
5	Moderately weathered limestone（12-4-3）	-	-	0.25	10.2	40.9
6	Segment of tunnel	25.0	25000	0.2		
7	Concrete	25.0	22000	0.2		
8	Reinforced soil	25.0	50	0.28	10	39

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4.2. The simulation of working condition of construction
Before the excavation of the cross passage, the simulation of initial in-situ stress and the excavation of tunnel are carried out first. After the displacement is cleared, the excavation of the cross passage is started.In order to simulate the influence of the excavation of soil on tunnel and ground settlement, the process of construction is divided into three conditions of working. The first condition of working is that the Right-Line tunnel opens the segment and excavates to 1/5 of the cross passage, the second condition of working is to excavate to the middle of the connecting passage, and the third condition of working is to complete the construction of the cross passage. Every step of excavation is carried out according to the principle of "digging with support".

4.3. The results of calculation and analysis

4.3.1. The influence of excavation of cross passage on vertical deformation of tunnel
Fig. 4-2 and Fig. 4-5 are the deformation chart of the upper and lower segments of the tunnel; Fig. 4-3 and Fig. 4-4 are the settlement values of the upper segments of the left and right tunnel respectively under different working conditions; Fig. 4-6 and 4-7 are the uplift values of the lower segments of the left and right tunnel respectively under different working conditions. It can be seen from the diagram that the excavation of the cross passage will cause the settlement and uplift of the upper segment and the lower segment of the tunnel. The tunnel shows a tendency to become flat. Due to the large rebound of the excavation, the tunnel eventually has an upward displacement of about 5mm. From the range of influence, the settlement value of 30 m away from the tunnel center line is less than 1 mm, and the uplift value of 20 m away from the tunnel center line is less than 1 mm. Compared with the above figure, the settlement and uplift value of the side opening tunnel is larger than that of the other. This is due to the stress concentration at the entrance of the tunnel after the removal of the portal segment.The stress redistribution occurs immediately in the tunnel, and the excavation of cross passage makes the lateral pressure of the tunnel increase obviously.

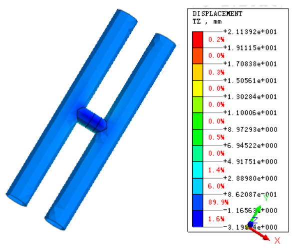

Fig. 4-2. The deformation cloud chart of upper part of tunnel

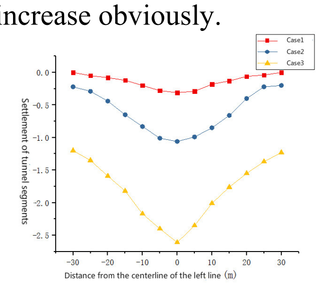

Fig. 4-3. The curve diagram of change of settlement of left line tunnel

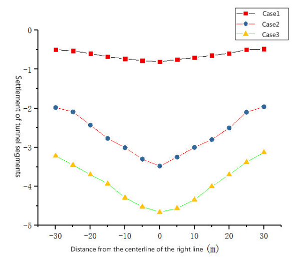

Fig. 4-4. The curve diagram of change of settlement of right line tunnel

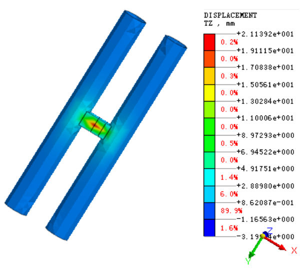

Fig. 4-5. The deformation cloud chart of lower part of tunnel

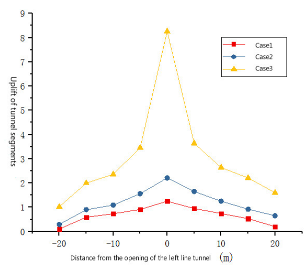

Fig. 4-6. The curve diagram of change of uplift of left line tunnel

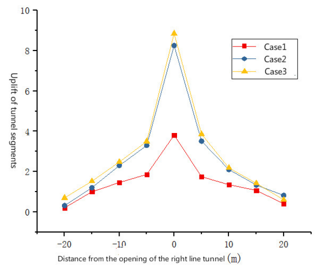

Fig. 4-7. The curve diagram of change of uplift of right line tunnel

4.3.2. The influence of excavation of cross passage on horizontal deformation of tunnel
Fig. 4-8 shows the horizontal deformation of the tunnel; Fig. 4-9 and Fig. 4-10 show the convergence values of the left and right tunnel under different working conditions. As can be seen from the diagram,

the construction of the cross passage reduces the lateral pressure of the tunnel on one side, and the horizontal additional stress moving in the direction of the cross passage appears at the segment.

Compared with the figure above, the convergence value of the left tunnel increases faster than that of the right tunnel.But the horizontal deformation of the right line tunnel is larger than that of the left line tunnel on the whole.Due to the stress concentration at the entrance and the greater disturbance to the soil near the entrance, the horizontal deformation of the segment at the entrance is larger.

