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Research Article

Deformation and Failure Law of Roadway along Goaf and Reserve Width of Section Coal Pillar

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It was a non-negligible problem in the reserve of section coal pillar in coal mining. Reasonable section coal pillar width and support parameters can not only ensure the stability of surrounding rock of roadway but also produce more coal resources and save support cost. In this paper, the mining of 9106 workface of Linfen Tianyu Hengsheng Coal Industry of Wanbei Coal Power Group was taken as the research engineering background. FLAC^{3D} numerical simulation software was used to simulate and analyze the laws of deformation failure of 6 m, 7 m, 8 m, 9 m, and 10 m coal pillars and surrounding rock of roadway along goaf without support conditions during the mining of 9106 workface. On this basis, the deformation failure law of 7 m and 8 m coal pillars and surrounding rock of roadway along goaf under different supporting conditions (bolt and cable with different row spacing) were further simulated and analyzed. The results showed that when 7 m coal pillars were reserved in 9106 roadway along goaf, the optimal bolt row spacing was 800 mm. When 8 m coal pillars were reserved, the bolt row spacing was preferred to be 900 mm. At this time, the width of coal pillar and support parameters can ensure the stability of roadway surrounding rock during the mining process of 9106 workface and can produce more coal resources and save support cost.

1. Introduction

The section coal pillar is a problem that cannot be ignored in coal mining, and the width of coal pillar plays a vital role in the safe mining of workface. If a large coal pillar is reserved to protect the roadway, the strength of coal pillar is high and the bearing capacity is strong, which is beneficial to the stability and maintenance of the surrounding rock of the roadway. However, there are more coal resources left, which reduces the coal recovery rate. If a narrow coal pillar is reserved, it is easy to cause coal pillar instability. Due to the influence of dynamic pressure in fully mechanized caving mining, the distribution range of lateral abutment pressure will increase, and the deformation and failure of roadway surrounding rock will be serious, resulting in difficulty in roadway maintenance [1–8]. Reasonable width of section coal pillar and support parameters can not only ensure the stability of roadway surrounding rock but also extract more coal resources and save support costs. Therefore, it is of great scientific significance and engineering application value to study the deformation and failure law of roadway along goaf and the width of section coal pillar [9–15].

Many scholars have made many research results on the deformation and failure law of roadway along goaf and the width of section coal pillars. Zhao et al. [16] used theoretical analysis, numerical simulation, and field test methods to study the deformation and failure characteristics of roadway surrounding rock in fully mechanized caving workface, which showed that the stability of coal pillar was mainly affected by the main roof fracture and multiple mining activities. With the increase of coal pillar width,

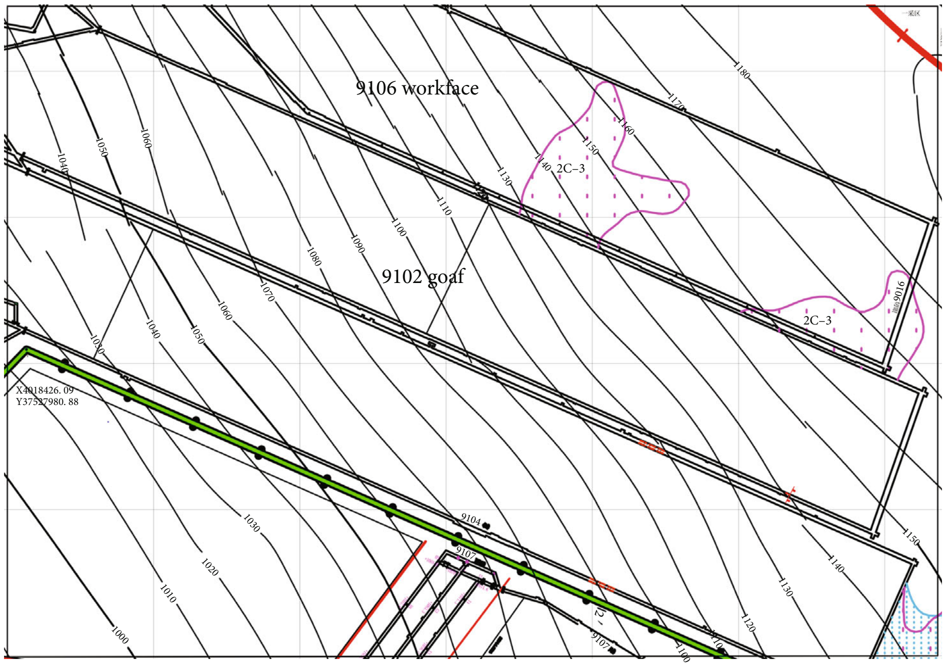


Figure 1: Coal seam mineral component testing.

the stress concentration area is transferred from the middle of the solid coal side to the middle of the coal pillar, and the plastic failure area shows a "X" penetration trend from both sides to the middle of the coal pillar. Zhang et al. [17] took 8407 fully mechanized caving workface of Yangquan No. 5 Coal Mine as an example, based on the basic roof fracture mechanics model of the goaf and the limit equilibrium theory of surrounding rock, calculated the upper and lower limits of reasonable coal pillar width. And using the borehole stress monitoring method, the internal stress distribution of the coal pillar during mining process of the 8407 fully mechanized caving workface was measured, and then the support parameters of the roadway along the gob were determined. Based on in-situ stress measurement and three-dimensional modeling technology, Jiang et al. [18] analyzed the vertical stress distribution characteristics of the coal roof at different positions on the edge of the 15111 workface in the tectonic province, as well as the vertical stress on the coal pillars of different widths, the horizontal stress of the roadway roof, and the deformation of the surrounding rock of roadway, to explore a method to determine the reasonable coal pillar width along the goaf roadway in the tectonic stress zone. Li et al. [19] made statistics of 6 typical coal mine cases in eastern and western China, analyzed the key factors affecting the deformation and failure of narrow coal pillar, and studied the deformation and failure characteristics of narrow coal pillar under the influence of different coal seam strength and thickness, coal seam buried depth, basic roof strength, tunneling, mining, and support strength by using FLAC numerical simulation, and put forward the control countermeasures to ensure the stability of narrow coal pillar under different influencing factors. Based on the engineering background of 1310 workface under the strip coal pillar in Jinqiao Coal Mine, through theoretical analysis, similar simulation, and numerical simulation, Yang et al. [20] studied the stress distribution law, plastic failure range, and rationality of coal pillar setting in different width sections, and determined the reasonable roadway position of workface under strip coal pillar in rock burst mine.

In order to improve the recovery rate of coal resources, many mines generally use narrow coal pillars. However, due to the mining impact of workface, the deformation and failure of roadway surrounding rock are serious. Especially when one side of the workface is mined, the deformation and failure of surrounding rock of roadway along goaf are more serious, and roadway maintenance is difficult [21–24]. Therefore, based on the engineering background of 9106 workface of Linfen Tianyu Hengsheng Coal Industry of Wanbei Coal Power Group, the numerical simulation method was used to study and analyze the deformation and failure law of 9106 roadway along goaf (Machine lane), and the width of coal pillars and supporting parameters. The research results can ensure the stability of the surrounding rock of roadway along goaf during the mining of 9106 workface, at the same time, more coal resources can be mined and the support cost can be saved.

2. Engineering Situation

The 9106 workface of Hengsheng Coal Industry is located in the north of first mining area of mine, and the west of 9106 workface is adjacent to the boundary of mining area and the north of the third mining area 9301 goaf, and the east of the 9102 goaf, south of the east wing track downhill. The 9106

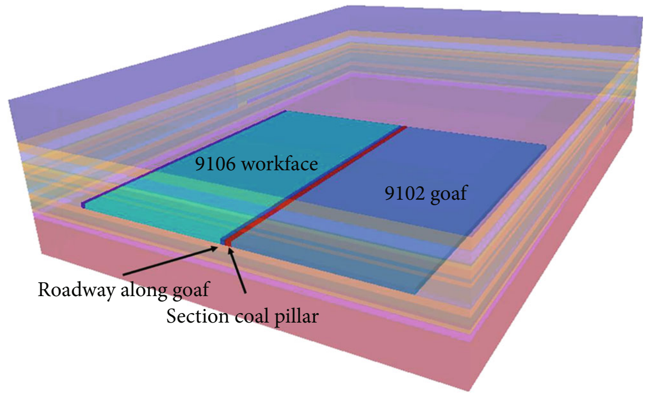


Figure 2: Numerical calculation model of 9106 workface.

