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Calculation theory of surrounding rock pressure ofunsymmetric tunnel with short net distance

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ABSTRACT: Based on the load calculation method of shallow buried tunnel in the current highway tunnel design specification, the calculation formula of surrounding rock pressure of unsymmetric small clear distance tunnel is derived, and the variation of surrounding rock pressure under the influence of the thickness of middle rock wall and the internal friction angle of soil is further analyzed. The results show that the excavation of the back tunnel will lead to the bias-pressure phenomenon of the surrounding rock pressure of the tunnel; the horizontal lateral pressure of the inner side of the tunnel is less than that of the outer side of the tunnel, while the vertical pressure of the vault of the inner side of the tunnel is larger than that of the outer side of the tunnel;with the increase of the thickness of the middle rock wall, the vertical pressure bias ratio of the vault decreases, and the horizontal lateral pressure increases;with the increase of the friction angle in the soil, the vertical pressure bias ratio of the vault first increases and then decreases; when the internal friction angle $\phi_c = 30°$, the bias ratio reaches the maximum; the horizontal lateral pressure increases with the increase of the friction angle of the soil, and generally changes with the influence parameters. The bias ratio tends to be 1; the bias is related to the geometric parameters of successive tunnels, so that the larger the geometric parameters of the tunnel, the closer the bias ratio tends to be 1; for unsymmetric tunnels with short net distance, the overall bias ratio is closer to 1 when the preceding tunnel is large; in other words, when the excavation width of the preceding tunnel is larger than that of the posterior tunnel, it is more conducive to the load distribution and stability of the tunnel structure, and if the excavation width of the preceding tunnel is larger, it is more conducive to the load distribution and stability of the surrounding rock of the tunnel.

Keywords:unsymmetric; short net distance tunnel; surrounding rock pressure; bias ratio

I. INTRODUCTION

With the continuousdevelopment of urban rail transportation in recent years, the underground space is also gradually occupied. In order to satisfy the demand of urban traffic in the limited underground space, the tunnel withshortnet distance is invented as the time requires. The tunnel withshortnet distance draws on the advantages of separate tunnel,which is completely and separatelyarranged, which can not only satisfy the requirements of connection mode between bridge and tunnel and overall alignment of tunnel under complex terrain conditions, but also can make full use of the self stability of the rock wall in the tunnel, shorten the construction period, and control the construction safety and quality[1].The phenomenon that the tunnel bears eccentric pressure of surrounding rock is serious in tunnels with short net distance, especially in unsymmetrical tunnels with short net distance[2], which is unfavorable to the whole structure of the tunnel. However, the existing research rarely gives a specific calculation method for the surrounding rock pressure of unsymmetrical tunnels with short net distance, which is difficult to give a quantitative analysis reference for specific engineering problems. Therefore, it is necessary to study the surrounding rock stress of unsymmetrical tunnels with short net distance. As for the research on surrounding rock pressure of tunnel, Liu Jiguo et al[3] and others analyzed the surrounding rock pressure formula of deep-buried tunnel with short net distance on the basis of Proctor's theory, and studied the reinforcement measures of middle rock wall; Based on "Load Calculation Principle of Shallow Tunnel" from Xie Jiajie , Xiao Mingqing[4] analyzed the influencing factors of surrounding rock pressure and lateral pressure coefficient, and proposed the theoretical calculation method of surrounding rock pressure and lateral pressure coefficient of shallow tunnel with short net distance; Shu Zhile et al[5] studied surrounding rock pressure of tunnel with short net distance, proposed the theoretical calculation formulas of sliding fracture angle, lateral pressure coefficient and vertical surrounding rock

