Journal of Geoscience and Environment Protection, 2022, 10, 17-28
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Comparative Analysis of the Distribution Characteristics of Floor Stress Field between Gob-Side Entry Retaining with Roof Cutting and Conventional Mining

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How to cite this paper: Xue, W. F., Liu, C. Y., Li, C., Chen, Y. G., Xi, X. P., & Wang, F. (2022). Comparative Analysis of the Distribution Characteristics of Floor Stress Field between Gob-Side Entry Retaining with Roof Cutting and Conventional Mining. *Journal of Geoscience and Environment Protection, 10,* 17-28.
https://doi.org/10.4236/gep.2022.1012002

Received: November 3, 2022
Accepted: December 4, 2022
Published: December 7, 2022

Abstract

All coal fields in North China are affected by floor confined water to varying degrees, floor failure and water inrush risk have always been a major problem to baffle coal mining activities. Roof cutting and pressure relief and the lack of protective coal pillar can cause the change of floor stress field, leading to the change of the floor failure depth, stress field of floor is the key to determine the depth of floor failure. In order to deeply study the distribution characteristics of floor stress field in gob-side entry retaining mining with roof cutting, taking the 50107 and 50109 working faces of Dongdong Coal Mine in Chenghe as the research objects, the numerical simulation software is used to simulate the floor stress field distribution of gob-side entry retaining mining with roof cutting and conventional mining. The distribution characteristics of the floor stress field of the working face are compared and analyzed under the three modes of conventional mining of reserved coal pillar, the first mining face of gob-side entry retaining with roof cutting and gob-side entry retaining with roof cutting. The results show that the peak stress concentration in front of the working face all occurs at 10 m under the three mining modes. The stress concentration area in front of conventional working face of reserved coal pillar is mainly in the middle of the working face. The stress concentration area in front of the first working face of gob-side entry retaining with roof cutting (50107) is located in the middle of the working face and the side of the working face of the retaining roadway. The stress concentration area of the working face (50109) is mainly in the middle and the two ends of the working face. The order of the peak value of the maximum concentrated stress in front of the working face is conventional working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109). There is a stress reduction zone behind the working face, but there is a stress concentration phenomenon extending to the outside of the roadway, and the stress distribution is obviously different. Conventional working face of reserved coal pillar and the first working face of gob-side retaining with roof cutting (50107) show a double peak form of stress concentration on the outside of the two ends of the roadway, and the peak value of the concentrated stress at the rear of the working face is in the following order: On the side close to the transportation roadway, conventional working face of reserved coal pillar = the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109); on the side close to the return airway, conventional working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109).

Keywords

Roof Cutting and Pressure Relief, Gob-Side Entry Retaining, Floor Stress Field, Stress Concentration

1. Introduction

All coal fields in North China are affected by floor confined water to varying degrees. In coal seam mining areas affected by confined water, floor failure and water inrush risk have always been a major problem to baffle coal mining activities (Luo & Peng 2005; Yang et al., 2007; Wu et al., 2013). As an efficient, safe and intensive mining method, gob-side entry retaining with roof cutting has been increasingly recognized by everyone (He et al., 2017a). Gob-side entry retaining with roof cutting means that the original mining roadway is maintained along the edge of gob without leaving protective coal pillar, and the retained roadway by roof cutting and pressure relief as the roadway for next working face. Roof cutting and pressure relief and the lack of protective coal pillar can cause the change of floor stress field (He et al., 2017b; He et al., 2018; Zhang et al., 2020), leading to the change of the floor failure depth, therefore, it is necessary to compare and analyze the distribution characteristics of floor stress field between gob-side entry retaining mining with roof cutting and conventional mining, analyze the similarities and differences between the two mining methods, and provide a basis for evaluating the risk of floor water inrush (Liu et al., 1988; Mironenko & Strelsky, 1993; Yavuz, 2004). Lin revealed the law of floor stress distribution in the process of coal mining by using similar material simulation experiments (Lin, 1990). Zhu et al. established the stress analysis and calculation model of the coal seam floor, solved the stress distribution law of the vertical section of the coal seam floor using the elastic theory, and believed that the floor stress decreases with the increase of the floor depth, and the direction of the maximum principal stress changes from the vertical direction to the horizontal direction (Zhu et al., 2007). Meng et al. established an elastic mechanics model for calculating the stress at any point of the floor and gave a criterion for the failure of the floor rock mass (Meng et al., 2010). Xue et al. constructed the mechanical calculation model of stope floor under periodic pressure, studied the failure pattern of the floor in gob-side entry retaining with roof cutting, and believed that the failure pattern of the floor in gob-side entry retaining with roof cutting was "scoop shape" along the tendency and strike (Xue et al., 2020). The above studies provide a basis for analyzing the distribution characteristics and transformation law of floor stress field. However, there is a lack of research on the characteristics of floor stress field under the condition of gob-side entry retaining with roof cutting and the transformation and similarities and differences of floor stress field compared with conventional mining. Based on the above reasons, this paper adopts numerical simulation to compare and analyze the distribution characteristics of floor stress field between gob-side entry retaining with roof cutting and conventional mining.

