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Numerical simulation study on surrounding rock stability in large section coal roadway by different lateral pressure coefficient

Based on the special conditions of Changzhi 3# coal seam in Shanxi province, the stress field and plastic zone of surrounding rock in thick coal seam roadway with large cross section under different side pressure coefficient (λ) are studied by using finite element software FLAC^{3D}. The weak position of roadway is analyzed, and the stress direction of roadway support under different side pressure coefficient (λ<1) is put forward. (2). When λ = 1, both sides of the roadway and the roof are equally important and should not be neglected; (3) When λ>1, the stress concentration zone gradually shifts to the vicinity of the floor, and the maintenance of the floor should also be considered. According to the measured lateral pressure coefficients and numerical simulation results of the auxiliary roadway in the Changzhi coal mine, the main support direction of the roadway is provided. According to the convergence of the field section, the deformation law of the surrounding rock is basically consistent with the simulation results, which provides a new idea for the design of the roadway support.

Keywords: *Numerical simulation, lateral pressure coefficient; stress field; plastic zone.*

1. Introduction

In underground engineering, most of the roadways are in shallow stratum; its stability is closely related to the stress field in the environment, and the general horizontal stress plays a leading role in the shallow stratum [1]. Therefore, the study of the interaction between the ground stress in shallow stratum and the surrounding rock of roadway is the premise to ensure the safety of mine production [2, 3].

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Over the past decades, a great deal of research has been done on this in China and abroad. Yutian Zheng deduced the expressions of stress and displacement of surrounding rock of space roadway by establishing generalized plane strain model [4]. Feng Gao considered that the layout of roadway was significantly affected by the maximum horizontal principal stress [5]. Tongqiang Xiao combined with numerical simulation to analyze the relationship between the stability of roadway surrounding rock and the angle between thick seam roadway and horizontal principal stress [6]. Haiquan Liu deduced the formula about the influence of ground stress on the stability of roadway surrounding rock and analyzed the distribution law of stress and displacement in the deep of surrounding rock[7]. The distribution of stress field caused by free surface in roadway excavation is changed when the stress exceeds the strength of surrounding rock or causes the roadway to be unstable when the surrounding rock is excessively deformed [8], and whether the change of stress distribution will affect the roadway instability depends on the size, direction, distribution, rock state and excavation order of the ground stress field [9, 10]; horizontal stress is one of the main factors that affect the safety and stability of underground engineering (shallow strata) [11]. The ratio of the mean horizontal stress to the vertical stress is the lateral pressure ratio k, and the k value varies with different regions and depths [12]. The experimental results show that the lateral pressure has an important influence on the failure mechanism of rock, besides the deformation and strength characteristics of the rock. Therefore, lateral pressure is a factor that must be taken into account when the roadway is unstable (the lateral pressure coefficient can be obtained by measured ground stress on site).

Based on the numerical analysis, this paper mainly deals with the distribution of the surrounding rock stress area and the plastic zone under the condition of different lateral pressure coefficients of 3# coal (buried depth 420m or so, average 6.5m) in Shanxi province, and the research results will help to provide the basis for the stability evaluation and support design of the roadway surrounding rock.

2. Numerical analysis method and model parameters

The average depth of 3# coal is about 420m in Changzhi, Shanxi province, the average thickness of coal is 6.5m, dip 3~8°. The roadway sections in this area are all large-section rectangular roadways. This paper takes the auxiliary roadway of a certain mine in Changzhi as the research object. Digging along the bottom, size: 5840mm × 4370mm (width × height), The lithology of the rock is shown in Fig.1.

