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Research on Roof Cutting and Pressure Relief Technology of Gob-side Entry Retaining with Hard Roof

Chao Hu

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

Abstract: Traditional coal pillar roadway protection is easy to cause roadway stress concentration, roadway deformation instability, and low recovery rate of coal resources. In order to solve the stability of roadway mining process and coal mine efficiency. Aiming at the problem of gob-side entry protection by deep hole pre-splitting blasting with hard roof, taking 1207 working face of Jiegou Coal Mine as the engineering background, through theoretical analysis, numerical simulation, field industrial test and other methods, the technology of roof cutting and pressure relief and constant resistance anchor cable reinforcement and roadway protection is put forward, and the key parameters such as appropriate roof cutting height and roof cutting angle are analyzed to achieve the effect of roof cutting and pressure relief, and the roadway reinforcement support scheme is designed. The field research shows that the roof cutting and roadway protection technology has a good control effect on 1207 working face roadway, realizes the safe production of working face, and provides certain reference value for this similar condition.

Keywords: Along the empty lane; Roof cutting and pressure releasing; Numerical simulation; Reinforcement support.

1. Introduction

Coal is an important strategic resource in China 's energy field, and it is expected to occupy the dominant position of energy for a long time in the future[1-2]. In China 's coal mining, underground mining is the main way of coal mining, and roadway surrounding rock control is one of the important factors of safe production[3-4]. The emergence of gob-side entry retaining technology can effectively reduce the retention of section coal pillars[5], improve the mining rate of coal mining to a greater extent, and reduce the amount of roadway excavation, which is extremely beneficial to the improvement of coal mine economic benefits[6].In view of the roof cutting and roadway protection technology of such hard roof, many scholars have done a lot of research. Wang Hongsheng[7] and other scholars have carried out a lot of research on the fracture form of the main roof of the gob-side entry. The research shows that the fracture position of the main roof has a great influence on the stability of the roadway. When the fracture position is located on the upper side of the roadway near the goaf, the stress concentration of the surrounding rock of the roadway is effectively improved. Based on the ' S-R ' stability principle of surrounding rock structure, Chen et al.[8] obtained the theoretical calculation formula of the key parameters of roof cutting height and roof cutting angle. Zhang Dongsheng et al.[9] established a mechanical model of the fracture structure of the main roof overburden rock, analyzed the influence of the fracture form on the stability of the coal pillar, and proposed the roadway protection measures along the goaf.

Therefore, this paper takes the control of surrounding rock of roadway affected by dynamic pressure in 1207 working face of Anhui Jiegou Coal Mine as the engineering background. Through theoretical analysis, numerical simulation and field industrial test, this paper puts forward the technology of roof cutting and pressure relief and constant resistance anchor cable reinforcement to realize the stability control of roadway in working face.

2. Engineering Background

The north of 1027 working face is 1026 working face, the west is the south wing track roadway of East No.1 (10) lower mining area, the east is the mine boundary, and the south is 1028 working face. There are two mining roadways in the 1027 working face, including the air roadway and the machine roadway. The air roadway is the gob-side entry retaining of the 1026 working face, with a length of 796 m, and the length of the 1027 working face is 941 m.

The mining coal seam of 1027 working face is 10 coal, black, powder~broken block, glass luster, mainly dark coal and bright coal. The average distance from the bottom of No.10 coal seam to the top of the floor is about 53 m, and the elevation of the working face is-493 m to-558 m, which belongs to the pressure mining. The occurrence of coal seam is relatively stable. The dip angle of coal seam is 5°~ 23°, with an average of 13°. The structure of coal seam is simple. The thickness of coal seam is 0.6 ~ 3.0 m, with an average of 1.6 m. The coal seam gradually becomes thicker from air roadway to machine roadway. The immediate roof of No.10 coal is mudstone, 0-2.33 m thick, dark gray ; the main roof is 7-9 m thick fine sandstone, dark gray. The strike length of the working face is 672 ~ 688 m, with an average of 680 m, and the length of the open-off cut is 189 m. The mining engineering plan of 1027 working face is shown in Fig.1.The length of gob-side entry retaining section is 307 m, and the length of roof cutting reinforcement section is 427 m.

