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Study on Mine Pressure Behavior Law of Mining Roadway Passing Concentrated Coal Pillar and Goaf

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Abstract: Based on the special spatial position of 1–2 coal and 2–2 coal, this paper adopts a new way of modeling by fish and overcomes the difficulty of modeling, simulates the influence of the coal pillar on the 22,206 return airway after mining 1–2 coal seam by Flac3D, studies the 22,206 return airway under the influence of primary and secondary mining, and puts forward the support scheme of the 22,206 return airway. The following conclusions are obtained: (1) After mining 1–2 coal, the stress of the 22,206–return airway under the residual coal pillar of 1–2 coal increased. The maximum stress position is below the middle coal pillar of 1–2 coal, and its maximum vertical stress (σv_{max}) and maximum horizontal stress (σh_{max}) are 6.24 MPa and 4.09 MPa, respectively. (2) The rule of 22,206 return airway's pressure appearance is that the stress and plastic zone becomes larger when near the coal pillar, becomes smaller when far from the coal pillar, the maximum failure radius of roof and floor is only 1.3 m, and 0.6 m, the maximum failure radius of roadway side is 0.6 m and 1.5 m after the second mining. (3) According to the proposed support scheme, field experiments found that the maximum displacement is less than 120 mm, which can effectively guarantee the stability of the roadway.

Keywords: centralized coal pillar; stress distribution; numerical simulation; roadway support

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1. Introduction

To make ventilation, transportation, and workface replacement convenient, a double roadway layout is often used in coal mines [1–3]. However, after the protective coal pillar left by the double roadway layout is mined in the workface, when the lower coal seam is mined through the overlying coal pillar, the stress may change due to the change of the stress field. The excessive force of the coal pillar causes the phenomenon of crushing, roof fall, and other mine pressure behaviors. In addition, the mining roadway may also be damaged during the period of passing the concentrated coal pillar, which affects the normal mining and propulsion of the workface and causes economic losses. There have been many achievements in this problem: Yang, J.Z. and Li, H.D. and others have studied the dynamic pressure of shallow coal seam passing through overlying goaf and coal pillar [4,5], and Zhou, H.F. analyzed the mechanism of support crushing of fully mechanized mining face passing through overlying concentrated coal pillar [6], Tian, C. et al. studied the mining of overlying concentrated coal pillar and goaf in a fully mechanized mining face and analyzed the causes of roof fall accidents in the process of workface passing through overlying concentrated coal pillars and goaf [7]. Fu, X.Y. et al. studied the causes of induced dynamic pressure under concentrated coal pillars [8]. Wang, H. and Zhao, Y.X. et al. studied the induced burst mechanism and prevention method of coal pillar stress deviator concentration area to undermine earthquake disturbance [9]. Rezaei, M. et al. researched the stability of the goaf area in longwall mining underground strata and the stress concentration coefficient by a soft computing methodology and potential energy theory [10–12]. In the deformation and failure mechanism of the roadway and the influence of mining, Ma, N.J. et al. put forward the theory of a butterfly plastic zone under the condition of roadway non-uniform stress field, explained the mechanism of roadway non-uniform deformation, and put forward the theory of butterfly rock burst and its related application [13,14], Li, C. et al. studied the influence of mining and the evolution characteristics of the plastic zone [15,16], Ma, N.J. et al. put forward lengthening bolt and coordination technology [17–20]

The workfaces of 1–2 coal and 2–2 coal in the Huojitu well of Daliuta Coal Mine in Shendong Daliuta Coal Mine are staggered at a certain angle (79°) in space. After mining 1–2 coal, the residual coal pillar is subjected to a large force. When mining the 22,204 workface, due to the influence of overlying goaf and coal pillar while passing the residual coal pillar of overlying 1–2 coal, the stress and plastic zone of different positions of mining roadway will be different, and there will be roof subsidence, side drum, and other manifestations. This may cause accidents such as crushing or even rock bursts. Therefore, this paper is based on the special spatial location relationship between 1–2 coal and 2–2 coal. The residual coal pillar of 1–2 coal seam and the law of mine pressure appearing in the mining roadway under the goaf are studied, and a suitable support scheme is proposed.

2. Project Overview and Methods

22,204 workface of 2–2 coal seam is mining in Daliuta Huojitu mine of Shendong. Two layers of parting are developed in the coal seam of the workface. The total thickness of the parting is 0.2~1.2 m, and the thickness of each layer is 0~0.6 m and 0~0.7 m. The parting lithology is sandy mudstone and siltstone, and the macro coal rock type is mainly semi-dark coal. The dip angle of the coal seam is 1~3°, the coal seam is stable, the mining height of the workface is 4.5 m, the buried depth is about 103 m, the size of the coal pillar is 15 m, and the double roadway layout is adopted. The long wall retreating one-time full-height comprehensive mechanized coal mining method is adopted to manage the goaf roof by the full caving method.

Above the 22,204–1 and 22,204–2 open-off cut area of Huojitu mine, there are partial goaf of 12,315, 12 lower 208, 12 lower 206, 12 lower 204 and 12 lower 202 workfaces. The distance between the 2–2 coal and 1–2 coal seam is 20.58~32.97 m. During the mining of the 22,204 workface, there are coal pillars between 12,315 haulage roadway and the 1–2 lower 208 haulage roadway, 1–2 lower 208 haulage roadway and 1–2 lower 206 haulage roadway, 1–2 lower 206 haulage roadway and 1–2 lower 204 haulage roadway, 1–2 lower 204 haulage roadway and 1–2 lower 202 haulage roadway in the upper part of it, and the width of coal pillars is 18.2 m, 13 m, 12.5 m and 13.1 m, respectively. Chose the typical area for research and made an appropriate simplification. The upper and lower working faces of 12,206 and 12,208 are merged into 12,206 and 12,208 workfaces to study the influence of the coal pillar on lower mining roadway. The spatial position diagram of 1–2 coal workface and 2–2 coal workface is shown in Figure 1.

