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Research Article

The Research of the Influence on Stress below the Roadway Floor of the Coal Seam Becoming Thin

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Stress is the important factor of dynamic disaster in the coal mine. Stress is closely related with surrounding geological conditions. The geological tectonic area which exists high stress has a greater impact on dynamic disaster. However, local changes of the coal seam in the thickness may be sedimentary in origin and also result in the dynamic disasters. The paper studies the influence on stress with coal seam thickness varying below the roadway floor by means of numerical models. And the degree of influence on stress of the thinning with the burial depth is studied, too. The results of the research carried out were similar to the field test. Meantime, the results show that the shorter and narrower of the coal seam with thinning, the greater both horizontal and vertical stresses generated in that area. The difference is that the horizontal overstress increment is more than the vertical's. It also reveals an overstress phenomenon has a great relationship with the geometry of the coal seam more and not the burial depth of the heading face. The results drawn in this paper may be helpful to predict and control dynamic disasters when the geometry of the coal seam varies.

1. Introduction

Coal and gas outburst and coal bumps, as well as the others dynamic disasters related to stress, are a worldwide difficult problem in underground coal mining. Stress is considered as an important factor of the dynamic disasters [1–3]. The top three coal mine accidents and casualties are roof, gas, and water damage in Guizhou Province. These disasters are closely related to stress [4]. Stress is closely related with surrounding geological conditions, that is, the actual nature of the coal and surrounding rock. Geological tectonic, such as thrusts, strike-slip, normal faults, igneous intrusions, and recumbent fold hinges, is related to high stress and thought to cause dynamic disasters frequently [1, 5–12].

Besides local changes of the coal seam in the thickness, dip angle can also influence the increase in the probability of gas disasters [9, 13]. It is considered to be more difficult to prevent and control gas outburst in thin coal seams [14]. These changes may be tectonic or sedimentary in origin [15]. And the location without geological tectonic where the coal seam becoming thin, especially below the roadway floor, is often ignored so that dynamic disaster accident happens occasionally. Meanwhile, some abnormal phoneme related to stress such as roadway floor heave often exists in the roadway before dynamic disasters. And the field workers often meet the phenomenon and may consider it as a result of mining influence, so there is no danger. Moreover, the other omens, such as coal booming and drill sucking, exist once in a while.

So, there may be some relationship between the stress and the thickness of the coal seam varied below the roadway floor. COMSOL Multiphysics is a good simulation software about stress [16–18]. So we consider simulating the influence on stress with coal seam thickness changing below the roadway floor. And the degree of influence on stress of the thinning with the burial depth is considered, too.

On the basis of the simulate results, it is helpful to understand the reason for abnormal roadway floor heave, coal

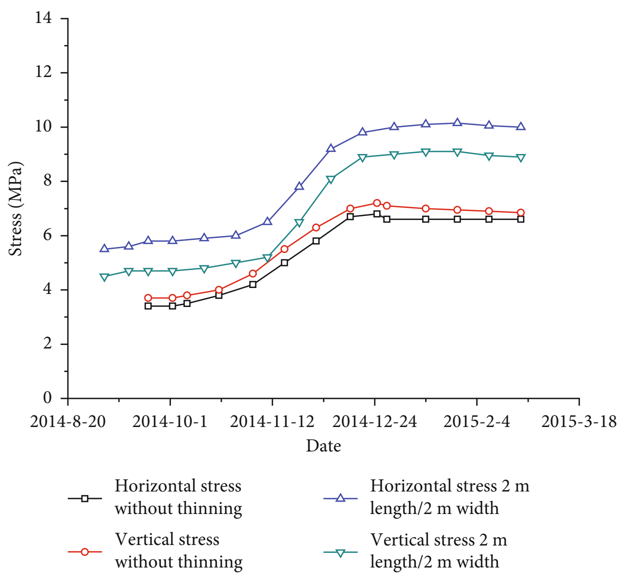

Figure 1: The test result of stressmeters.

Table 1: Properties of the coal and rock.

	Density kg/m^3	Bulk modulus (Pa)	Poisson's coefficient	Cohesion (Pa)	Friction angle (°)
Coal	1400	2*E*9	0.26	2.5*E*6	30
Rock	2500	3E10	0.3	4*E*7	40

booming, drill sucking, etc., when the coal seam is thinning below the roadway floor so that safety measures can be taken.