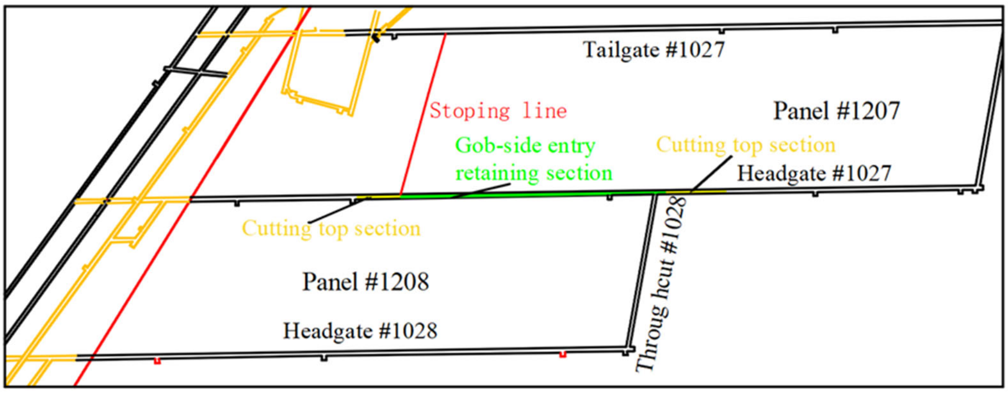


Figure 1. Plan of 1027 working face

3. Numerical Simulation Analysis of Gob-side Entry Retaining with Roof Cutting in 1027 Machine Roadway

The implementation and effect of roof cutting technology is the premise to maintain the stability of gob-side entry retaining. By using the numerical simulation method, the 3DEC numerical analysis model is established. The influence of the cutting height and the cutting angle on the cutting effect is studied, and the appropriate cutting parameters are determined.

The size of the model is long×wide×high (X×Y×Z) = 110m×20m×73.5m, which is divided into 1661740 units. Considering that coal seam and roadway are the main research objects of the model, mesh refinement is carried out to ensure the continuity of stress transfer. The horizontal boundary and bottom boundary of the model are fixed, and the vertical stress of 12 MPa is applied to the top boundary to simulate the buried depth of 550 m. In the model, the coal seam adopts the strain softening constitutive model, and the rock layer adopts the Mohr-Coulomb constitutive model.

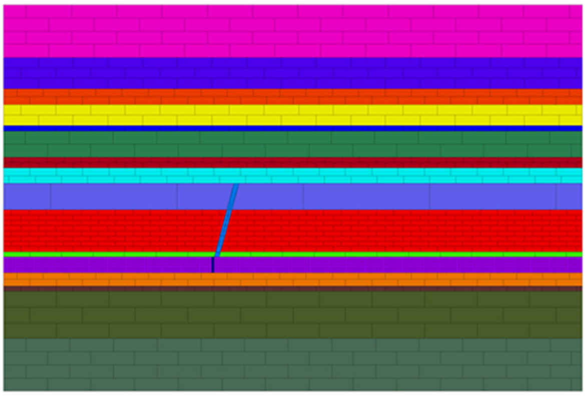


Figure 2. 3DEC numerical simulation test model

3.1. The effect of roof cutting height on the stability of roadway surrounding rock

(1) Effect of roof cutting height on roadway roof displacement

The simulation schemes under different roof cutting heights are set up, which are no roof cutting, roof cutting height of 4 m, roof cutting height of 7 m, roof cutting height of 10 m and roof cutting height of 13 m, respectively. Among them, no roof cutting is the control group. Figure 3 shows the curve of roadway roof subsidence with roof cutting height.