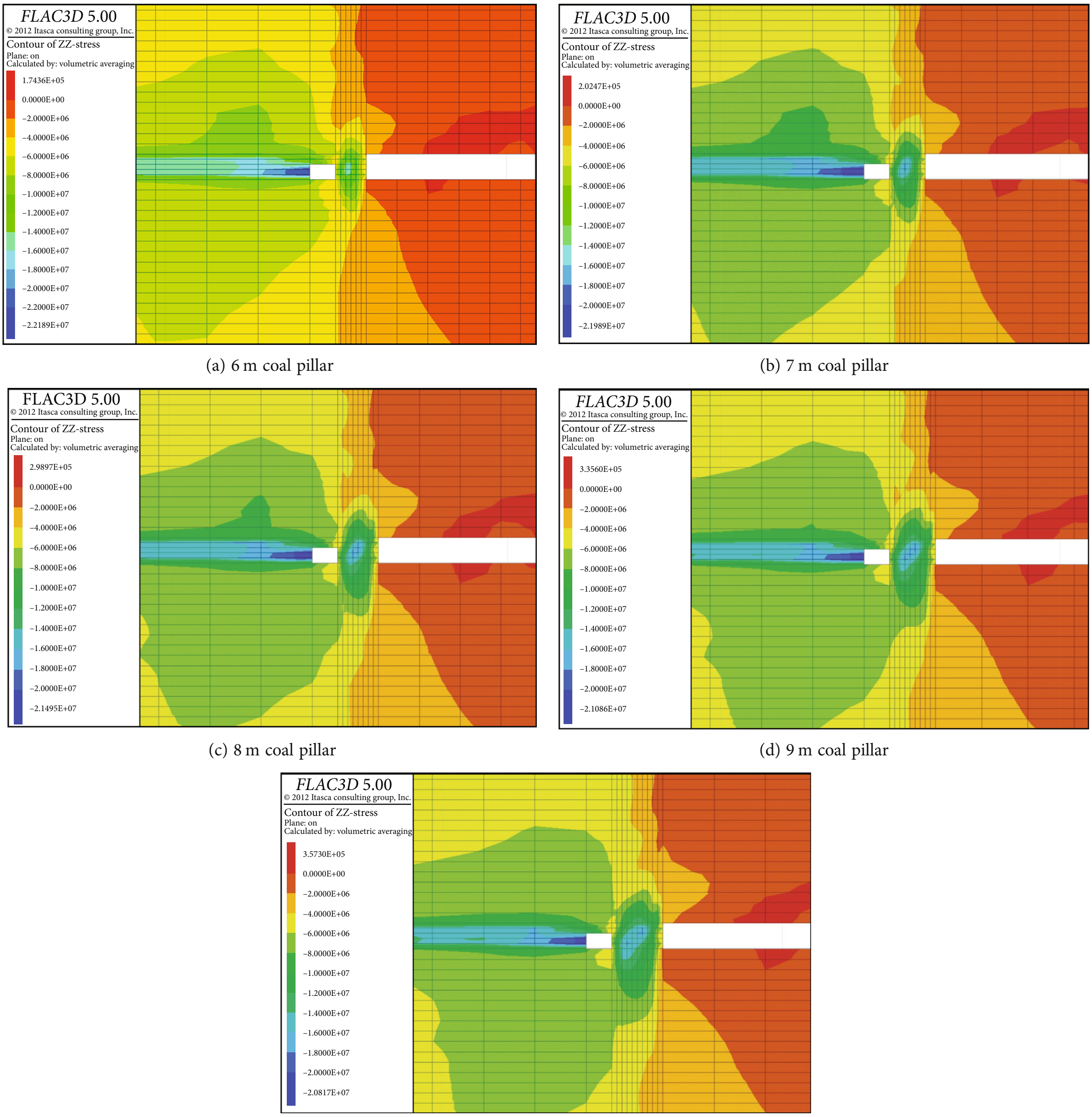
Table 1: Physical and mechanical parameters of roof and floor of 9106 workface.

No.	Lithology	Thickness/ m	Density/ $kg.m^{-3}$	Bulk modulus/ GPa	Shear modulus/ GPa	Tensile strength/ MPa	Cohesion/ MPa	Internal friction angle/°
1	Overburden strata	59.0	2650	1.90	0.90	3.30	1.85	30
2	Sandstone	12.0	2650	4.0	1.20	1.80	1.17	28
3	K4 fine sandstone	2.0	2650	16.9	6.00	1.80	2.46	35
4	Fine sandstone	4.0	2650	9.0	3.20	1.80	2.87	32
5	Mudstone	8.0	2650	1.50	0.50	1.30	1.55	30
6	K3 limestone	4.0	2650	16.9	6.00	1.80	2.46	35
7	Mudstone	4.0	2650	1.50	0.50	1.30	1.55	30
8	K2 limestone	15.0	2650	16.9	6.00	1.80	2.46	35
9	Coal seam	5.0	1400	2.40	1.07	0.60	1.26	27
10	Mudstone	8.0	2650	1.50	0.50	1.30	1.55	30
11	Aluminum mudstone	4.0	2650	2.25	1.40	1.60	1.42	30
12	K1 fine sandstone	4.0	2650	9.00	3.20	1.80	2.87	32
13	Fine sandstone	4.0	2650	9.00	3.20	1.80	2.87	32
14	Mudstone	6.0	2650	1.50	0.50	1.30	1.55	30
15	Limestone	8.0	2650	9.00	3.20	1.80	2.87	32
16	Underlying strata	50.0	2650	29.3	12.4	3.30	4.20	42

workface is 712 m length and 202 m width, with a mining area of 143918 m^2. The dip angle of mining No. 9 + 10 coal seam is 3 ~ 9°, with an average dip angle of 7°. The occurrence elevation of coal floor is 1095 ~ 1190 m, the thickness of coal seam is 4.9 ~ 8.1 m, and the average coal thickness is 6.5 m (net coal thickness is 5.1 m). The direct roof of 9106 workface is dominated by K2 limestone, with a stable thickness of 13.1 m on average. The compressive strength is large, and cracks are developed and compact and hard. The direct bottom of 9106 workface is mainly mudstone, with an average thickness of 10.8 m, belonging to floppy disk rock, and partially bauxite. The engine lane of 9106 workface is roadway along goaf, which makes the 9106 engine lane be affected by the mined-out area of 9102 and the workface in the mining process of 9106 workface, as shown in Figure 1. Therefore, it is necessary to study the deformation and failure law of 9106 roadway along goaf (engine roadway) and the width of section coal pillar to ensure the safety of 9106 workface mining.

3. Numerical Calculation Model

Based on the hydrogeological data of Hengsheng Coal Industry and the comprehensive geological histogram of 9106 workface, $FLAC^{3D}$ numerical calculation software was used to establish the mining numerical calculation model of 9106 workface as shown in Figure 2. The length, width, and height of the model are 774 m, 566 m, and 200 m, respectively. The numerical calculation model adopted Mohr-Coulomb yield criterion, including 9102



(a) 6 m coal pillar

(b) 7 m coal pillar

(c) 8 m coal pillar

(d) 9 m coal pillar

(e) 10 m coal pillar

Figure 3: Vertical stress distribution in coal pillars with different widths and surrounding rock of roadway along goaf when the workface was advanced 50 m.

