

Control Method of Roadway Surrounding Rock Under the Influence of Residual Coal Pillars in Goaf

Dongshan Huang

School of Energy Science and Engineering, Henan Polytechnic University, Henan 454003, China

ABSTRACT

In the process of close coal seam mining, the lower coal seam is affected by the concentrated stress of the remaining coal pillars in the goaf area of the upper coal seam, and the surrounding rock of the roadway may appear in the surrounding rock of the roadway, such as large deformation, strong sheet gang, and roofing, and the targeted surrounding rock control countermeasures are the key to ensure the stability of the surrounding rock. In order to solve the above problems, taking the thick-topped coal mining roadway of the B1 coal seam of Kuangou mine as the engineering background, the comprehensive research methods such as numerical simulation, theoretical analysis and field test were used to analyze the environmental characteristics of high deviator stress, such as the maximum principal stress and the difference of principal stress at different roadway locations of the B1 coal seam under the influence of the legacy coal pillars, and the plastic failure law of the surrounding rock under the action. The results show that under the condition of the remaining coal pillars in the 15m goaf, the maximum principal stress concentration area is located in the range of 10.0m~15.0m, and the peak value is about 0.95 times of the original rock stress.

KEYWORDS

Legacy coal pillars, stress environment, Failure patterns of surrounding rocks, Principal stress difference.

1. INTRODUCTION

Due to the influence of geological structure, most of the coal occurrence in China is close coal seams, and the mining of close coal seams is limited by technology and equipment, and downward mining technology is generally adopted, which will inevitably produce the coal structure of residual coal pillars, and at the same time increase the difficulty of mining the underlying coal [1-3]. The difference with single coal seam mining is that after the mining of the middle and upper coal seams of the close coal seam, the surrounding rock failure degree is significantly different due to the influence of the concentrated stress of the remaining coal pillars in the goaf of the upper coal seam, which increases the difficulty of mining roadway control [4-7].

In view of the layout of the mining roadway and the control of the surrounding rock in the lower part of the coal seam mining of multiple coal seams, many scholars have carried out many studies in recent years on the complex stress environment under the coal pillar, the failure law of the surrounding rock of the mining roadway, and the layout of the roadway under the coal pillar. He Fulian et al. [8-10] studied the regional characteristics of the deviatorial stress invariance of the bottom plate of the coal pillar, the occurrence mechanism of the coal pillar pressing frame disaster and the scale effect of the coal pillar pressing frame disaster in the working face under the coal pillar in view of the adverse effects of the remaining coal pillar on the adverse effects of the remaining coal pillar on the background of the downward mining of the coal seam, using theoretical analysis and field

measurement. The goaf pillar on one side of the working face was successfully converted into two small-scale coal pillars, so as to realize the early prevention and control of stope frame disasters. Ma Nianjie and Wang Weijun et al. [11-15] formed the "butterfly plastic zone theory" of borehole and roadway surrounding rock based on a large number of engineering practices, which fully considered the influence of factors closely related to mining, such as the direction of the surrounding stress of the roadway, the difference of principal stress, and the ratio of principal stress, on the deformation and failure of the surrounding rock of the roadway, and provided a basis for clarifying the deformation and failure law of the surrounding rock of the roadway under complex stress and surrounding rock environment.

The above research results and technical practices have played a vital role in the study of the failure law and layout of the surrounding rock of the mining roadway under the influence of the remaining coal pillars in the goaf, but most of the existing studies are carried out around the specific multi-coal seam geological conditions, which is difficult to provide technical support for the relevant engineering practices under other coal seam geological types. Accordingly, taking the Kuangou B1 coal seam as the engineering background and based on the commonly used coal pillar types in the coal mine, the failure law of the surrounding rock of the mining roadway under the influence of the remaining coal pillars in the goaf was systematically studied, and the reasonable layout position of the mining roadway was determined, which enriched the theoretical system and technical approach of the control of the surrounding rock of the gently inclined and repetitive mining roadway.