2. Methodology

2.1. Establishment of Numerical Model

The mining coal seam of Chenghe Dongdong Coal Mine is No. 5 coal, and the 50107 working face is the first working face of gob-side entry retaining with roof cutting. The mining height is 3.25 m, the buried depth is about 397 m, and the length of test area is 224 m (**Figure 1**). Taking the 50107 and 50109 working face as the research background, the mining models of conventional working face of reserved coal pillar, the first working face of gob-side entry retaining with roof cutting (50107) and gob-side entry retaining with roof cutting (50109) are established, and the relationship between floor stress field and floor failure development is analyzed. The model selects 12 layers of rock such as limestone, carbonized mudstone, siltstone and coal seam for mechanical calculation, select relevant drilling mechanical parameters (**Table 1**) as model parameters and the overburden rock is loaded with length (X) × width (Y) × height (Z) = 355 m × 200 m × 67 m. The Mohr-Coulomb constitutive model is adopted, and the strain mode is large strain deformation mode. The working face and its roof and floor strata are formed by a six-sided grid of blocks, which limits vertical movement at the bottom of the model and horizontal movement at the front and back of the model (**Figure 2**). The calculation process: establishing model → generating original rock stress → roadway excavation → roof cutting → mining → calculation result output. Working face dimensions are as follows:

Working face width: 120 m;

Roadway width: 5 m;

Width of boundary coal pillar: 50 m;

Width of conventional mining coal pillar: 30 m.

Table 1. Physical and mechanical parameters of coal and rock mass.

Rock name	Thickness (m)	Unit weight (kg/m³)	Bulk modulus (MPa)	Shear modulus (MPa)	Tensile strength (MPa)	Cohesiveness (MPa)	Internal friction angle (˚)
Siltstone	7.0	2530	5690	3290	5.5	8.3	41.5
Fine-Sandstone	9.0	2630	3600	3600	6.8	6.3	36
Medium grained sandstone	4.0	2630	3860	3500	6.7	6.2	38.5
Sandy mudstone	4.0	2400	4167	2869	1.8	3.2	37
Siltstone	8.0	2530	5690	3290	5.5	8.3	41.5
Sandy mudstone	2.0	2400	4167	2869	1.8	3.2	37
Coal seam (No. 5)	3.25	1340	1670	1480	3.8	2.75	36.5
Quartz sandstone	1.44	2530	7120	8350	7.9	9.3	26
Siltstone	5.15	2530	5690	3290	5.5	8.3	41.5
Quartz sandstone	8.51	2530	7120	8350	7.9	9.3	26
Siltstone	2.9	2530	5690	3290	5.5	8.3	41.5
K_2 limestone	3.22	2090	2260	1110	1.71	3.65	37

