The Effects of Different Excavation Angle on Intersecting Tunnel Surrounding Rock Stability

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***Abstract*—Various contacting channels and intersecting tunnels often need to be constructed in the tunnel construction process. While in the process of intersecting tunnel construction, the excavation of back tunnel will cause surrounding rock and supporting structure stress adjustment and redistribution. The excavation of two crossing tunnels will cause lots of changes in the rock and supporting structure mechanical characteristics. It has great impact on the intersection of the stress and deformation. The background of this paper is the Dalian subway project and selects excavation angle of 30°, 45°and 90°. In order to obtain the supporting structure stress change and deformation of surrounding rock in the process of main tunnel and intersecting tunnel excavation with different angle, this paper use MIDAS/GTS to carry on the numerical simulation and analysis earth surface settlement, vault, clear convergence variation. Finally it obtains the reasonable angle of intersecting tunnel and to guide the construction of the project smoothly.**

Keywords-Intersecting tunne; Excavation angle; Numerical simulation; Supporting structure; Deformation of surrounding rock.

I. INTRODUCTION

Our Academy of Engineering, Wang Mengshu from the height of "sustainable development", proposed the "era of the 21st century is the tunnel and underground space development"[1]. In the field of tunnel construction, attracted a growing number of scholars to explore and study. Currently, there are many domestic and foreign scholars have related research on intersecting tunnel [2-8], and gradually accumulated some experience and results, But they mostly concentrated in the form of tunnel section, mechanics, construction methods, construction technology and support systems, etc. They studied relatively few and inadequate in the rationality of the excavated angle and there are many problems to be solved. This paper use MIDAS-GTS finite element numerical simulation to choice the reasonable angle of intersecting tunnel as well as provide reference for similar tunnel projects according to the engineering geological conditions, difficulty in construction and design requirements.

II. PROJECT SUMMARY

The interval from promotion road station to Spring Street station adopt excavation method and design scope for mileage, DK11+365.945~DK12+013.350, right line length 647.405m, left line length 644.039m. The line of this range layout along north-south of promotion road, via Xiang Zhou Road and through the "second industrial erection engineering company" factory and the "Dalian iceberg Sanyo washing limited company" factory. The distance between lines is 13m~4.6m~12.615m. In order to ensure the tunnel away from buildings on both sides of road as far as possible, the engineer set up 300m and 1000m radius curve each side. The distance between lines is from 13.4m to 4.6m. The engineer set a single cross the line and set a 400m radius curve after Xiang Zhou Road. Tunnel surface topography fluctuation is bigger. The ground elevation is from 7.79m to 10.58m. Tunnel vault covering the largest is 16.9m and the minimum is 13.14m. The section of the paper selected AK11+908. Artificial accumulation thickness is 4.2m. Diluvium thickness is 3.5m and slate thickness is 34.5m. Intersecting tunnel layout and tunnel profile as shown:

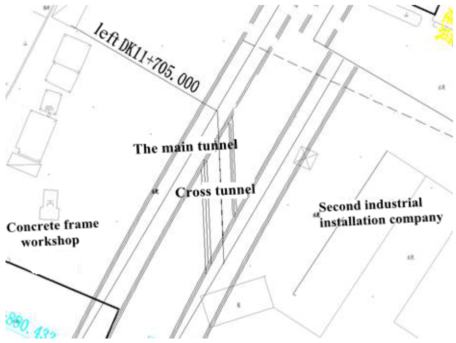


Figure 1. The actual engineering plan

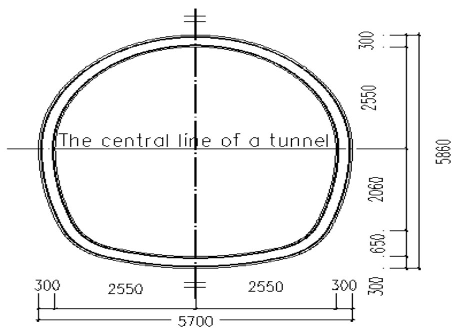


Figure 2. The section size of tunnel

III. PARAMETER SELECTION AND MODELING

This project uses shot concrete, anchor rod as the main means of support. Because bolt shot concrete support capable of forming a tight bond of flexible thin retractable supporting structure. It allows a certain degree of coordination surrounding rock deformation of supporting structure to withstand without causing excessive pressure.