2. CHARACTERISTICS OF ROADWAY SURROUNDING ROCK STRUCTURE AND RESIDUAL COAL PILLAR

In the mining field of Kuangou Coal mine, there are seven layers of coal seams available for mining, all of which are gently inclined coal seams. In the previous mining process of coal seams, most of the remaining coal pillars are 15m coal pillars. Coupled with the influence of coal seam inclination Angle and coal seam spacing, the mining pressure development law of the mining roadway of the lower group coal seam is inconsistent, and reasonable support technology cannot be scientifically determined.

At present, the mining of the I010206 working face of B2 coal seam has basically ended, and the residual coal pillar (15m) generated between the lower running groove of I010203 and the upper running groove of I010205 has a certain influence on the stability of the mining roadway of the lower B1 coal seam. The working face of I010101 of B1 coal seam is the first mining face of the lower coal seam, and the coal seam inclination is $12^{\circ}\sim 16^{\circ}$. The thickness of the coal seam varies from 4.44 to 9.21m, the average thickness is 6.9m, the burial depth is 310 to 705m, and the spacing between it and the B2 coal seam is 25m. The roof lithology of the coal seam is mainly coarse-grained sandstone, fine-grained sandstone and mudstone with a thickness of 0.60 to 12.49m, while the bottom lithology is mainly mudstone and siltstone with a thickness of 0.78 to 15.10m.

3. ANALYSIS OF STRESS DISTRIBUTION AROUND MINING ROADWAY UNDER THE INFLUENCE OF COAL PILLARS LEFT OVER FROM GOAF

3.1. Numerical modeling

In order to clarify the general law, the stress environment of coal seam is assumed to be equal pressure stress environment, and the stratified homogeneous model is used to study the failure law of roadway surrounding rock under different mining roadway layout positions. The numerical model was established by using FLAC3D simulation software. The physical and mechanical parameters of coal and rock are listed in Table 1. The length \times height of the model is 428m \times 260m. Figure 2 shows the

numerical simulation calculation model when the rock layer inclination is 12° and the coal seam spacing is 25m when the 15m coal pillar is left. During loading, a uniform vertical stress of 13MPa is applied to the upper surface of the model to simulate the dead weight of the overlying strata, and the surrounding and bottom of the model are fixed constraints. The simulation adopts the Moore-Coulomb criterion based on the elastic-plastic theory.

Table 1: Mechanical parameters of coal and rock mass

Rock Category	Formation	density (kg/m ³)	Bulk modulus (GPa)	Shear modulus (GPa)	cohesion (MPa)	Internal friction angle (°)
Upper group of coal roofs		2700	1.0	3.40	3.0	32
Upper group coal		1423	1.20	1.70	2.9	30
Upper group coal floor		2700	1.33	3.4	3.3	32
Lower group coal		1423	1.20	1.70	2.9	30
The lower group of coal floors		2700	1.33	3.40	3.3	32