In order to study the influence of the residual coal pillar of 1–2 coal seam on the mining roadway of the lower 2–2 coal seam, according to the drilling map and geological data of the Huojitu well and based on the special spatial position relationship of 1–2 coal seam, the workface grid of 1–2 coal seam is rotated by FLAC3D with its fish language, as shown in Figure 2, and a large-scale three-dimensional numerical model is established as shown in Figure 3. The length, width, and height of the model are 1000 m, 1000 m, and 170 m respectively. Fixed model perimeter boundary. The stress ratio is 1.2. The Mohr-Coulomb model is used, and the model grid unit is 1,052,476. The mechanical parameters of each rock layer are shown in Table 1.

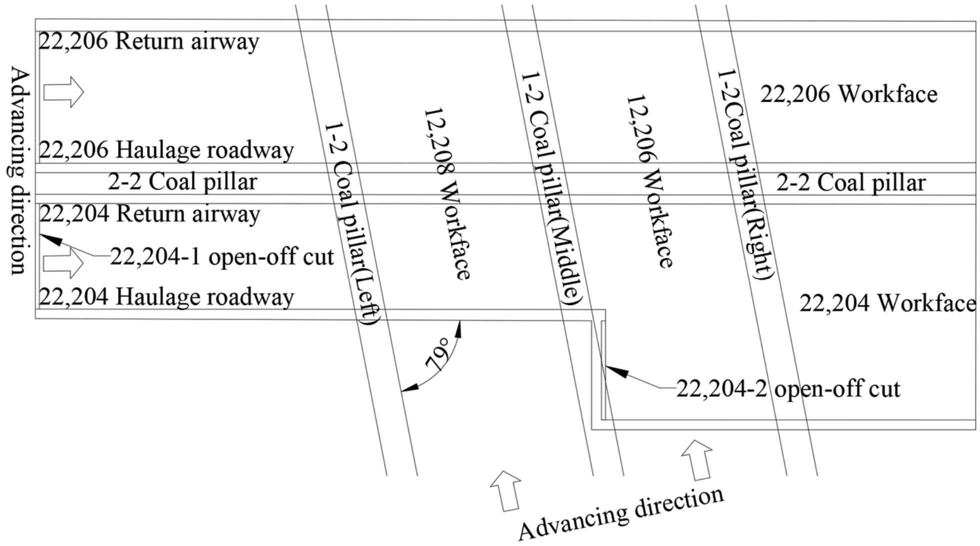

Figure 1. 1–2 Coal 2–2 Coal Position Diagram.

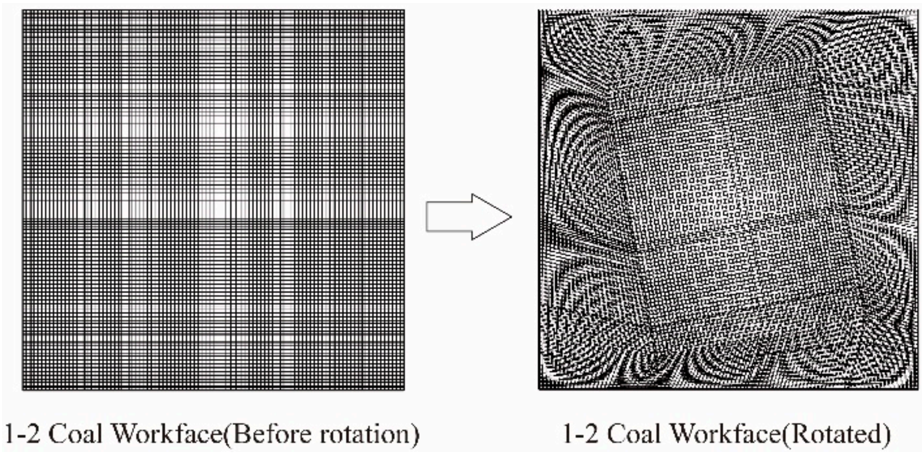

Figure 2. 1–2 coal workface rotation diagram.

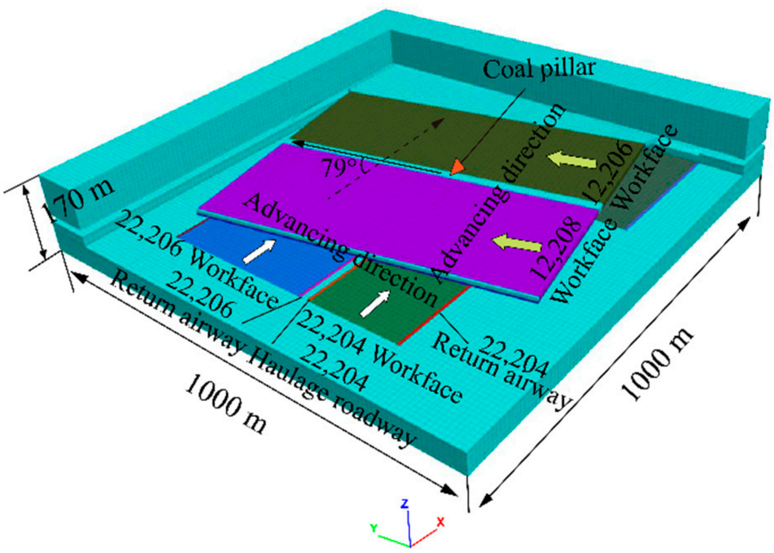

Figure 3. Diagram of numerical simulation.FLAC3D is a continuous model, therefore it cannot simulate the process of roof caving and filling goaf due to the excavation of the workface. Therefore, the double yield model is used to fill goaf to simulate the real mining stress field.