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pressure, and analyzed the influence of net distance between tunnels on surrounding rock pressure and the influence of ground inclination and net distance on inner pressure coefficient of tunnels; Gong Jianwu[6] reasoned out a relatively consistent calculation formula of surrounding rock pressure based on the monitoring and measuring results of tunnels and relevant specifications, and studied the relationship between buried depth and surrounding rock stress of tunnels with short net distance by using the formula; Shi Xiaomin and Deng Hongliang[7] used the finite element analysis software MIDAS / GTS to simulate and analyze the stress and strain of the tunnel, and combined with the monitoring measuring result to compare with the simulation result so as to predict the possible surrounding rock and lining stress in the construction process of this kind of tunnels, which provides a certain reference for tunnel engineering design and construction; Yang Xiaoli, Mu Zhirong et al[8] carried out numerical simulation calculation and analysis on construction mechanics of shallow-buried highway tunnel under bias pressure with double hole, six lanes and short net distance, adopting double side heading method and changing excavation sequence at the same time; Liu Xuezeng and ye Kang et al[9] studied a large number of field measured data of surrounding rock pressure of highway tunnels, compared with the theoretical calculation results of deep-buried tunnel method and Proctor coefficient method under similar engineering conditions, and obtained the difference between the actual measured value and the theoretical calculated value, and put forward some suggestions for the theoretical calculation of surrounding rock pressure. The above researches are mainly based on measured data in situ and numerical simulation software. The theoretical researches are mostly on tunnels with single hole or symmetrical tunnels with double hole and short net distance. The research on the surrounding rock pressure of asymmetric tunnel with short net distance needs to be further discussed. It is generally believed that different failure forms of tunnel surrounding rock should be solved by its corresponding theory. The calculation of deformation pressure usually adopts Fenner formula, castelney formula, etc., while the calculation of loosening pressure mainly uses proctor's theory, Rankine formula, Coulomb formula, etc [10].Based on the load calculation of shallow-buried tunnel in the current highway tunnel design specification, this paper makes a theoretical discussion on the calculation of surrounding rock pressure of unsymmetric tunnel with short net distance, so as to provide theoretical support for the design and construction of similar projects.

II. CALCULATION AND ANALYSIS OF SURROUNDING ROCK PRESSURE OF SYMMETRICAL TUNNEL WITH SHORT NET DISTANCE

Referring to the load calculation model of shallow-buried tunnel in the current highway tunnel design specification, for the convenience of calculation, the stress condition of the unsymmetric tunnel with short net distance is simplified as shown in Figure 1.

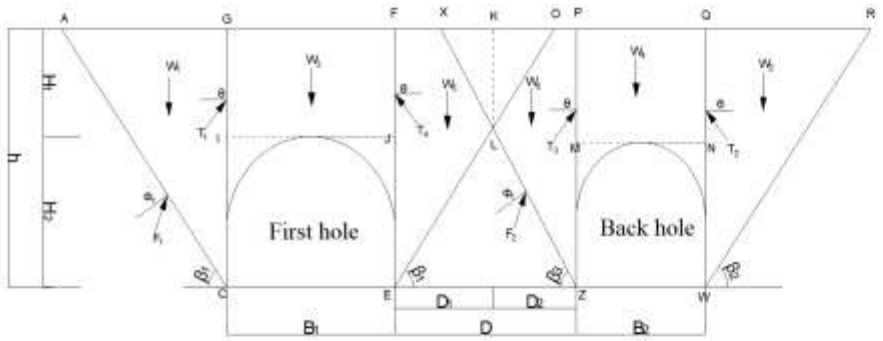

Fig .1 Force diagram of tunnel with short net distance

Referring to the rock force calculation of surrounding rock of single tunnel described in the specification, it's considered that in the figure, W is the gravity of the corresponding soil mass; F is the supporting force of the corresponding soil mass; T is the friction force of the soil on both sides of the tunnel on the vault settlement soil after the tunnel excavation; ϕ_c is the internal friction angle of the soil, H_1 represents the vertical height of the tunnel vault to the surface, H_2 represents the tunnel excavation height, and h represents the height of the tunnel arch foot to the horizontal surface , B_1 indicates the excavation

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width of the preceding tunnel and B_2 indicatesthat of the posterior tunnel.
For the convenience of calculation, the following assumptions are made for the calculation model above:
(1) It is assumed that the fracture surfaces of soil after tunnel excavation are AC, OE, XZ and RW;
(2) Considering that the cavity separates the soil inside and outside the tunnel after the tunnel excavation, the influence of the preceding tunnel and the posterior tunnel on the outside of each other is negligible. In other words, the interaction between the preceding tunnel and the posterior tunnel only affects the inside of each other. Regardless of the preceding tunnel or the posterior tunnel, the stress calculation on the outside of the tunnel can be calculated according to the surrounding rock pressure of the single tunnel;
(3) After the excavation of the preceding tunnel, the soil block EFO tends to slide down to the left. After the excavation of the posterior tunnel, the soil block ZPX tends to slide down to the right. Due to the looseness of the soil, there must be a fracture surface with zero normal force between the overlapped parts of the two soil blocks. For the convenience of calculation, this paper assumes a vertical fracture surface, namely KL in the figure, and the normal force on the fracture surface KL is 0;
(4) The horizontal pressure around the tunnel and the vertical load on the vault vary linearly;
(5) It is considered that the soil is a loose medium without tensile and bending capacity.
The analysis of calculation of the surrounding rock pressure for the preceding tunnel and the posterior tunnel is as follows:

1) Excavation for the preceding tunnel
When the preceding tunnel is excavated, it is not affected by the later tunnel excavation, so that the surrounding rock pressure is the same as that of single tunnel excavation, showing a symmetrical distribution. The calculation diagram is shown in Figure 2.