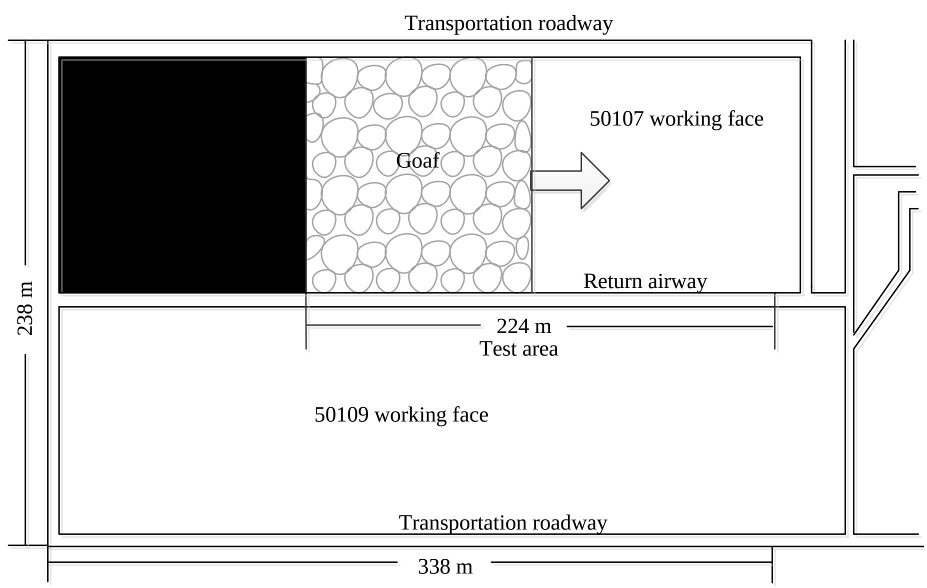

Figure 1. Mining layout of working face.

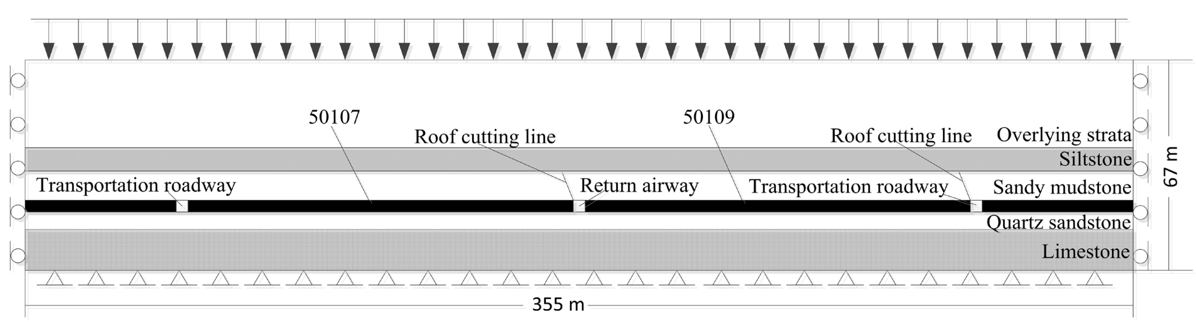

Figure 2. Numerical calculation model.

2.2. Setting of Monitoring Line

According to the numerical calculation model mentioned above, conventional working face of reserved coal pillar, the first working face of gob-side entry retaining with roof cutting (50107) and the working face of gob-side entry retaining with roof cutting (50109) were designed and excavated respectively. According to the results of numerical simulation, we respectively arranged 8 monitoring lines at the floor of three working faces with a vertical depth of 2 m.

1) Along the strike of the working face

Three monitoring lines are arranged in this direction, namely monitoring line 1, monitoring line 2 and monitoring line 3. Take 50107 working face as an example, the monitoring line 1 is located at 3.5 m near the working face of the transportation roadway, the monitoring line 2 is located at the middle of the three working faces, the monitoring line 3 is located at 14 m near the working face of the return airway, the three monitoring lines are also at the same position in the other two working faces.

2) Along the tendency of working face

The monitoring lines 4, 5, 6, 7 and 8 are arranged along the tendency of working face. Take 50107 working face as an example, the monitoring line 4 is located 10 m ahead of the working face, and the monitoring lines 5, 6, 7 and 8 are located 10, 15, 20 and 25 m behind the working face. The five monitoring lines are also at the same position in the other two working faces.

Specific analysis steps: Step 1, the vertical stress profiles are generated by slicing along the vertical direction of each monitoring line. Step 2, the vertical stress data of the floor is extracted from the generated stress profile. Step 3, Draw the stress curve. Through the above methods, the stress distribution of the floor under the three mining methods is analyzed, so as to grasp the distribution characteristics of the floor stress field.

