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Research on the influence of the intercalated rock stress by the approach of three tunnels

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Abstract. The article relies on the Guang-Xing section of the southern section of the third phase of Chengdu Metro Line 1 to cross the Cheng-Hua Railway. The change of the stress with the approaching is analyzed. Study the stress change law of the intercalated rock under the change of the distance and angle: when the distance decreases, the maximum principal stress increases more obviously, which shows that the smaller distance, the easier the damage of intercalated rock. The stress state of the rock at different angles is that it is safer to overpassing and undercrossing, the horizontal approach is the most dangerous, and the other angles tend to be between the two. Through three-dimensional numerical simulation, the influence of the excavation process and construction method is analyzed, and it is found that the change of the secondary stress on the sandwiched rock by the mining method is relatively larger than that of the shield method. This makes the surrounding rock disturbance relatively large, resulting in the weakening of the sandwiched rock, which is directly manifested as the increase of the subgrade displacement.

1. Introduction

With the continuous improvement of Chinese infrastructure construction, a boom in subway construction has emerged in large and medium-sized cities, and the urban subway network has become increasingly dense. While the criss-crossing subway lines make it convenient for people to travel, they will inevitably intersect with the city's existing transportation facilities (such as railways, highways, and underground passages) at close distances, causing difficulties for construction. Analyzing the impact of nearby construction and ensuring the smooth progress of construction has an important guiding role in my country's infrastructure construction.

There has been a lot of analysis on the proximity of the three holes. Chao K ^[1] made a correlation analysis on the damage patterns of the three holes in close proximity. Because tunnel excavation will inevitably lead to the redistribution of stress in surrounding rock, the more times of excavation, the more times of stress redistribution. Therefore, studying the stress state of the bedrock is very important for the analysis of the influence of multiple tunnel excavation studies. Since distance is one of the common factors in construction, many scholars have conducted relevant discussions on it ^[2]. There are relatively few researches on the influence of surrounding rock. Chuanqing Z ^[3-5] analyzed various effects of surrounding rock under tunnel construction through stress path. HuiJian Z ^[6] analyzed the



stress state of the sandwiched rock section based on the Mohr circle analysis method, and obtained that the stress state of the sandwiched rock when the upper and lower overlapped is relatively safe. In addition, the influence of the construction method in the construction phase needs to be considered and analyzed. For this, Xufeng Z^[7] analyzed the influence of shield construction on the existing tunnel under the action of three thrust forces on the shield machine by using numerical model. Jun Z^[8-9] analyzed the changes of working procedures under the mining method and shield method based on the change of construction method. Hong Xing W^[10] simulated the mutual influence of shield method and mining method in parallel construction.