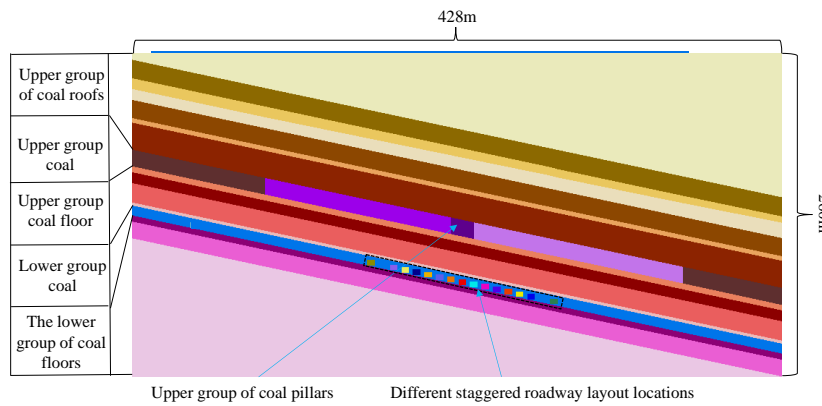


Figure 2: Numerical simulation of the calculation model

3.2. Analysis of stress environment around mining roadway of B1 coal seam

Different from the roadway type under the condition of traditional single coal seam, the direction of the maximum principal stress around the roadway with different dislocation arrangement is different under the influence of the concentrated stress of the remaining coal pillars in the upper group coal seam, resulting in the unequal pressure stress environment around the roadway. In order to further obtain some key stress factors affecting the surrounding rock failure of mining roadway, the main stress difference, maximum principal stress and distribution characteristics around mining roadway under the condition of 15m coal pillar type are explored, and then the mechanical mechanism of surrounding rock deformation and failure under different conditions of mining roadway is revealed.

3.2.1. Characteristics of maximum principal stress distribution

When the maximum principal stress around the mining roadway exceeds the compressive strength of the surrounding rock of the roadway, there is a possibility of failure of the surrounding rock. Therefore, numerical simulation software is used to carry out excavation calculation of the upper coal, and the cloud map and curve of the maximum principal stress around the mining roadway in the lower coal

layer under the condition of 15m coal pillar and 25m coal seam spacing are obtained, as shown in Figure 3.

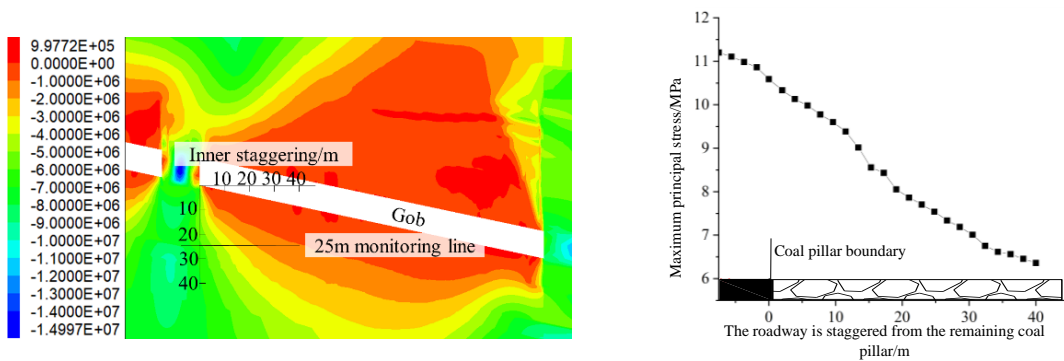


Figure 3: Characteristics of principal stress distribution around the mining roadway under the 15m coal pillar

With the increase of the distance between roadway and coal pillar center, the maximum principal stress around roadway surrounding rock shows a decreasing trend, and the influence of coal pillar on mining roadway decreases gradually. Because the spacing of coal seam is 25m, the maximum principal stress around the roadway is 7.75~11.2MPa when the spacing of stoping roadway is 22m in the horizontal direction below the coal pillar. When the internal fault distance is greater than 22m, the maximum principal stress range around the roadway is 6.25~ 7.75MPa.

3.2.2. Distribution characteristics of principal stress difference

The difference between maximum principal deviator stress and minimum principal deviator stress $\sigma_1-\sigma_3$ is the core factor affecting the distribution of plastic zone of roadway surrounding rock, and the greater the difference of principal stress, the greater the component of deviator stress, and the more easily the surrounding rock shear failure occurs. Accordingly, the distribution cloud map and curve of principal stress difference ($\sigma_1-\sigma_3$) around the lower coal mining roadway under the condition of spacing between 15m coal pillar and 25m coal seam are calculated by numerical simulation software, as shown in Figure 4.