Cross tunnel construction include: advance support, excavation, grill installation, after initial support backfill grouting construction. Formations and various supporting structure parameters in the following table:

TABLE I. THE PARAMETERS OF CALCULATION

Project	Bulk density γ (kN/m^3)	Elastic modulus E (MPa)	Cohesive force C (kPa)	Internalfriction angle $\varphi(^0)$	Poisson ratio μ
Plain fill	17	50	10	8	0.35
Pebble	22	200	5	30	0.3
Full weathered calcareous slate	20	120	30	16	0.33
Shotcrete	25	30000			0.2
Bolt	78	2000000			0.3

Theoretical analysis shows that the circular tunnel excavated in infinite domain of homogeneous and elastic is less than 1% when it's 5 times outside the scope of hole diameter is less than 5% when it's 3 times outside the scope of hole diameter because of the changes in stress and displacement of surrounding rock due to load release. considering the needs of engineering, the finite element discrete error and calculation error, the general selection calculation along the hole diameter in all directions are not less than 3~5 times hole diameter. The whole model is divided into three layers, the thickness of each layer are respectively 2m, 3.5m, 34.5m. The selected model: length 130m, width 60m, high 40m. The crossing tunnel and the whole model as shown:

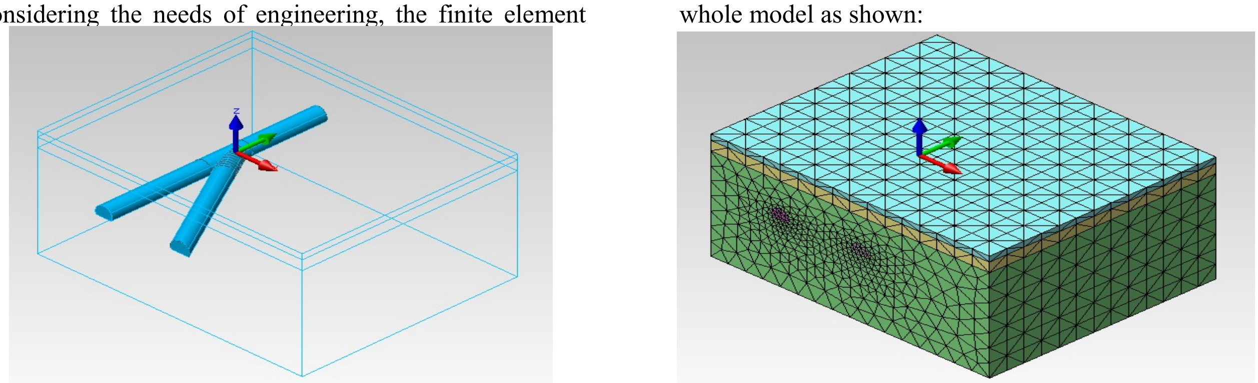
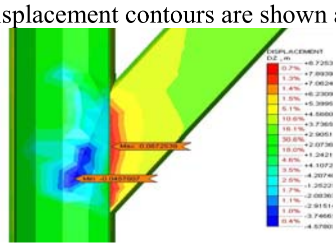


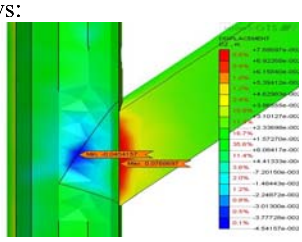
Figure 3. The Schematic Model of Calculation