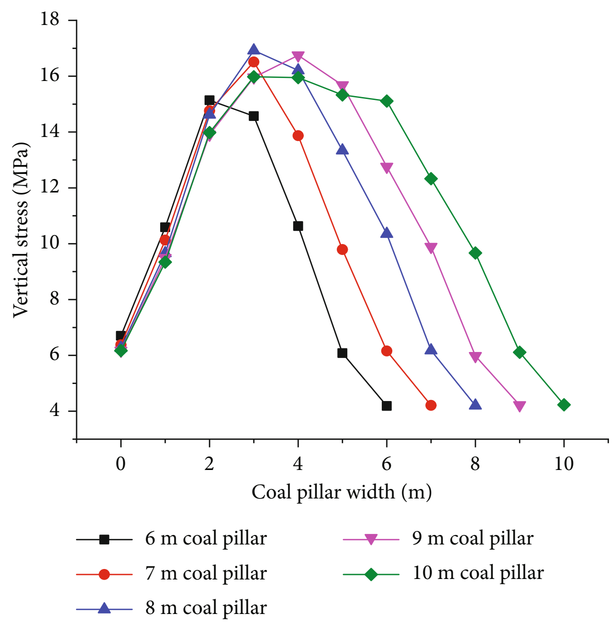


FIGURE 4: Vertical stress distribution law of coal pillars with different widths when the workface was advanced 50 m.

goaf, 9106 workface, and section and mining area coal pillar. In the model, x direction is the workface tendency, Y direction is the workface trend, the trend length of 9106 workface (x direction) is 200 m, and the trend length of 9106 workface (Y direction) is 400 m.

In the model, the dip angle of rock strata and coal seam is 0°, coal pillars with width of 50 m are set around the model, the excavation of 9106 workface was carried out from Y=50 m (the open-off cut position), and the excavation was stopped at Y=400 m, with a total excavation of 350 m forward. The bottom of the model constrains the vertical displacement, and the front, rear, left, and right sides constrain the horizontal displacement. The upper surface of the model is a free surface, and the overburden strata except the roof of coal seam are loaded on the upper surface of the model in the form of uniform load (8.2 Mpa load). Physical and mechanical parameters of roof and floor strata of coal seam and workface in the model are shown in Table 1.

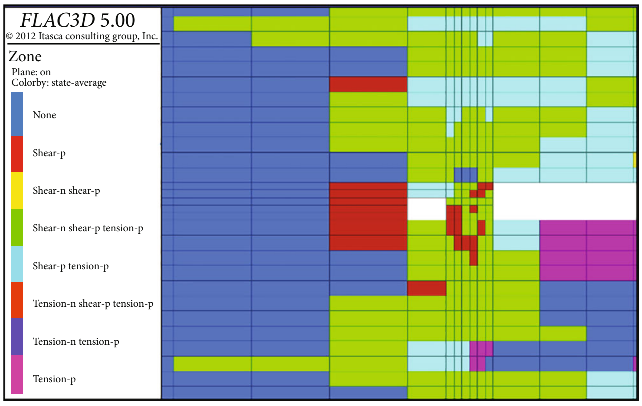
4. Deformation and Failure Law of 9106 Roadway along Goaf without Supporting Condition

In order to study the deformation and failure law of 9106 roadway along goaf and determine the reasonable width of coal pillar and support parameters, in the following we focus on the simulation study of the deformation and failure law of 6 m, 7 m, 8 m, 9 m, and 10 m width coal pillars and surrounding rock of roadway along goaf without support when 9106 workface advanced 50 m (initial weighting of 9106 workface) and 200 m (square of 9106 workface) from the open-off cut position, including the stress field and plastic zone distribution of coal pillar and surrounding rock of roadway along goaf.

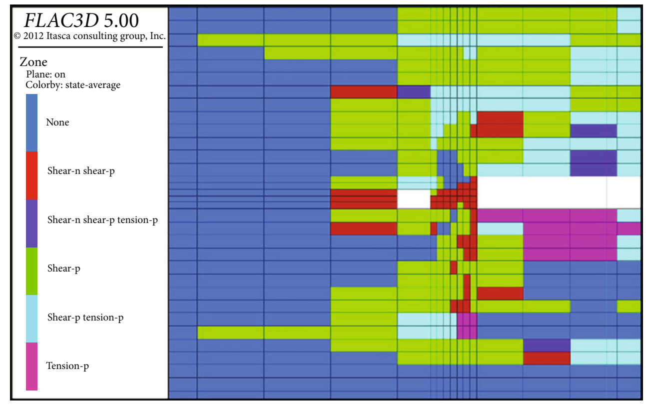
4.1. Deformation and Failure Law of Coal Pillars with Different Widths when Workface Advanced 50 m

4.1.1. Distribution of Vertical Stress in Coal Pillars and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 50 m from the open-off cut position, the vertical stress distribution of 6 m, 7 m, 8 m, 9 m, and 10 m coal pillars and surrounding rock of roadway along goaf under no support condition is shown in Figure 3. It can be seen that the vertical stress distribution of coal pillars with different widths is basically the same, the vertical stress concentration area of coal pillars is inclined "elliptic," and the vertical stress in coal pillars increased first and then decreased from the side of roadway to the side of 9102 goaf.

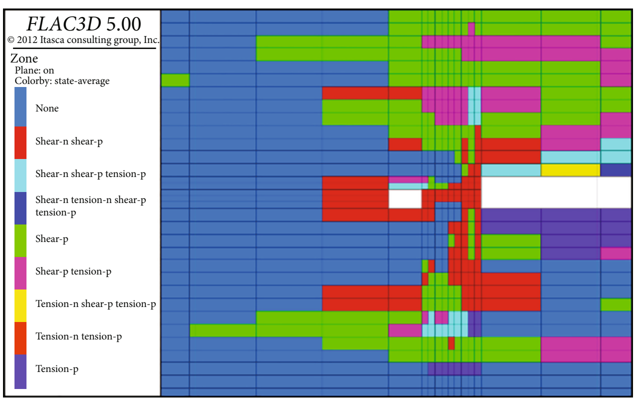
The peak value of vertical stress of coal pillar is closely related to the width of coal pillar. When the width of coal pillar is 6 m, 7 m, 8 m, 9 m, and 10 m, the peak value of vertical stress of coal pillar is 15.14 Mpa, 16.51 Mpa, 17.32 Mpa, 16.75 Mpa, and 15.95 Mpa, respectively, as shown in Figure 4. When the width of coal pillar increased from 6 m to 7 m, the peak value of vertical stress in coal pillar increased by 9.04%, indicating that the bearing capacity of coal pillar increased significantly at this time, and the stability of coal pillar and surrounding rock of roadway along goaf was good. When the width of coal pillar increased from 7 m to 8 m, the peak value of vertical stress in coal pillar increased by 4.90%, indicating that the bearing capacity of coal pillar continued to increase, but the increase was greatly reduced. At this time, the bearing capacity of coal pillar tended to limit. When the width of coal pillar continued to increase, the peak value