3. Analysis of the Stress Distribution of Working Face

3.1. Analysis of the Stress Distribution in Front of Working Face

Under the three mining modes, there is stress concentration phenomenon ahead of the working face, and the stress changes from low to high and then to low. At the same time, there are significant differences in the size, shape and peak value of advanced stress concentration area under the above mining modes. Under the three mining modes, the peak stress concentration occurs at 10 m in front of the working face. The stress concentration area in front of conventional working face of reserved coal pillar is mainly in the middle of the working face, and the shape is "spindle", which gradually pinched out from the middle of the working face to the two ends, and the peak value of stress concentration also decreased from the middle of the working face to the two ends. The stress concentration area in front of the first working face of gob-side entry retaining with roof cutting (50107), and the shape is "spoon", the position of the spoon handle is located in the middle of the working face, and the position of the scoop head is located about 14.3 m from the working face to the return airway. The size of the advanced stress concentration area is significantly larger than that of conventional working face. The stress concentration resulted in a shift from the middle of the working face to the side of the return airway (retaining roadway). The local stress concentration phenomenon is generated in the working face (50109) of gob-side entry retaining with roof cutting about 2.5 m near the return airway, which is oval in shape, and the stress concentration pattern on the other side of the working face is similar to the corresponding position of the 50107 working face.

1) Along the tendency of working face

In monitoring line 4, the vertical stress 10 m in front of the working face along the tendency is shown in Figure 3. The stress distribution characteristics of conventional working face of reserved coal pillar are high in the middle and low at both ends, with a left-right symmetry form. The peak value of the concentrated stress is 20.95 MPa, which is located in the middle of the working face. The stress distribution of the first working face of gob-side entry retaining with roof cutting (50107) is asymmetrical. The stress distribution pattern of the side close to the transportation roadway is similar to that of conventional working face of reserved coal pillar. The peak value of the concentrated stress of the working face is 20.39 MPa, and the distance from the roadway is 46.6 m. The stress distribution characteristics of the side close to the return airway (retaining roadway) are as follows: the stress in the working face decreases sharply within a range of about 10 m near the return airway (retaining roadway), and there is a sharp increase of stress at 14.3 m, where the peak value of stress is 18.94 MPa. The overall stress concentration peak of 50107 working face is lower than that of conventional working face of reserved coal pillar. The stress distribution characteristics

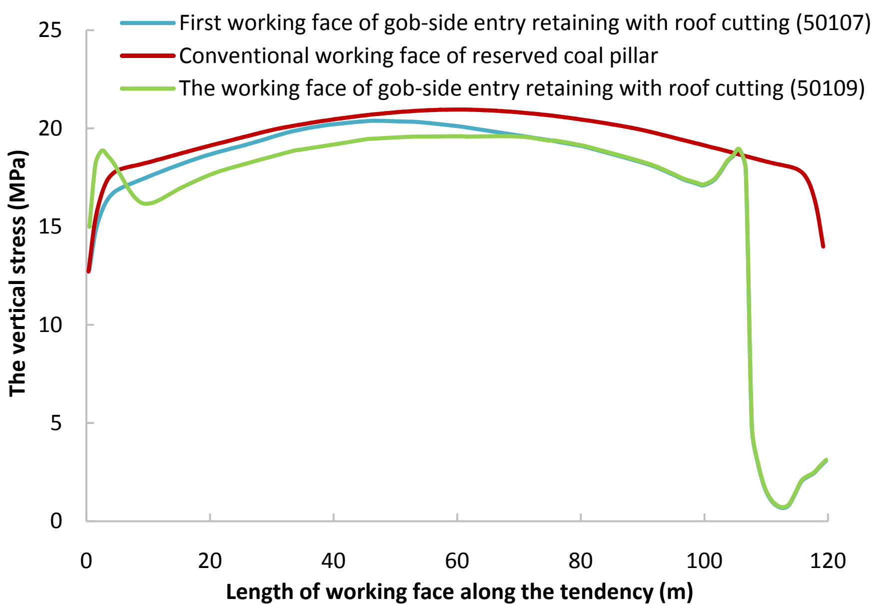

Figure 3. Vertical stress distribution curve of monitoring line 4.