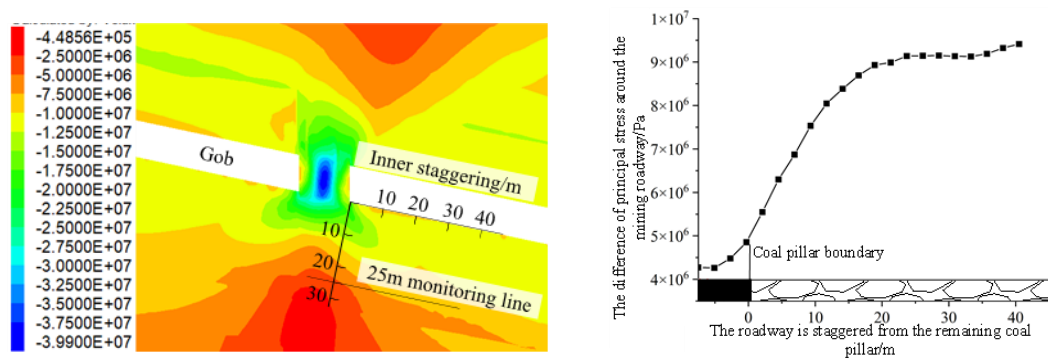


Figure 4: Distribution characteristics of the principal stress difference ($\sigma_1-\sigma_3$) around the mining roadway under the 15m coal pillar

Under the condition of spacing between 15m coal pillar and 25m coal seam, the difference of the principal stress around the roadway increases gradually with the increase of the horizontal deviation

of the mining roadway. Within the range of measuring line setting, the maximum difference of principal stress at 40m internal fault is 10.6MPa.

4. ANALYSIS OF PLASTIC FAILURE LAW OF MINING ROADWAY UNDER THE INFLUENCE OF 15M RESIDUAL COAL PILLAR

4.1. Numerical simulation scheme

Considering that the average inclination of B1 coal seam is 12° and the relative position relationship with the central position of coal pillar, the position of roadway is divided into upper and lower sections in order to analyze the location of roadway scientifically and reasonably. In order to facilitate numerical simulation calculation, the following scheme is proposed for the layout of mining roadway in the lower group coal seam. According to the position relationship between roadway and coal pillar center, all roadway are divided into upper and lower sections. Among them, the position of roadway 8# is 10m(edge-to-edge-to-edge), that is, the roadway is directly below the coal pillar. 1#~7# and 9#~15# are symmetrical arrangements based on the vertical normal line of B1 coal seam at the center of 8# roadway as the symmetry axis, so the above section layout is taken as an example, the specific layout is:

The position of No. 7 roadway is 2.5m outside the upper and lower sections respectively, that is, overlapping layout; The positions of the 1#~6# and 10#~15# tunnels are respectively 5~40m (edge-edge-edge) in the upper and lower sections, that is, the minimum distance between the edge of the mining roadway and the edge of the coal pillar. Figure 5 shows the layout scheme of the mining roadway in the upper group coal seam.