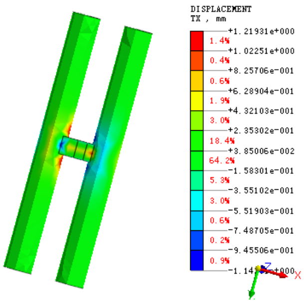

Fig.4-8. The deformation cloud chart of tunnel

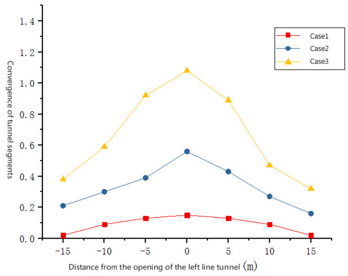

Fig.4-9. The curve chart of change of the constriction of left line tunnel

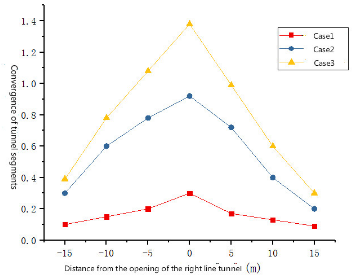

Fig.4-10. The curve chart of change of the constriction of right line tunnel

4.3.3. Influence of excavation of cross passage on settlement of ground

Figures 4-11, 4-12 and 4-13 show the change of settlement of ground under different conditions. It can be seen from the drawings that during the construction of cross passage, the stress disturbed area in the strata spread to the surface and change of mechanics of surrounding rock is reflected to large extent by continuous settlement of ground. As shown in figures 4-11 and 4-12, there is no obvious change in settlement of ground after the removal of segments.After the excavation and initial support work, the 5mm settlement around the surface occurred. Therefore, the loss of stratum caused by excavation of cross passage is the most important factor causing settlement of ground.From the above picture, the rate of change of settlement of ground is nearly 2 times higher than that of case 1.This is caused by factors such as the re-consolidation settlement of the existing soil after disturbance and settlement of soil caused by the pressure on the upper soil of the support. As can be seen from Figure 4-13, the maximum settlement of ground is 6.21 mm appears above the central line of the two tunnels.The maximum bending occurs in the supporting action of the main tunnel on the soil above it, and the arch roof and floor of the tunnel are the main factors.

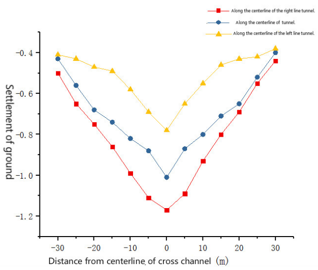

Fig. 4-11.The curve chart of change of ground settlement in case1

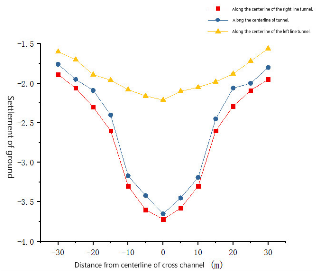

Fig. 4-12.The curve chart of change of ground settlement in case2

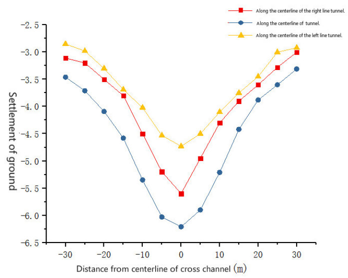

Fig. 4-13.The curve chart of change of ground settlement in case3

5. Conclusion

Through the finite element software, the excavation of a connecting passage in Xuzhou city is simulated, and the following conclusions can be drawn.

1) The curve of settlement of ground caused by the excavation of cross passage is basically U-shaped, and the main influence area is within 15 m from the center line of it.Therefore, the soil in this

area should be reinforced to improve the resistance to deformation for some cross passages below the main road or the effect of reinforcement is limited.After excavation, it should be supported and closed in time to form a combined support system with surrounding rock.

2) The curves of settlement, uplift and convergence of the tunnel caused by the excavation of cross passage are basically U-shaped, semi-pentagonal star-shaped and triangular under different working conditions.The main influence area of tunnel settlement is within 30 m of center line of cross passage on the side of leading construction and 20 m of center line of cross passage on the other side.The main influence area of uplift and convergence is basically 15m within the longitudinal segment of tunnel portal.The vertical deformation and horizontal deformation of the tunnel increase obviously during the excavation of the connecting passage.Therefore, after the deformation of the tunnel is stable, the construction of cross passage can be carried out and the reinforcement should be taken for each tunnel.

3) Informational construction should be adopted in connection corridor construction.The monitoring and measurement should be strengthened in the main affected areas, and the measuring should be laid along the maximum settlement.During the excavation, the monitoring of the side of leading construction and the surface above the tunnel should be increased.

4) The calculation shows that the change of soil layer and existing tunnel can not exceed 10 mm by grouting during the excavation of cross passage.This reinforcement greatly reduces the risk of construction of cross passage.

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