of gob-side entry retaining with cutting (50109) are as follows: There are three stress concentration peaks along the tendency. The first one is located 2.5 m close to the coal side of the return airway, where the peak concentration stress is 18.87 MPa; the second one is located in the middle of the working face, where the peak concentration stress is 19.59 MPa; the third one is located 14.3 m away from the coal side of 50109 return airway. The peak value of the concentrated stress is 18.94 MPa. The stress variation characteristics of the side working face close to 50109 transportation roadway (retained roadway) are consistent with that of 50107 working face, and the stress reduction zone is generated within about 10 m near the retained roadway. The order of stress concentration degree of the three mining modes is as follows: conventional working face of reserved coal pillar > first working face of gob-side entry retaining with cutting (50107) > the working face of gob-side entry retaining with cutting (50109).

2) Along strike of working face

The vertical stress curve of monitoring line 1 on one side of the working face is shown in Figure 4. Under the three mining modes, the peak value of the concentrated stress is at about 10 m of the advanced working face, and the peak value of concentrated stress is in the order of working face of gob-side entry retaining with roof cutting (50109) > conventional coal working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107). The peak value of concentrated stress is 18.7 MPa, 16.5 MPa, 15.3 MPa, the lowest peak value of concentrated stress is 50107 working face, and the stress concentration factor is 1.65, 1.45, 1.35 from large to small. The vertical stress curve of monitoring line 2 in the middle of the working face is shown in Figure 5, under the three mining modes, the location of stress peak is the same as that of monitoring line 1, and it is also located about 10 m away from the advanced working face, peak value of stress concentration order for conventional coal working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with

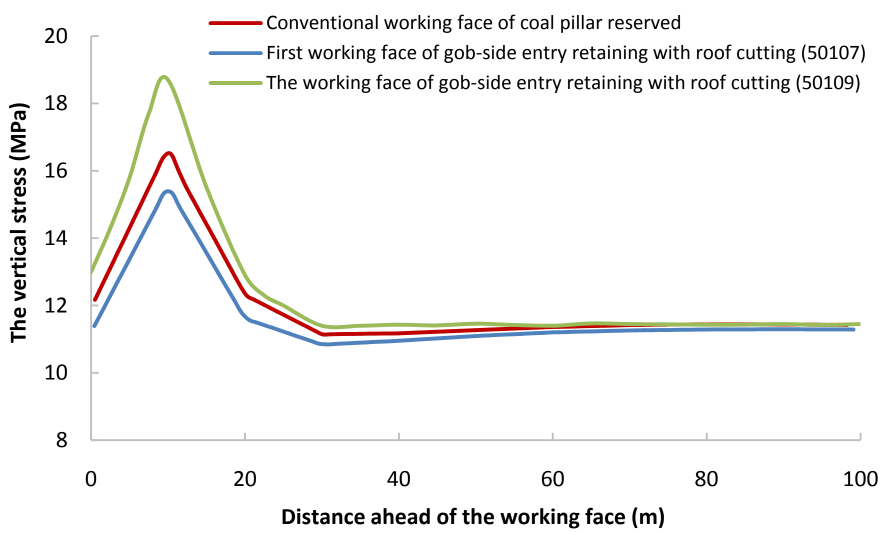

Figure 4. Vertical stress distribution curve of monitoring line 1.