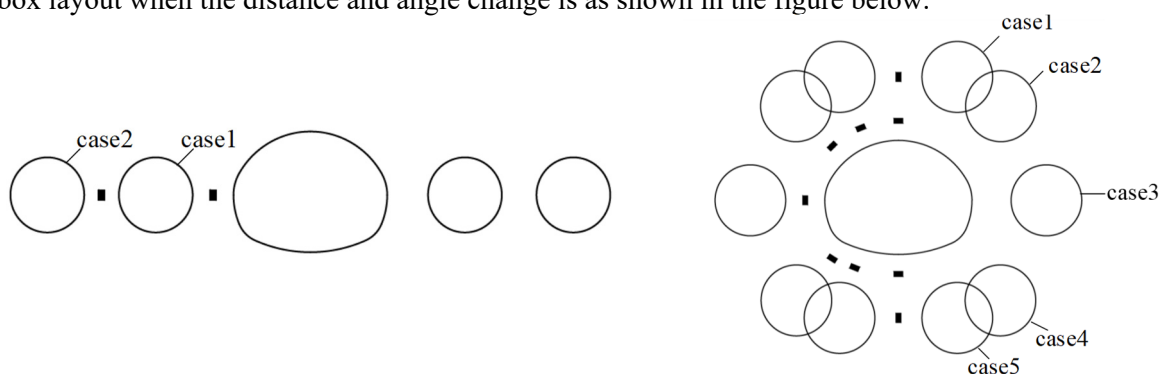
2. Project background

The section between Guangzhou Road Station and Xinglong Lake Station, the southern section of Phase 3 of Chengdu Metro Line 1, and the entrance and exit lines are located on the east side of Tianfu Avenue, Tianfu New District, Chengdu. The intersection angle between the subway tunnel line and the Cheng-Hua Railway is 68° , the length of the left line is 1124 m, and the length of the crossing is 15 m; the length of the right line is 1127 m, the length of the crossing is 13m, and the distance between the center of the left and right lines is 31.56 m. The vertical distance from the top of the shield tunnel to the railway track is 21.9 m, and the vertical distance from the top of the shield tunnel to the railway track is 20 m. The minimum horizontal curve radius of the tunnel is 600 m, the maximum longitudinal slope is 28‰, the outer diameter of the tunnel segment is 6000 mm, the inner diameter is 5400 mm, the segment thickness is 300 mm, and the segment width is 1500 mm.

The subway train entry and exit line is set between two shield tunnels, with a length of 141 m and a horseshoe-shaped cross-section. It is constructed by mining method and has a composite lining structure. The excavation is from north to south and the construction is undercut. The crossing length is 11.9 m, and the vertical distance from the top of the tunnel to the top of the railway track is 14.3 m.

3. The influence of approaching factors on stress

This article uses Mohr Coulomb's criterion as the basis for judgment under stress changes. As the intercalation is affected by multiple proximity factors, the difference in distance and spatial angle is relatively obvious. This article analyzes these two aspects. The excavation sequence is to first excavate the mining method tunnel in the middle, and then excavate the shield tunnels on both sides at the same time. In order to facilitate the extraction and analysis of the mechanical changes of the interbedded rock, the element attribute of the interbedded rock is set as an elastic model in the construction model, which is equivalent to the pressure box, and its related parameters are consistent with the surrounding rock parameters. The pressure box is arranged in the middle of the sandwiched rock, and the pressure box layout when the distance and angle change is as shown in the figure below.



(a) Position of measuring point of distance

(b) Position of measuring points of angles

Figure 1. Position of measuring point

3.1. Effect of distance change on stress

After excavation, the stress states at different distances are shown in Figure a, b. The change of distance has a greater impact on the change of tangential stress, and the change of tangential stress is more obvious when the distance is closer. When the distance is small, the tangential stress increases more obviously. In the opposite case, the increase in tangential stress is small.