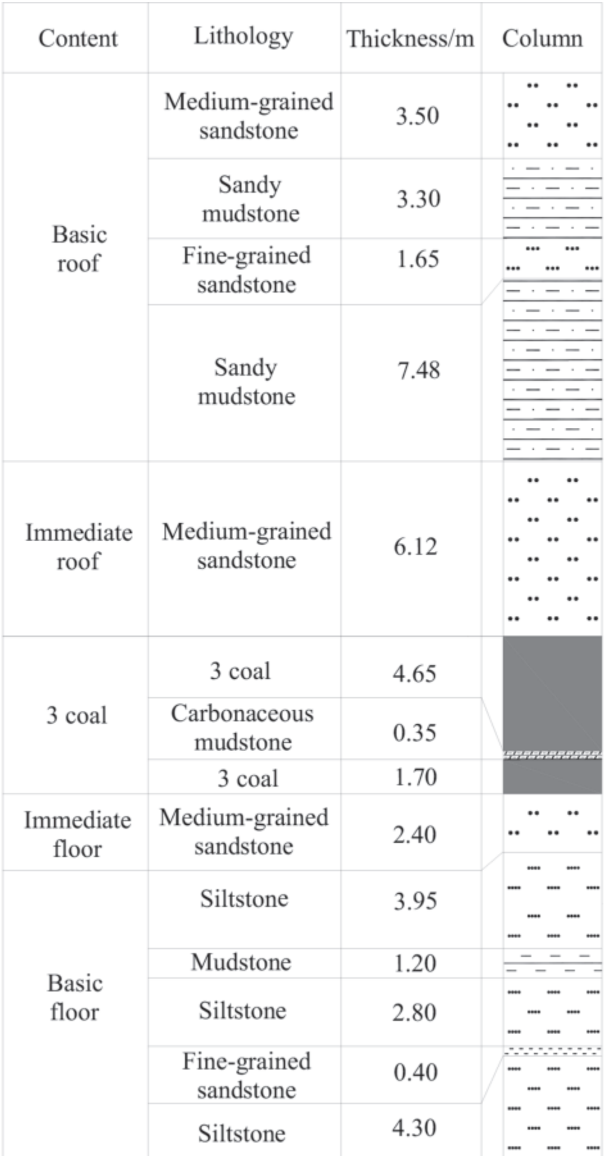


Fig.1 Comprehensive histogram of the rock

In view of this geological condition (the condition of the thick coal seam large section), this paper uses FLAC3D numerical simulation method as the analysis tool, selects seven different side pressure coefficients and simulates the side pressure coefficient under the condition of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 respectively, considering the requirements of numerical simulation calculation model, the selected model range: 80m×40m×50m (width×length×height), and the roadway size: 5800mm×4400mm (width×height). Apply a uniform load on the top of the model to simulate a coal seam with a depth of 420 m. At the same time, apply horizontal stress to the model according to different lateral pressure coefficients. Fig.2 is the initial equilibrium diagram. The mechanical parameters of coal (rock) are shown in Table 1.

In this simulation, the Mohr-Coulomb plasticity model is selected. According to the actual support parameters of the roadway, the cable unit in the FIAC3D software is selected as the support unit (the bolt and the anchor cable) in the simulated roadway.

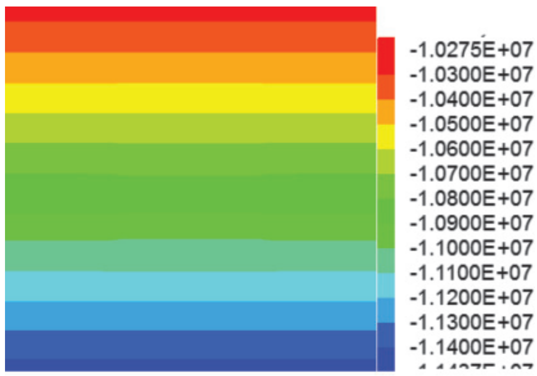


Fig.2 Model initial balance diagram

3. Analysis of calculation results

3.1 Influence of lateral pressure coefficient on stress field

Fig.3 shows the distribution of vertical stress, horizontal stress and plastic zone around the roadway when the lateral pressure coefficient is 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5.