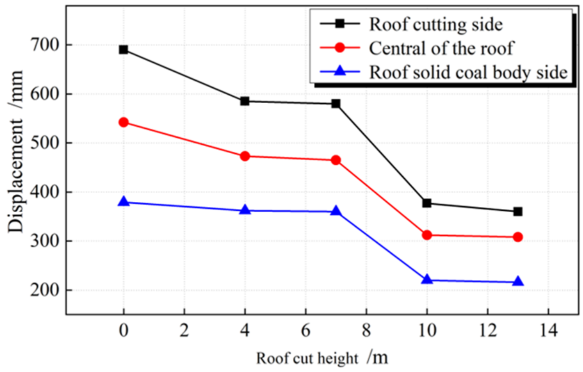


Figure 3. Variation curve of roadway roof subsidence with roof cutting height

When the roof cutting height is 0 m, the lower rock layer of the basic roof is broken in the solid coal side. Under the action of the rotary subsidence and extrusion of the overlying rock layer, the surrounding rock of the retained roadway is greatly deformed. At this time, the subsidence of the roof cutting side of the retained roadway is about 690 mm, the subsidence of the central roadway is about 542 mm, and the side of the solid coal body is about 379 mm. The convergence of the solid coal body is large, and the stability of the retained roadway is poor. When the roof cutting height is 4 m, the roof on the side of the goaf collapses along the cutting surface, and the roof of the retaining roadway forms a short cantilever beam structure. However, there is a clear gap between the collapsed gangue and the upper rock layer of the basic roof, indicating that when the roof cutting height is small, the gangue can not fully and effectively support the overlying rock layer after crushing and expanding. The unfilled space leads to the rotation and sinking of the upper rock layer of the basic roof to form a balanced structure. In the process of roof sinking, the short cantilever beam structure will be squeezed, resulting in the deformation of the surrounding rock of the retaining roadway. However, the deformation of the retaining roadway is lower than that of the uncut roof, and the subsidence of the cutting side of the roof of the retaining roadway is about 585 mm. The central subsidence of the roadway is about 473 mm, and the side of the solid coal body is about 362 mm. The stability of the retained roadway is slightly improved. When the roof cutting height is 7 m, the vertical displacement distribution map of the retained roadway can be seen. Compared with the roof cutting height of 4 m, the roof subsidence of the roadway and the convergence of the solid coal body are slightly reduced, but the reduction amplitude is small, indicating that the gangue cut off at this time is still unable to fully and effectively support the overlying strata. The unfilled space leads to the rotation and sinking of the upper strata of the basic roof to form a balanced structure, which is basically the same as the 4 m roof cutting effect.

When the roof cutting height is 10 m, the subsidence of the roof cutting side of the retaining roadway is about 377 mm, the subsidence of the roadway center is about 312 mm, and the subsidence of the solid coal side is about 220 mm. The deformation of the surrounding rock of the retaining roadway is significantly reduced. The main reason for this phenomenon is that the collapsed gangue after roof cutting can support the overlying strata and reduce the gap between the collapsed gangue and the upper strata of the main roof. It shows that the increase of the roof cutting height is beneficial to the filling of the goaf. At this time, the upper strata of the main roof only need a small amount of subsidence to reach the equilibrium structure, which greatly reduces the squeezing effect on the short cantilever beam. As a result, the roof subsidence of the roadway and the convergence of the solid coal body are greatly reduced, and the stability of the retained roadway is significantly improved. When the roof cutting height is 13 m, through the vertical displacement distribution map of the retained roadway, it can be seen that compared with the roof cutting height of 10 m, the roof subsidence of the roadway and the convergence of the solid coal body are slightly reduced, but the reduction amplitude is small, indicating that the roof cutting effect at this time is basically the same as that of the roof cutting height of 10 m.

Based on the above analysis, the roof cutting can play a role in pressure relief. The change of the roof cutting height mainly affects the filling degree of the goaf and the thickness of the short cantilever beam. The reasonable roof cutting height can effectively fill the goaf and support the overlying strata, increasing the stability of the retaining roadway. The roof cutting height is small, the caving gangue can not effectively fill the goaf, and the stability of the retaining roadway is poor ; if the roof cutting height is too large, the self-weight of the short cantilever beam structure will increase, which is not conducive to the stability of the retained roadway. At the same time, the roof cutting height will increase, and the construction difficulty and the cost of the retained roadway will increase.

(2) The effect of roof cutting height on the vertical stress of roadway

The simulation schemes under different roof cutting heights are set up, which are no roof cutting, 4 m height of roof cutting, 7 m height of roof cutting, 10 m height of roof cutting and 13 m height of roof cutting. Among them, no roof cutting is the control group. Figure 4 gives the vertical stress distribution cloud map of different roof cutting heights. Comparing the vertical stress distribution cloud diagram of different roof cutting heights, it can be seen that before the roof cutting, the roof of the retained roadway forms a long cantilever beam structure, and the roof of the goaf transfers stress to the roof of the retained roadway. The pressure of the single pillar beside the retained roadway is large, about 48.26 MPa, which is prone to failure and instability. After the roof cutting, the roof of the retaining roadway becomes a short cantilever beam structure, which cuts off the stress transfer between the roof of the goaf and the roof of the retaining roadway within the height range of the roof cutting, so that the stress distribution of the surrounding rock of the retaining roadway is changed, thus affecting the effect of the retaining roadway.

