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Stability Analysis of Rock Wall in Small Clear -distance Tunnel

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ABSRACT: Based on the surrounding rock strength criterion, by establishing a medium rock wall stress model, a discriminant formula for the stability of the rock wall in an asymmetric small clearance tunnel is proposed, and the influence of different factors on the ultimate bearing capacity of the medium rock wall is analyzed. The results show that: The ultimate bearing capacity of the middle rock wall increases linearly with the increase of the tunnel burial depth and the prestress of the anchor rod; when the anchor rod is laid on the middle rock wall, the density of the anchor rod should be controlled to ensure that the bearing capacity is significantly improved; The increase of the ultimate bearing capacity of the middle rock wall is related to its own cohesion.

Keywords: asymmetric small clear - distance tunnel; medium rock wall; stability criterion; ultimate bearing capacity

I. INTRODUCTION

With the development of traffic demand and the rapid layout of underground transportation network, the construction of small clear distance tunnel has increasingly become the general trend of urban underground rail transit. Small clear distance tunnel is a new tunnel structure mainly to adapt to special terrain or meet special requirements. It is generally used for medium and short tunnels with special requirements. It has the advantages of convenient portal connection, land saving and small space requirements. Small clear distance tunnel generally refers to the clear distance between two tunnels, that is, the thickness of middle rock wall is less than the value in Table 1**Error! Reference source not found.**.

Table 1 discrimination of small short distance tunnel

Surrounding rock grade	I	II	III	IV	V	VI
Tunneldistance	B	1.5B	2B	2.5B	3.5B	4B

Note: B is the width of tunnel excavation section

For small clear distance tunnels, the tunnel instability may be caused by small tunnel spacing, small medium rock wall thickness or small bearing capacity. Therefore, it is very necessary to judge the stability of medium rock wall in advance and put forward corresponding reinforcement measures when building small clear distance tunnels. At present, scholars have done a lot of research on this. Zhou Xiaoming, Liu Changwu and others [2] have systematically analyzed the stress distribution law and influencing factors of rock columns, and put forward a progressive failure mechanical mechanism of rock columns, which provides a basis for the instability criterion of rock columns; Zhao Xiaohui, Xu Guoyuan [3] used ANSYS finite element analysis software to analyze the stress and deformation characteristics of the middle rock column under different clear distance, and gave the variation characteristics of stress and displacement at the characteristic points of the middle rock column; Cai Ziyong [4] studied the construction mechanics and interaction of small clear distance tunnel through numerical simulation and field monitoring measurement, and determined the relationship between surrounding rock stability and excavation time and space; Tang Taowen, Fu Helin et al. [5] used FLAC 3D to simulate the middle rock column with different thickness, and deduced the expression of surrounding rock pressure of bifurcated tunnel in combination with proctor's theory. It is necessary to strengthen the middle rock column and reduce its thickness; Wu Feng [6] used the finite element software MIDAS / GTS to analyze the mechanical properties and deformation law of the middle rock column, and gave the corresponding optimal reinforcement method; Based on Fukuoka Metro Line 3 project, Hiroshi et al. [7] analyzed the influence of different medium rock column reinforcement methods on surrounding rock stability with the help of numerical simulation and field monitoring measurement data. Most of the above studies focus on symmetrical tunnels, and there is still a lack of sufficient theoretical support for the surrounding rock stress and stability of rock walls in asymmetric small clear distance tunnels.

Considering the asymmetry of the excavation sections of the left and right tunnels, this paper analyzes the load borne by the middle rock wall and the bearing capacity of the middle rock wall itself, and gives the stability discriminant of the middle rock wall in the small clear distance tunnel, in order to provide reference for the construction of this kind of project.

II. STRESSMODE ANDSTABILITY CRITERION OF ROCK WALL

It is an important issue to ensure the stability of surrounding rock after tunnel excavation. The existing research on the stability of surrounding rock mostly focuses on strength and deformation:

(1) Surrounding rock strength criterion

The strength criterion of surrounding rock mainly uses the strength failure theory of rock mass such as Mohr Coulomb. It is considered that the surrounding rock of tunnel will be damaged when the stress of surrounding rock exceeds the ultimate bearing capacity of surrounding rock of tunnel.

(2) Criterion of cumulative deformation or deformation rate of surrounding rock

Some studies believe that the failure of surrounding rock can be defined according to the deformation of surrounding rock or the deformation rate of surrounding rock. When the limit strain of surrounding rock or the inward convergence displacement and convergence ratio of surrounding rock to measure the deformation of tunnel surrounding rock exceed a certain limit, the surrounding rock will be damaged [8].