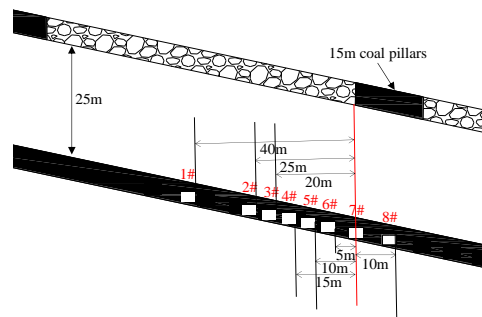


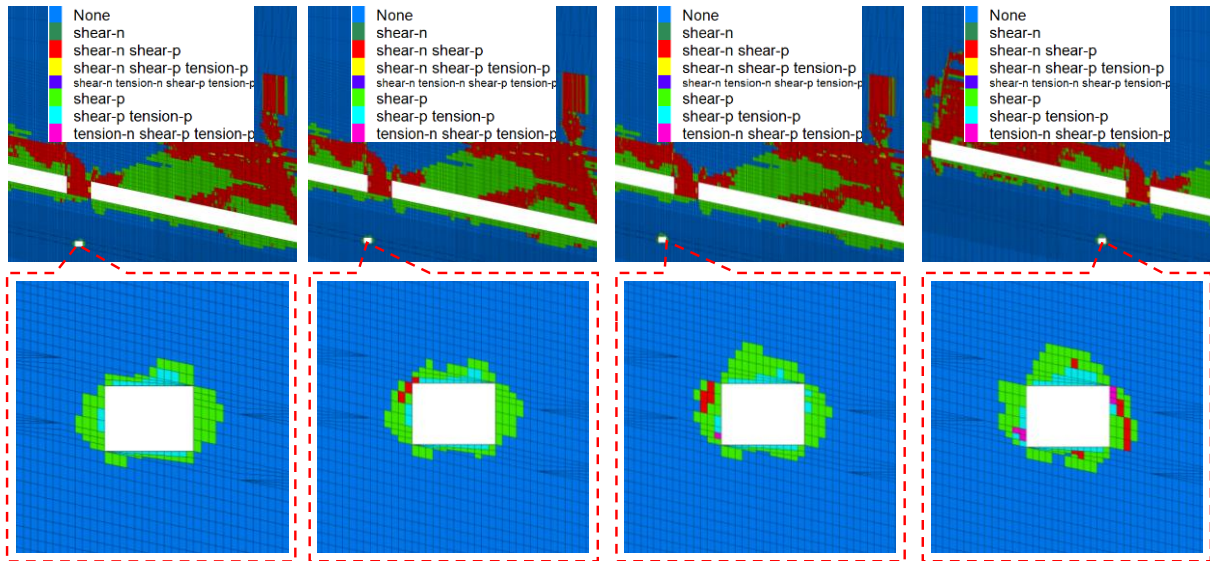
Figure 5: Layout scheme of the mining roadway of the lower group of coal seams

4.2. Numerical simulation analysis of mining roadway under 15m legacy coal pillar

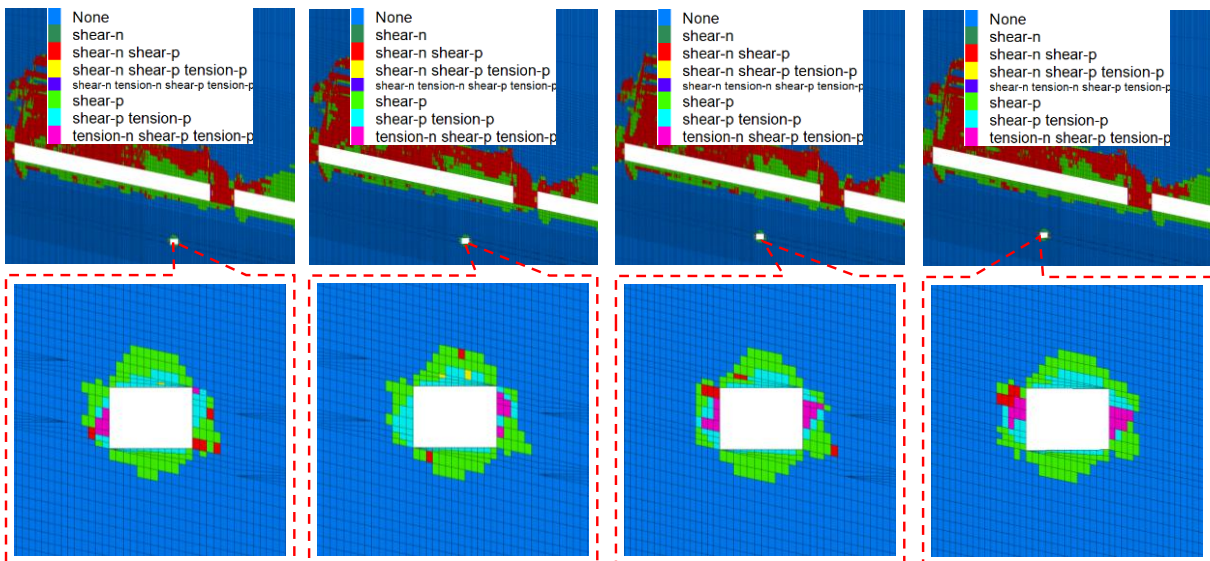
4.2.1. Numerical simulation analysis of mining roadway arranged on the upper section side of the left coal pillar