When the roof cutting depth is 4 m, the pressure of the single pillar next to the retaining roadway is still large, about 44.35 MPa, and the stability of the retaining roadway is poor, indicating that when the roof cutting height is small, the roof cutting pressure relief control effect cannot reach the expectation. When the roof cutting depth is increased to 7 m, the stress of the single support is about 44.21 MPa, which is similar to the 4 m roof cutting depth, and can not effectively improve the stress environment of the retaining roadway. Once the depth of roof cutting reaches 10 m (the key stratum is completely cut off), the stress of roadside single support is greatly reduced, which is about 37.66 MPa, and the stress environment of retained roadway is obviously improved. As the depth of roof cutting increases to 13 m, the stress reduction of roadside single support is small, about 36.73 MPa, indicating that after the key stratum is cut off, there is no need to continue to increase the height of roof cutting. Combined with the site production conditions, it is generally appropriate to cut off the key stratum during construction.

In summary, the optimal cutting depth is determined to be 10 m.

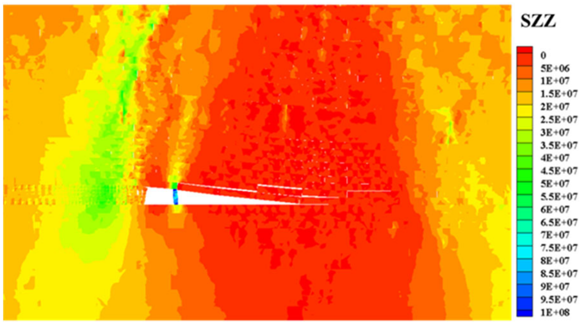
3.2. The effect of roof cutting angle on the stability of roadway surrounding rock

In order to prevent large-scale subsidence of the roof after pre-splitting blasting, in the actual roof cutting drilling process on site, the drilling direction often deflects a certain angle to the goaf. In order to analyze the influence of the roof cutting angle, three different roof cutting angles are carried out. The numerical simulation is carried out. The roof cutting height is 10 m. In addition to the previous roof cutting angle of 0°, the roof cutting angles are increased by 10° and 15° respectively. By comparing the displacement changes of the surrounding rock of the roof cutting roadway when the roof cutting angle is 0°, the best roof cutting angle is determined.

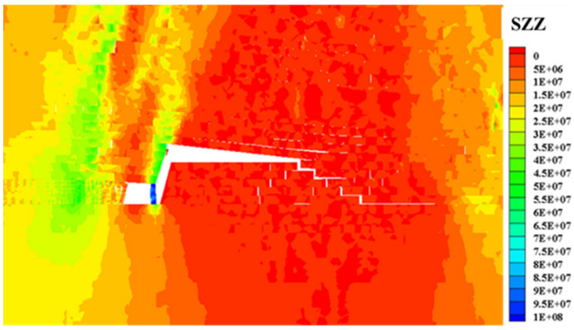
(1) Effect of roof cutting angle on roadway roof displacement

Figure 5 is the vertical displacement distribution cloud map of the retaining roadway under different roof cutting angle schemes. Comparing the vertical displacement nephograms of different roof cutting angles, it can be found that when the roof cutting angle is 0, that is, the angle between the direction of the roof cutting borehole and the vertical direction is 0°, the subsidence of the roadway roof is the largest, and the cutting seam is about 462 mm. Under this scheme, when the roof of the goaf collapses, there is obvious pressure on the cantilever beam structure of the roof of the retaining roadway, which will cause the subsidence deformation of the roof of the retaining roadway.

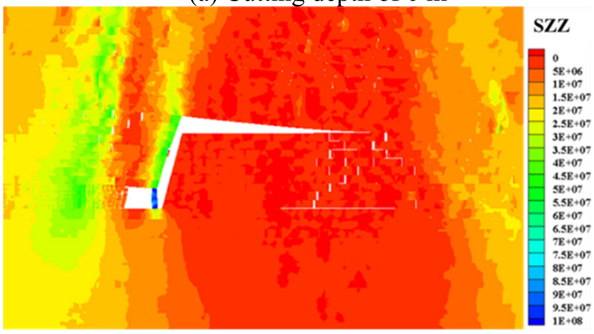
When the roof cutting angle increases to 10°, it can be seen that the subsidence of the roadway roof decreases as a whole, and the slit side is about 272 mm. At this time, the falling gangue in the goaf not only has a vertical support effect on the overlying strata, but also has a lateral support effect on the cantilever beam structure, which reduces the pressure of the retaining roadway to a certain extent, reduces the roof subsidence, and improves the stability of the surrounding rock of the retaining roadway. When the roof cutting angle continues to increase to 15°, the subsidence of the roadway roof increases as a whole, and the slit side is about 377 mm. The reason for this phenomenon is that with the increase of the roof cutting angle, the length of the cantilever beam increases, and its own weight will increase. To a certain extent, the pressure effect on the roof of the retained roadway is greater than the lateral support effect of the caving gangue on the short cantilever beam structure, resulting in an overall increase in the subsidence of the roof. This shows that continuing to increase the roof cutting angle is not conducive to the stability of the roadway.