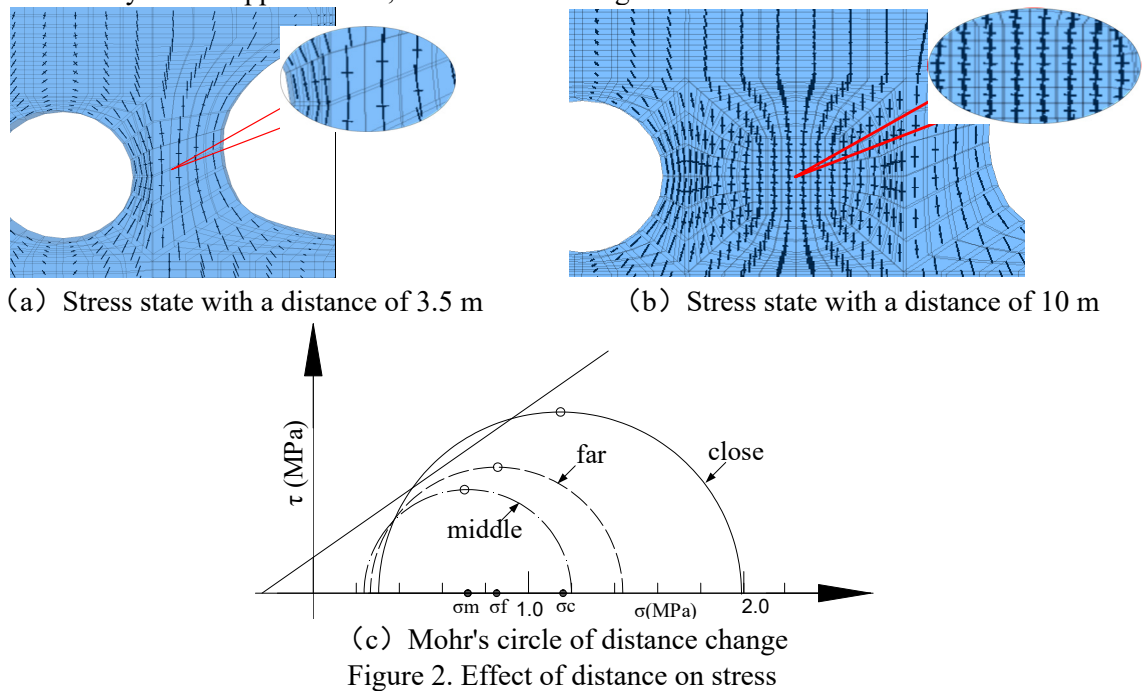


Figure 2. Effect of distance on stress

According to the analysis of Moore's circle, the excavation of the tunnel causes the center of Moore's circle to move positively to the coordinate axis, and the radius is enlarged. The change of the Mohr circle shows that the excavation on both sides increases the maximum principal stress and the minimum principal stress. However, the maximum principal stress increase is greater than the minimum principal stress, so that the radius increases faster than the movement of the center of the circle. As the distance decreases, the maximum principal stress increases more obviously, so that the smaller the distance, the easier it is to achieve inter-rock failure.

3.2. Stress changes in different positions

When the measuring points are in the overpassing and undercrossing sections, there are multiple intercalation effects. Therefore, the principal stresses at three positions are selected for comparison and selection:

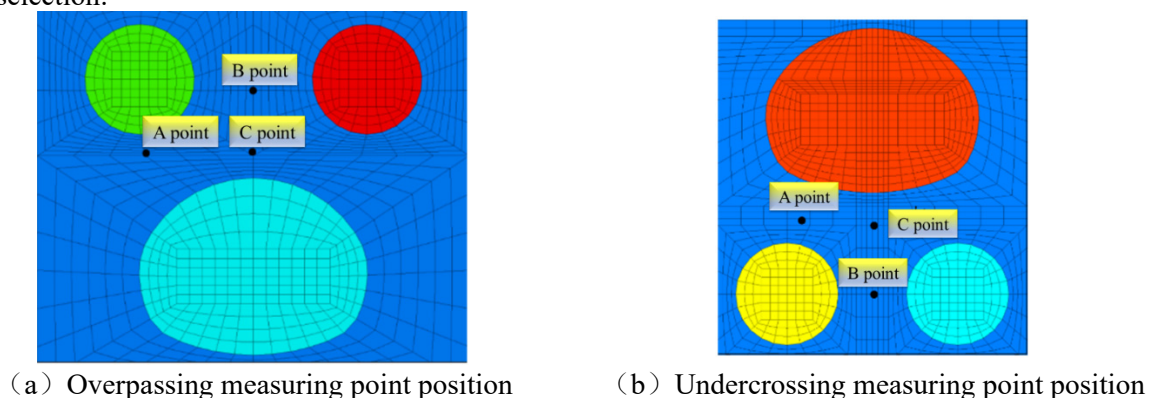
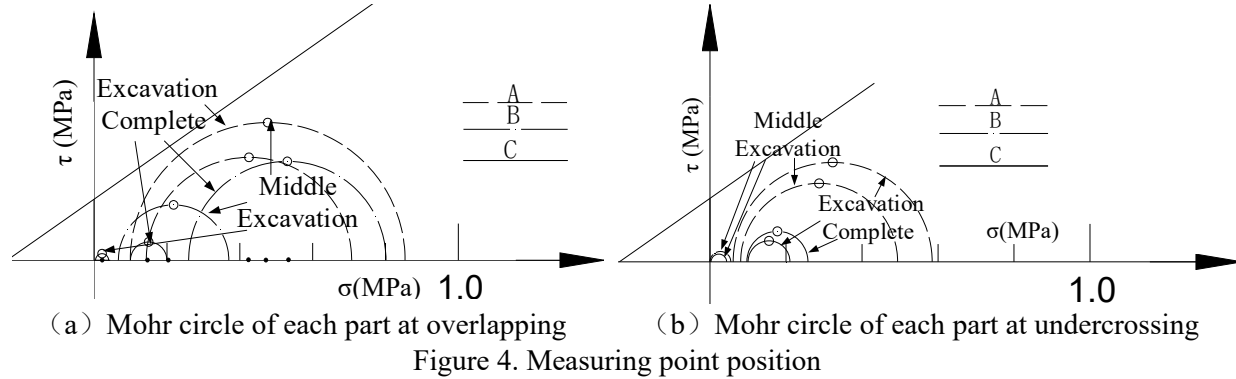