As shown in figure 3A:

When $\lambda < 1$, the vertical stress is mainly reflected in the compressive stress on both sides of the roadway, the tensile

Table 1 The mechanical parameters of surrounding rock

Content	Compressive strength/MPa	Tensile strength/MPa	Elasticity modulus/GPa	Poisson ratio	Cohesion/MPa	Internal friction angle/°
Sandy mudstone	38.60	3.15	2.56	0.27	2.34	34.0
Mudstone	22.94	1.5	1.55	0.29	1.87	33.0
Coal	9.49	1.12	0.77	0.27	1.06	32.4
Sandstone	45.46	3.58	12.35	0.17	2.99	34.8

stress on the roof and floor, the tensile stress on the horizontal stress on the two sides of the roadway, the tensile stress on the roof and floor, and the plastic zone on the two sides of the roadway.

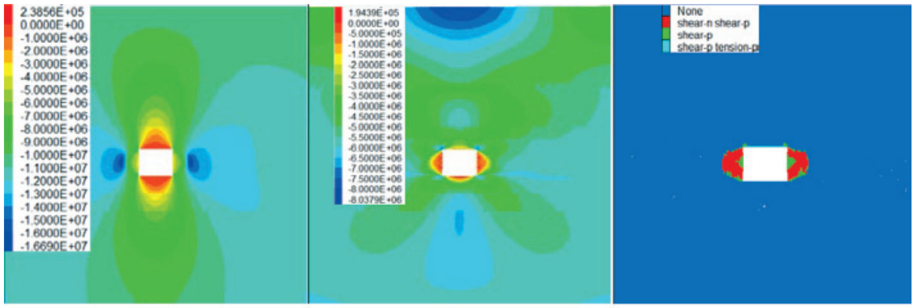
As can be seen from Fig.3B:

When λ=1, the vertical stress in both sides of the roadway and roof and floor are reflected as compressive stress, the stress in both sides is greater than that in roof and floor, the horizontal stress is also reflected as compressive stress in both sides of the roadway and roof and floor, the stress near the two sides is greater than that near the roof and floor, and the plastic zone of the roof becomes larger.

It can be seen from Fig.3C~G:

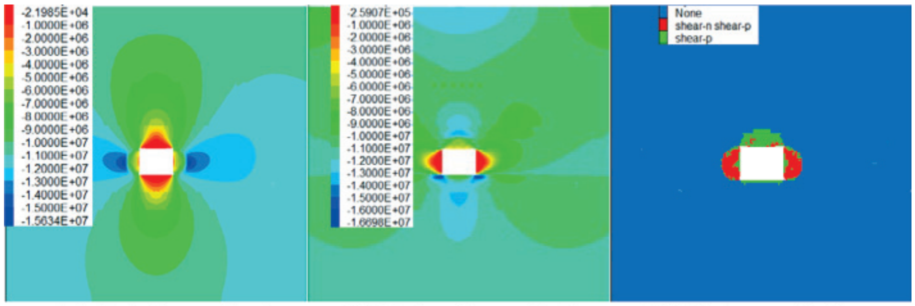
When λ>1, the vertical stress is mainly reflected in the compressive stress on both sides of the roadway and the tensile stress on the roof and floor. The horizontal stress is reflected in the compressive stress on both sides of the roadway and the roof and floor, the compressive stress on both sides is less than the compressive stress on the roof and floor, and the plastic zone of the roof and floor increases. With the increase of λ, the plastic zone of both sides of the roadway and the roof gradually increases. The stress concentration area is mainly transferred to the floor of the roadway.