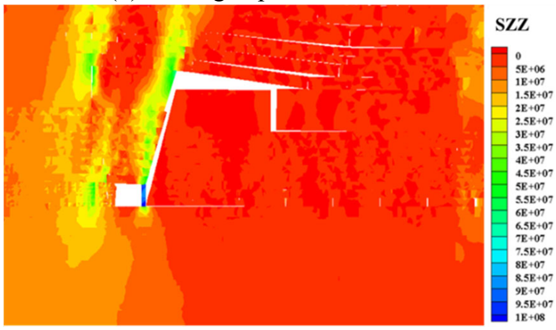
(a) Cutting depth of 0 m



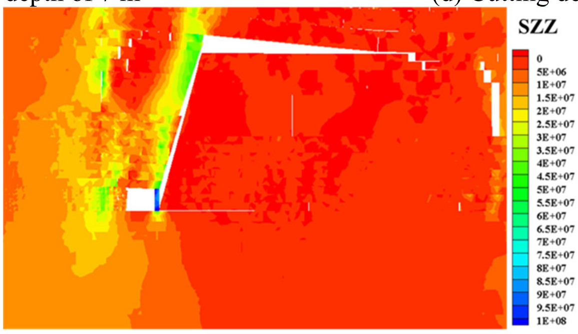
(b) Cutting depth of 4 m



(c) Cutting depth of 7 m

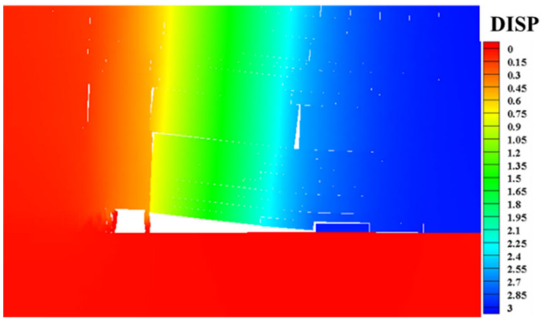


(d) Cutting depth of 10 m

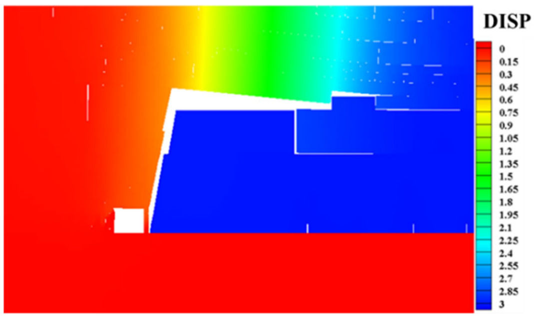


(e) Cutting depth of 13 m

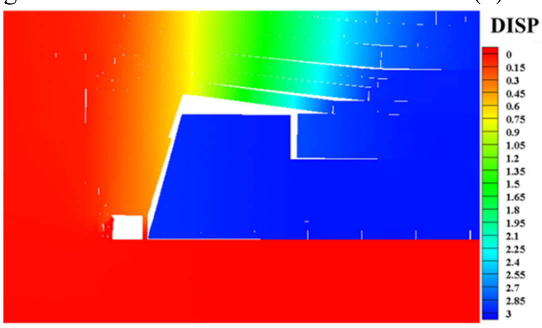
Figure 4. The vertical stress distribution cloud chart of different roof cutting heights



(a) Cutting angle 0°



(b) Cutting angle 10°.



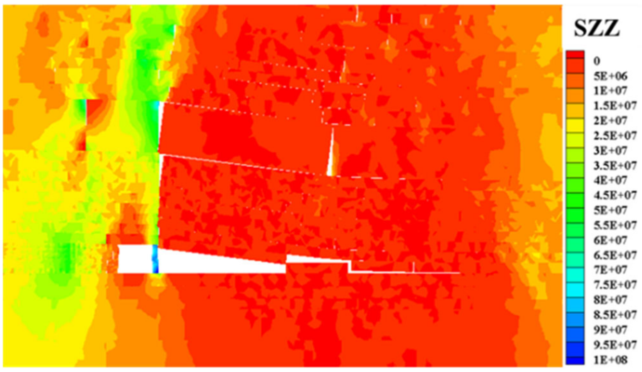
(c) Cutting angle 15°

Figure 5. Vertical displacement distribution cloud diagram of entry retaining under different roof cutting angle schemes