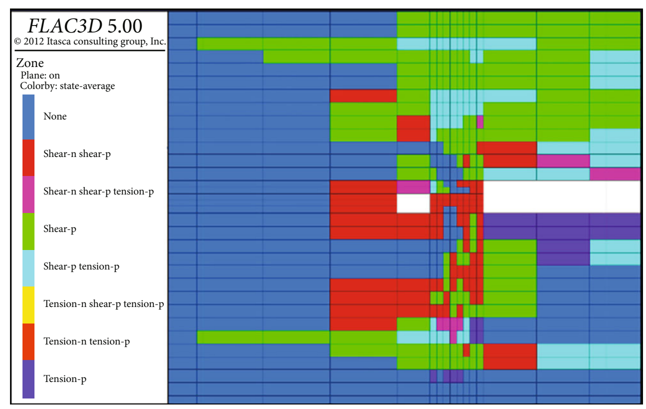
(a) 6 m coal pillar



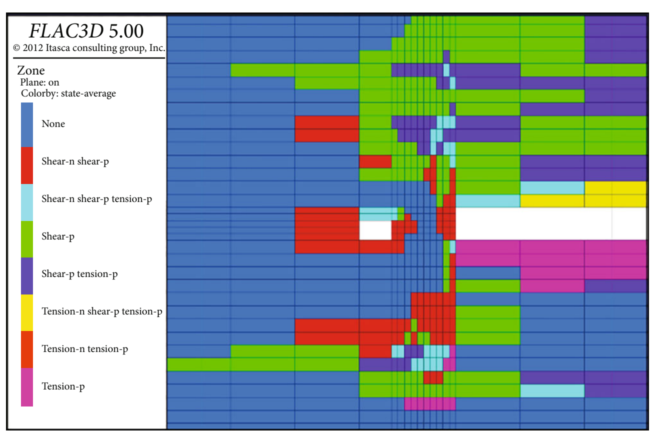
(b) 7 m coal pillar



(c) 8 m coal pillar

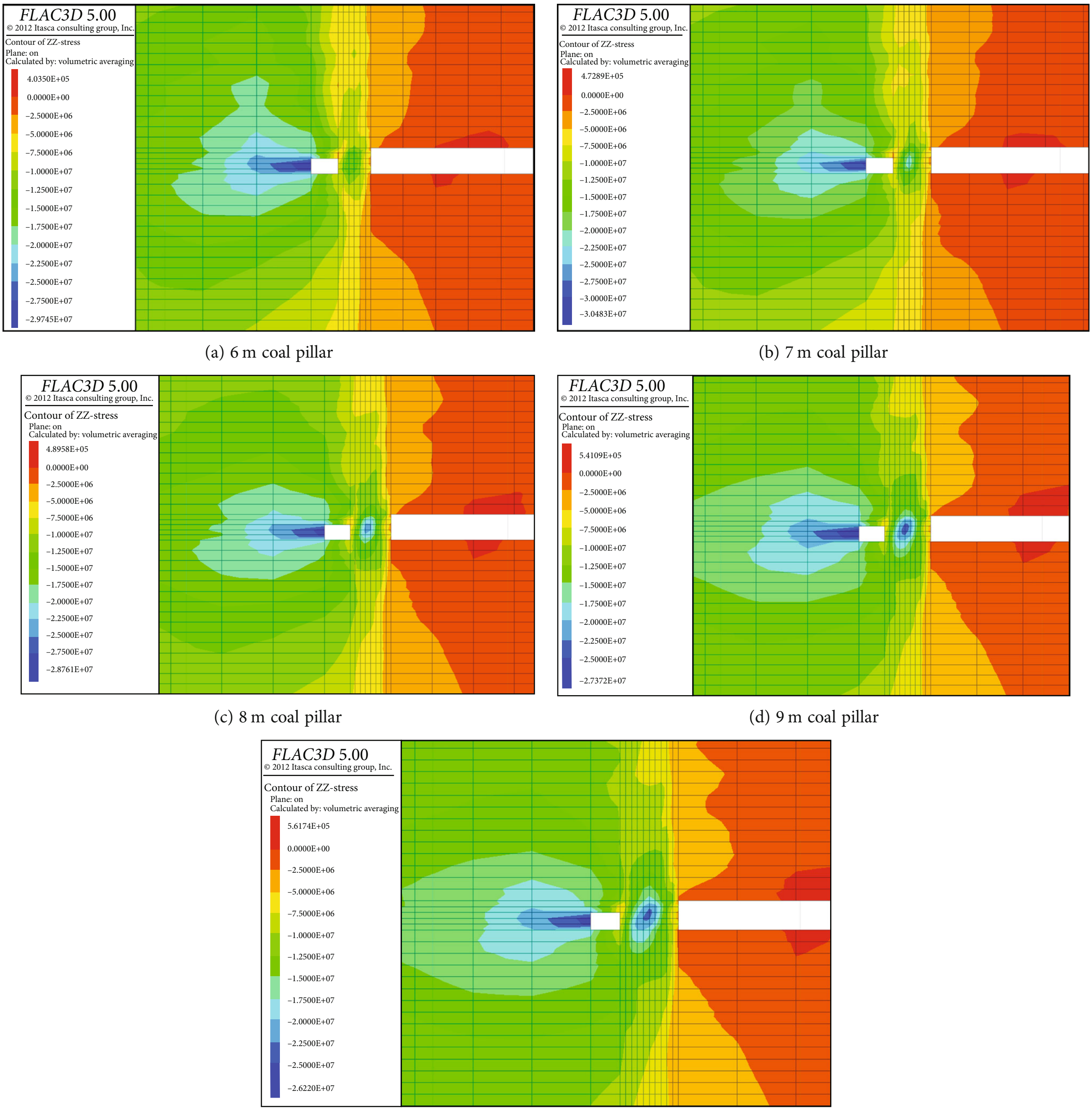


(d) 9 m coal pillar



(e) 10 m coal pillar

Figure 5: Plastic zone distribution in coal pillars with different widths and surrounding rock along goaf when the workface was advanced 50 m.



(a) 6 m coal pillar

(b) 7 m coal pillar

(c) 8 m coal pillar

(d) 9 m coal pillar

(e) 10 m coal pillar

Figure 6: Vertical stress distribution in coal pillars with different widths and surrounding rock of roadway along goaf when the workface was advanced 200 m.

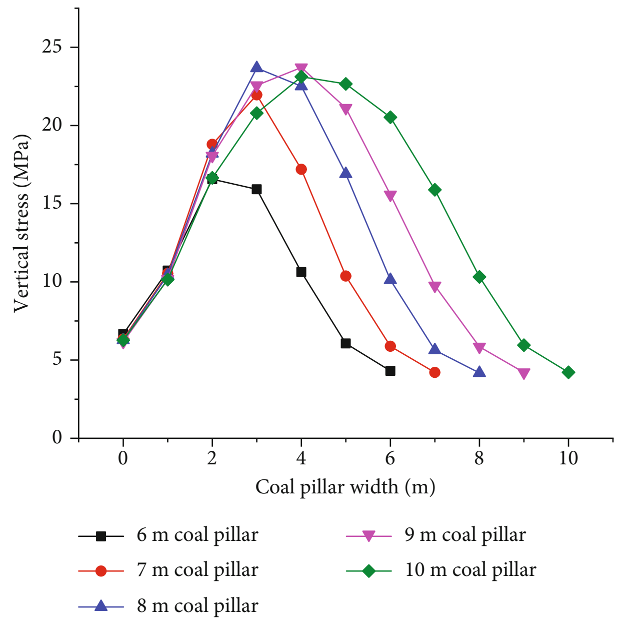


Figure 7: Vertical stress distribution law of coal pillars with different widths when the workface was advanced 200 m.

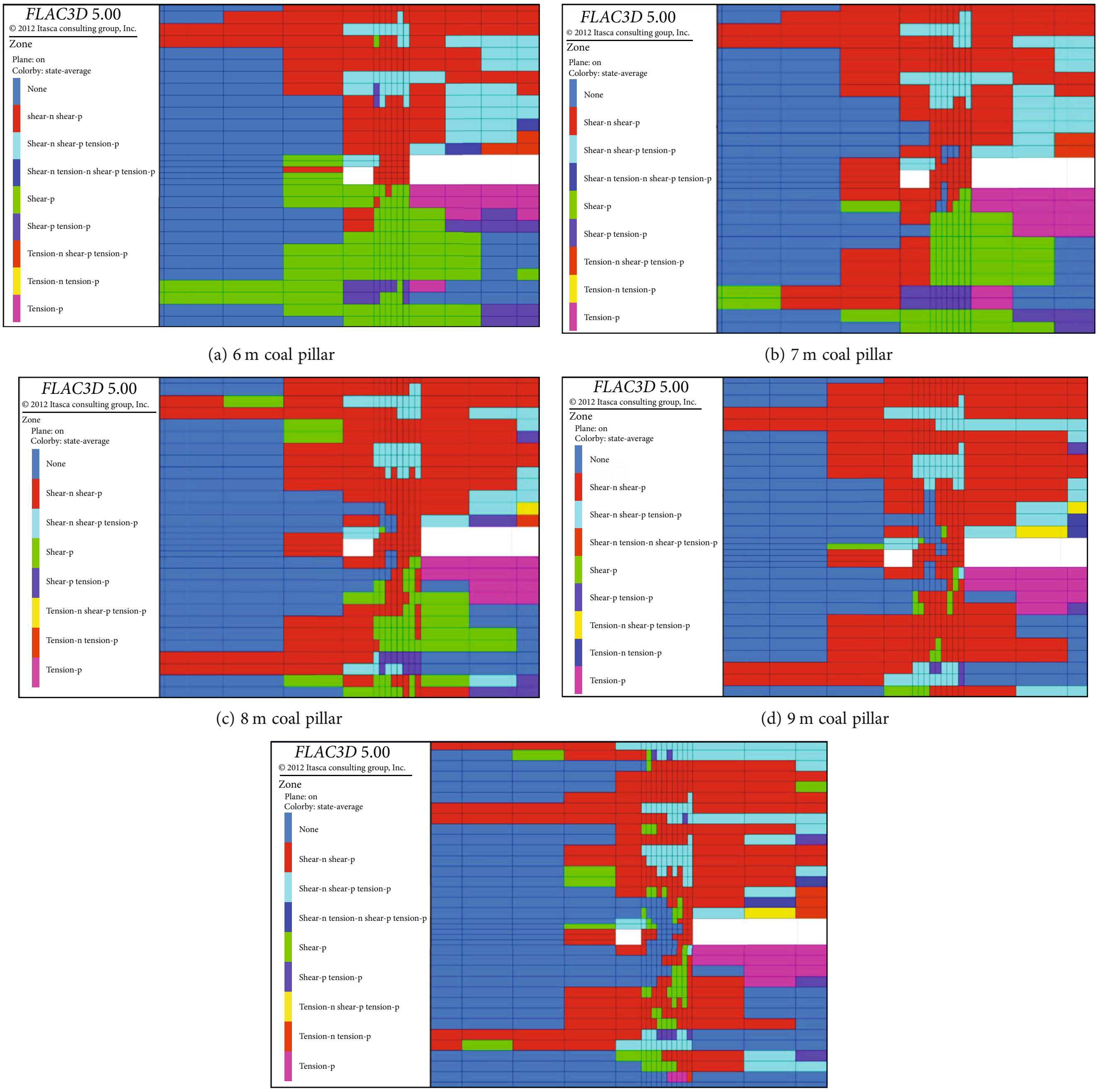
of vertical stress in coal pillar showed a downward trend, indicating that the width of 7 m and 8 m was the critical width for the change of coal pillar bearing capacity. In conclusion, considering the recovery rate of coal resources, reasonable coal pillar width should be 7 m and 8 m.