Figure 3. Measuring point position

The stress state of each point is shown in Figure 4. It is found that point A is more dangerous than point B and point C, which shows that the stress state on both sides at this time has a greater impact than the middle.

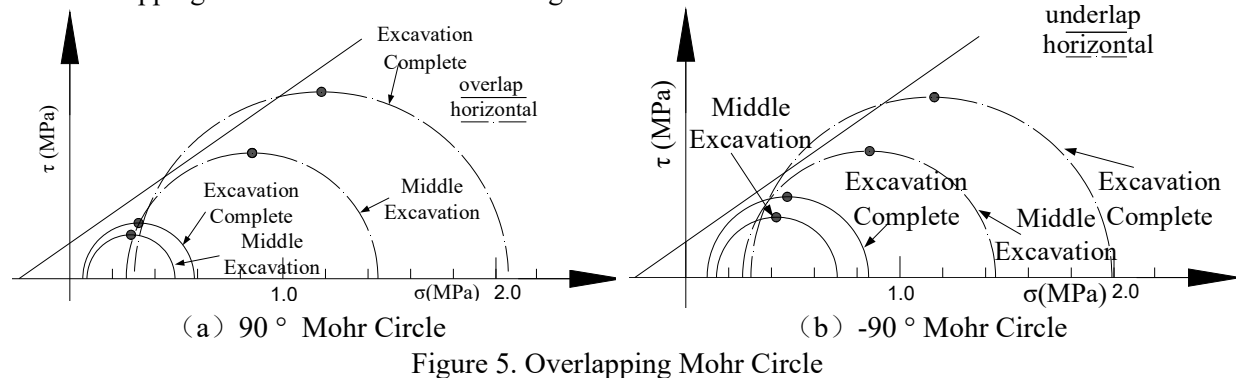


3.3. Effect of angle change on stress

In order to analyze the influence of angle on the stress, five approach angles of 0° , $\pm 45^\circ$, and $\pm 90^\circ$ were selected to analyze the influence of different angle changes on the principal stress of the sandwiched rock. At the same time, the comparison is made with 0° as the benchmark, and the Mohr circle stress change at each angle is obtained as follows:

3.3.1 Overlapping stress changes

The overlapping stress state is shown in the figure 5.



According to the Moore circle, compared with the horizontal tunnel excavation, the overlapping have less impact on the stress of the interlayer, and the stress values of both are in a safe state. At the same time, the stress value of the -90° is greater than that of the upper overlap, which is due to the deeper buried depth. As the maximum principal stress increases and the minimum principal stress decreases, the radius increases toward the Coulomb line, while the center of the circle moves to the right as it moves away from the Coulomb line. However, the effect of increasing the radius is relatively obvious, which eventually causes the Mohr circle to be more biased toward the envelope.