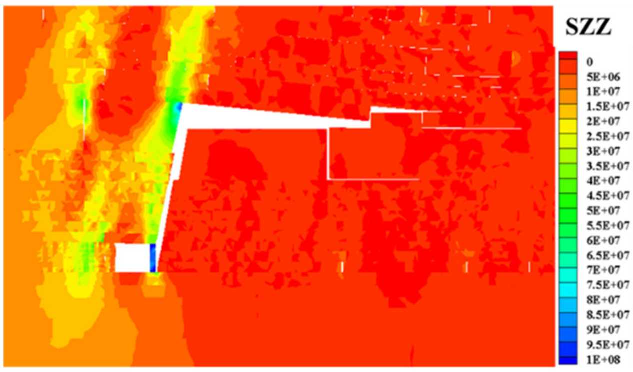
(2) The effect of roof cutting angle on the vertical stress of roadway

Figure 6 is the vertical stress distribution cloud map of the retaining roadway under different roof cutting angle schemes. By comparing the vertical stress distribution nephograms of different roof cutting angles, it can be seen that when the roof cutting angle is 0°, the pressure of the single pillar beside the retaining roadway decreases significantly compared with that without roof cutting, about 37.33 MPa, but the vertical stress of the roof increases, about 5.23 MPa. At this time, the stress accumulation area is directly above the roadway, which is not conducive to the stability of the roadway roof. It shows that when the roof cutting angle is small, the roof cutting pressure relief control effect can not reach the expectation.

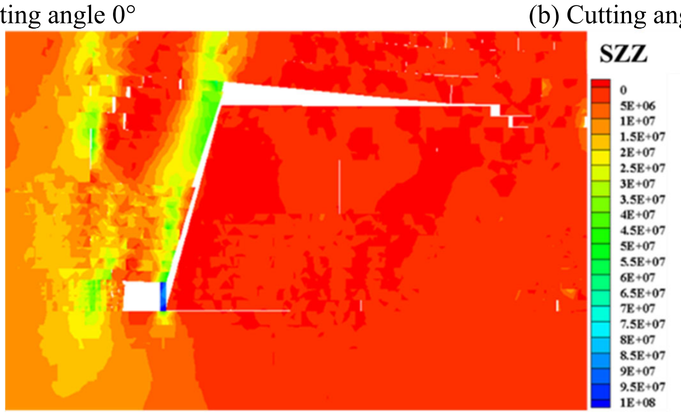
When the roof cutting angle is 10°, the stress of the single support next to the roadway decreases again, about 35.82 MPa, and the vertical stress of the roof decreases to 4.66 MPa. At this time, the stress accumulation area above the roof of the roadway transfers to the side of the goaf, and the range of the stress accumulation area is greatly reduced. Compared with the roof cutting angle of 0°, the stress accumulation stress of the roadway side is greatly reduced, and the stress environment of the retained roadway is obviously improved. When the roof cutting angle is 15°, the vertical stress of the roof is greatly reduced to 3.26 MPa, which is conducive to the stability of the roof of the gob-side entry retaining. At this time, the roof stress accumulation area is greatly reduced, and the main accumulation area is above the roof of the roadway side. Therefore, the stress of the roadside single support is greatly increased, about 41.23 MPa, which is prone to failure and instability, which is not conducive to the stability of the gob-side entry retaining.



(a) Cutting angle 0°



(b) Cutting angle 10°.



(c) Cutting angle 15°

Figure 6. Vertical stress distribution cloud diagram of entry retaining under different roof cutting angle schemes

In summary, combined with the actual situation on site, it is determined that the borehole is constructed at an angle of β = 10° (towards the goaf) with the vertical direction.

4. Roadway Reinforcement Support Scheme

In order to effectively control the stability of surrounding rock during and after mining in the working face of gob-side roadway, blasting roof cutting and pressure relief were carried out in the mining roadway, and reinforcement support was carried out to ensure the long-term stability of surrounding rock after mining stress disturbance in gob-side roadway. The 1207 roadway adopts the roof constant resistance yielding anchor cable and the side anchor cable for reinforcement support. The specific support parameters are as follows :

When the gob-side entry retaining is carried out in the roadway, 100 m ahead of the working face is needed, and the roof cutting anchor cable (constant resistance yielding anchor cable) is added to strengthen the support. The roof is strengthened by constant resistance yielding anchor cable. The roof cutting anchor cable is arranged in the ' 303 ' way, the row spacing is 1600 mm, and the ' 333 ' arrangement is formed with the original design. The diameter of the roof cutting anchor cable is 21.8 mm, the length is 6400 mm and 8300 mm. At the same time, a row of side anchor cables is added to strengthen the support. The diameter of the side anchor cable is 21.8 mm and the length is 6400 mm. The reinforcement support of 1207 machine roadway is shown in figure 7.

