Hindawi
Advances in Civil Engineering
Volume 2021, Article ID 9990465, 9 pages
https://doi.org/10.1155/2021/9990465

Research Article

Study on Development Law of Mining-Induced Slope Fracture in Gully Mining Area

Tao Yang,[1,2] Yiran Yang,[1,2,3] Jie Zhang,[1,2] Shoushi Gao,[1,2] and Tong Li[1,2]

[1]*Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, China*
[2]*Key Laboratory of Western Mine Exploitation and Hazard Prevention with Ministry of Education, Xi'an University of Science and Technology, Xi'an 710054, China*
[3]*Shaanxi Key Laboratory of Safety and Durability of Concrete Structures, School of Civil Engineering, Xijing University, Xi'an 710054, Shaanxi, China*

Correspondence should be addressed to Yiran Yang; 1306373793@qq.com

Received 11 March 2021; Accepted 22 May 2021; Published 4 June 2021

Academic Editor: Hao Wu

The development law of mining cracks in shallow coal seams under gully topography was used as the research base to analyze the development characteristics of mining cracks in the 5-2 coal mining face of Anshan Coal Mine, and the weak strength was established. The basic top force model under the action of the overburden is the "nonuniformly distributed load beam" structure model. Through similar simulation research and theoretical calculation analysis, the fracture development law of the working face passing through the valley is studied. Based on the mechanical analysis of the beam structure with nonuniform load, the discriminant conditions of the stability of the bearing structure of the bedrock are derived, the calculation formulas of the parameters such as the pressure, shear force, and the ultimate span of the basic roof at both ends are determined, the influence law of the thickness and slope change of the weak strength overburden on the mining crack spacing is revealed, and the influence of the slope of the weak strength overburden on the weighting step distance on the beam with nonuniform load is obtained. The phenomenon is that the burial depth has a great influence on the step distance of weighting. The practice shows that the distance between the mining-induced fractures determined by the nonuniformly distributed load beam model and the periodic weighting step, the height of fracture development, and the buried depth are approximately the same; the mining-induced fractures in the overburden develop and evolve periodically with the failure and instability of the bedrock. The research results will clarify the development mechanism of surface cracks in the gully mining area, which is of great significance to reduce terrain disasters.

1. Introduction

The area where the working face of Shenfu coalfield is located has complex and craggy terrain. In most areas, the coal seam is buried shallowly, only dozens of meters away from the surface, and thin bedrock outcropping is common. The bedrock is covered by thick Quaternary loess and Neogene laterite. Compared with other coal mines, the characteristics of overlying strata fracture, the form of instability movement, and the evolution law of mining-induced fracture are significantly different.

Since the 1990s, with the expansion of the mining of shallow-buried coal seams, in-depth studies have been conducted on the instability characteristics of overlying strata failure and the development law of fracture. Until now, many achievements have been obtained. Through the study on the stability of roof structure, the mechanism of roof failure and instability is well revealed, and the collapse pattern of overlying strata is vividly described [1–3]. Based on the study of strata behaviors when the working face is mining in gully in Shendong mining area, the reason of roof cutting and caving occurs easily when the working face is in the uphill stage is pointed out, which provides important theoretical guidance for the determination of the location of the overlying strata failure and instability during the mining [4]. Based on the roof failure characteristics and the development height of two zones in the shallow-buried working face with large mining height, the measured law

which is closer to the traditional calculation formula of caving zone height is obtained [5, 6], providing an important guarantee for safe mining. On the basis of fractal geometry theory and numerical simulation, the fracture development characteristics of mining-induced rock mass are well characterized from the perspective of fractal dimension, providing references for the study of fracture development under different damage degrees [7, 8]. In view of overlying strata structure fracture, the factors and mechanism that affect the distribution of surface fractures in goaf are given, which can provide some ideas for the prevention and control of surface disasters under similar conditions [9, 10]. Based on the study of fracture development characteristics under different mining intensities in the Yushenfu mining area, the zoning of ground fissures distribution is revealed [11, 12]. Taking Shendong mining area as the study target, the dynamic development law of ground fissures is revealed using continuous field monitoring, and the corresponding function relationship is established [13, 14]. Based on the method of overlying strata composite structure and rock strata tensile deformation, the correlation between the development law of water-conducting fracture zone and strata structure was studied, and a reasonable formula for calculating tensile ratio was deduced [15].