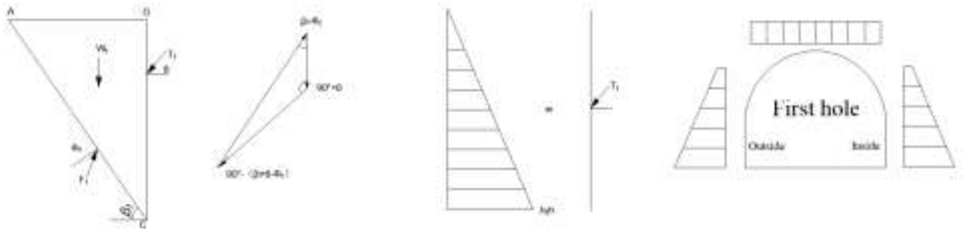

Fig .2 A schematic diagram of the calculation of the surrounding rock pressure of a single tunnel

$$W_1 = \frac{1}{2}\gamma h \frac{h}{\tan\beta_1} \#(1)$$

$$T_1 = \frac{\sin(\beta_1 - \emptyset_c)}{\sin[90° - (\beta_1 + \theta - \emptyset_c)]} W_1 = \frac{\sin(\beta_1 - \emptyset_c)}{2\sin[90° - (\beta_1 + \theta - \emptyset_c)]\tan\beta_1}\gamma h^2 \#(2)$$

If the coefficient of horizontal lateral pressure around the single tunnel is set as λ_1, the looseness of the soil is considered and the bending capacity of the soil is ignored. So the bending moment of the soil is zero, then it can be determined by the principle of equivalence:

$$T_1 \cos\theta = \frac{1}{2}\lambda_1 \gamma h^2 \#(3)$$

The horizontal lateral pressure coefficient λ_1 of surrounding rock of single tunnel is obtained:

$$\lambda_1 = \frac{\sin(\beta_1 - \emptyset_c)\cos\theta}{\sin[90° - (\beta_1 + \theta - \emptyset_c)]\tan\beta_1} \#(4)$$

Then the vertical load distribution of vault of single tunnel is :

$$q = \frac{W_3 - 2T_1\sin\theta}{B_1} = \frac{\gamma H_1 B_1 - \lambda_1 \gamma {H_1}^2 \tan\theta}{B_1} = \gamma H_1\left(1 - \lambda_1 \tan\theta \frac{H_1}{B_1}\right) \#(5)$$

Equation (5) is the expression of the vertical pressure on the vault of a single tunnel. γ is the weighted unit weight of each soil layer above the vault. The angle θ is selected according to the specification [11]. B_1 is the excavation width of the single tunnel. H_1 is the height of the vault from the horizontal surface. The other algebras are the same as above.

2) Excavation of theposterior tunnel
When the posterior tunnel is excavated, the

pressure of the surrounding rock inside the tunnel will be affected by the excavation of the preceding tunnel, while the pressure of the surrounding rock outside the tunnel will not be affected because of the partition effect of the tunnel excavation cavity, and its calculation method is the same as that of the single tunnel.On the contrary, the excavation of the posterior tunnel will also affect the surrounding rock inside the preceding tunnel, but will not affect the surrounding rock outside the preceding tunnel. The calculation of the surrounding rock pressure outside the posterior tunnel can be carried out according to the single tunnel discussed above.

The calculation diagram of the surrounding rock inside the tunnel is shown in figure 3.

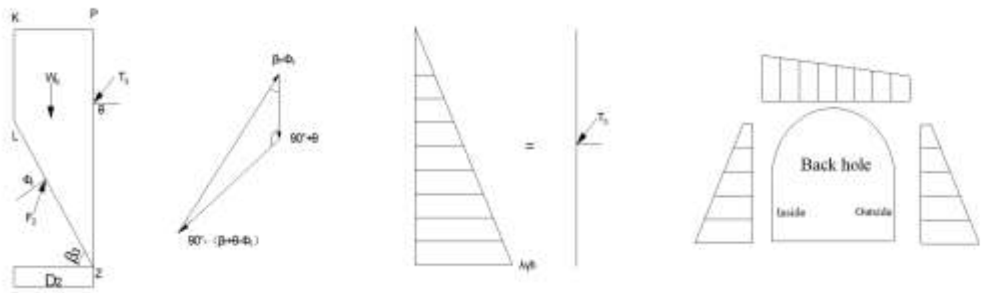

Fig .3 A schematic diagram of the calculation of the surrounding rock pressure of a double-line posterior tunnel

$$W_6 = \gamma h D_2 - \frac{1}{2}\gamma H_2 \frac{H_2}{\tan\beta_3} \#(6)$$

$$T_3 = \frac{\sin(\beta_3 - \emptyset_c)}{\sin[90° - (\beta_3 + \theta - \emptyset_c)]} W_6 \#(7)$$