IV. RESULTS ANALYSIS

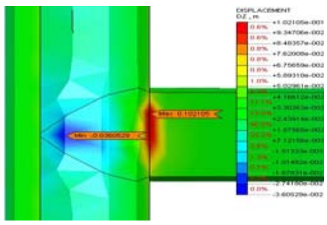
Different Crossing Angle Settlement Analysis. The main tunnel and crossing tunnels before and after excavation displacement contours are shown as follows:



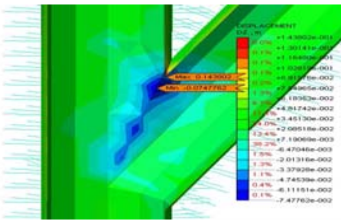
After the 30° main tunnel excavation completed



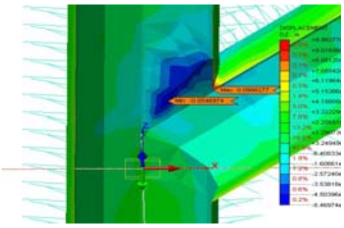
After the 45°main tunnel excavation completed



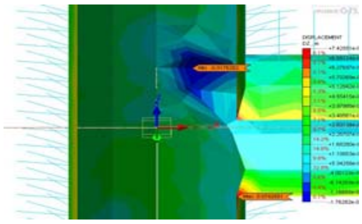
After the 90° main tunnel excavation completed



After the 30°crossing tunnel excavation completed



After the 45°crossing tunnel excavation completed



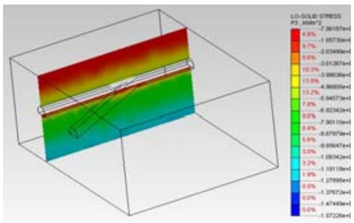
After the 90°crossing tunnel excavation completed

Figure 4. The completion settlement comparison of different bifurcation angle of tunnel excavation

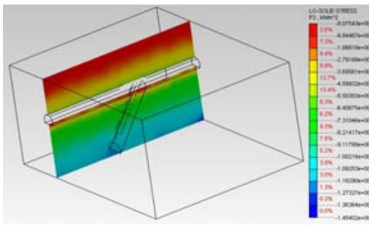
After the main tunnel excavation completed and before crossing tunnel excavated, sedimentation vault and floor uplift occurs at the intersection. 30° vault settlement value is -45.78mm. Surface uplift is 87.25mm. 45° vault settlement value is -35.54mm. Surface uplift is 56.87mm. Dome 90° settlement value is -36.05mm. Surface uplift is 61.10mm. Visible, 45°excavation vault settlement value is minimum and the settlement value of the dome 30° excavation has produced the greatest. The value of surface uplift generated by 90° excavation is the largest and 45° excavation surface uplift value is the minimum.

After cross tunnel excavation completed, 30° excavation vault settlement value of the maximum reach -74.77mm.Surface uplift is 143.8mm. 45° excavation dome maximum settlement value is -54.69 mm. Surface uplift is 68.82mm. 90° state excavation, vault settlement value up to -67.62 mm. Surface uplift is 74.25mm. According to above numerical simulation results, the maximum settlement value of the dome all occurred in the intersection of the tunnel. During the excavation of the tunnel along with ground uplift, its maximum value occurred in the bottom of the main tunnel and crossing tunnel.

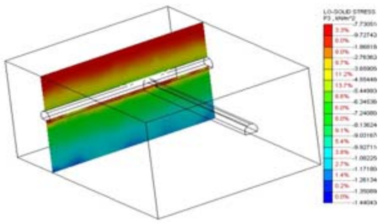
Different Crossing Angle Principal Stress Analysis. Stress cloud chart is shown as follows:



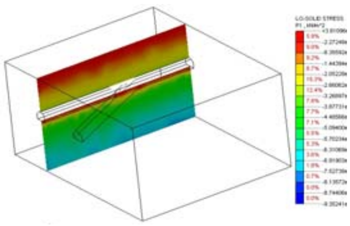
The 30°tunnel maximum principal stress



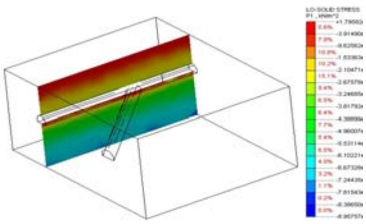
The 45°tunnel maximum principal stress



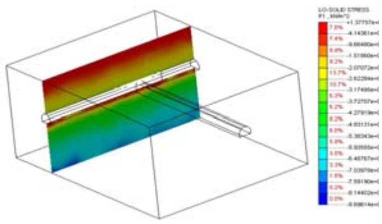
The 90°tunnel maximum principal stress



The 30°tunnel minimum principal stress



The 45°tunnel minimum principal stress



The 90°tunnel minimum principal stress

Figure 5. The stress distribution nephogram of the main tunnel

In the range of 20m, all region is crossing tunnel principal stress area. Within the scope, all crossing tunnel surrounding rock stress is compressive stress and the maximum compressive stress occurred in vaults. The first principal stress of 30^0 crossing tunnel is 0.65MPa and the third principal stress is 0.32MPa. The first and the third principal stress on arch foot is 0.038MPa, 0.008MPa. The first principal stress of 45^0 crossing tunnel is 0.63MPa and the third principal stress is 0.28MPa. The first and the third principal stress on arch foot is 0.018MPa, 0.0075MPa. The first principal stress of 90^0 crossing tunnel is 0.63MPa and the third principal stress is 0.31MPa. The first and the third principal stress on arch foot is 0.023MPa, 0.0077MPa.Visible, the value of 45°excavation vault principal stress is least and previous secondary stress field is disturbed. Finally, it form the thrid stress field. Therefore the construction of crossing tunnels is the biggest risk source during tunnel construction and it need pay close attention to the timely support the need for personnel construction and monitoring the scene, to avoid the dangerous.

Different Crossing Angle Shot Concrete Stress Analysis. Shot concrete stress cloud is as follows:

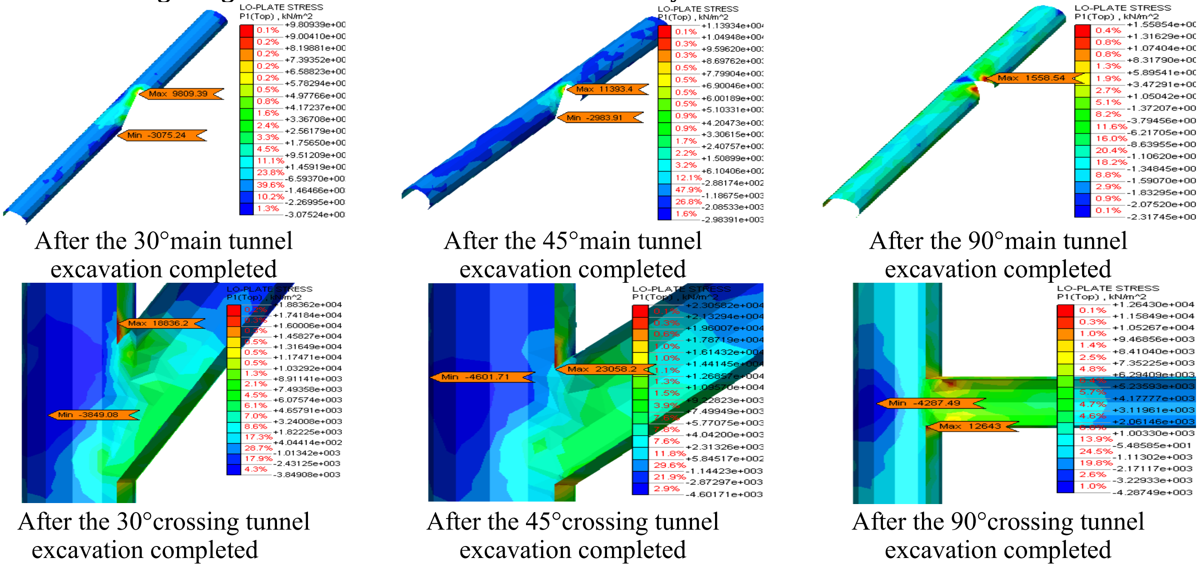


Figure 6. The different bifurcation point of shot concrete stress analysis

Respectively with 30°, 45° and 90° excavation, the maximum principal stress in the early stages of the tunnel support occurred in the main tunnel vault which is 12.8Mpa, 9.4Mpa, 11.6Mpa. Maximum compressive stress occurred in the arch foot which is 3.2Mpa, 2.1MPa, 2.3MPa. After the crossing tunnel excavation completed, the maximum principal stress in the early stages of the tunnel support occurred in the arch foot which is 18.8Mpa,10.2Mpa,12.6Mpa, The maximum compressive stress appeared in the arch foot of the other side which is 3.8MPa, 2.6MPa, 4.3Mpa. According to the numerical simulation results, with 30° and 45° excavation, the maximum principal stress appeared in the same position and direction. If it chooses 90 ° excavation, the maximum principal stress at the dome compared to the previous two much is larger. So the second excavation scheme is reasonable.

Different Crossing Angle Bolt Stress Analysis. Different cross Angle, the main tunnel and cross tunnel anchor stress are shown in table 2 below:

TABLE II. BOLT STRESS VARIATION

Cross Angle	main tunnel excavation(MPa)		Cross tunnel excavation(MPa)	
30°	maximum tensile stress	4.75E+05	maximum tensile stress	8.76E+05
	maximum compressive stress	-3.16E+05	maximum compressive stress	-8.64E+05
45°	maximum tensile stress	3.96E+05	maximum tensile stress	7.81E+05
	maximum compressive stress	-2.15E+05	maximum compressive stress	-5.83E+05
90°	maximum tensile stress	3.76E+05	maximum tensile stress	4.69E+05
	maximum compressive stress	-2.20E+05	maximum compressive stress	-6.26E+05

As can be seen from the above table data, with 30° excavation, bolt tensile stress and compressive stress is the biggest. On the contrary, with 45° excavation, it is the minimum. The construction of crossing tunnel has little disturbance on the formations. The stress of formation can be released in a certain degree. So the degree of bolt stress concentration is smaller Compared with the other programs. It has increased the stability of the tunnel supporting structure and ensured the safety of construction workers. In terms of the anchor rod stress, the second solution is more reasonable.

V. CONCLUSIONS

(1) With the main tunnel excavation completed, the initial stress field has been destroyed and the surrounding rock and supporting structure formed the secondary stress field. With the intersecting tunnel excavation completed, previous secondary stress field has been disturbed and finally formed the third stress field. Therefore the construction of crossing tunnels is the biggest risk source during the construction of intersecting tunnel. It needs to pay close attention to the situation of surrounding rock deformation and support timely to avoid the dangerous.

(2) This paper uses MIDAS/GTS software for numerical simulation of tunnel construction process. It obtains that the supporting structure stress and deformation of surrounding rock of the main tunnel and cross tunnel under different excavation Angle. Excavated by 30°, at the intersection of two tunnels adjacent, surrounding rock stability has been greatest impact on, especially in the acute need to enhance support. Excavated by 45°, because of the soil thickening in the acute angle, the degree of stress concentration is reduced and bolt stress is smaller. In the same state supporting structure, the overall stability of the rock has been improved significantly and excavated by 90°, the value of vault settlement and the stress is larger.

(3) Excavated by 45°, it proves the rationality in the process of tunnel excavation at the aspects of the deformation of surrounding rock and supporting structure stress. Considering went in and out of the excavator, forklift in between two tunnels easily and the laying track, finally engineers select the second solution.

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