In summary, with the increase of the λ, the range of the plastic zone which of the roof and floor and the two sides of the roadway increases, and the stress concentration zone gradually transfers from the left, right and upper of the roadway to the vicinity of the roadway floor. The stress concentration zone is near the roadway floor, which may cause the roadway floor heave. According to this analysis, side pressure and roadway floor must be taken into account when supporting design. The traditional supporting theory and method generally only consider the roof pressure and the supporting pressure, but neglect the side pressure and the condition of roadway floor, so the supporting design often cannot meet the site demand, thus cannot achieve the best technical and economic double effect. Under the condition of shallow thick seam mining, the tectonic stress often makes the horizontal stress play a dominant role. Therefore, under the same rock stratum



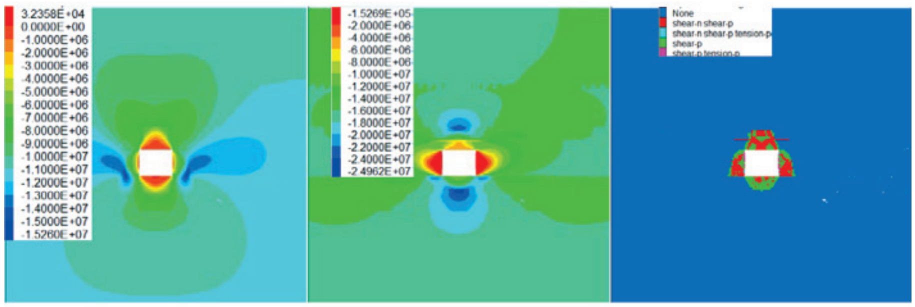
a) Vertical stress cloud (b) Horizontal stress cloud (c) Plastic zone cloud

A λ = 0.5



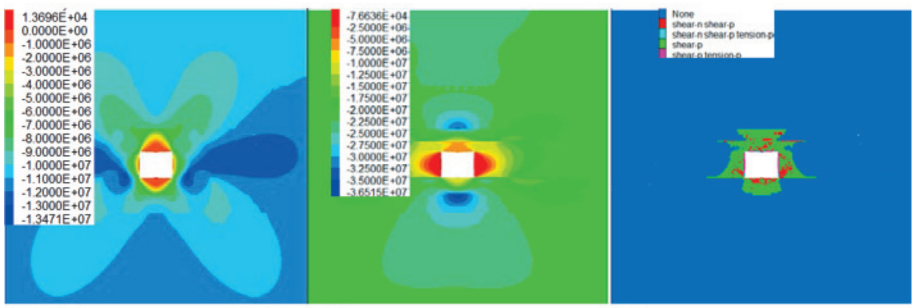
(a) Vertical stress cloud (b) Horizontal stress cloud (c) Plastic zone cloud