2.1 stress mode analysis of medium rock wall

For small clear distance tunnel, the key to study its stability is the stability of rock wall. According to the stress mode of the spacer rock column in the small clear distance tunnel, combined with the coal pillar load determination method [9-10], the load on the rock wall in the small clear distance tunnel is simplified as the self weight of the overlying rock and soil between the midlines of the two tunnels, and the following stress model of the middle rock wall is established.

For the convenience of analysis and calculation, the establishment and calculation of the model are based on the following assumptions:

1) The load on the middle rock wall is only the soil load directly above it, that is, the mechanical effect of the soil on both sides on the middle rock wall is ignored;

2) Ignoring the mechanical effect of tunnel structure on middle rock wall;

3) Compared with the direct reinforcement of the middle rock wall such as grouting and anchor bolt, the reinforcement of the middle rock wall by shotcrete and secondary lining of the tunnel wall is ignored.

Based on the above assumptions, the small clear distance tunnel structure is simplified as shown in the following figure 1.

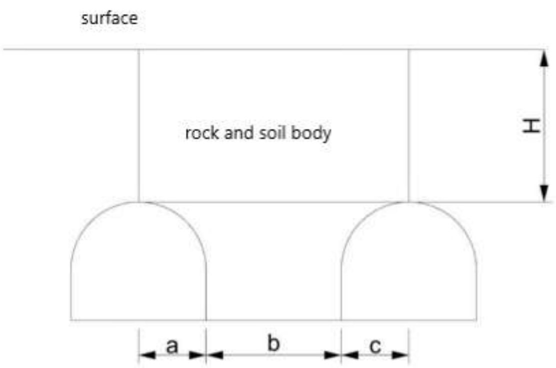

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Fig. 1 stress mode of septum pillar 茳倢

The distance between the center line of the double track tunnel and the intermediate rock column is a and C respectively, and the width of the intermediate rock column is B. It can be seen from the above figure that the load borne by the intermediate rock column is the schematic area of the soil block in the above figure, and the size is:

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$P = \gamma H(^{a}/_{2} + b + {}^{c}/_{2})L$ （1）

Where:γ is the average unit weight of overlying strata; H is the thickness of overburden; L is the length of the middle wall. Then the stress on the middle wall is:

$\sigma = K \cdot \frac{P}{bL} = \frac{k\gamma H(^{a}/_{2}+b+{}^{c}/_{2})}{b}$茳俥 （2）

Where: K is the stress correction coefficient of rock column in the middle wall.

It can be seen from the formula that the upper load stress of the spacer rock column is mainly affected by the specific working conditions of the tunnel, and is mainly related to the clear distance, tunnel span, buried depth and gravity. In addition, the introduced stress of the septal rock column will also affect the stress state of the septal rock column. For a specific working condition, determining the correction coefficient K can calculate the load on the spacer rock column under the specific working condition.

Wang Hanpeng [9] through polynomial regression on the data obtained under various working conditions, it is concluded that the relationship between K and a and B is: 茳 俥 茳 俥

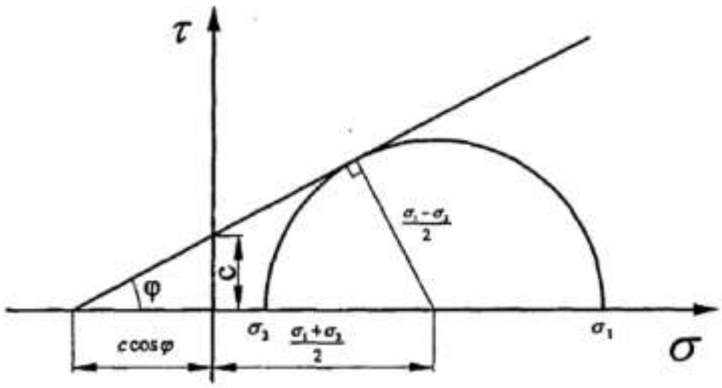
$K = -0.2768\ln(A) + 1.0791$ （3）

Where：$A = \frac{a+b+c}{b}$。

2.2 stability criterion of medium rock wall

Based on the surrounding rock strength criterion, when the load borne by the middle rock wall is less than its ultimate bearing capacity, it is considered that the middle rock wall is in a safe and stable state. Otherwise, in order to maintain the safety and stability of the middle rock wall, reinforcement measures need to be taken.