In summary, the existing study results have made significant achievements in rock structure failure and instability, caving morphology of overlying strata, and fracture development law [16, 17]. However, the mechanism and law of dynamic evolution of mining-induced fractures caused by the bedrock failure and instability in the mining of shallow-buried coal seam with thin bedrock in gully remain to be studied [18–20]. Anshan coal mine belongs to the Loess Hilly and gully area, with deep gully, steep slope, and thick soil layer load on the surface. When the working face passes through the gully bottom, the coal wall spalling is serious, and the support working resistance increases. This is inconsistent with the mine pressure behavior law of the working face passing through the gully bottom under general conditions, and whether there will be dynamic load and other contents need to be further studied, which is also the key to the prevention of mine pressure in Anshan coal mine. Therefore, in combination with the mining conditions of 5-2 working face in Anshan coal mine, the mechanism and law of dynamic evolution of mining-induced fractures caused by bedrock failure and instability in the mining of shallow-buried coal seam with thin bedrock in gully were studied in this paper.

2. Engineering Overview

Anshan minefield is in a typical loess ridge landform. The lowest elevation is 1075.9 m, and the highest elevation is 1364.5 m, with a large drop. In this region, there are many gullies with the buried depth of coal seam about 20~70 m. The topography of the minefield is shown in Figure 1.

Currently, the main coal seam of the mine is 5-2. The average coal thickness of 125203 working face is 2.3 m, the inclination angle is 0~1°, the strike length of working face is 3152 m, the dip length is 270.5 m, the horizontal elevation of the coal seam is +1165 m, and the ground elevation is +1191~+1304 m. It is located in the north side of Shasongliang and the northwest side of Caigou. The working face adopts a full-height and long-wall comprehensive mechanized coal mining method, and the roof is treated by the full caving. According to the drilling data and outcrop information, the lithology of the roof is generally stable. The average thickness of the pseudo-roof is 0.2 m, and it is carbonaceous shale. The direct roof is fine-grained sandstone with an average thickness of 1.12 m. The basic roof is a silty, fine-grained sandstone with an average thickness of 12 m, and the bedrock is covered by a sandy soil layer.

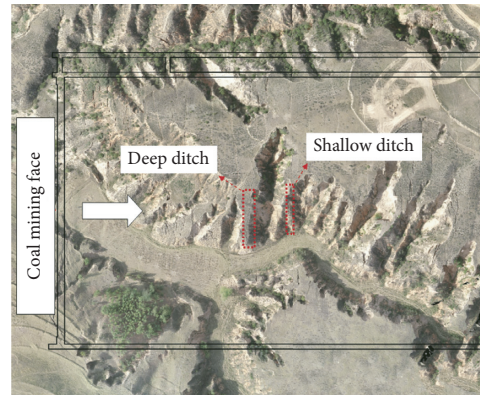

Figure 1: Landform map of Anshan mine field.

3. Similar Simulation Experiment Analysis

3.1. Experiment Design. During working face stoping, it is difficult to obtain the dynamic development law of mining-induced fractures induced by bedrock failure and instability through on-site detection. This paper aims to study intuitively the dynamic evolution of mining fractures induced by bedrock failure and instability when different surface forms (deep gully and shallow gully) are in the downslope, gully bottom, and upslope stages. Therefore, based on the actual occurrence of 125203 working face in Anshan coal mine, this paper builds a plane simulation test platform as shown in Figure 2 according to the similarity theory. The size of the similar model was 3000 × 1000 × 200 mm, and the geometric similarity ratio was 1 : 100. When the material is prepared, river sand is used as aggregate, and gypsum and calcium carbonate are used as cement. In the laying process of the model, mica sheets were laid to reduce the size effect caused by the whole layer laying. The thickness and ratio of the model are shown in Table 1. The stratum selection is based on the geological data provided by the mine. The reason for selecting these six strata is that these strata can represent the coal seam occurrence conditions of the mine. The material ratio is based on the authors' previous research results.