According to the principle of equivalence, if the lateral pressure coefficient outside the posterior tunnel is λ_2, and the lateral pressure coefficient inside the posterior tunnel is λ_3, there is the following equation:

$$\lambda_2 = \frac{\sin(\beta_2 - \emptyset_c)\cos\theta}{\sin[90° - (\beta_2 + \theta - \emptyset_c)]\tan\beta_2} \#(8)$$

$$T_3 \cos\theta = \frac{1}{2}\lambda_3 \gamma h^2 \#(9)$$

$$\lambda_3 = \left[2\frac{D_2}{h} - \left(\frac{H_2}{h}\right)^2 \frac{1}{\tan\beta_3}\right] \frac{\sin(\beta_2 - \emptyset_c)\cos\theta}{\sin[90° - (\beta_2 + \theta - \emptyset_c)]} \#(10)$$

According to the assumption, the vertical load distribution of vault in the posterior tunnel changes linearly, and the vertical load distribution outside the vault in the posterior tunnel keeps the uniform distributed load of the single tunnel unchanged. If the linear growth factor of the distributed load is k^r, it can be analyzed:

$$W_4 - T_2 \sin\theta - T_3 \sin\theta = B_2 \left[\gamma H_1 \left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right) + k^r \gamma H_1 \left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right)\right] \#(11)$$

$$\gamma H_1 B_2 - \frac{1}{2}\lambda_2 \gamma {H_1}^2 \tan\theta - \frac{1}{2}\lambda_3 \gamma {H_1}^2 \tan\theta = B_2 \left[\gamma H_1 \left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right) + k^r \gamma H_1 \left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right)\right] \#(12)$$

So the k^r is:

$$k^r = \frac{\lambda_2 \tan\theta \frac{H_1}{B_2} - \lambda_3 \tan\theta \frac{H_1}{B_2}}{2\left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right)} \#(13)$$

If the vertical load outsidethe tunnel vault is ${q_o}^r$ and vertical load inside the tunnel vault is ${q_i}^r$

$${q_o}^r = \gamma H_1 \left(1 - \lambda_2 \tan\theta \frac{H_1}{B_2}\right) \#(14)$$

$${q_i}^r = \gamma H_1 \left(1 - \lambda_3 \tan\theta \frac{H_1}{B_2}\right) \#(15)$$

3) The surrounding rock pressure inside the preceding tunnel after its excavation

According to the above assumption, the excavation of the posterior tunnel will only affect the

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inner side of the preceding tunnel. Since the fracture surface has been formed during the excavation of the preceding tunnel, it can be considered that the excavation of the posterior tunnel will not change the position of the fracture surface of the preceding tunnel. The rupture angle β_1 of the inner side of the tunnel with the preceding tunnel remains unchanged, but only the shape of the rupture body is changed. In this paper, it is considered that the fracture body changes from triangle to quadrilateral. The calculation diagram of surrounding rock pressure inside the preceding tunnel is shown in Figure 4.

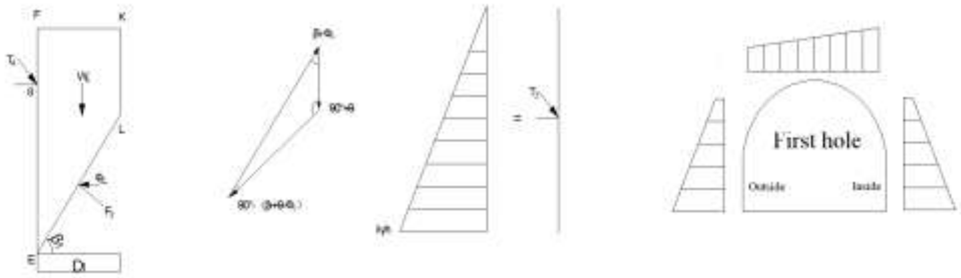

Fig .4 A schematic diagram of the calculation of the surrounding rock pressure of the preceding tunnel with two lines

$$W_5 = \gamma h D_1 - \frac{1}{2}\gamma H_2 \frac{H_2}{tan\,\beta_1} \#(16)$$

$$T_4 = \frac{sin(\beta_1 - \emptyset_c)}{sin[90° - (\beta_1 + \theta - \emptyset_c)]} W_5 \#(17)$$