Table 1. Numerical simulation of rock mechanics parameters.

Lithologic Characters	Internal Friction Angle/°	Cohesion/MPa	Tensile Strength/MPa	Elastic Modulus/GPa	Poisson	Density/kg·m^3
Yellow soil	22	0.5	0.116	0.77	0.34	1750
Medium grained sandstone	35.6	4.8	1.73	8.22	0.22	2167
Fine sandstone	39.9	4.5	2.8	7.3	0.25	2340
Siltstone	36.4	3.28	2.15	3.6	0.25	2400
Siltstone 2	26	3.3	0.68	3.6	0.25	2400
Siltstone 3	28	4	2.15	3.6	0.25	2400
1–2Coal	30	1.9	1.69	1.76	0.24	1280
2–2Coal	30	2.5	1.69	7.76	0.24	1500
Mudstone	32.3	2.8	1.5	5.3	0.16	2500

According to the double yield theory and the calculation formula of the caving zone mentioned by Salamon and Li, W. et al. [21,22], the rock mechanical parameters are substituted into the calculation, so calculate out the height of caving zone of 1–2 coal and 2–2 coal is 17 m and 15 m respectively, the maximum volumetric strain ε_m and gangue bulking coefficient b of 1–2 coal goaf are 0.304 and 1.437 respectively, and the maximum volumetric strain ε_m and gangue bulking coefficient b of 2–2 coal goaf are 0.297 and 1.423 respectively. Based on the above data and adopting the numerical model trial inversion, the mechanical parameters of the goaf caving zone in Table 2 are obtained.

Table 2. Mechanical parameters of goaf caving zone.

Rock Formation	K (GPa)	G (GPa)	*P* (kg/m^{-3})	C (MPa)	φ (°)	σ_t (MPa)
1–2 Coal	7.14	4.92	1431	0.001	1	0
2–2 Coal	7.14	4.92	1740	0.001	1	0

3. Results

According to the large-scale numerical model after a coordinate transformation. Firstly, we simulated the mining of the 12,206 and 12,208 workfaces, and get the stress of 22,206 return airway after excavation of 12,206 and 12,208 workfaces then study the influence of overlying coal seam mining on 22,206 return airway. Secondly, excavating the 22,204 workface to study the change of stress and plastic zone of 22,206 return airway passing through coal pillar and goaf under primary mining. Thirdly, we simulated the stress and plastic zone of the 22,206 return airway passing through coal pillar and goaf under secondary mining when the 22,206 workface is mined at 400 m. Finally, summarizing the mine pressure behavior law of 22,206 return airway. The influence of 1–2 coal on the 22,206 return airway is shown in Figure 4, and it can be seen from the figure that after the excavation of 12,206 and 12,208 working faces, the σv_{max} and σh_{max} on the 22,206 return airway below the middle coal pillar of 1–2 coal are 6.24 MPa and 4.09 MPa, respectively, while the vertical and horizontal stresses of the original rock are only 2.75 MPa and 3.3 MPa. The σv_{max} and σh_{max} of the roadway directly below the coal pillar are greater than the original rock stress. This is because the overlying strata are affected by the 1–2 coal workface, which causes the coal pillar to produce a stress concentration and deliver it to the lower mining roadway so that it is in the pressurized area [23]. Under the 1–2 coal goaf, because the collapsed rock in the goaf is filled, the values of σ_v and σ_h are less than the vertical and horizontal original rock stress, which is in the pressure relief area. At the same time, the horizontal and vertical original rock stress of 22,206 return airway under the left and right edge coal pillars of 1–2 coal increased slightly to 3.8~3.9 MPa and 4~4.6 MPa, respectively. The distance between 1–2 coal and 2–2 coal is about 23 m, and the σv_{max} and

σh_{max} under the coal pillar are 2.27 and 1.24 times the original rock stress, so the stress field of the roadway will be affected when it passes the overlying 1–2 coal pillar area [24].

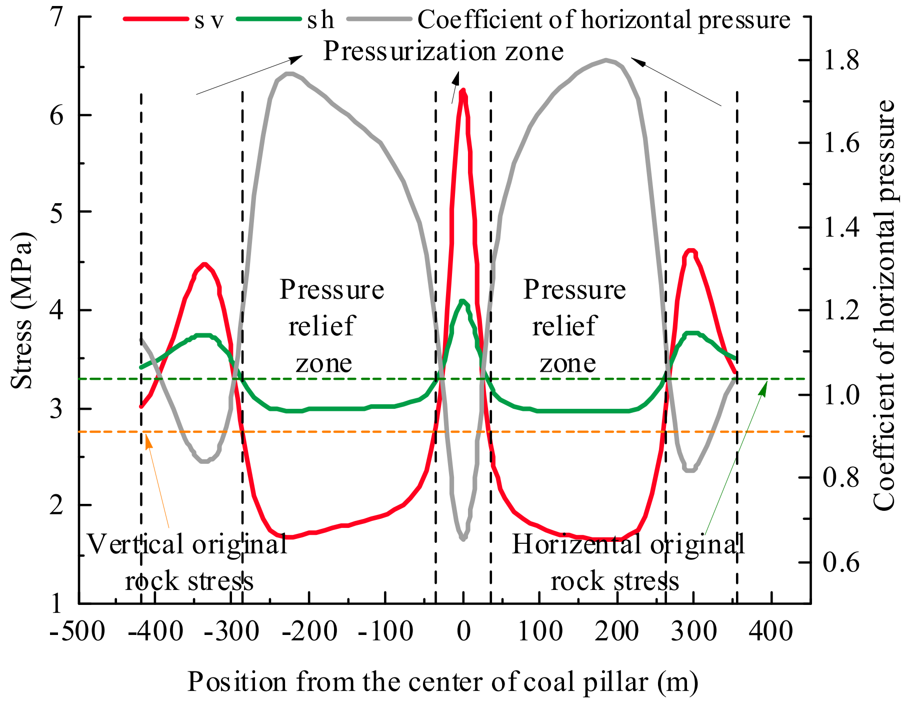

Figure 4. 22,206 return airway stress distribution diagram of excavating 1–2 coal only.