4.1.2. Plastic Zone Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 50 m from the open-off cut position, the plastic zone in 6 m, 7 m, 8 m, 9 m, and 10 m coal pillars and surrounding rock of roadway along goaf were distributed without supporting condition, as shown in Figure 5. It can be seen that with the increase of coal pillar width, the roof and floor failure area of coal pillar and roadway along goaf have gradually decreased. When the width of the coal pillar is 6 m, the coal pillar presented a plastic failure state as a whole, and the roof and floor of roadway along goaf also appeared a certain range of plastic failure due to the mining influence of 9102 goaf and 9106 workface mining. When the width of coal pillar was 7 m, the overall bearing capacity of coal pillar increased, some elastic zones appeared in coal pillar, and the plastic failure zone of roof and floor of roadway decreased. When the width of coal pillar was 8 m, with the continuous increase of the bearing capacity of coal pillar, the elastic zone range of coal pillar and roof and floor of roadway along goaf also further increased, and there was a certain degree of connectivity. When the width of coal pillar was 9 m and 10 m, the plastic failure range of coal pillar continues to decrease, only the plastic failure zone appeared to a certain extent on both sides of coal pillar, and the elastic zone range of coal pillar and roof and floor of roadway along goaf continued to increase and connect.

4.2. Deformation and Failure Law of Coal Pillars with Different Widths when Workface Advanced 200 m

4.2.1. Vertical Stress Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, the vertical stress distribution of 6 m, 7 m, 8 m, 9 m, and 10 m coal pillars and surrounding rock of roadway along goaf without supporting condition are shown in Figure 6. It can be seen that the vertical stress distribution of coal pillars with different widths and surrounding rock of roadway along goaf is basically the same. With the increase of coal pillar width, the vertical stress of coal pillar and surrounding rock of roadway along goaf increased first and then decreased, and as the width of coal pillar increased, the concentration range of vertical stress of coal pillar increased. When the width of coal pillar is 6, 7, 8, 9, and 10 m, the peak values of vertical stress are 16.57 Mpa, 21.96 Mpa, 23.67 Mpa, 23.71 Mpa, and 23.12 Mpa, respectively, as shown in Figure 7.

The results showed that the peak value of vertical stress increased firstly and then decreased slowly with the increase of pillar width. When the width of coal pillar increased from 6 m to 7 m, the peak value of vertical stress of coal pillar increased by 32.5%, indicating that the bearing capacity of coal pillar was greatly improved. When the width of coal pillar increased from 7 m to 8 m, the peak value of vertical stress of coal pillar increased by 7.7%, indicating that the bearing capacity of coal pillar continued to increase, but the increase amplitude decreased. At this time, the bearing capacity of coal pillar had approached the limit. When the width of coal pillar increased from 8 m to 9 m, the peak value of vertical stress increased by 0.16%. When the width of coal pillar increased from 9 m to 10 m, the peak value of vertical



(a) 6 m coal pillar

(b) 7 m coal pillar

(c) 8 m coal pillar

(d) 9 m coal pillar

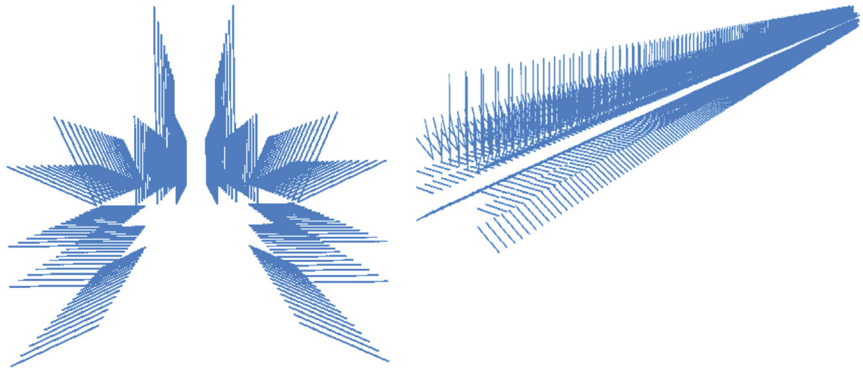
(e) 10 m coal pillar

Figure 8: Plastic zone distribution in coal pillars with different widths and surrounding rock of roadway along goaf when the workface was advanced 200 m.

stress of coal pillar decreased by 2.48%, indicating that the coal pillar had reached the yield limit state and the plastic zone range of coal pillar further increased.

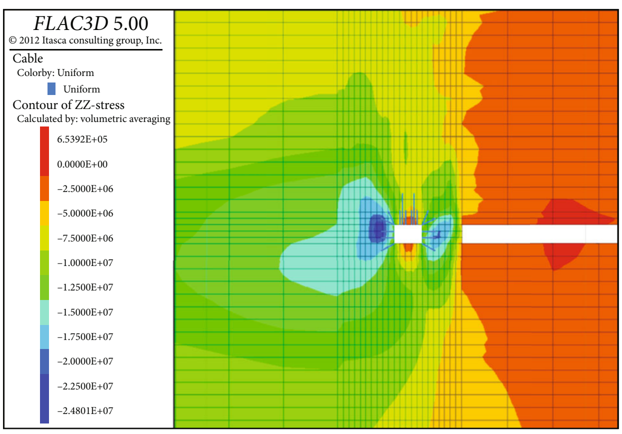
4.2.2. Plastic Zone Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, the plastic zone in 6 m, 7 m, 8 m, 9 m, and 10 m coal pillars and surrounding rock of roadway along goaf were distributed without supporting condition, as shown in Figure 8. It can be seen that the 9102 goaf had a great influence on the deformation and failure of surrounding rock of roadway along goaf, which made the plastic failure zone formed after mining of 9102 and 9106 workface connect with the plastic failure zone of surrounding rock of roadway along goaf.