According to the principle of equivalence, if the horizontal lateral pressure coefficient of the inner side of the preceding tunnel isλ_4, then the following equation can be obtained:

$$T_4\,cos\,\theta = \frac{1}{2}\lambda_4 \gamma\, h^2 \#(18)$$

$$\lambda_4 = \left[2\frac{D_1}{h} - \left(\frac{H_2}{h}\right)^2 \frac{1}{tan\,\beta_1}\right] \frac{sin(\beta_1 - \emptyset_c)\,cos\,\theta}{sin[90° - (\beta_1 + \theta - \emptyset_c)]} \#(19)$$

According to the assumption, the vertical distributed load on the vault of the preceding tunnel changes linearly; the vertical distributed load outside the vault of the preceding tunnel equals the uniform load of the single tunnel and remains unchanged. If the linear growth coefficient of the distributed load is k^l, it can be calculated that:

$$W_3 - T_1\,sin\,\theta - T_4\,sin\,\theta = B_1\left[\gamma H_1\left(1 - \lambda_1\,tan\,\theta\frac{H_1}{B_1}\right) + k^l \gamma H_1\left(1 - \lambda_1\,tan\,\theta\frac{H_1}{B_2}\right)\right] \#(20)$$

$$\gamma H_1 B_1 - \frac{1}{2}\lambda_1 \gamma {H_1}^2\,tan\,\theta - \frac{1}{2}\lambda_4 \gamma {H_1}^2\,tan\,\theta = \frac{1}{2}B_1\left[\gamma H_1\left(1 - \lambda_1\,tan\,\theta\frac{H_1}{B_1}\right) + k^l \gamma H_1\left(1 - \lambda_1\,tan\,\theta\frac{H_1}{B_1}\right)\right] \#(21)$$

The solution for k^l is as follows:

$$k^l = \frac{\lambda_1\,tan\,\theta\frac{H_1}{B_1} - \lambda_4\,tan\,\theta\frac{H_1}{B_1}}{2\left(1 - \lambda_2\,tan\,\theta\frac{H_1}{B_1}\right)} \#(22)$$

If the vertical distributed load outside the tunnel vault is ${q_o}^l$ and that inside the tunnel vault is ${q_i}^l$, the vertical pressure on the vault of the preceding tunnel is as follows:

$${q_o}^l = \gamma H_1\left(1 - \lambda_1\,tan\,\theta\frac{H_1}{B_1}\right) \#(23)$$

$${q_i}^l = \gamma H_1\left(1 - \lambda_4\,tan\,\theta\frac{H_1}{B_1}\right) \#(24)$$

In the above formula, only the inclination angleβ of fracture surface is unknown. If T is taken as the derivative of the inclination angle β and the derivative value is equal to zero, the inclination angle of the fracture surface in the most dangerous state can be obtained:

$$\frac{dT}{d\beta} = 0 \#(25)$$

Solution:

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$$tan(\beta_1) = tan\,\emptyset_c + \sqrt{\frac{tan\,\emptyset_c\,(tan\,\emptyset_c{}^2 + 1)}{tan\,\emptyset_c - tan\,\theta}}\#(26)$$

$$\tan(\beta_2) = \sqrt{\frac{(\tan\emptyset_c{}^2 + 1)}{\tan\emptyset_c - \tan\theta}\left[\frac{1}{\tan(\emptyset_c - \theta)} + \frac{4h}{D_2}\right]} - \frac{1}{\tan(\emptyset_c - \theta)}\#(27)$$

Obviously, when the inclination angle of any fracture surface equals the solution of formulas above, the other fracture surfaces are in a stable state before reaching the most dangerous fracture surface. Take the $\frac{T_3}{T_1}$ into the formula:

$$\frac{T_3}{T_1} = \frac{\gamma h\frac{H_2}{\tan\beta} - \frac{1}{2}\gamma H_2\frac{H_2}{\tan\beta}}{\frac{1}{2}\gamma h\frac{h}{\tan\beta}} = \frac{\left(2 - \frac{H_2}{h}\right)H_2}{h} = \left(1 + \frac{H_1}{h}\right)\left(1 - \frac{H_1}{h}\right) = 1 - \left(\frac{H_1}{h}\right)^2 < 1\#(28)$$

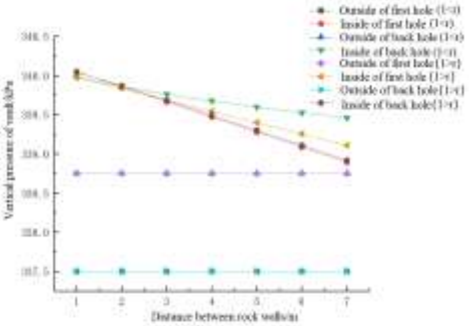
The results show that the most dangerous fracture surface occurs outside the surrounding rock for the tunnel with short net distance.