When the mining roadway is arranged on the side of the upper section of the remaining coal pillar, the plastic failure characteristics around the mining roadway depend on the location of the roadway. The numerical simulation results are shown in Figure 6. When the external fault of the mining roadway is 5.0~10.0m, the plastic failure pattern of the roadway surrounding rock is approximately elliptical, as shown in Figure 6(a~b). The maximum plastic failure depth of roof increases to 2.0m when the internal fault of mining roadway is 5.0m. When the internal fault of the mining roadway is 10.0m, the maximum plastic failure depth of the roof is 2.0m, as shown in Figure 6(c). When the deviation distance within the mining roadway is greater than 10m, the distribution range and size of the plastic zone in the surrounding rock of the roadway are basically unchanged. At this time, the

mining roadway can be considered to be free from the influence of the stress concentration of the remaining coal pillars, and the average plastic failure depth of the surrounding rock roof of the roadway is about 1.75m, as shown in Figure 6 (d-h).



(a) External error 10.0m (b) External error 2.5m (c) Internal errors 5.0m (d) Internal errors 10.0m



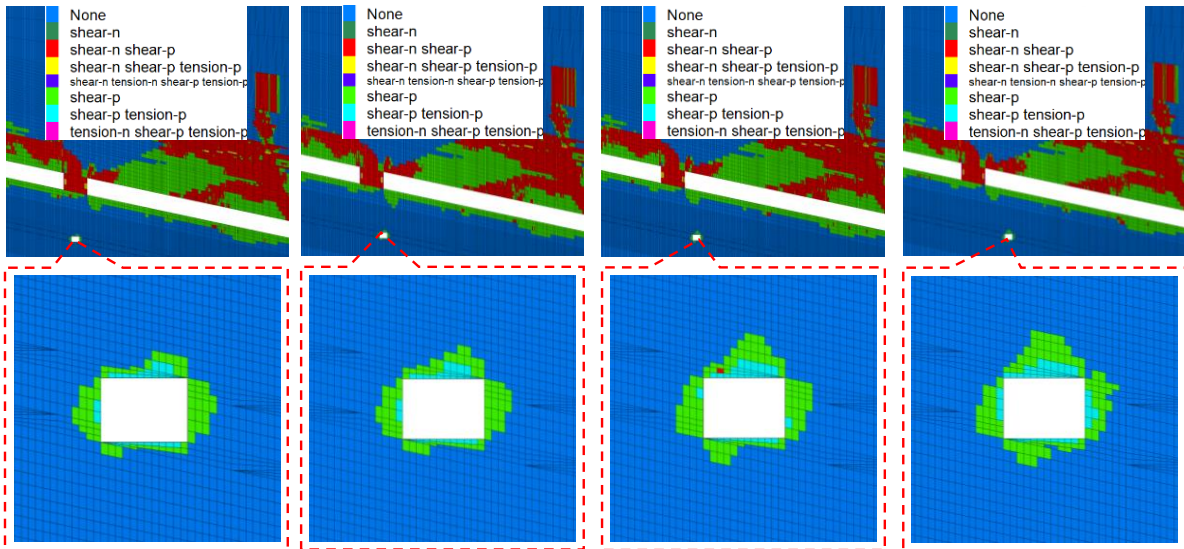
(e) Internal errors 15.0m (f) Internal errors 20.0m (g) Internal errors 25.0m (h) Internal errors 40.0m

Figure 6: Numerical simulation results of plastic failure of surrounding rock when the mining roadway is arranged at the lower left of the remaining coal pillar