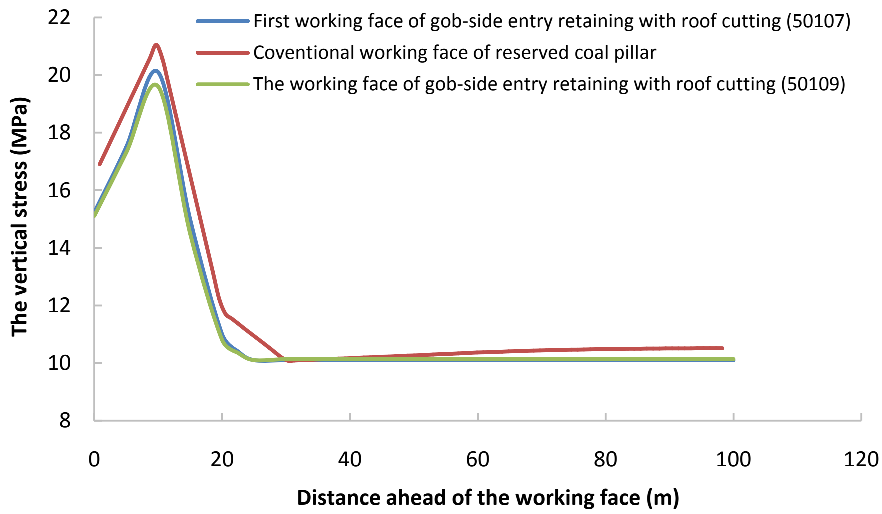

Figure 5. Vertical stress distribution curve of monitoring line 2.

roof cutting (50109), The peak value of concentrated stress is 20.95 MPa, 20.10 MPa, 19.59 MPa, and the stress concentration factors are 2.00, 1.91 and 1.86 from high to low. The vertical stress curve of monitoring line 3 on one side of the working face is shown in **Figure 6**, under the three mining modes, the location of the stress peak is the same as that of the first two monitoring lines, and it is also about 10 m ahead of the working face, the magnitude order of the peak value of the concentrated stress is: the first working face of gob-side entry retaining with roof cutting (50107) = working face of gob-side entry retaining with roof cutting (50109) > conventional coal working face of reserved coal pillar. The peak value of the concentrated stress is 18.7 MPa in 18.9 MPa, and the stress concentration factors are 1.79 and 1.77 respectively.

3.2. Analysis of the Stress Distribution behind Working Face

Under the three mining modes, there is a stress reduction zone behind the working face, but there is a stress concentration phenomenon extending to the outside of the roadway, and the stress distribution is obviously different. Due to the existence of coal pillars, the stress concentration double peak shape appears at the outer side of the head roadway at both ends of conventional working face of reserved coal pillar and the first working face of gob-side entry retaining with roof cutting (50107). The coal pillar retaining near the side of the transport roadway is consistent with the first working face of gob-side entry retaining with roof cutting. The stress peak appears about 3 m away from the wall of roadway, and the size and shape of the stress peak are consistent. The stress peak value of coal pillar and entity coal at the side close to the return airway shows great difference. The stress peak value of entity coal side of the first working face of gob-side entry retaining with roof cutting is significantly lower than that of conventional working face of reserved coal pillar. According to **Figures 7-10**, the peak stress at 10 m, 15 m, 20 m and 25 m behind the working face of monitoring lines 5, 6, 7 and 8 decreased by 12.4%, 18.0%, 19.8% and 23.0% respectively. The

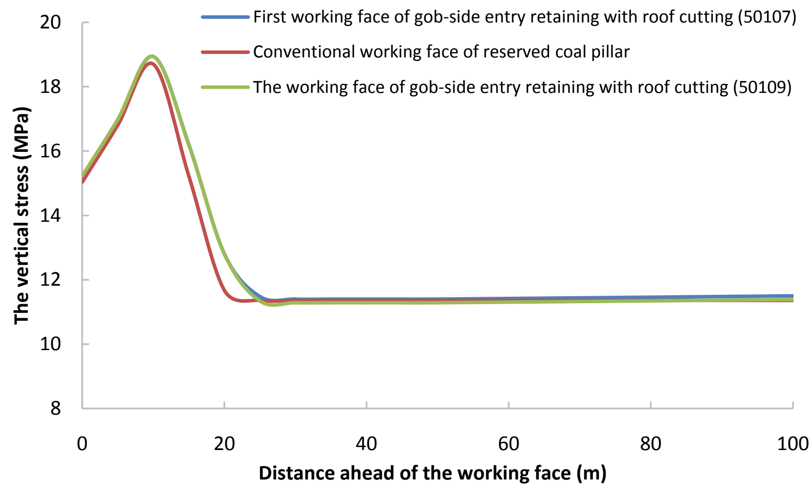

Figure 6. Vertical stress distribution curve of monitoring line 3.