According to the analysis, it is found that the increase of tangential stress makes it reach the failure criterion when excavating horizontally. For overlapping, due to the release of radial stress, the increase of the maximum principal stress is slowed down. This shows that the overlap is safer than the horizontal.

3.3.2 $\pm 45^\circ$ stress changes

The $\pm 45^\circ$ stress state is shown in the figure 6. According to the Moore circle, the stress state of $\pm 45^\circ$ is safer than the horizontal angle approach. The maximum and minimum principal stresses of $\pm 45^\circ$ increase. The maximum principal stress increases significantly, making the radius increase faster than

the center of the circle. Compared with the horizontal angle, the Mohr circle is close to the Coulomb line, and the stress state is safer than horizontal and more dangerous than overlapping.

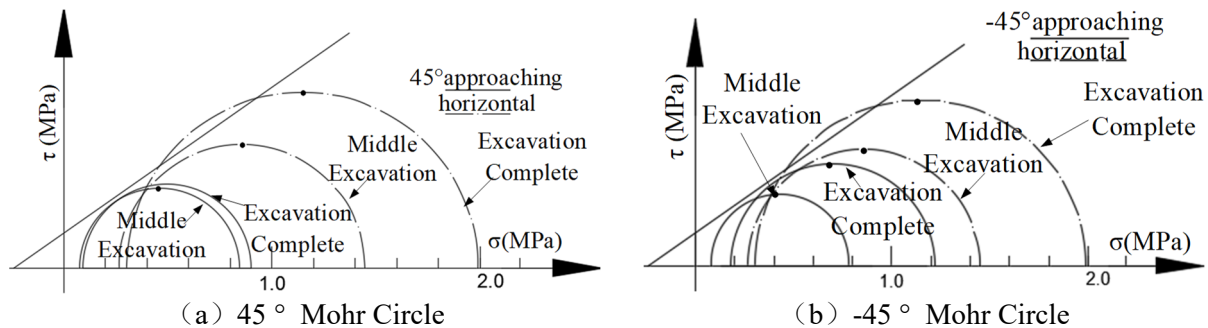


Figure 6. $\pm 45^\circ$ Mohr Circle

4. Effect of construction on stress

4.1 Construction method simulation

4.1.1 Construction simulation

The entrance and exit tunnels are constructed by the mining method. The maximum span of the tunnel is 12.5 m and the height is 9.64 m. The excavation method uses the CD method for excavation, the tunnel is set with vertical supports, and the excavation interval is 0.5 m. The construction sequence is ①—③—②—④—⑥—⑤. The interval between step ① and step ② is 5 m, and the interval between step ① and step ③ is 0.5 m. In the project, 0.5 m behind the tunnel face was used for initial support and temporary support. The thickness of the initial support is 350 mm, and the thickness of the temporary support is 300 mm. The section shield earth pressure balance shield machine is used for tunneling. Combined with the field data, it is obtained that the pressure of the soil bin remains stable between 1.4 and 1.5 bar, and the total thrust of the tunneling is between 16000 kN.m and 19000 kN.m, which fluctuates roughly around 17500 kN.m. The layout is shown in the figure 7.