2. Local Phenomena Analyzed

The field study was carried out in the Yizhong coal mine at a depth of approximately 280 m. The coal mine lies in the Liupanshui City, Guizhou Province, China. The coal mine disaster in Guizhou is very serious, which is closely related to the geological conditions. The coal seams in Guizhou are mainly deposited in the Permian strata and have undergone complex geological tectonic movements. There are several large faults in Guizhou Province, namely, the Mid-Guizhou fault from east to west, the Ziyun-Yadu fault from northwest to southeast, the Panjiazhuang fault, and the Hengce arc fault from southwest to northeast, and these faults intersect in the rich areas of coal such as Liupanshui, Bijie, and Qianxinan [4].

The Yizhong coal mine annual design production capacity is 600,000 tones. An accident of coal and gas outburst occurred as early as its well construction period. China Coal Technology Engineering Group Chongqing Research Institute assessed the outburst risk of its No. 11 coaled and identified it to be the outburst coal seam in 2012. No. 11 coal seam has the thickness of 0.94~6.29 m with an average of 3.18 m, and its roof and floor mainly are mudstone. The coal seam belongs to class III destructive coal mass and has Pro-

Table 2: Models for analyzing the influence of thinning on the No. 11 coal seam.

Model	Angle of the coal seam (°)	Thinning in the length (m)	Thinning in the width (m)
1	20	1	1
2	20	2	1
3	20	3	1
4	20	1	2
5	20	2	2
6	20	3	2
7		Normal	

todyakonov coefficient of 0.13, initial velocity of gas emission of 40 mmHg, gas pressure of 0.55~1 MPa, and gas content of 8.05~11.04 m^3/t.

Gas pressure and gas content decreased to 0.28 MPa and 4 m^3/t separately, and it achieved the standard after gas drainage for 16 months. However, drill sucking, coal booming, abnormal floor heave, or other phenomena related to significant increases in stress levels in the 11112 heading face were still often observed during the excavation. After analyzing many normal indexes about dynamic disasters and getting information on similar phenomena that had occurred previously, the conclusion was reached that the main causes of these phenomena were faults as well as anomalies in the geometry of the coal seam.

The workers met drill sucking at 5:50 on 22, June 2014. And after 6 hours, a worker discovered that there was a crack with 7 cm in width and 6 m in length in the roadway floor behind the heading face 8 m. The maximum of floor heave was 0.6 m. Finally, a thinning coal seam with about 1.7 m in length and 0.9 m in width below the roadway floor was detected.

Shortly after this happened, borehole stress meters were installed to monitor the stress where the thickness anomaly existed as well as without variation. Figure 1 is the test result of a thinning coal seam with about 2 m in length and 2 m in width as well as without thinning lies in 11112 heading face without faults. The horizontal stress and vertical stress of the thickness of the coal seam becoming thin were more relative to without thinning from Figures 1 and 2. And it should be noted that the horizontal stress is higher than vertical stress when the thickness of the coal seam is becoming thin. The stress increased as a result of mining influence. This phenomenon that vertical stress increases as a result of mining influence also existed in Pingdingshan, Huaibei, and Huainan Mining [19, 20]. Once the area with stressmeters had been passed, the stressmeters remain constant almost.

3. Research Method

On the basis of above analysis and some scholars' methods [14, 21–23], numerical simulation was considered to study the influence as a result of a thinning of different geometries in the seam. And this simulation was carried out by means of a COMSOL Multiphysics 2D model representing the No. 11 coal seam and its rock walls from the surface to a

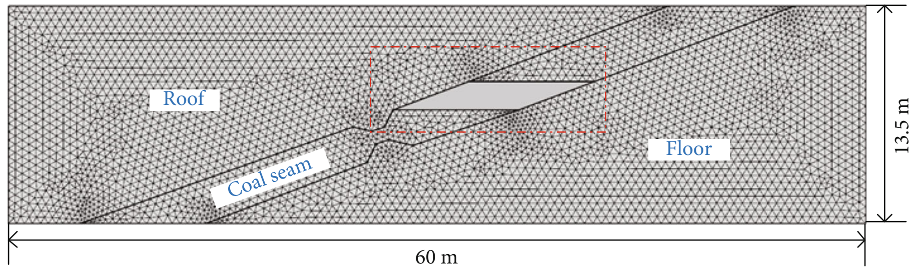

FIGURE 2: Scheme of the model created to simulate thinning in the No. 11 coal seam.