III. EXAMPLE ANALYSIS OF UNSYMMETRICAL TUNNELS WITH SHORT NET DISTANCE

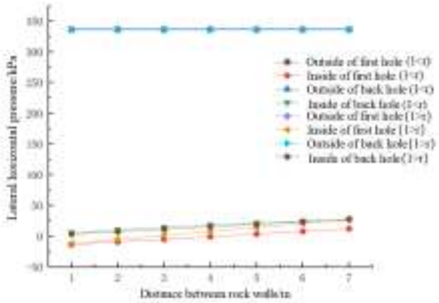
The surrounding rock of the tunnel is grade IV, and the geometric parameters of the tunnel are as follows: the excavation width of the preceding tunnel is $8m$, and that of the posterior tunnel is $16m$, and the excavation height of\ both tunnels is $9m$; The unit weight of surrounding rock is weighted average unit weight, and the buried depth is $20m$; In order to ensure the safety of the tunnel, the dip angle of the fracture surface around the tunnel surrounding rock is calculated as the most dangerous fracture angle, so that $\theta = 0.7\emptyset_c$ is taken. The other parameters are selected according to the calculation conditions, and the influence of tunnel geometric parameters is considered to define the geometric parameters [12]:

$$k = \frac{H_1}{H_1 + H_2}\frac{B}{2(H_1 + H_2)}\#(29)$$

The lateral pressure and vertical pressure of the surrounding rock of the unsymmetrical tunnel with short net distance, changes with the thickness of the middle rock wall and the internal friction angle of the soil:



（a） Vertical pressure of vault



（b） Lateral horizontal pressure

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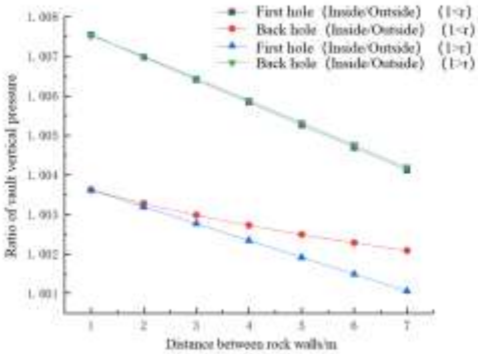
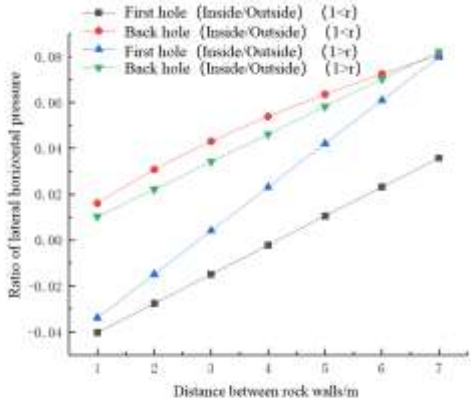
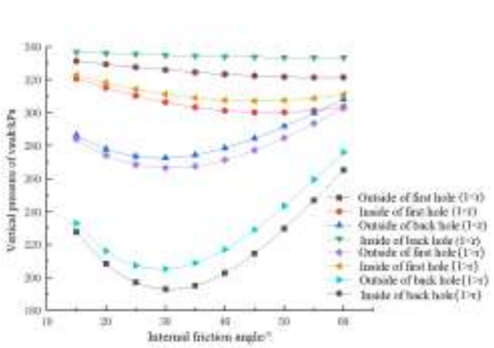
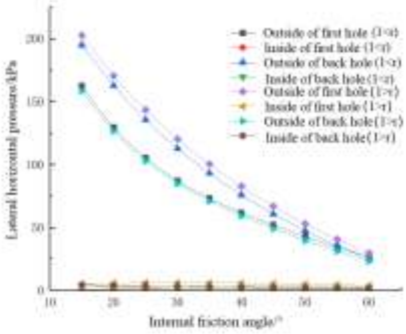




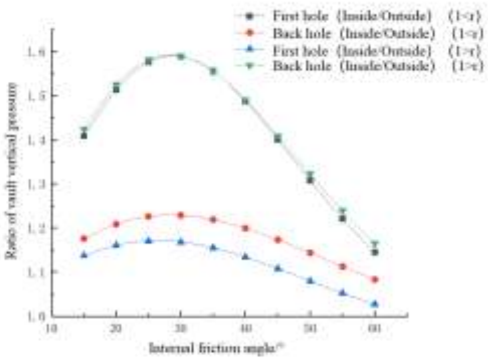
(c) Ratio of vault vertical pressure (d) Ratio of lateral horizontal pressure