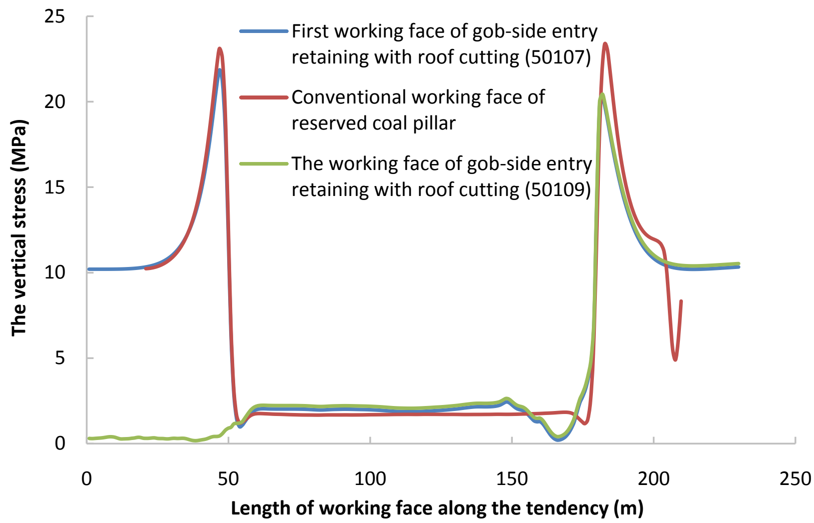

Figure 7. Vertical stress distribution curve of monitoring line 5.

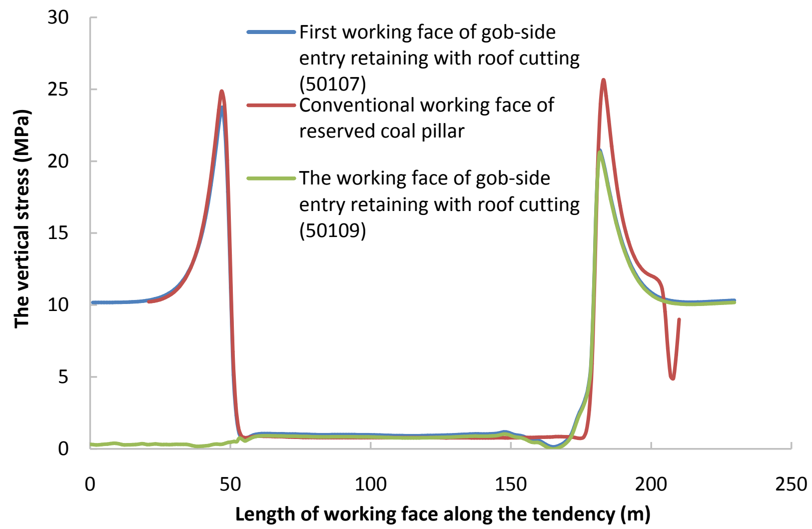

Figure 8. Vertical stress distribution curve of monitoring line 6.

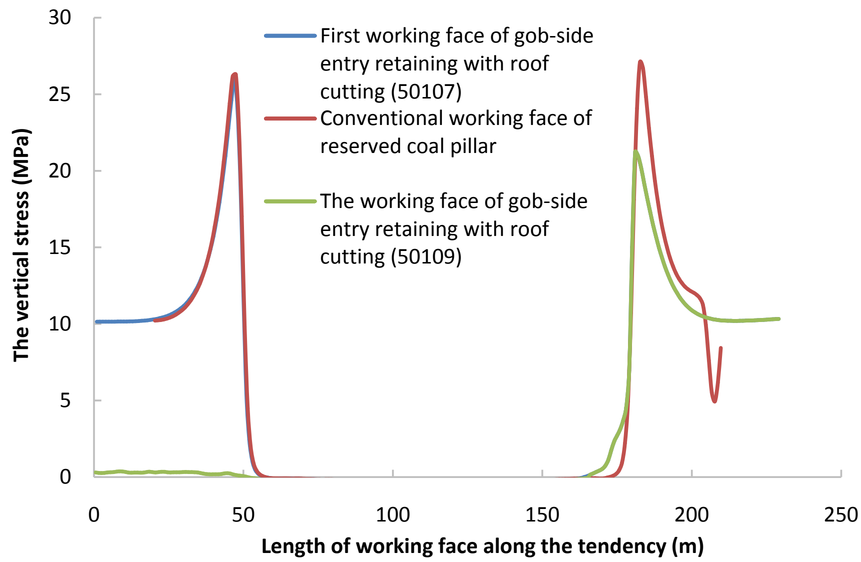

Figure 9. Vertical stress distribution curve of monitoring line 7.