The law of mine pressure appearance through coal pillar and goaf After mining 22,204 workface, the stress distribution of 22,206 return airway under primary mining is shown in Figure 5, and the three-dimensional stress diagram of 2–2 coal overall σv is shown in Figure 6.

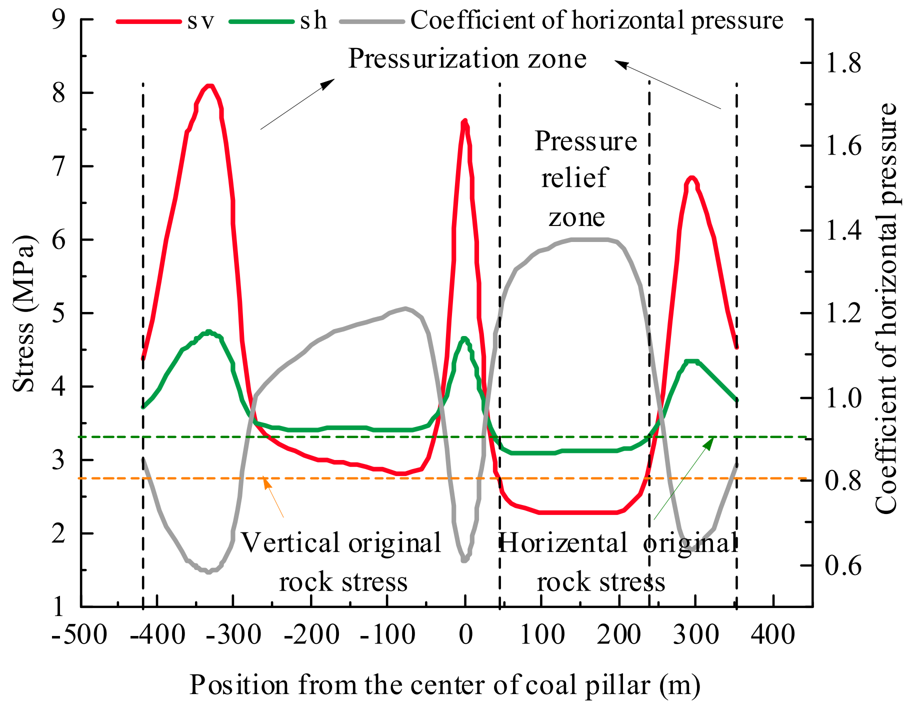

Figure 5. 22,206 return airway stress distribution diagram of primary mining.

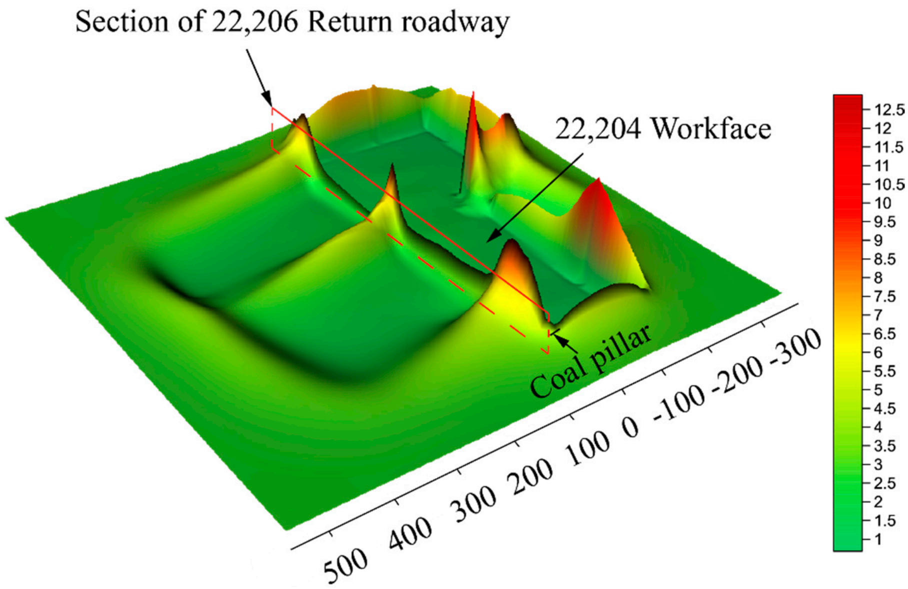

Figure 6. Three-dimensional vertical stress diagram of coal 2-2 under primary mining.

According to the analysis of the diagram, after the 22,204 working face is mined, the stress of the 22,206 return airway is higher than that of the 22,204 working face, and the σv_{min} value increases from 1.6 MPa to 2.3 MPa, and the σh_{min} increases from 3 MPa to 3.14 MPa. The value of σv_{max} increased from 6.25 MPa to 8.1 MPa, and the value of σh_{max} increased from 4.1 MPa to 4.74 MPa. This is because the advancement of the 22,204 working face led to the support pressure of the workface transferred to the upper part of the 22,206 return airway and the boundary of the goaf, which led to the general increase of σv. During the period of passing the concentrated coal pillars, the existence of overlying coal pillars and the influence of mining led to the change of the stress field, which made the σv_{max} of the left and right positions of the 22,206 return airway under the residual coal pillars at the left and right edges of the 1–2 coal seam reach 8.1 MPa and 6.8 MPa, respectively. The σh_{max} increases to 4.8 MPa and 4.4 MPa, respectively. When passing through 12,208 goaf, the σh and σv of the 22,206 return airway increase slightly compared with the original rock stress, and the σh and σv decrease slightly when passing through the 12,206 goaf.