When the width of the coal pillar was 6 m, the overall coal pillar was in a plastic failure state, and the roof and floor of roadway along goaf were in a plastic failure state in a certain range, indicating that the mining influence of 9102 goaf and 9106 workface mining was large, resulting in large stress of the coal pillar, and the bearing capacity of the coal pillar was weak. When the width of coal pillar was 7 m, some

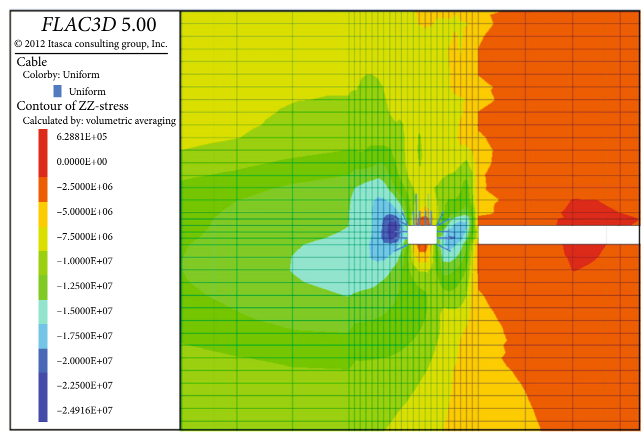


(a) Bolt (cable) supporting section (b) Anchor (cable) overall support

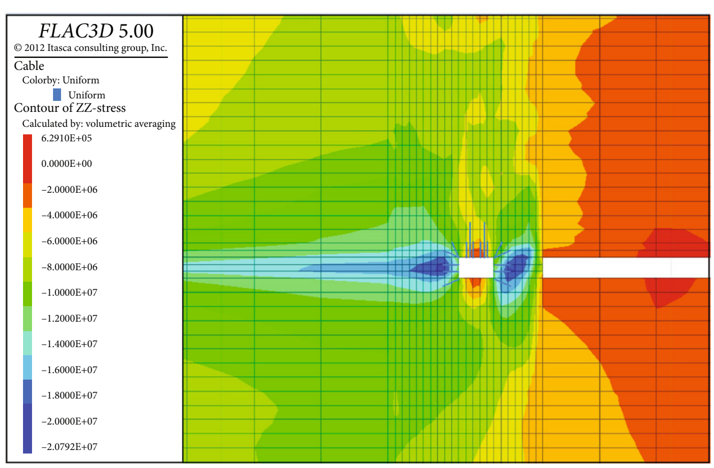
Figure 9: Anchor (cable) support model.



(a) 800 mm row distance



(b) 900 mm row distance



(c) 1000 mm row distance

Figure 10: Vertical stress distribution in 7 m width coal pillar and surrounding rock of roadway along goaf under the condition of different bolt (cable) support row distance.

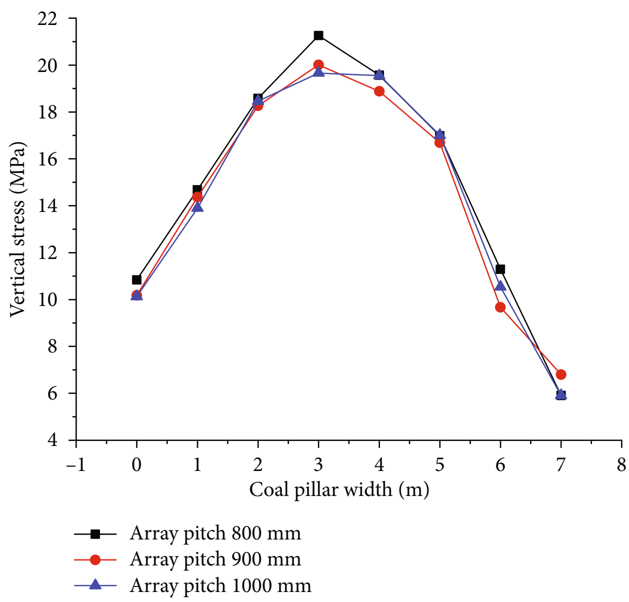


Figure 11: Vertical stress distribution law in 7 m width coal pillar under the condition of different bolt (cable) support row distance.

elastic zones appeared in the roof and floor of coal pillar and roadway along goaf, indicating that the bearing capacity of coal pillar was improving to some extent at this time. When the width of coal pillar was 8 m, the elastic zone of coal pillar and roof and floor of roadway along goaf expanded and connected with the elastic zone of solid coal side, indicating that the bearing capacity of coal pillar continued to increase and can effectively withstand the influence of mining in 9102 goaf and 9106 workface mining. When the widths of the coal pillar were 9 m and 10 m, the elastic zone of the roof and floor of coal pillar and roadway along goaf was further expanded, and the coal pillar presented a state of plastic zone on both sides and elastic zone in the middle, indicating that the coal pillar can fully withstand the mining influence of 9102 goaf and 9106 workface mining at this time. In summary, the width of coal pillar should be greater than or equal to 8 m. Considering the recovery rate of coal resources, a reasonable width of coal pillar should be 8 m.

5. Deformation and Failure Law of 9106 Roadway along Goaf under Supporting Condition

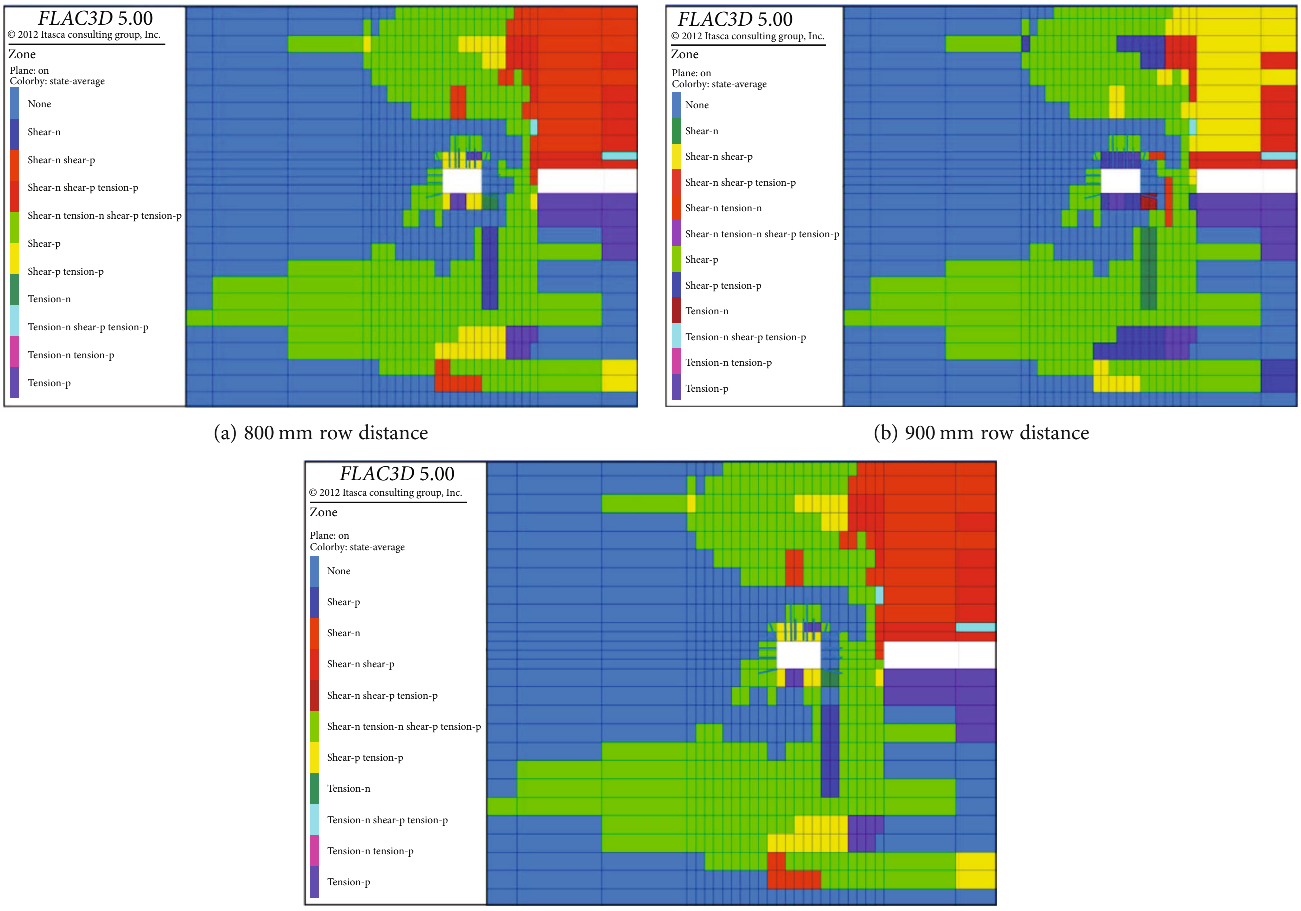
Deformation and failure law of 9106 roadway along goaf without supporting condition showed that the 9106 roadway along goaf was greatly affected by 9102 goaf and 9106 workface mining. Especially when 9106 workface advanced 200 m from the open-off cut position (square of 9106 workface), the vertical stress of coal pillar and surrounding rock of roadway along goaf was generally greater than that when 9106 workface advanced 50 m from the open-off cut position (initial weighting of 9106 workface). At the same time, the simulation study also showed that the deformation and failure law of coal pillar and surrounding rock of roadway along goaf were closely related to the width of coal pillar. Under the premise of considering safe production and improving the recovery rate of coal resources, 8 m width coal pillar should be preferred, followed by 7 m width coal pillar. Therefore, the following simulation study focused on the deformation and failure law of 7 m and 8 m width coal pillar and surrounding rock of roadway along goaf under different support conditions when 9106 workface advanced 200 m from the open-off cut position, including the stress field and plastic zone distribution in coal pillar and surrounding rock of roadway along goaf, to determine the best coal pillar width and support parameters.