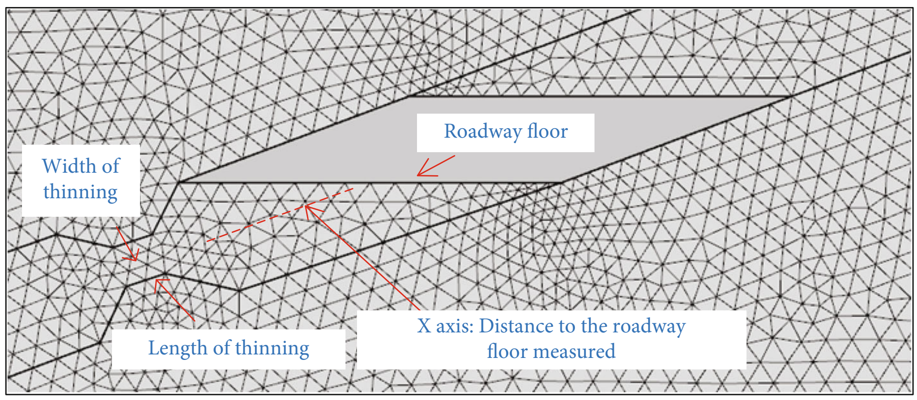

FIGURE 3: Enlarge region of the red rectangle from Figure 2.

depth of 280 m. The values of coal and rock properties are given in Table 1. Stress was calculated by using the steady-state method under the coal plasticity with D-P and Mohr-Coulomb criterion.

Now we shall describe the working method followed in analyzing the influence of thinning on the local stress state. First, a 2-dimensional model was generated using the COMSOL Multiphysics which represents the heading face and its nearest surroundings (some 60 m length and 13.5 m width), as shown in Figure 2. And Figure 3 is enlarging region of Figure 2, red rectangle.

Located original stress is applied at the top, to simulate the existing stresses at the depth at which the sublevel is actual. Maximum principal stress has been applied perpendicular to roof and floor. The stress factor estimated from these models for the case under study is 1.4. The thinning of the coal seam may be varied in this model, which may be varied both in length and width. Seven different models were calculated, using the dimensions of the thinning given in Table 2. Model 7 is used as the standard for comparison with the other cases, as it is assumed that in this model, the No. 11 coal seam presents a constant thickness of 3 m.

4. Results and Discussions

4.1. Influence of the Geometry of the Thinning on the Local Stress State. In order to evaluate what extent it may give rise to the phenomena of overstress below the roadway floor, the part of the research focused on the general analysis of the influence on horizontal and vertical stresses that different geometries of coal seam becoming thin below the heading face may have.

Figures 4 and 5 show the evolution of horizontal and vertical stresses evaluated at the center of the coal seam. The origin of the x axis corresponds with the roadway floor of the heading face, evaluating from this point the stress that exists with the increasing depth. Figure 2 shows how the x axes of the graphs are considered.

The peaks of stresses are produced below the roadway floor, and the stresses remain almost constant away from the roadway floor from Figures 4 and 5. However, a higher peak was generated in the existence of thinning relative to without thinning.

As an example of coal seam with 1 m width, the horizontal overstress with respect to the model without thinning varies between 10 and 17.2 MPa and it increases of about 100~170% with shorter relative to without thinning. However, the vertical overstress varies between 6.2 and 13.7 MPa, and it increases of about 60~130% with shorter relative to without thinning.

Meanwhile, the horizontal overstress with 2 m width varies between 3 and 4.4 MPa, and it increases of about 30~45%; the vertical overstress with 2 m width varies between 1 and 2.8 MPa, and it increases of about 10~29%.

As can be seen in Figures 4 and 5, the model with a thinning of 2 m in length and 2 m in width presents a horizontal overstress increase of 3.2 MPa and a vertical overstress increase of 2 MPa with respect to the model without thinning. This result is similar to that obtained with stressmeter measurements, in which the difference between the stress increase in a zone near a thinning and the increase in stress in a zone without thinning was about 3.35 and 1.9 MPa.