The soil layer (the overburden) is mainly distributed in the Xinmin district and exposed on the surface, which is a very poor water area. Laterite is mainly distributed in Yushen mining area, which is located between the aquifer of Salawusu formation and the overlying bedrock of the coal seam. In the ancient gully section, due to erosion, the

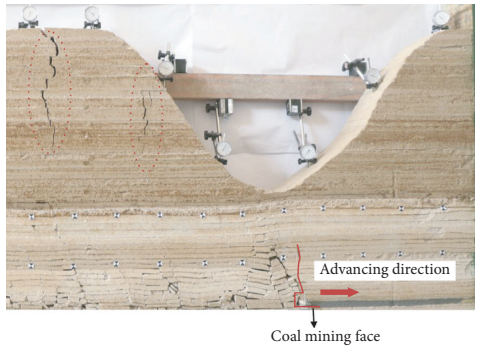

Figure 2: Deep ditch downhill stage.

Table 1: Material ratio of selected typical strata.

Number	Strata	Height (cm)	Mean thickness (cm)	Material ratio					
				Ratio number	Sand	Gypsum	White powder	Coal ash	Loess
1	Soil	100.0	83.0	Sand: soil (20 : 1)	9.14	—	—	—	0.45
2	Siltstone	17.0	3.0	837	8.53	0.32	0.75	—	—
3	Fine-sandstone	14.0	6.0	846	8.53	0.43	0.64	—	—
4	Siltstone	8.0	3.0	746	8.40	0.48	0.72	—	—
5	5-2 coal	5.0	2.5	20 : 1 : 5 : 20	4.17	0.21	1.04	4.17	—
6	Fine-sandstone	2.5	2.5	746	8.40	0.48	0.72	—	—

weathered rock remains thin. After long-term weathering, the physical and chemical properties of the bedrock have changed significantly, and the hydrogeological characteristics have also changed. The pumping data show that the unit water inflow is less than 0.01 l/s·m, and the permeability coefficient is between 0.006 and 0.04 m/d. It can be seen that the water yield and conductivity of the weathering zone are very weak, and it has good water resistance, but it also reduces the strength of the rock mass.

As mentioned above, in the mountain gully of the shallow-thin bedrock coal seam, the overlying strata are prone to full-thickness cutting off, and the mine pressure is obvious. Therefore, the plane simulation model is divided into left and right gully depth terrains for comparative study. A steel ruler and protractor were used to measure the bedrock breaking step, mining-induced fracture characteristic parameters (fracture development angle, fracture opening and height, etc.), and the evolution law during working face advancement. All data are recorded in real time [21, 22].

3.2. Analysis of Dynamic Evolution Law of Mining-Induced Fracture. When the initial pressure of the working face occurs in the advancing process of the deep gully downhill section (as illustrated in Figure 2), the basic roof is ruptured behind the coal wall, causing slipping instability. However, the full-thickness cutting off of the overlying strata does not occur along with the basic roof failure, but the whole cutting off occurs first at the lower part of the overlying strata. Although there are vertical cracks developed in the upper part of the overlying strata, the friction force on the upper part of the overlying strata is greater than its gravity due to horizontal stress, and the overlying strata do not slide. As the working face continues to advance, the overlying strata will collapse as the bedrock cuts down along the coal wall. The vertical cracks are developed through the surface, and the surface forms step-subsidence.

When the working face passes through the bottom of the gully, the bedrock is subjected to nonuniform loads. Because the load above the coal wall is relatively small, and the load behind the coal wall is relatively large, the rotation of the rock pillar near the bottom of the gully causes the cracks that penetrate the ground surface, and the development angle is approximately vertical. However, the fractures in the gully are gradually closed by horizontal compression caused by two different turning directions of the upward and downward slope. Surface uplift appeared, water-air leakage of overlying strata was reduced, and the air leakage in the gully was not the maximum. Therefore, the fracture development of overlying strata is different from that of other areas.

During the advancing of working face in the upslope of deep gully (Figure 3), because the load above the coal wall is relatively large, the load behind the coal wall is relatively small, and the overlying strata at the back of the working face are airborne in the horizontal direction; the bedrock gradually transforms from cantilever beam structure to hinged structure under nonuniformly distributed loads. The overlying strata above the working face are stretched to form "inverted trapezoidal" open fractures with wide upper and narrow lower. As the working face continues to advance, with the increase of bedrock rotation angle, the hinge of bedrock will eventually be crushed, and the hinged rock block will slip and become unstable. The fractures penetrated the ground surface. There was obvious step-subsidence, and the rear fractures gradually closed under the turning of the overlying strata.

Figure 3: Deep ditch uphill stage.