From Figure 7, the plastic zone damage range of 22,206 return airway is small due to the influence of primary mining. The overall law is as follows: the plastic zone damage becomes larger when it is close to the coal pillar, and the plastic zone decreases when it is far away from the concentrated coal pillar. When the roadway is 15 m away from the center of the middle coal pillar of the 1–2 coal seam, the plastic zone almost disappears. From the stress distribution map, this is due to the load of the overlying strata. Overall, the 22,206 return airway has no obvious damage under the influence of primary mining. Under the middle-concentrated coal pillar, the maximum failure radius of 22,206 return airway roof and floor is only 0.4 m and 0.6 m, respectively, and the maximum failure radius of the pillar and goaf sides is only 0.5 m and 1 m, respectively. The damage of other positions is less than the plastic zone of the 22,206 return airway under the concentrated coal pillar. The 22,206 return airway is less affected by mining.

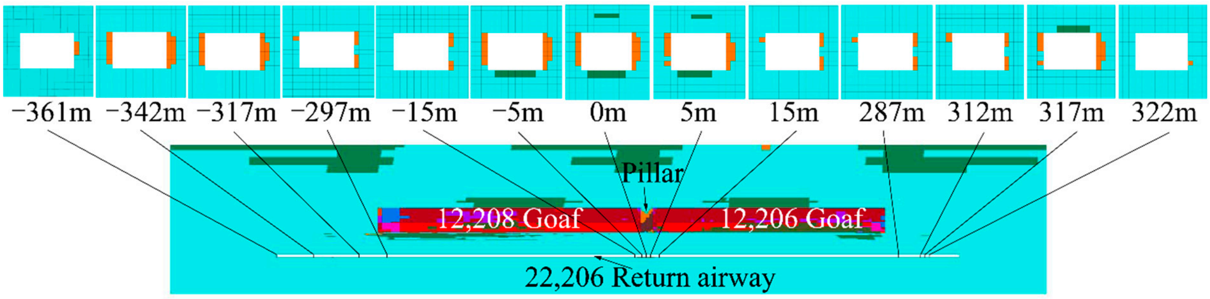

Figure 7. Evolution law of plastic zone of 22,206 return airway under primary mining.

In the secondary mining, after the 22,206 workface advances 400 m, as shown in Figure 8, because the advancing stress field of the working face has changed, the force above the roadway is transferred to the front of the 22,206 return airway, and the stress on the working face of 400 m has been released, which is less than the horizontal stress and vertical stress of the original rock. Affected by the advance support pressure, the σv_{max} on the 22,206 return airway is 8.52 MPa, which is located at 1.5 m in the advance workface. At this time, the σv of the center of the coal pillar is also increased to 8.38 MPa due to the influence of the advance support pressure (which is about to pass the 1–2 coal's middle coal pillar), while the σh and σv of the return airway under the 12,206 goaf are smaller than the original rock stress.

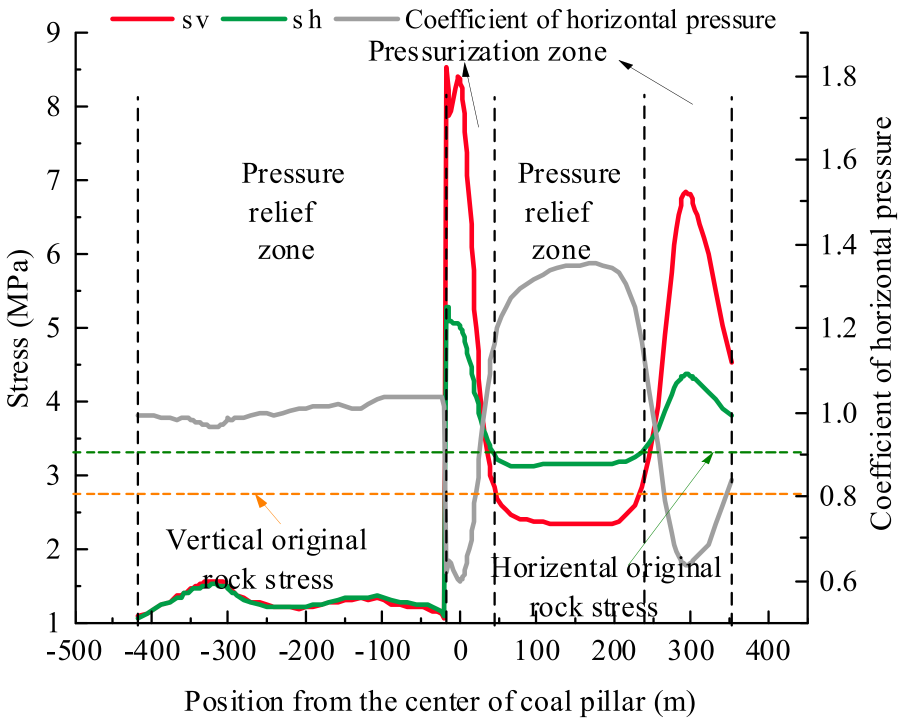

Figure 8. Diagram of stress distribution in 22,206 return airway under secondary mining.

Figure 9 is the three-dimensional vertical stress diagram of 2-2 coal under secondary mining. It can be seen from the figure that the advance support pressure is transferred to the 2-2 coal pillar after the 22,206 workface advances 400 m. Currently, the maximum σv above the 2-2 coal pillar is as high as 19 MPa.