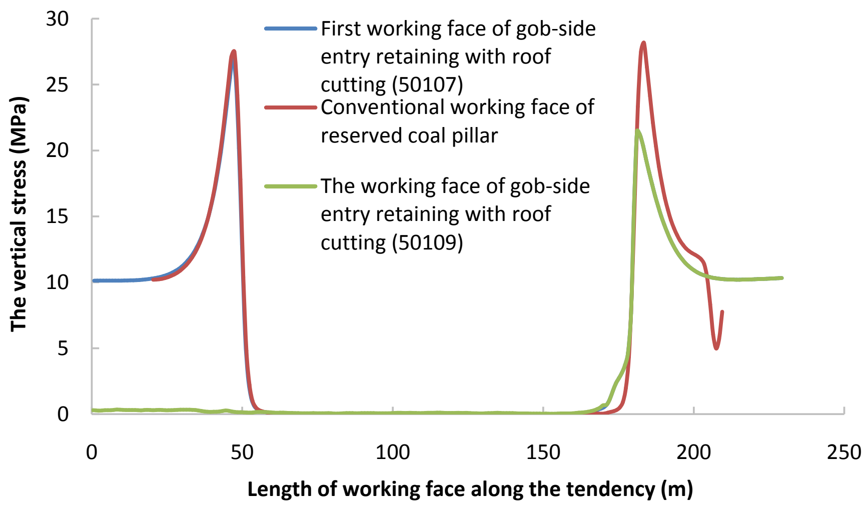

Figure 10. Vertical stress distribution curve of monitoring line 8.

stress distribution pattern, stress peak value and stress peak position of the entity coal near the return airway side of 50109 working face are consistent with those of 50107 working face. The positions of the stress peak values are 1.1 - 1.9 m away from the roadway, and the stress reduction area is located at the goaf side of the other side of the roadway extending to the working face 50107, without stress concentration. In general, the stress peak values behind the working face under the three mining modes are in the following order: On the side close to the transportation roadway, conventional working face of reserved coal pillar = the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109); on the side close to the return airway, conventional working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109).

4. Conclusion

Under the three mining modes, the peak stress concentration in front of the working face occurs at 10 m. The stress concentration area in front of conventional working face of reserved coal pillar is mainly in the middle of the working face. The stress concentration area in front of the first working face of gob-side entry retaining with roof cutting (50107) is located in the middle of the working face and the side of the working face of the retaining roadway. The stress concentration area of the 50109 working face is mainly in the middle and the two ends of the working face. The order of peak value of maximum concentrated stress in front of working face is conventional working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109), and the peak value of concentrated stress is 20.95 MPa, 20.10 MPa, 19.59 MPa, respectively. The stress concentration factors from large to small are 2.00, 1.91, 1.86. Under the three mining modes, there is a stress reduction zone behind the working face, but there is a stress concentration phenomenon extending to the outside of the roadway, and the stress distribution is obviously different. Due to the presence of coal pillar and entity coal, the two ends of the roadway outside of conventional working face of reserved coal pillar and the first working face of gob-side entry retaining with roof cutting (50107) show a double peak form of stress concentration, and the magnitude of the peak value of the concentrated stress at the rear of the working face is in the following order: On the side close to the transportation roadway, conventional working face of reserved coal pillar = the first working face of gob-side entry retaining with roof cutting (50107) > working of gob-side entry retaining with roof cutting (50109); on the side close to the return airway, conventional working face of reserved coal pillar > the first working face of gob-side entry retaining with roof cutting (50107) > working face of gob-side entry retaining with roof cutting (50109). The above study focuses on describing the influence of mining activities on the stress field of the floor, the influence of floor water pressure on the evolution of stress field is not considered. In the future research, it is hoped to further study the change characteristics of the stress field of gob-side entry retaining with roof cutting and conventional mining under different confined water pressure.

Fund Project

Basic Natural Science Research Program of Shaanxi Province (2019JLP-01).

Conflicts of Interest

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

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