B λ = 1.0



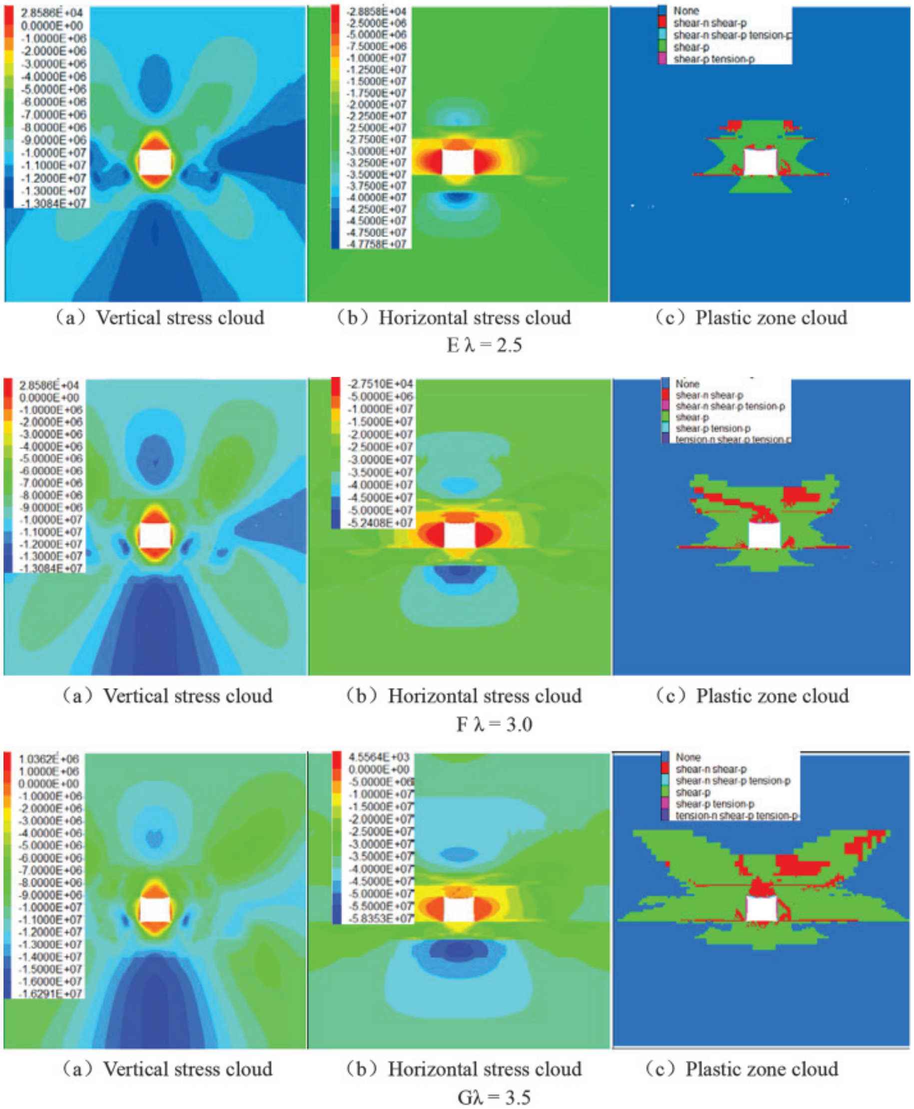
(a) Vertical stress cloud (b) Horizontal stress cloud (c) Plastic zone cloud

C λ = 1.5



(a) Vertical stress cloud (b) Horizontal stress cloud (c) Plastic zone cloud

D λ = 2.0



（a）Vertical stress cloud （b）Horizontal stress cloud （c）Plastic zone cloud

E λ = 2.5

（a）Vertical stress cloud （b）Horizontal stress cloud （c）Plastic zone cloud

F λ = 3.0

（a）Vertical stress cloud （b）Horizontal stress cloud （c）Plastic zone cloud

Gλ = 3.5

Fig.3 Influence of different lateral pressure coefficients on distribution of stress field in roadway

condition, different roadway layout directions often appear the situation of λ>1, λ=1 and λ<1. Therefore, the corresponding supporting scheme should be designed according to the actual situation.

(1) When λ<1, the vertical stress plays a leading role, and the two sides of the roadway may be the first to destroy. If the plastic zone of the two sides can be effectively controlled to weaken the vertical stress, it will be beneficial to the overall stability of the roadway.

(2) When λ=1, the compressive stress around the roadway plays a leading role, and the compressive stress may damage the roadway on the roof and the local free surface of the two sides. If the plastic zone of the two sides and the roof can be strengthened, it will be beneficial to the overall stability of the roadway.

(3) When λ>1, the plastic zone of both sides and roof of roadway increases and the stress concentration zone shifts gradually. In this case, the angle between the direction of roadway layout and the maximum horizontal principal stress should be considered. When the direction of roadway orientation is parallel to the direction of maximum horizontal principal stress, the influence of roadway lateral pressure is the smallest. When the maximum horizontal principal stress exists at a certain angle, measures should be taken to maintain the roof and two sides of the roadway as well as the bottom of the roadway.