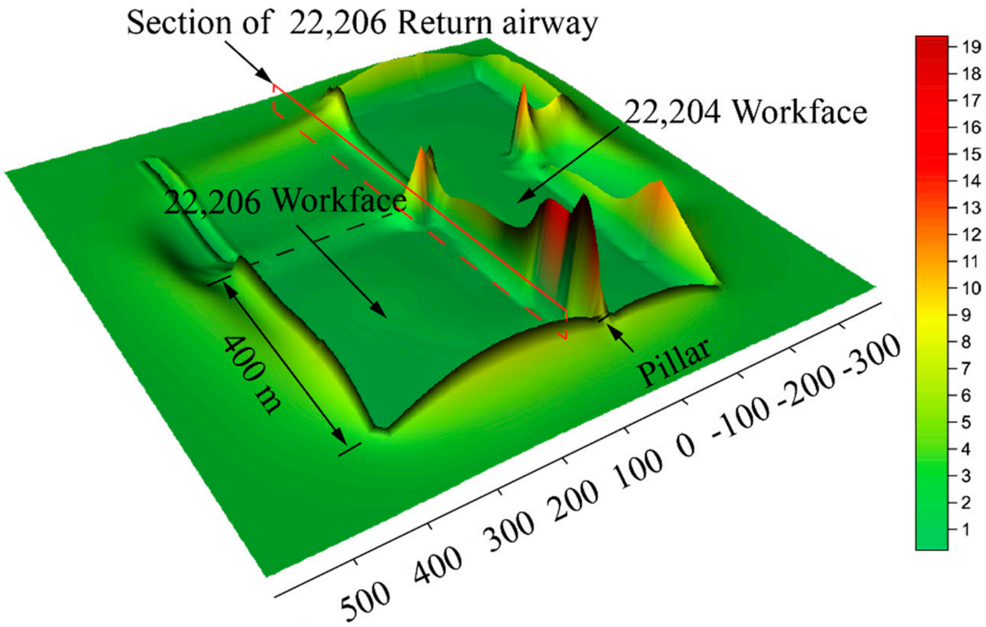

Figure 9. Three-dimensional vertical stress diagram of 2–2 coal under secondary mining.

It can be seen from Figure 10 that with the advance of the 22,206 working face, the influence of secondary mining on the 22,206 return airway is greater than that of primary mining. The evolution law of the plastic zone of the 22,206 roadway section is consistent with that of primary mining: it will increase near the coal pillar and decreases away from the coal pillar. The plastic zone under the concentrated coal pillar in the middle of 1–2 coal is the largest, the maximum radius of the plastic zone of the roof and floor is 1.3 m and 0.6 m respectively, and the maximum failure radius of the pillar and goaf sides of the roadway is only 0.6 m and 1.5 m, respectively.

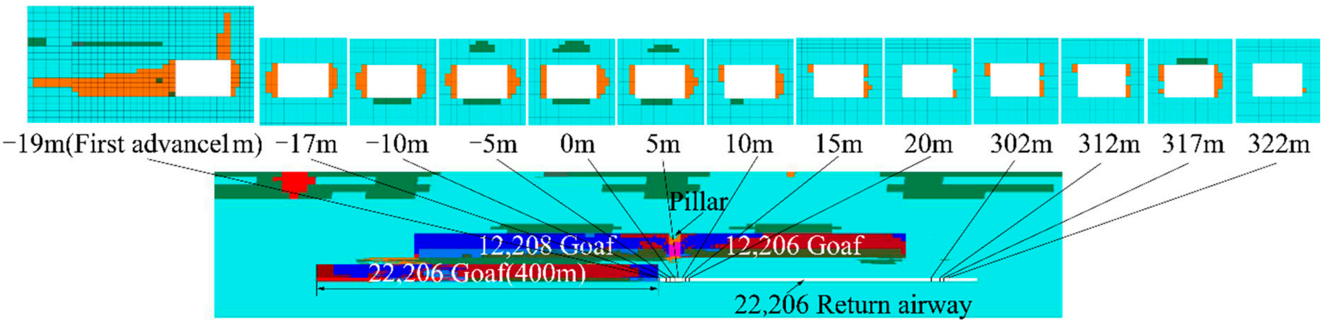

Figure 10. Evolution law of plastic zone of 22,206 return airway under secondary mining.

4. Discussion

4.1. Summary of Mine Pressure Law

According to the stress change of the 22,206 return airway and the evolution characteristics of the plastic zone after primary and secondary mining, the overall mine pressure law of the 22,206 return airway is as follows: under primary mining, the σv of over-concentrated coal is gradually increased by the influence of advanced support pressure and concentrated stress of the coal pillar, and its plastic zone is also expanded due to the increase of σv. On the contrary, σv begins to decrease when it is gradually away from the coal pillar, and the plastic zone also decreases with it until the plastic zone almost disappears after 40 m in the advance working face. The plastic zone of the 22,206 return airway under the influence of secondary mining is larger than that of primary mining, and the evolution law of the plastic zone is consistent with that of primary mining. In general, the numerical simulation is basically consistent with the field situation. The surrounding rock condition of 2-2 coal is great and the roof is stable.

4.2. Support Parameters

From the above content, the roof of 2–2 coal and the stress environment are excellent, and the evolution of the plastic zone is not severe. Based on this, the support scheme of Figures 11 and 12 is come up:

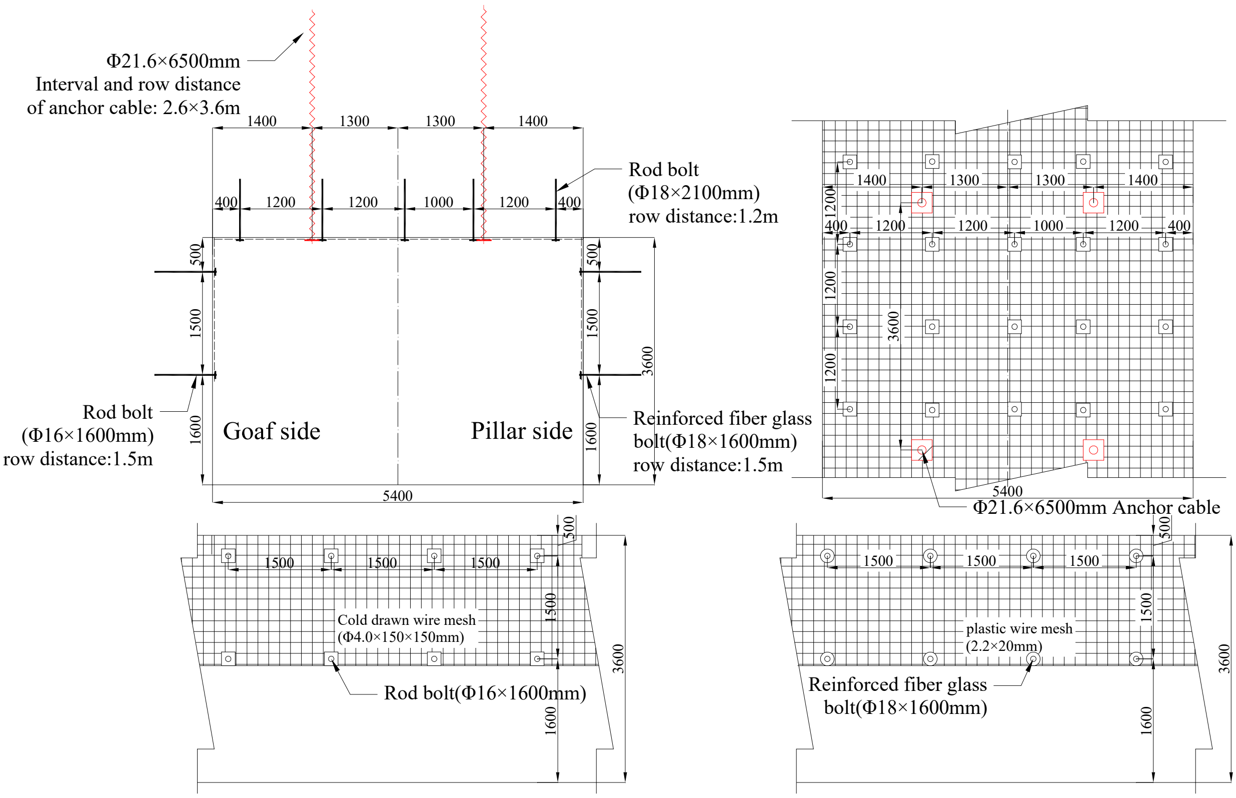

Figure 11. Supporting schematic diagram of primary mining roadway.

Primary mining roadway: the roof adopts rod bolt (Φ18 × 2100 mm) row spacing of 1.2 m each row of 5, using Φ 21.6 × 6500 mm anchor cable row spacing of 2.6 × 3.6 m; the pillar side use reinforced fiber glass bolt (Φ18 × 1600 mm); the goaf side with rod bolt (Φ16 × 1600 mm) row spacing is 1.5 m, each row of 4.

The secondary mining roadway: change the row spacing between the primary roof anchor cables to 2.6 × 2.4 m, and the other parameters remain unchanged. The pillar side adopts the reinforced fiber glass bolt (Φ22 × 2000 mm). The row spacing of 1.5 × 1.2 m, 4 in each row and the goaf side adopts the rod bolt (Φ16 × 1600 mm). The row spacing of 1.5 × 1.2 m, 4 in each row.

4.3. Field Test

So as to verify the effectiveness of the support scheme, stations are arranged every 5 m from the center of the coal pillar from −15 m to 15 m, and a total of seven stations are arranged to record the maximum displacement of the roof and floor and the two sides of the roadway after the secondary mining. The results are shown in Figure 13.