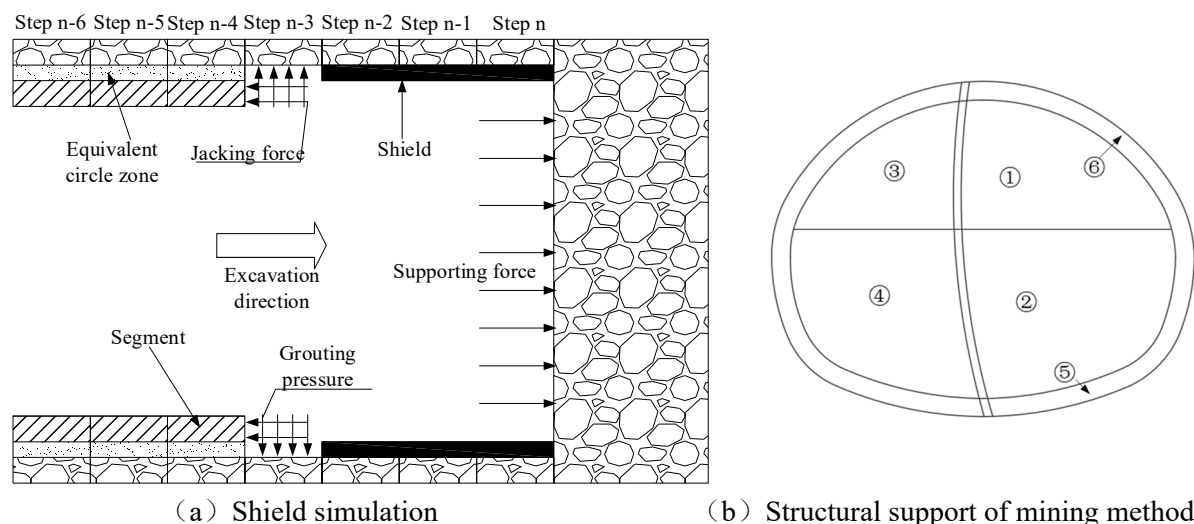


Figure 7. Construction simulation

4.1.2 Parameters simulation

The calculation parameters are selected based on the field data, and the jacking force and grouting pressure of the shield construction method are shown in the table 1. According to the construction data, the specific parameters of the construction stage are shown in the table 2.

table 1. Jacking force and grouting pressure (MPa)

Buried depth (m)	Jacking force	Grouting pressure	Pressure value
20.0~20.1	0.342	0.2~0.4	0.398

table 2. Physical and mechanical parameters

	Weight (kN/m ³)	Elastic modulus (GPa)	Poisson	Cohesion (MPa)	Friction angle (°)
Sandstone	23.8	2.4	0.33	0.35	35
Segment	26.6	37.4	0.2	/	/
Shield casing	78	206	0.25	/	/
Second lining	25	35	0.2	/	/
Initial support	23	20	0.25	/	/
Mortar bolt	78	200	/	200	25
Grouting layer	22.6	2.5	0.2	/	/

4.2 Stress path

The research conducts research and analysis from two aspects of excavation process and construction method. Two excavation procedures were selected for comparison. In case 1, the excavation sequence is left hole, right hole, and middle tunnel; in case 2, the excavation sequence is middle tunnel, left hole, and right hole. Monitoring the stress on the left and right sides, the stress changes in each construction stage are as follows.