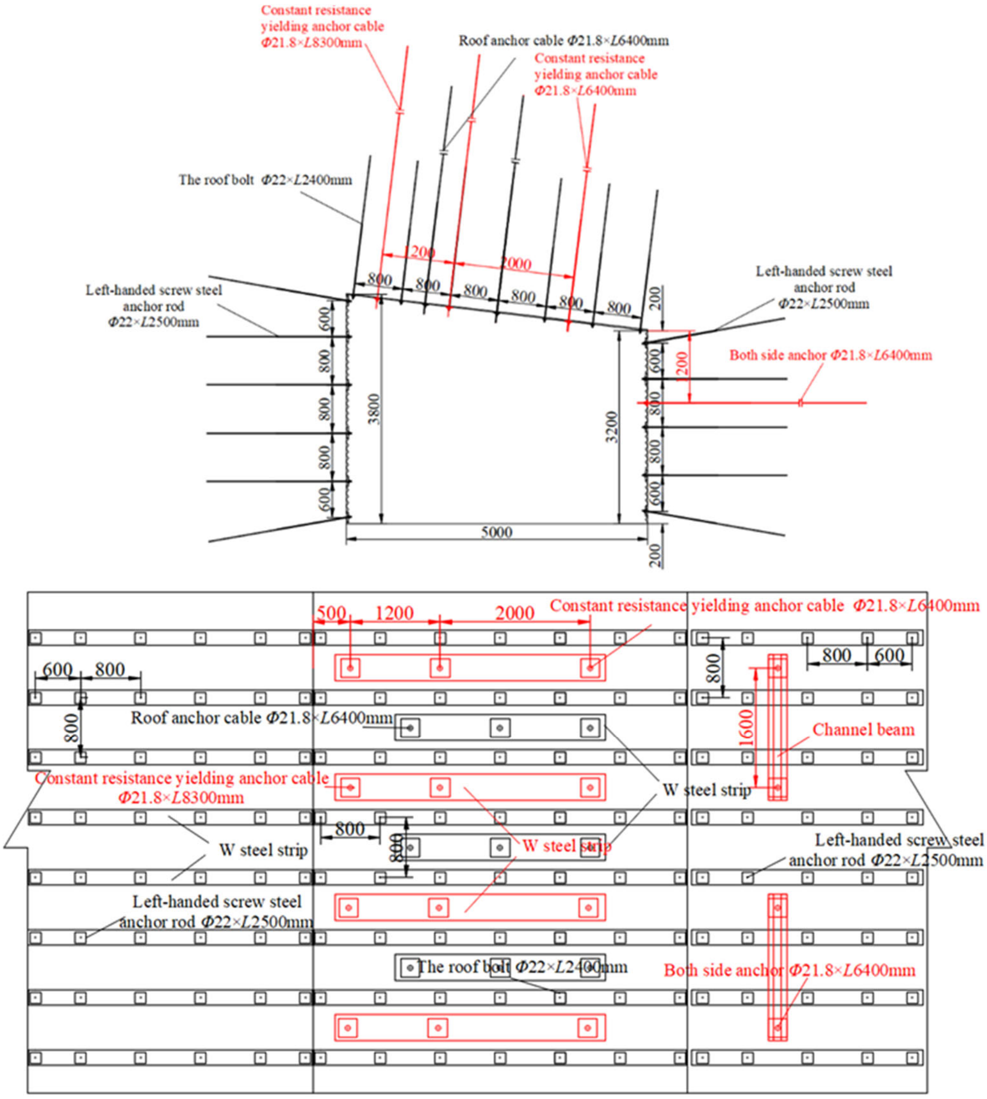


Figure 7. Reinforcement support diagram of roof cutting anchor cable

5. Industrial Test

In order to verify the application effect of roof cutting and roadway protection technology in gob-side entry, an industrial test was carried out on 1207 machine roadway, and the deformation of surrounding rock of 1207 machine roadway during the mining influence of 1207 working face was monitored. The deformation curve is shown in Fig. 8. It can be seen from the figure that 1207 machine roadway began to deform at about 30 m ahead of the working face. The deformation speed of surrounding rock was relatively fast in the range of 15 m ahead of the working face to 90 m behind the working face. Outside the range of 90 m behind the working face, the surrounding rock tended to be stable, and the deformation of roadway did not increase significantly. At this time, the deformation of roof and floor of roadway was about 93 mm, and the deformation of two sides was about 82 mm. It shows that the control effect of the test roadway is good after adopting the scheme.