Using FLAC^{3D} numerical simulation software to establish the supporting model of coal pillar and roadway along goaf under different supporting conditions and analyze the deformation and failure law of coal pillar and surrounding rock of roadway along goaf. As shown in Figure 9, 9106 roadway along goaf adopted bolt-anchor cable combined support (anchor cable only arranged in the roof of roadway). The concrete supporting parameters are fixed anchor rod distance is 1000 mm, and row distance is 800 mm, 900 mm, and 1000 mm. At the same time, the fixed anchor rope distance is 2000 mm, and when the anchor rod distance is 800 mm, the anchor row distance is 1600 mm; and when the anchor rod distance is 900 mm, the anchor rope distance is 1800 mm; and when the anchor rod distance is 1000 mm, the anchor rope distance is 2000 mm.

5.1. Deformation and Failure Law of 7 m Width Coal Pillar and Surrounding Rock of Roadway along Goaf

5.1.1. Vertical Stress Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, under the condition of the row distance of bolt support was 800 mm, 900 mm, and 1000 mm (the support spacing is 1000 mm), the vertical stress distribution of 7 m width coal pillar and surrounding rock of roadway along goaf is shown in Figure 10. It can be seen that the vertical stress distribution of 7 m width coal pillar and surrounding rock of roadway along goaf was roughly the same under the conditions of 800 mm, 900 mm, and 1000 mm bolt support row distance. Under the influence of 9102 gob and 9106 workface mining, "elliptical" stress concentration occurred in coal pillars and solid coal, and the stress concentration range on the side of solid coal was larger.

The vertical stress distribution in coal pillar from the roadway to the 9102 goaf showed a trend of increasing first and then decreasing, and the vertical stress in coal pillar on the side of roadway was significantly greater than that in the coal pillar of 9102 goaf, as shown in Figure 11. The vertical stress distribution in coal pillar showed that the bolt (cable) support effect was good, and the plastic zone of surrounding rock of roadway side decreased and the supporting capacity increased. In addition, the peak value of vertical stress in coal pillar decreased with the increase of bolt (cable) support row distance, indicating that reducing bolt (cable) support row distance can increase the supporting capacity of coal pillar and surrounding rock of roadway along goaf to a certain extent, and reducing the influence



(a) 800 mm row distance

(b) 900 mm row distance

(c) 1000 mm row distance

Figure 12: Plastic zone distribution of 7 m width coal pillars and surrounding rock of roadway along goaf under the condition of different bolt (cable) support row distance.

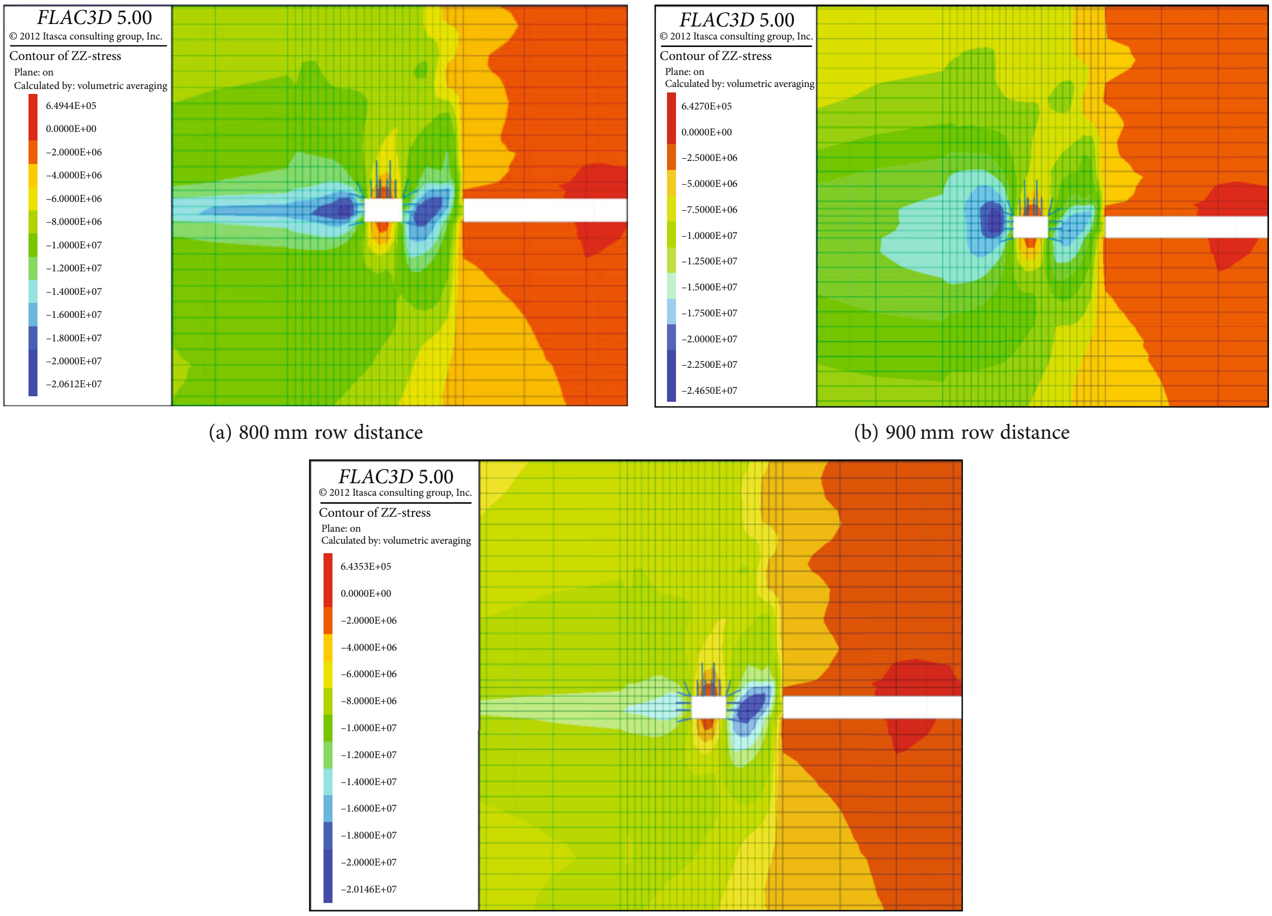
of 9102 goaf and 9106 workface mining on coal pillar and surrounding rock of roadway.

5.1.2. Plastic Zone Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, under the condition of the row distance of bolt support was 800 mm, 900 mm, and 1000 mm (the support spacing was 1000 mm), the plastic zone distribution of 8 m width coal pillar and surrounding rock of roadway along goaf is shown in Figure 12. It can be seen that under the conditions of bolt support row distance of 800 mm, 900 mm, and 1000 mm, the coal pillar and surrounding rock of roadway along goaf occurred plastic failure to varying degrees due to the influence of 9102 goaf and 9106 workface mining. With the increase of bolt (cable) support row distance, the plastic failure zone of coal pillar and surrounding rock increased accordingly. When the bolt row distance was 800 mm, most of the coal pillar was elastic zone, indicating that the bolt row distance of 800 mm can effectively increase the supporting capacity of coal pillar and surrounding rock of roadway along goaf. When the bolting row distance was 900 mm and 1000 mm, the failure zone of coal pillar and surrounding rock of roadway along goaf increased. In summary, when a 7 m width coal pillar was left, the 800 mm bolt support row distance can effectively reduce the impact of 9102 goaf and 9106 workface mining and increase the supporting capacity of coal pillar.