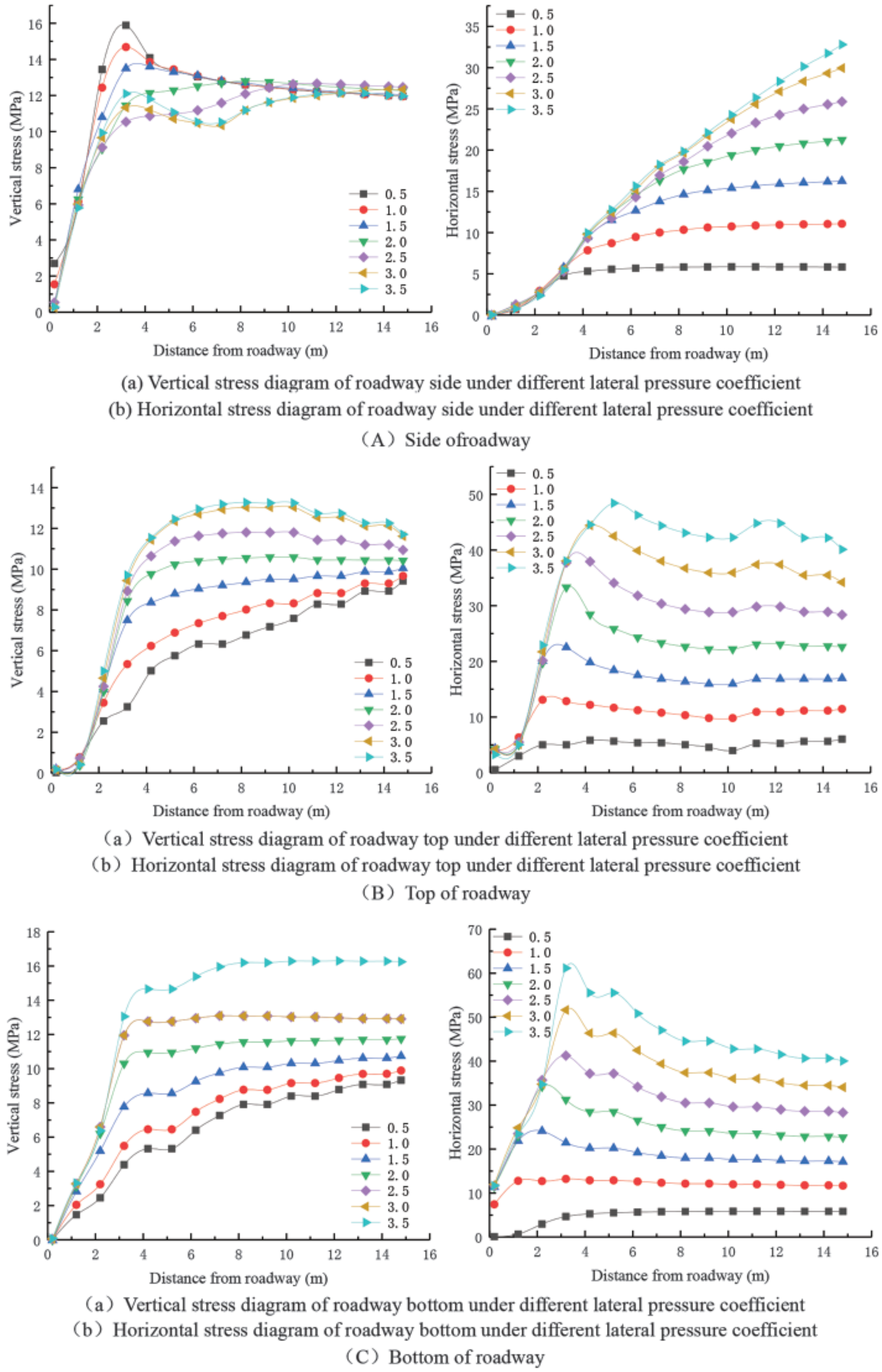
3.2 Analysis of roadway instability under different lateral pressure coefficients

In order to study the influencing factors of roadway instability under different lateral pressure coefficients, the vertical and horizontal stresses of roadway wall, roof and floor within 15m from the roadway surface are plotted under different lateral pressure coefficients. The leading factors causing roadway instability are analyzed by comparing the different lateral pressure coefficients, as shown in Fig.4.