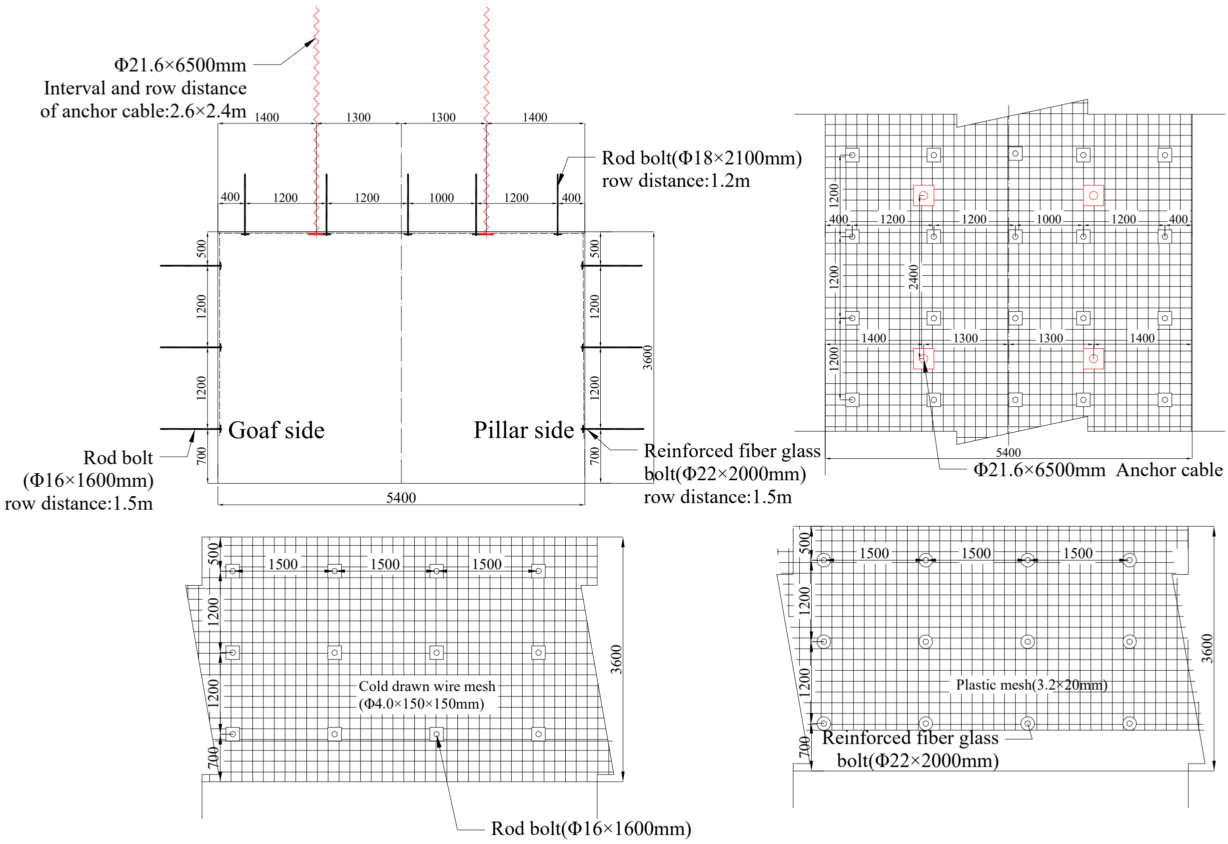

Figure 12. Supporting schematic diagram of secondary mining roadway.

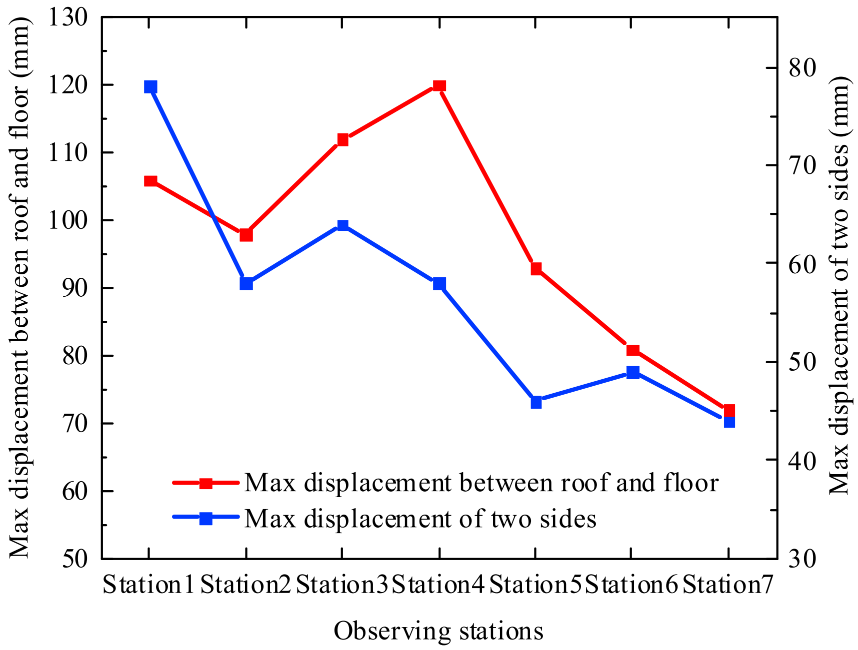

Figure 13. Displacements of top-bottom and two sides.

Overall, the deformation and displacement of the 22,206 return airway affected by secondary mining are small, and the largest displacement of the roof and floor are bigger than the maximum displacement of the two sides in the monitoring range. In the range of −15 m~0 m below the center of the 1–2 residual coal pillar, the displacement of the roof and floor first decreases and then increases. The maximum value is 120 mm and gradually decreases between 0 m~15 m, and the minimum value is 72 mm. The maximum value of the two sides in the distance of 1–2 residual coal pillar center −15 m~15 m below the overall trend of decreasing; the maximum value is 78 mm at the −15 m position and is finally stabilized. The overall deformation of the return airway affected by the secondary mining is small, under the proposed support scheme, the roadway is relatively stable (as shown in Figure 14) and the support scheme is feasible.

Figure 14. Picture of roadway.

5. Conclusions

(1) A special spatial position model (the workfaces of 1–2 coal and 2–2 coal are staggered at a certain angle of 79° in space) was built in a new way which come true by utilizing fish language to change the grid of coordinate in Flac3D numerical simulation software. After applying this way to the background of the Huojitu well, we found that this new way of modeling has great effectiveness.

(2) The stress distribution characteristics of the 22,206 return airway after 1–2 coal mining were obtained. The results showed that the mining of 1–2 coal led to the increase of stress on the 22,206 return airway. The stress in the lower part of the middle coal pillar changed the most, and σv_{max} and σh_{max} reached 6.24 MPa and 4.09 MPa, respectively.

(3) Through the numerical simulation analysis, the stress variation law and the evolution of the plastic zone of the 22,206 return airway under the influence of primary and secondary mining were obtained. That is, the 22,206 return airway is affected by the advanced support pressure and the superimposed stress field of the overlying concentrated coal pillar in the advanced workface. Thus, the stress increases (σv_{max} 8.1 MPa,8.4 MPa respectively in primary and secondary mining) when near the coal pillar and decreases away from the coal pillar. In general, the influence of the 22,206 return airway under the secondary mining is small, the maximum radius of the plastic zone of the roof and floor is 1.3 m and 0.6 m respectively, and the maximum failure radius of the pillar and goaf sides of the roadway is only 0.6 m and 1.5 m, respectively.

(4) A reasonable supporting scheme is proposed and tested. The maximum deformation of the roof and floor is less than 120 mm, and the maximum deformation of the two sides is less than 78 mm.

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