5.2. Deformation and Failure Law of 8 m Width Coal Pillar and Surrounding Rock of Roadway along Goaf

5.2.1. Vertical Stress Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, under the condition of the row distance of bolt support was 800 mm, 900 mm, and 1000 mm (the support spacing was 1000 mm), the vertical stress distribution of 8 m width coal pillar and surrounding rock of roadway along goaf is shown in Figure 13. It can be seen that the vertical stress distribution in 8 m width coal pillar and surrounding rock of roadway along goaf was roughly the same under the conditions of 800 mm, 900 mm, and 1000 mm bolt support row distance.

The vertical stress distribution in coal pillar showed a trend of increasing first and then decreasing, and the vertical stress in coal pillar on the side of roadway was significantly greater than that in the coal pillar of 9102 goaf, indicating



(a) 800 mm row distance

(b) 900 mm row distance

(c) 1000 mm row distance

Figure 13: Vertical stress distribution in 8 m width coal pillar and surrounding rock of roadway along goaf under the condition of different bolt (cable) support row distance.

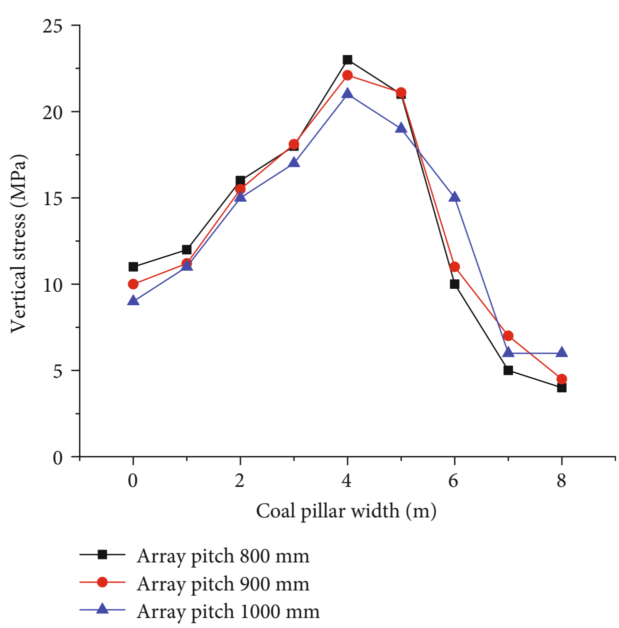
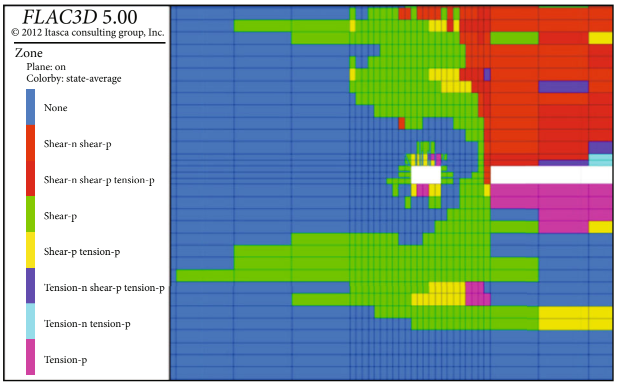


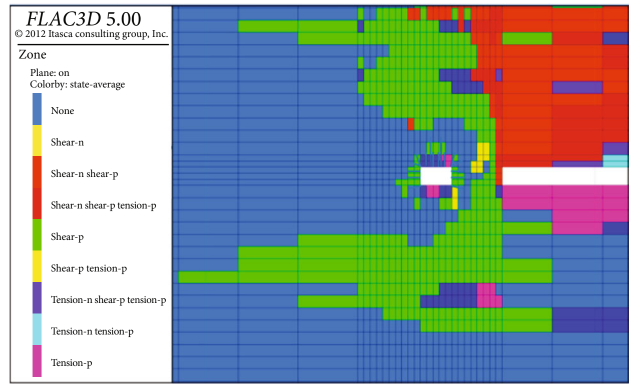
Figure 14: Vertical stress distribution law in 8 m width coal pillar under the condition of different bolt (cable) support row distance.

that the supporting effect was good, as shown in Figure 14. When the bolting row distance was 800 mm and 900 mm, the stress concentration range in coal pillar on the side of roadway was large. On the contrary, when the bolt supporting row distance was 1000 mm, the stress concentration range was small. The results showed that when the bolting row distance was 800 mm and 900 mm, the integrity of coal pillar was better, the failure area of coal pillar was smaller, and the supporting capacity was larger. However, when the bolting row distance was 1000 mm, the condition was opposite.

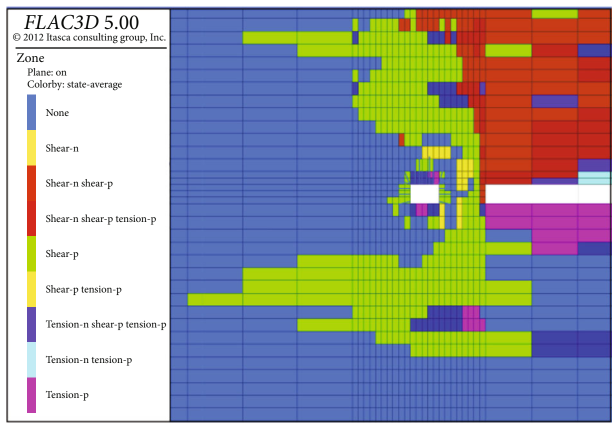
5.2.2. Plastic Zone Distribution in Coal Pillar and Surrounding Rock of Roadway along Goaf. When the 9106 workface advanced 200 m from the open-off cut position, under the condition of the row distance of bolt support was 800 mm, 900 mm, and 1000 mm (the support spacing was 1000 mm), the plastic zone distribution of 8 m width coal pillar and surrounding rock of roadway along goaf is shown in Figure 15. It can be seen that with the increase of bolt (cable) support row distance, the plastic failure zone of coal pillar and surrounding rock increased accordingly. When the bolting row distance was 800 mm and 900 mm, the damage range in coal pillar was small. When the bolting



(a) 800 mm row distance



(b) 900 mm row distance



(c) 1000 mm row distance

Figure 15: Plastic zone distribution of 8 m width coal pillars and surrounding rock of roadway along goaf under the condition of different bolt (cable) support row distance.

row distance was 1000 mm, the damage range in coal pillar increased. In summary, when setting 8 m width coal pillar, the 800 mm bolt support row distance can effectively reduce the impact of 9102 goaf and 9106 workface mining and increase the supporting capacity of coal pillar.

6. Conclusions

Based on hydrogeological data of 9106 workface of Hengsheng Coal Industry, a mining numerical calculation model of 9106 workface was established by using FLAC numerical simulation software. The deformation and failure laws in 6 m, 7 m, 8 m, 9 m, and 10 m width coal pillars and surrounding rock of roadway along goaf without support were simulated and analyzed, as well as the deformation and failure laws in 7 m and 8 m width coal pillars and surrounding rock of roadway along goaf under different support conditions. The main conclusions are as follows:

(1) Vertical stress distribution of coal pillars with different widths is basically the same. The vertical stress in coal pillars increases firstly and then decreases from the side of roadway to the side of 9102 goaf, and the vertical stress of coal pillars at the side of roadway is obviously greater than that at 9102 goaf

(2) With the increase of the width of coal pillar, the failure area of coal pillar and roof and floor of roadway along goaf decreases gradually, the elastic area increases gradually, and the bearing capacity increases gradually

(3) Reducing the bolt (cable) support row distance can reduce the plastic zone of coal pillar and surrounding rock of roadway along goaf to a certain extent and increase the bearing capacity of coal pillar and surrounding rock of roadway along goaf, so as to reduce the influence of 9102 goaf and 9106 workface mining on coal pillar and surrounding rock of roadway along goaf

(4) When 7 m coal pillar is left in 9106 roadway along goaf, the optimal bolt row distance is 800 mm; when 8 m coal pillar is left, the optimal bolt row distance is 900 mm, which can not only ensure the stability of roadway surrounding rock in the mining process of 9106 workface but also produce more coal resources and save support cost

Data Availability

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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