From Fig.4:

(1) When λ<=1, the dominant stress causing roadway failure is the vertical stress of roadway wall, which is concentrated at 2~4 m away from roadway wall, then decreases rapidly until the original rock stress; the horizontal stress of roadway wall gradually tends to the original rock stress with the increase of distance from roadway wall; the vertical stress and horizontal stress of roadway roof and roadway bottom should be concentrated. With the increase of the distance from the roadway surface, the force gradually increases to the original rock stress.

(2) When λ>1, the dominant stress causing roadway damage gradually transforms from the vertical stress of roadway to the horizontal stress, and a horizontal stress concentration area appears near the roof and roadway bottom. With the increase of λ, the peak stress of roadway roof and roadway floor increases, and the peak stress of roadway roof moves away from the roadway surface with the increase of distance from the roadway surface. When the peak value of stress at the roadway bottom is 1<λ< 2.5, the peak value of horizontal stress gradually moves away from



(a) Vertical stress diagram of roadway side under different lateral pressure coefficient
(b) Horizontal stress diagram of roadway side under different lateral pressure coefficient
（A）Side ofroadway

（a）Vertical stress diagram of roadway top under different lateral pressure coefficient
（b）Horizontal stress diagram of roadway top under different lateral pressure coefficient
（B）Top of roadway

（a）Vertical stress diagram of roadway bottom under different lateral pressure coefficient
（b）Horizontal stress diagram of roadway bottom under different lateral pressure coefficient
（C）Bottom of roadway

Fig.4 Influence of different lateral pressure coefficients on roadway stress field

the floor. When λ>2.5, the peak value of horizontal stress will be concentrated in the range of 2~5m from the roadway bottom, which is one of the reasons for roadway floor heave [13].

It is verified that the surrounding rock is brittle tensile failure when the lateral pressure coefficient is small, and with the increase of the lateral pressure coefficient, the surrounding rock will be transformed from shear-tensile failure (i.e. the main failure mode is tension failure and the secondary failure mode is shear failure) to tensile-shear failure (i.e., shear failure is the main failure mode, tensile failure is the secondary failure mode), and then to shear failure. Under the condition of high lateral pressure, the surrounding rock will be plastic failure, which will present a large range of plastic zone [14]. At the same time, the undisturbed stress concentration zone will transfer to the failure plastic zone, the roof stress transmission will cause roof failure, the stress transmission between the two sides will cause roadway failure, and the stress concentration at the bottom of the roadway will cause roadway heave.

3.3 Industrial test

The auxiliary roadway layout of the mine is shown in Fig.5.

In-situ stress near the auxiliary transport roadway on the northern flank is mainly horizontal stress, and the lateral pressure coefficient is between 1.7 and 1.9; the main cause of roadway instability is horizontal stress, and the horizontal stress is concentrated near the roof and the roadway floor. The lateral pressure coefficient of the roadway is less than 2, and the peak value of the horizontal stress of the floor moves away from the floor gradually. The roof is more vulnerable than the floor.

Based on this, the support parameters of the roadway are designed, considering the influence of lateral pressure coefficient. The roadway support parameters are designed in combination with the above analysis. The roof bolt of the auxiliary transport roadway is 2.4m (2.6m). In order to verify the support effect, the surface displacement measuring station is arranged on the spot. The monitoring results are shown in Fig.6.

From Fig.6:

The cumulative approaching amount of roadway surrounding rock is not large, the approaching amount of roof and floor is not more than 200 mm, the approaching amount of two sides is less than 100 mm, and the floor heave is about 40 mm. Generally speaking, the supporting effect is good and