When the thinning geometry is narrower, the recorded stress varies obviously with respect to that of the model

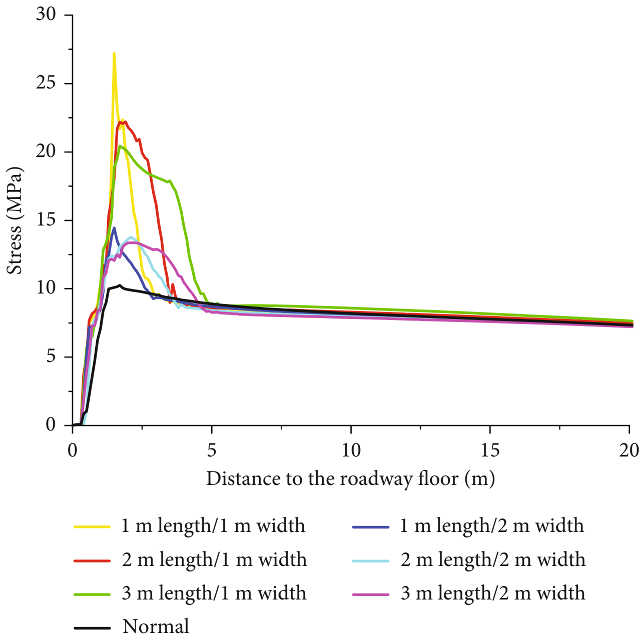

FIGURE 4: Horizontal stresses below the floor of the heading face for each model.

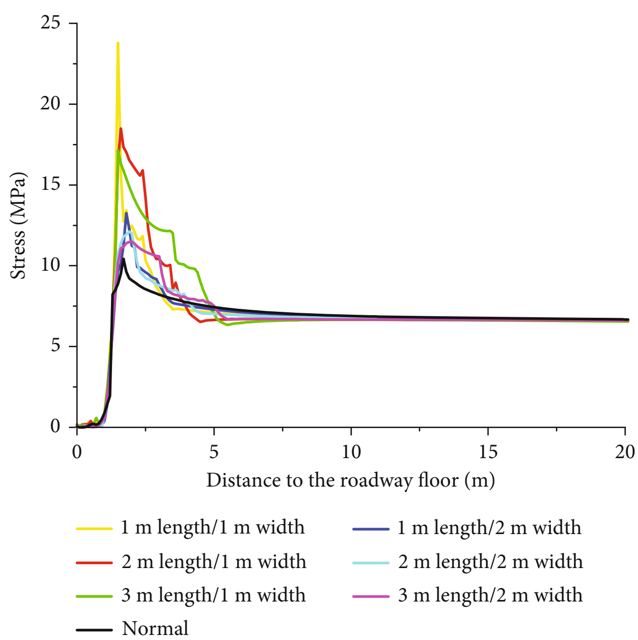

FIGURE 5: Vertical stresses below the floor of the heading face for each model.

without thinning. It implies that the tensions were accumulated more when coal seam becomes narrow. The difference is that the horizontal overstress increment is more than the vertical's. The similar phenomenon was found by hydraulic fracturing stress measurements [24].

Besides, its stress peak is higher when the thinning geometry is shorter, although its overstress area is small. It implies that the tensions were partially accumulated easily when coal seam becomes short, too. And it is not the same

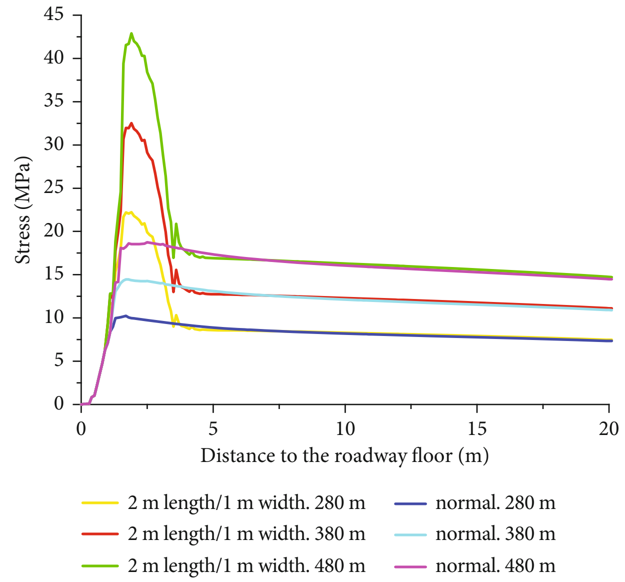

FIGURE 6: Horizontal stresses below the roadway floor at different burial depths.