According to the limit equilibrium conditions shown in Fig. 2 and Mohr Coulomb strength theory, the limit equilibrium state of rock column in small clear distance tunnel is:



茳 **Fig. 2** Mohr Coulomb strength criterion (limit equilibrium condition)

俥$\tau = c + \sigma\tan\varphi$ （4）

Where: τnormal stress σ Ultimate shear stress under action (MPA)，c is cohesion of rock (MPA);φis the internal friction angle of rock (°)

Then, the Mohr Coulomb criterion is changed into the form of taking the maximum principal stress as the ordinate and the minimum principal stress as the abscissa, and its expression is 茳俥茳俥

$\sigma_1 = \frac{2c\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\sigma_3$ （5）

Where: c is the cohesion of the middle wall, MPa; φis the internal friction angle of the middle wall, (°); $\sigma_3$is the lateral stress, MPa.

When the middle wall is not reinforced by grouting or adding anchor bolts, the ultimate bearing capacity of the middle wall is the bearing capacity of the middle wall's own rock and soil mass, and its horizontal stress $\sigma_3 = K_0\gamma H$, K_0 is the lateral pressure coefficient of the original rock stress. At this time, when the stress borne by the middle wall reaches its peak stress, the middle wall gradually changes from elastic state to plastic state, and the middle wall loses stability.

For small clear distance tunnel, the wall is the rock mass after support. When the middle wall is supported by prestressed anchor bolt, it is set as the prestress of anchor bolt P, MPa; R is the row spacing of anchor bolts, m; L is the spacing of anchor bolts, M. Then the horizontal stress in the middle wall is:

$\sigma_3 = K_0\gamma H + \frac{P}{RL}$ （6）

addσ_3 in formula（5）：

$\sigma_1 = \frac{2c\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\left(K_0\gamma H + \frac{P}{RL}\right)$ （7）

It can be seen from the above formula that the factors affecting the ultimate strength of the middle wall of the small clear distance tunnel mainly include the strength of the middle wall (including cohesion c, internal friction angleφ, tunnel buried depth h and lateral pressure coefficient, prestress P of bolt support, and unit weight of rock mass γ It has little effect on the ultimate strength of the middle wall. Therefore, the ultimate strength of small clear

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distance tunnel is：

$$[\sigma] = \frac{2c\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\left(K_0\gamma H + \frac{P}{RL}\right) \quad (8)$$

When the tunnel depth h is constant, the ultimate strength of the middle wall can be improved by increasing the value of C and φ of the middle wall and increasing the prestress P of the prestressed anchor bolt; When the buried depth of the tunnel and the strength of the middle wall are determined, the greater the lateral pressure coefficientK_0, the greater the ultimate strength of the middle wall.

For small clear distance tunnel, the middle rock column bears stress σ Less than[σ] When, the structure is in a stable state, otherwise, the middle wall structure loses stability, that is:

$$\frac{k\gamma H(a+b+c)}{b} < \frac{2c\cos\varphi}{1-\sin\varphi} + \frac{1+\sin\varphi}{1-\sin\varphi}\left(K_0\gamma H + \frac{P}{RL}\right) \quad (9)$$

III. ANALYSIS ON INFLUENCING FACTORS OF ULTIMATE BEARING CAPACITY OF MEDIUM ROCK WALL

In order to analyze the influence of different factors on the ultimate bearing capacity of middle rock wall, taking class IV surrounding rock as an example, the basic parameters are taken: buried depth h-10m, left tunnel span B1= 16m, right tunnel span Br = 8m, cohesion c = 60kpa, internal friction angle φ= 35°, lateral pressure coefficient K_0 = 0.45, middle wall thickness B = 2m, soil gravity γ= 22 kn / m^3, anchor prestress P=10kN, anchor row spacing and spacing = 3m×2m The influencing factors such as the reinforcement coefficient of medium rock wall are analyzed. During the analysis, other factors remain unchanged and only the change of one factor is observed. The benchmark values of calculation example parameters are shown in Table 2.