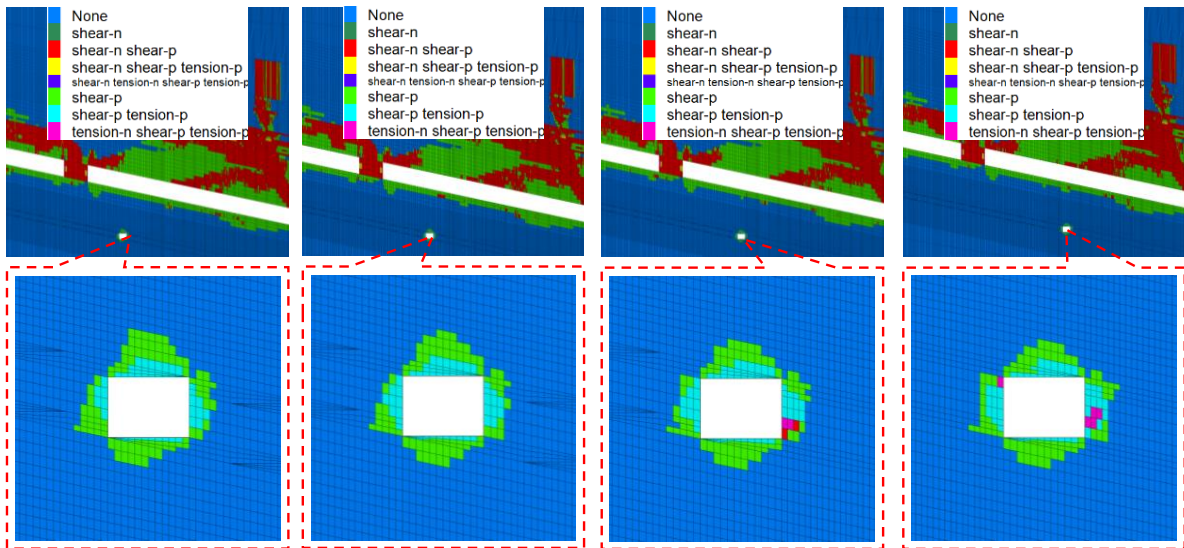
4.2.2. Numerical simulation analysis of mining roadway layout under the remaining coal pillar

When the mining roadway is arranged in the lower section of B1 coal seam, the plastic failure pattern of the surrounding rock of the roadway is basically the same with the center of the coal pillar as the symmetry axis and the same distance from the center of the coal pillar. When the external fault of the mining roadway is 10.0m, the maximum plastic failure depth of the roadway roof is 1.0m, and the maximum plastic failure depth of both sides is 2.0m. The plastic failure pattern of the roadway surrounding rock is approximately elliptical, as shown in FIG. 7(a). When the internal fault is

arranged at 5.0m, the failure depth of the plastic zone at the top left of the roadway roof increases slightly, and the maximum plastic failure depth of the roof increases to 2.5m, as shown in FIG. 7(c). When the internal error is 10.0~20.0m, the maximum plastic failure depth of the roof is 2.5m, as shown in Figure 7(d~f). When the internal fault distance is greater than 20.0m, the plastic zone of the roadway roof decreases to 2.0m and does not change. At this time, it can be considered that the layout of the mining roadway does not consider the influence of the stress concentration of the remaining coal pillars, and the average plastic failure depth of the roadway surrounding rock roof is about 1.75m, as shown in Figure 7(g~h).



(a) External error 10.0m (b) External error 2.5m (c) Internal errors 5.0m (d) Internal errors 10.0m



(e) Internal errors 15.0m (f) Internal errors 20.0m (g) Internal errors 25.0m (h) Internal errors 40.0m

Figure 7: Numerical simulation results of plastic failure of surrounding rock when the mining roadway is arranged at the lower right of the remaining coal pillar

In summary, when the mining roadway is arranged within 5m of the internal fault, the maximum plastic failure depth is mainly concentrated at the position of the roadway roof. When the inner fault distance of the mining roadway is greater than 5.0m, the plastic zone of the surrounding rock of the

roadway is similar to a circle. When the roadway is arranged in the upper and lower sections, the deformation and failure laws of surrounding rock are basically the same.

5. CONCLUSION

(1) The distribution characteristics of the maximum principal stress around the mining roadway, including the magnitude and direction of the maximum principal stress, the ratio of the principal stress and the principal stress difference, are obtained under the condition of retaining 15m coal pillar types. The peak area of the maximum principal stress around the surrounding wall rock of the mining roadway is mainly concentrated at the position below the coal pillar, but the principal stress difference around the roadway is small at this time.