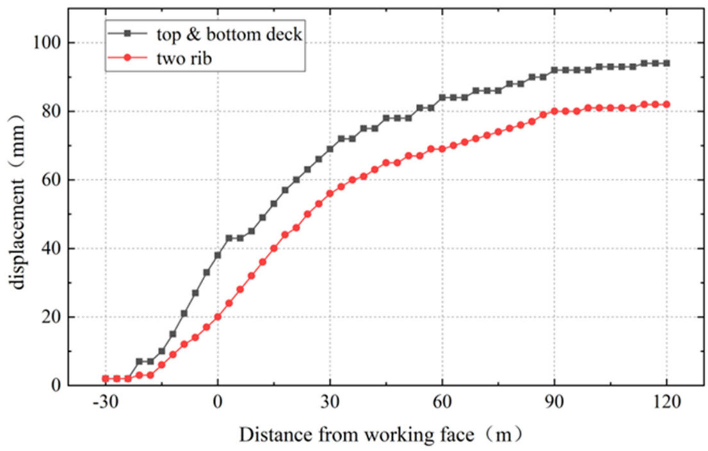


Figure 8. Roadway surrounding rock deformation curve diagram

6. Conclusion

(1) By cutting the hard roof to reduce the length of the hanging roof or reduce the thickness of the hanging roof, by considering the reasonable parameters of the angle and height of the cutting roof, it is helpful to block the stress transfer of the thick and hard roof. The broken rock mass can fill the goaf to support the overlying strata, so that some or all of the hard roof fall, so as to improve the stress environment of the surrounding rock of the retaining roadway and achieve the purpose of pressure relief.

(2) Based on the field engineering geological conditions, the key roof cutting and pressure relief parameters such as roof cutting angle and roof cutting height were determined by numerical simulation, and the roadway reinforcement support scheme was designed. The field industrial test verified the roof cutting and pressure relief gob-side entry retaining technology and achieved good results, which provided a certain reference value for similar mine conditions.

References

[1] Qian Minggao, Xu Jialin, Wang Jiachen. Revisiting the Scientific Mining of Coal [J]. Coal Journal, 2018,43 (01) : 1-13.

[2] Zhao Gaoming, Tu Min, Zhang Xiangyang, et al. Study on roof cutting pressure relief angle of lateral structure of gob-side entry [J].Mining research and development, 2023,43 (02) : 108-115.

[3] He Manchao, Wu Yiyi, Gao Yubing, etc. Advances in rock mechanics of deep mining [J]. Coal Journal, 2024, 49 (01) : 75-99.

[4] Wang Qi, Zhang Peng, Jiang Zhenhua, et al. Method and verification of deep high-strength bolt-grouting roof cutting self-forming roadway [J].Coal Journal, 2021,46 (02) : 382-397.

[5] Kang Hongpu. 70 years of development and prospect of surrounding rock control technology of coal mine roadway in China [J]. Journal of Rock Mechanics and Engineering, 2021, 40 (01) : 1-30.

[6] Yang Fengcai, Wu Dongmei, Zhao Wei. Research and practice of roof cutting and pressure relief gob-side entry retaining technology [J].Energy and environmental protection, 2017,39 (09) : 82-87.

[7] Wang Hongsheng, Zhang Dongsheng, Li Shugang, Wang Lin, Wu Linzi. Determination of reasonable width of narrow coal pillar based on the location of fracture line B of key rock block of main roof [J]. Journal of Mining and Safety Engineering, 2014,31 (01) : 10-16.

[8] Chen Shangyuan, Zhao Fei, Wang Hongjian, etc. Research and engineering application of key parameters of deep roof cutting gob-side entry [J]. Geotechnical mechanics, 2019,40 (1) : 332-342,350.

[9] Zhang Dongsheng, Ma Liqiang, Feng Guangming, Miao Xiexing. In-situ filling gob-side entry retaining technology in fully-mechanized caving roadway [J].Journal of rock mechanics and engineering, 2005 (07) : 1164-1168.