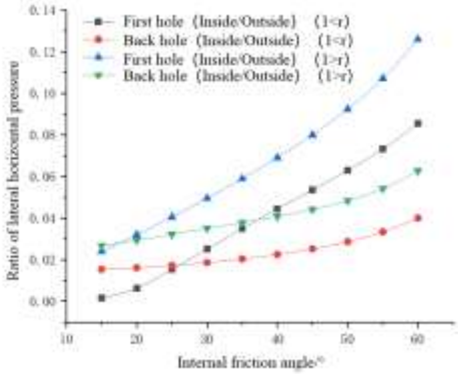
Fig. 5 Variation curve of surrounding rock pressure of unsymmetric tunnel with short net distance with the thickness of middle rock wall





(a) Vertical pressure of vault (b) Lateral horizontal pressure





(c) Ratio of vault vertical pressure (d) Ratio of lateral horizontal pressure

Fig .6 The variation curve of the surrounding rock pressure with the friction angle of the soil

Note: In the figure, $l > r$ indicates that the excavation width of the preceding tunnel is greater than that of the posterior tunnel; $l > r$ indicates that the excavation width of the preceding tunnel is less than that of the posterior tunnel

Obviously, if the excavation width of the preceding tunnel is larger than that of the posterior tunnel, and the rupture angle of the preceding tunnel is larger than that of the posterior tunnel, then $T_1 > T_2 > T_4 > T_3$, the lateral pressure coefficient $\lambda_1 > \lambda_2 > \lambda_4 > \lambda_3$, the vertical load distribution $q_i^r > q_i^l > q_o^r > q_o^l$; Correspondingly, if the excavation width of the preceding tunnel is less than that of the posterior tunnel, and the outer rupture angle of the preceding tunnel is less than that of the posterior tunnel, then $T_4 > T_3 > T_1 > T_2$, the lateral pressure coefficient $\lambda_4 > \lambda_3 > \lambda_1 > \lambda_2$, the vertical load distribution $q_i^{\,r} > q_i^{\,l} > q_o^{\,r} > q_o^{\,l}$. It can be seen that for double-track tunnels, after the excavation of the posterior tunnel, the preceding tunnel will change from the symmetrical compression state to the bias state, and the posterior tunnel will also be in the bias state due to the influence of the preceding tunnel, and the stress state is the most unfavorable; After the excavation of the back tunnel, the horizontal lateral pressure on the outside of the tunnel is greater than that on the inside of the tunnel, but the vertical pressure on the vault on the inside of the tunnel is greater than that on the outside. As a result, for the tunnel with short net distance, the maximum bearing capacity of the middle rock wall is highly required. In the actual construction process, grouting and pre-set bolt reinforcement measures should be taken to ensure that the middle rock wall has sufficient bearing capacity, so as to ensure the safety and stability of the tunnel under eccentric pressure.