wholly with the result by means of FLAC [15]. The smaller

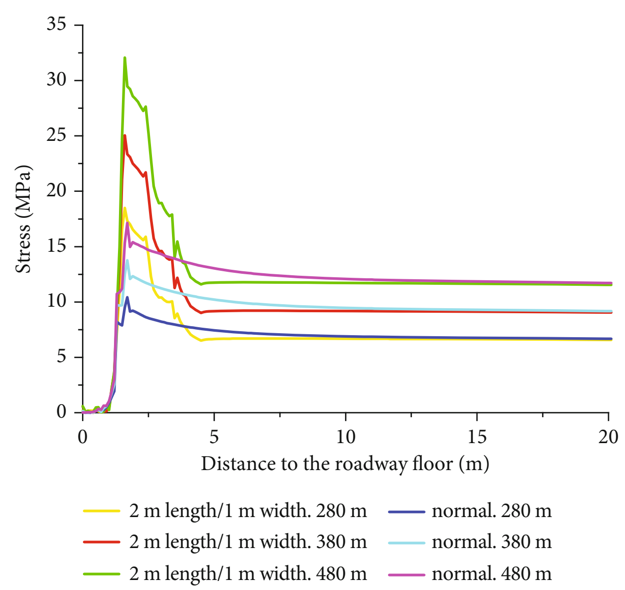

FIGURE 7: Vertical stresses below the roadway floor at different burial depths.

the geometry area of the thinning is, the more and easier accumulating tension is when the principal stresses are constant without geological tectonic. And the similar phenomenon was also met in some Shanxi Mining. It may accord with the reality more.

4.2. Influence of the Different Burial Depth of the Thinning on the Local Stress State. The following research study was to consider and analyze several models which evaluated the influence on overstress of the burial depth of the heading face under the coal seam with thinning. To test this influence, we choose the aforementioned models of 3 and "normal."

Both models of 3 and "normal" were simulated for a burial depth of around 280 m initially and then were calculated for burial depths of 380 m and 480 m repeatedly. To analyze the influence of the burial depth, the evolution of the horizontal and vertical stresses below the roadway floor was newly represented. And Figures 6 and 7 show the results obtained for all the models at different burial depths.

In view of the above simulation results, it can be seen easily that burial depth notably affects the value of the stress peak of not only horizontal stress but also vertical stress below the roadway floor.

However, it is also easy to find that not only horizontal stress but also vertical stress of the coal seam with thinning increase is relative to the coal seam without thinning at the same burial depth from Figures 6 and 7. And the increment of horizontal stress is 120-145%; the increment of vertical stress is 80-90%.

Therefore, it seems that the burial depth at which the thinning of the seam is located also generates the similar increase in horizontal and vertical stresses. The typical difference is that the increment of the stress peak is more obvious relative with normal model.

5. Conclusions

COMSOL Multiphysics was used to simulate stress in the Yizhong coal mine, focusing on the coal seam with thinning below the roadway floor in the paper. The research carried out has allowed us to reconstruct and explain the phenomena of abnormal floor heave, coal booming, drill sucking, or other omens related to dynamic disasters when the coal seam is thinning below the roadway floor.

The conclusion drawn was that these omens related to dynamic disasters are as a result of the existence of the coal seam becoming thin, which resulted in high concentration of horizontal and vertical stresses below the roadway floor.

The phenomenon of overstress observed in the mine was reconstructed by means of COMSOL Multiphysics model, and it is similar to the field test. It also explains it may be dangerous when the coal seam is thinning below the roadway floor.

In addition, the relationship between the overstress and the coal seam becoming thin was evaluated. It shows that the shorter and narrower of the coal seam of thinning, the greater both horizontal and vertical stresses generated in that area. The difference is that the horizontal overstress increment is more than the vertical's.

Finally, it explains that the thinning geometry's stress is higher relative to the normal mode regardless of the burial depth of the thinning. And it also reveals an overstress phenomenon has a great relationship with the geometry of the coal seam more and not the burial depth of the heading face.

The results drawn in this paper may be helpful to predict and control dynamic disasters when the geometry of the coal seam varies.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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