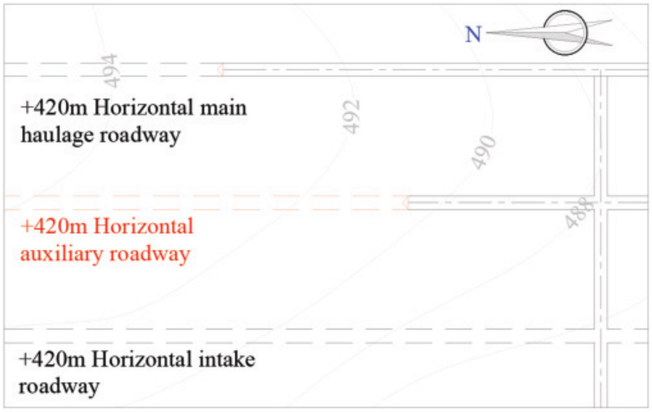
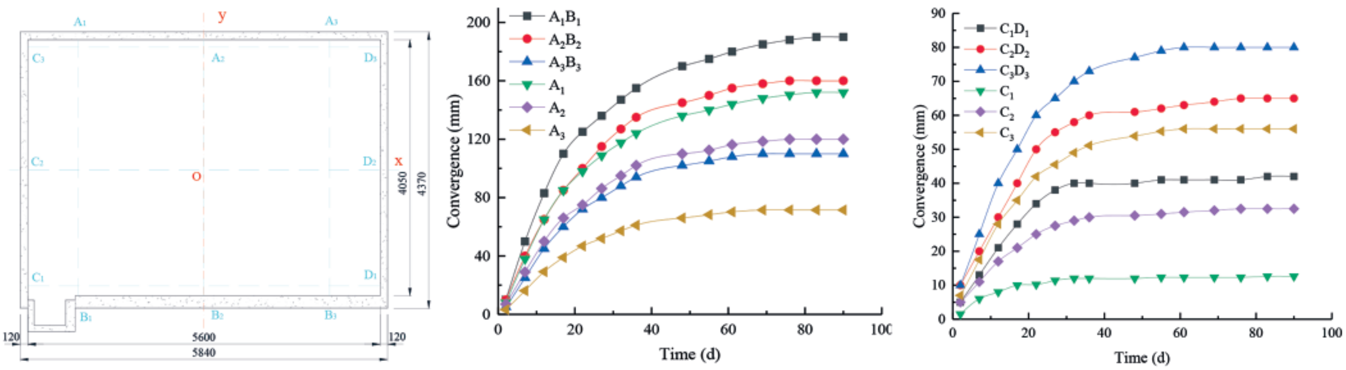


Fig.5 Schematic diagram of plane layout of auxiliary roadway

transforms to the deep part of rock mass. Under the action of sustained stress, when the failure strength of surrounding rock is reached, the plastic zone is formed and expands to the surrounding area.

2. Side pressure coefficient λ has obvious influence on the stress field and damage around the roadway, and the failure range of the roadway when λ>1 is larger than that when λ<1. Therefore, when choosing the direction of the roadway, the direction consistent with the maximum horizontal principal stress or at a small angle should be chosen as far as possible, so reducing the lateral stress is beneficial to the maintenance of the roadway.
3. Combined with the in-situ stress and lateral pressure coefficient of the auxiliary roadway in the Changzhi coal mine, the direction of roadway support is provided. The convergence law of the field section is basically consistent with the simulation results.



(a) Layout of measuring station (b) Roof and floor (c) Two sides

Fig.6 Convergence statistics of roadway cross-section

the surrounding rock is effectively controlled. From the convergence of roadway section, it can be seen that the larger convergence is located in the larger plastic zone of surrounding rock, and the overall distribution is basically consistent with the direction of the dominant stress in the surrounding rock, which is consistent with the simulation results.

In this paper, FLAC3D is used to simulate and analyze the large cross-section roadway excavated along the bottom of thick coal seam under different lateral pressure coefficients, which provides some reference for the support of the auxiliary haulage roadway in Changzhi coal mine conducted a more in-depth study.

4. Conclusions

In this paper, based on the condition of Changzhi 3 coal in Shanxi province, the variation of stress field and plastic zone around the roadway under different lateral pressure coefficients is studied by using numerical simulation method, and some causes of instability of the roadway are obtained through simulation, and the following conclusions are obtained through research:

1. After the excavation of the roadway, the stress concentration area of surrounding rock gradually

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