In addition, it can be found from Figure 6 that the geometric parameters of the tunnel also have a certain influence on the pressure of surrounding rock. When the excavation width of the preceding tunnel is larger than that of the posterior tunnel, the most dangerous fracture surface occurs outside the preceding tunnel, and the horizontal lateral pressure also occurs outside the preceding tunnel; Correspondingly, if the excavation width of the back tunnel is larger, the opposite result will be caused. The excavation width of the preceding tunnel is larger than that of the posterior tunnel, which will lead to greater eccentric pressure ratio of surrounding rock. When the internal friction angle of soil is fixed, the vertical pressure bias ratio of vault decreases with the increase of medium rock wall thickness, while the lateral horizontal pressure bias ratio increases with the increase of the thickness of middle rock wall. But their bias ratio equal to 1 with the increase of the thickness of the middle rock wall. If the thickness of the middle rock wall is large enough, vertical bias ratio and lateral horizontal bias ratio of the vault both are 1, and the influence between the preceding tunnel and the posterior tunnel can be ignored, so that the tunnel has no difference with the single track tunnel; When the thickness of the middle rock wall cannot be changed due to topographical conditions, the internal friction angle of the soil can be changed by grouting and strengthening the soil. It can be seen from the figure that the vertical pressure bias ratio of the vault first reaches its peak with the increase of the internal friction angle, and then decreases with the increase of the soil internal friction angle. The vertical bias ratio reaches its maximum value when the friction angle of soil is about 30°, while the lateral horizontal pressure bias ratio increases with the increase of friction angle of the soil. Therefore, when the thickness of the middle rock wall cannot be changed, the grouting reinforcement of the soil should be avoided to make the friction angle of the soil at closer to around 30°. In the case of comprehensive consideration of economic conditions, the internal friction angle of the soil should be increased as much as possible. In addition, it should be considered that the lateral horizontal pressure bias ratio of the tunnel deviates greatly from 1, when the rock wall thickness in the middle is very small (<=2m), and even the bias pressure ratio appears negative, indicating that the tunnel bias situation is more serious when the tunnel side is buried at a depth of 20m. When the buried depth is close to 0, the lateral pressure of the surrounding rock of the tunnel is approximately equal to the vertical pressure. It is foreseeable that the horizontal lateral pressure inside the tunnel will continue to decrease with increase of the buried depth of the tunnel, while the horizontal lateral pressure on the outside of the tunnel decreases at a lower rate than that on the inside, resulting in a continuous decrease in the lateral horizontal pressure bias ratio of the tunnel with the buried depth or even changing to a negative value, which is extremely detrimental to the bearing situation of the tunnel structure. Therefore, it is recommended to strengthen the strength of the support structure inside the tunnel. From the curve of the bias voltage ratio in the above figure, it can be found that the larger the geometric parameters of the tunnel, the closer the bias voltage ratio tends to 1. Generally, the larger excavation width is used for the preceding tunnel, so that the tunnel bias situation is better than the first excavation of a narrower one. Since the rupture angle of the preceding tunnel remains the same as the rupture angle of the single tunnel, if the geometric parameters of the preceding tunnel are larger than those of the posterior tunnel, the outer rupture angle of the preceding tunnel is greater than the rupture angle of the outside of the posterior tunnel. For tunnels with short net distance, $D_1 > D_2$ in the middle rock wall. As soon as the excavation of the back tunnel is completed, the middle rock wall structure is formed. At the meanwhile, due to the small inclination of the most dangerous fracture surface, in the same soil layer, the fracture angle outside the tunnel doesn't reach it, and slippage won't easily occur in the middle rock wall, which is more beneficial to the structure. Therefore, in actual construction, it is recommended to use the tunnel with large geometric parameters as the preceding tunnel. On the one hand, it is beneficial to ensure the bearing capacity of the middle rock wall. On the other hand, it

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is also beneficial to reduce the bias pressure of non-stacked tunnels with short net distance. In addition, when excavating large-width preceding tunnels, the side heading method can be used to further guarantee the safety and stability of the structure.

IV. CONCLUSION

In this paper, by establishing a calculation model for the surrounding rock pressure of unsymmetric tunnels with short net distance, the changes in surrounding rock pressures of unsymmetric tunnels with short net distance under different factors are analyzed, drawing the following conclusions:

(1) The excavation of the posterior tunnel of the double-track tunnel with short net distance will lead to the bias pressure of surrounding rock. The horizontal lateral pressure inside the tunnel is lower than that the outside the tunnel, while the vertical pressure of the vault inside the tunnel is higher than that outside the tunnel.

(2) The horizontal lateral pressure on the inside the double-track tunnel decreases with the depth of the tunnel, and the rate of decline is greater than the horizontal lateral pressure outside the tunnel. The horizontal lateral pressure bias ratio of the tunnel continues to decrease. The horizontal lateral pressure bias situation is aggravated with the depth of tunnel. It is recommended to improve the support structure of the inner side of the tunnel and strengthen the inner lining support of the tunnel.

(3) The vault vertical pressure bias ratio decreases with the increase of the middle rock wall thickness, while the horizontal lateral pressure increases with the increase of the middle rock wall thickness. If the thickness of the middle rock wall is large enough, vertical bias ratio and lateral horizontal bias ratio of the vault both are 1, which is not the obvious bias compression mode; When the thickness of the middle rock wall is constant, the vertical pressure bias ratio of the vault increases first and then decreases with the increase of the friction angle in the soil. After the internal friction angle exceeds $30°$, the bias ratio generally tends to be 1 as the internal friction angle increases. It shows that during the construction of the double-track tunnel, the thickness of the middle rock wall should be increased to avoid the friction angle in the soil reaching around 30°, and the soil parameters should be improved through reinforcement measures to increase the friction angle in the soil until it's beneficial to the surrounding rock force.

(4) The bias pressure of the double-track tunnel is related to the geometric parameters of the posterior tunnels. The larger the geometric parameter of the tunnel is, the closer the bias ratio tends to 1. When the excavation width of the preceding tunnel is greater than the excavation width of the posterior tunnel, it is more conducive to the stress and stability of the tunnel structure. It is recommended to excavate a tunnel with a larger width as the preceding tunnel, and during the construction of the preceding tunnel, the outside of the tunnel should be constructed first, and then the inside of the posterior tunnel is constructed, which can increase the thickness of the middle rock wall and reduce the disturbance between tunnels in a short period. To a certain extent, it has effect on grading stress release.

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