(2) The plastic failure rule of mining roadway is revealed under the influence of 15m residual coal pillar. The stress environment around mining roadway at different locations is obviously different, resulting in different distribution of plastic zone in mining roadway surrounding rock. The shape change of plastic zone in mining roadway surrounding rock varies from near to far and within 40m of coal pillar and internal dislocation is as follows: ellipse-butterfly shape - ellipse/butterfly shape.

REFERENCES

- [1] F. Liu, W.J. Cao, J.M. Zhang, et al. Current technological innovation and development direction of the 14th Five-Year Plan period in China coal industry, *Journal Of China Coal Society*, Vol.46(2021), No. 01, p: 1-15.
- [2] P.F. Jiang, H.P. Kang, J. Zhang, et al. Mechanism of Load-Transfer Between Coal Pillars with Different Widths in Mining the Short-Range Seams, *Journal of Mining & Safety Engineering*, Vol.28(2011), No. 03, p: 345-349.
- [3] G.C. Yan, Y.Q. Hu, X.M. Song, et al. Theory And Physical Simulation Of Conventional Staggered Distance During Combined Mining Of Ultra-close Thin Coal Seam Group, *Chinese Journal of Rock Mechanics and Engineering*, Vol.28(2009), No. 03, p: 591-597.
- [4] D.Y. Hao, Y.Z. Wu, H.J. Chen, et al. Instability mechanism and prevention technology of roadway in close distance and extra thick coal seam under goaf, *Journal of China Coal Society*, Vol.44(2019), No. 09, p: 2682-2690.
- [5] W.L. Li, S.H. Tu, H.S. Tu, et al. Failure characteristics and control techniques for mining roadway affected by stress accumulation of residual pillars in contiguous coal seams, *Engineering Failure Analysis*, Vol. 141(2022).
- [6] Q. Li, G.Y. Wu, D.Z. Kong, et al. Study on Stability of Stope Surrounding Rock under Repeated Mining in Close-Distance Coal Seams, *Geofluids*, 2022.
- [7] G.S. Yang, J.S. Wang. Overburden structure evolution and pressure law of second mining in close-range coal seam group, *Journal of China Coal Society*, Vol.43(2018), No. S2, p:353-358.
- [8] F.L. He, Y. Yang, L. Li, et al. Determining reasonable position of roadway for close coal seam, *Journal of Mining Science and Technology*, Vol.7(2022), No. 04, p:505-512.
- [9] K. Lv, F.L. He, X.H. Xu, et al. Layout of roadway under goaf based on scale effect of mining cross upper coal pillar, *Coal Science and Technology*, Vol.51(2023), No. 03, p:52-60.
- [10] F.L. He, L. Li, K. Lv, et al. Study on Evolution of Front Abutment Pressure at Working Face in Repeated Mining of Close-Distance Coal Seams, *Sustainability*, Vol.14(2022), No. 19.
- [11] N.J. Ma, J. Li, Z.Q. Zhao. Distribution of the deviatoric stress field and plastic zone in circular roadway surrounding rock, *Journal of China University of Mining & Technology*, Vol.44(2015), No. 02, p: 206-213.
- [12] H.S. Jia, K. Pan, D.F. Li, et al. Roof fall mechanism and control method of roof with weak interlayer in mining roadway, *Journal of China University of Mining & Technology*, Vol.51(2022), No. 01, p: 67-76+89.
- [13] H.S. Jia, N.J. Ma, Q.K. Qian. Mechanism and control method of roof fall resulted from butterfly plastic zone penetration, *Journal of China Coal Society*, Vol.41(2016), No. 06, p: 1384-1392.
- [14] HUANG Cong, WANG Weijun, YUAN Chao, et al. Study on the Influence of the Change of Principal Stress Direction on the Morphological Characteristics of Plastic Zone in Surrounding Rock of Roadway[J]. *Mineral Engineering Research*, 2020, 35(01): 7-11.