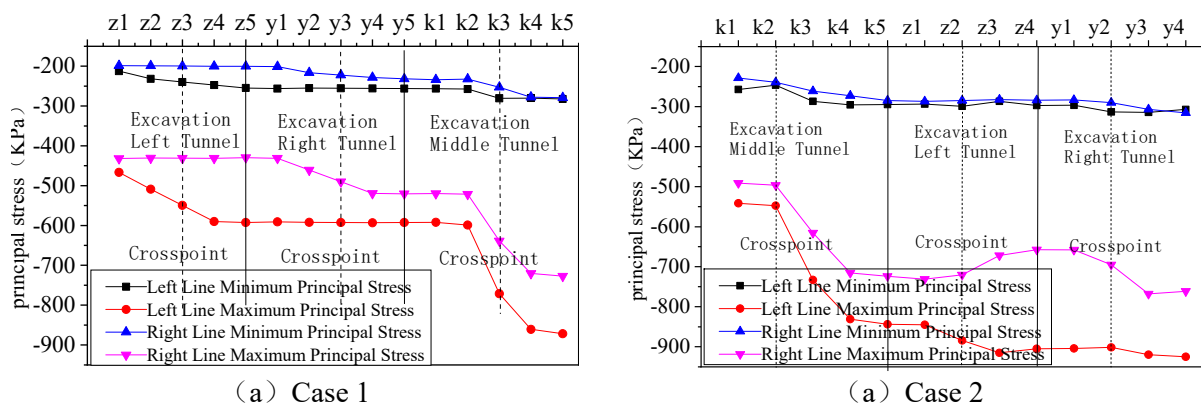


Figure 8. Stress in different processes

In condition 1, the left line is the most dangerous after the excavation is completed. The maximum principal stress is -0.871 MPa, the minimum principal stress is -0.275 MPa, and the principal stresses are all compressed. In case 2, the maximum stress also occurred with the rock in the left line, and its values were -0.924 MPa and -0.307 MPa, respectively. The rock on the left has the greatest impact, due to the close spacing. During the excavation of the mining method tunnel, the rock at the measuring point has the greatest impact, indicating that the mining method has the greatest impact on the intercalated rock.

The stress state of the measuring point is extracted, and the stress path of the rock is obtained as shown in Figure 9. According to the stress path, the case 1 appears as continuous loading at all stages, and the case 2 has an unloading stage. Although there is unloading in case 2, because the mining method tunnel is the last excavation, its stress increases faster than working case 1, indicating that case 1 is safer than case 2. According to the final stress state, the surrounding rock disturbance during the mining method construction is greater than that of the shield method, so that the stress increment of

the surrounding rock in case 2 is greater than that in case 1. In the end, the rock becomes weaker, and intuitively, the roadbed displacement becomes larger. The maximum displacement of the subgrade is extracted, and the subgrade displacement of case 2 is 4.31 mm, this is greater than 3.29 mm of case 1. This also illustrates the rationality of the excavation sequence of case 1 during the construction phase.

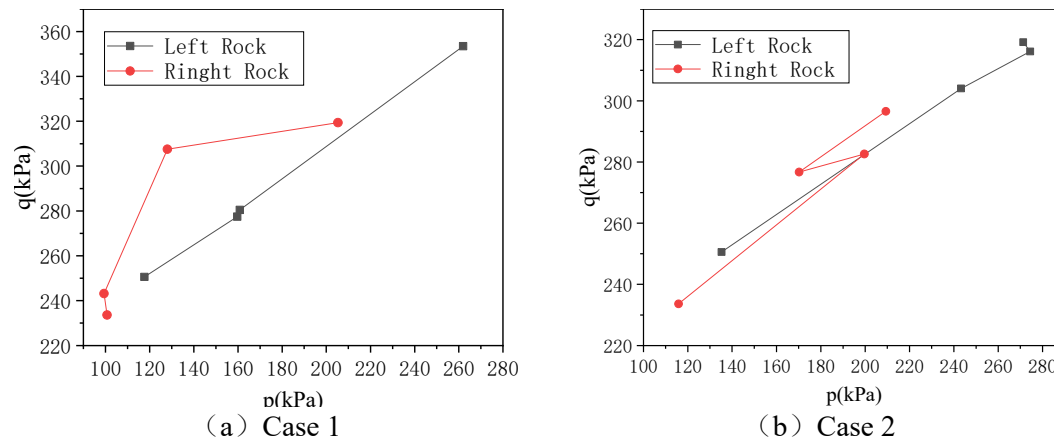


Figure 9. Stress path of different excavation sequence

5. Conclusion

Through numerical simulation and monitoring methods, the stress of the rock under the three tunnels is analyzed, and the following conclusions are drawn:

- (1) When the distance is changed, the decrease of the distance makes the maximum principal stress increase significantly, so that the smaller the distance, the easier it is to reach the rock failure.
- (2) At different angles, the stress state of the rock overlapping is the safest, and the stress state of the rock close to the horizontal angle is the most dangerous. The stress value of the rock at other angles is between the overlapping and the horizontal angle, and the stress is close to the failure line.
- (3) The first excavation of the mining method tunnel has more disturbance to the rock than the shield construction, which makes the increase of the secondary stress larger. Eventually the rock becomes weaker. The intuitive performance is that the roadbed displacement becomes larger.

Acknowledgments

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