Table 2 reference parameters

parameters	H/m	B^l/m	B^r/m	φ/°	K_0	B/m	γ /kN/m^3	P /kPa	R × L/m × m
value	5	16	8	35	0.45	2	22	10	3×2

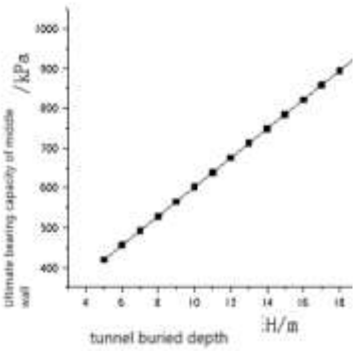

Fig. 3 relation curve between bearing capacity of middle wall and buried depth of tunnel

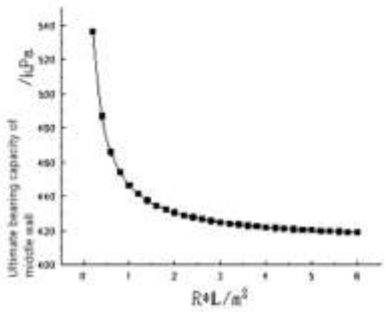

Fig. 4 Relationship curve between middle wall bearing capacity and anchor bolt layout spacing

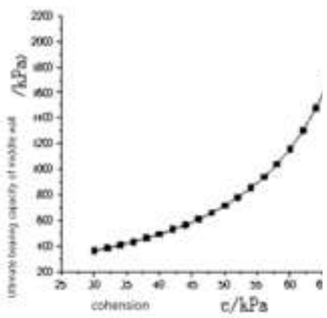

Fig. 5 Relationship curve between bearing capacity of middle wall and soil cohesion

Fig. 6 relationship curve between bearing capacity of middle wall and prestress of anchor bolt

It can be seen from the above that the bearing capacity of the middle rock wall increases with the increase of the buried depth of the tunnel[σ] It shows a linear rapid growth, that is, the buried depth of the tunnel has a significant impact on the ultimate bearing capacity of the middle rock wall. The greater the buried depth of the tunnel with small clear distance, the greater the bearing capacity of the rock wall tends to be stable and safe; When anchor bolts are used to reinforce the middle rock wall to improve its bearing capacity, the ultimate bearing capacity of the middle rock wall decreases with the increase of anchor bolt layout spacing. As can be seen from Figure 4, when the anchor bolt layout spacing increases to a certain value, the change of the bearing capacity of the middle rock wall tends to be gentle, indicating that at this time, too large anchor bolt layout spacing has no obvious effect on the improvement of the bearing capacity of the middle rock wall. On the contrary, When the bolt spacing is less than 1m2, the improvement of the bearing capacity of the middle rock wall is very significant. When strengthening the middle rock wall, the bolt layout should be as dense as possible if the economic conditions permit; The prestress applied by the bolt also increases linearly on the improvement of the bearing capacity of the middle rock wall, but the improvement degree is not as great as that with the buried depth and the bolt layout spacing. Therefore, when applying prestressed bolt reinforcement to the middle rock wall, the first consideration should be to change the bolt layout spacing, followed by increasing the bolt prestress; When grouting reinforcement is applied to the middle rock wall, the cohesion value of soil will be increased. As can be seen from Figure 5, the bearing capacity of the middle rock wall increases with the increase of soil cohesion. When the cohesion c is less than 55kpa, the growth rate is slow, and when it exceeds 55kpa, the bearing capacity increases rapidly. However, relevant studies show that it is difficult to greatly improve the cohesion of soil by grouting [11]. Therefore, it is suggested in this paper, Only when the cohesion of the soil itself is close to 55kpa or above, the bearing capacity of the middle rock wall strengthened by grouting can be significantly improved.

IV. CONCLUSION

By establishing the stress model of rock wall in asymmetric small clear distance tunnel, this paper analyzes the influence of different factors on the bearing capacity of rock wall in small clear distance tunnel, and draws the following conclusions:

1) The ultimate bearing capacity of rock wall in small clear distance tunnel increases significantly with the increase of tunnel buried depth. The larger the buried depth of small clear distance tunnel, the more stable and safe the medium rock wall is, and the lower the reinforcement requirements are;

2) When the prestressed anchor is used to reinforce the middle rock wall, under the comprehensive consideration of construction and economy, the anchor layout density should be increased to less than 1m2, and then the anchor prestress should be increased;

3) When the soil cohesion of the middle rock wall is close to 55kpa or above, it is obvious to use grouting reinforcement to improve the effect of the middle rock wall. In the actual construction reinforcement, it is recommended to use the combination of prestressed anchor bolt and grouting.

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