During the advancing of working face in the downslope of the shallow gully (Figure 4), the lower part of the overlying strata slipped and destabilized as the bedrock broke, while the upper part deflected backward under nonuniformly distributed loads, forming new tensile fractures. Fractures show obvious asynchrony in spatiotemporal development. When the working face is advancing in a shallow gully, because the gully bottom is relatively flat, the stress on bedrock is more uniform, and the opening and misalignment of surface fracture are small after the bedrock is cut integrally.

During the advancing of the working face in the upslope of the shallow gully (Figure 5), affected by the friction of the overlying strata above the working face, the bedrock breaks into a hinged structure with the adjacent rocks behind. New tensile ground fissures are formed in the upper part of the overlying strata as the bedrock rotates, while rear ground fissures close as the bedrock rotates. After the working face continues to advance for a certain distance, the hinged block slips and becomes unstable. In other words, the whole bedrock is cut off behind the coal wall. However, compared with the previous stages, the transmission speed of bedrock fracture becomes faster and the weighting interval becomes smaller.

The change law of the two groups of overburden movement measuring points after coal seam mining is shown in Figure 6. The data of displacement measurement points analyzed and arranged show that no matter in the downhill mining and uphill mining area of the valley, or in the general terrain mining area, the bedrock of the goaf has obvious cutting subsidence, and the subsidence near the coal wall is small, which indicates that the goaf is basically compacted due to the large breaking angle. The subsidence of bedrock under goaf in downhill mining and uphill mining area is the largest, the maximum value of deep valley is 1450 mm, and the maximum value of shallow valley is 1320 mm, which indicates that the whole overburden cutting phenomenon is obvious, while the subsidence of bedrock in general terrain mining area is relatively small, the maximum value is only 790 mm, and the formation of a certain hinge structure in the goaf slows down part of the surface cutting subsidence.

In conclusion, during the mining of shallow-buried coal seam in the gully, mining-induced fractures in the weak overlying strata show the characteristics of periodic dynamic development with the failure and instability of bedrock. The overlying strata slide with the bedrock instability, and

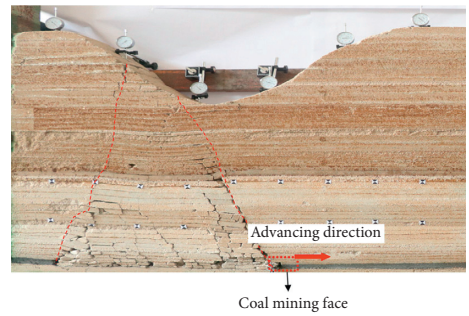

Figure 4: Shallow ditch downhill stage.

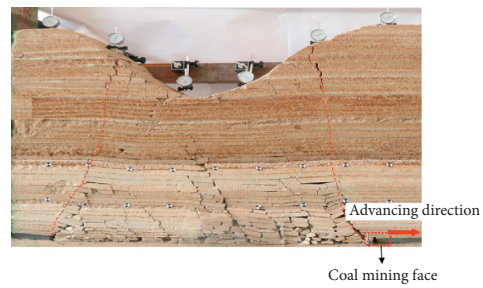

Figure 5: Shallow ditch uphill stage.

fracture morphology develops and changes rapidly. The surface macroscopic cutting is obvious, and collapsed and stepped mining fractures are relatively developed, forming periodically distributed water-air leakage channels. Under the influence of time effect and horizontal stress, the horizontal opening and vertical misalignment of surface fractures constantly change with the periodic pressure of the working face, and the opening of temporary open fractures gradually becomes small. Since the back of the overlying strata above the working face in the uphill stage is empty, the fracture opening in the uphill stage is larger than that in the downhill stage. The fractures in the deep gully are gradually closed by horizontal compression caused by two different turning directions of upward and downward slope. Surface uplift appeared, water-air leakage of overlying strata was reduced, and the air leakage in the gully was not the maximum.

4. Theoretical Model Analysis

4.1. Model Mechanics Analysis. According to the above analysis, the mining-induced fracture is controlled by the limit span. The failure and instability of bedrock directly cause the overall movement of overlying strata, resulting in penetrating mining-induced fractures. As a result, further study on the fracture mechanism and its influencing factors of shallow-thin bedrock in gully can lay an important foundation for the analysis of the development law of penetrating mining fractures in shallow coal seam mining.

The overlying strata above the bedrock are semi-consolidated with low strength. Therefore, when the self-

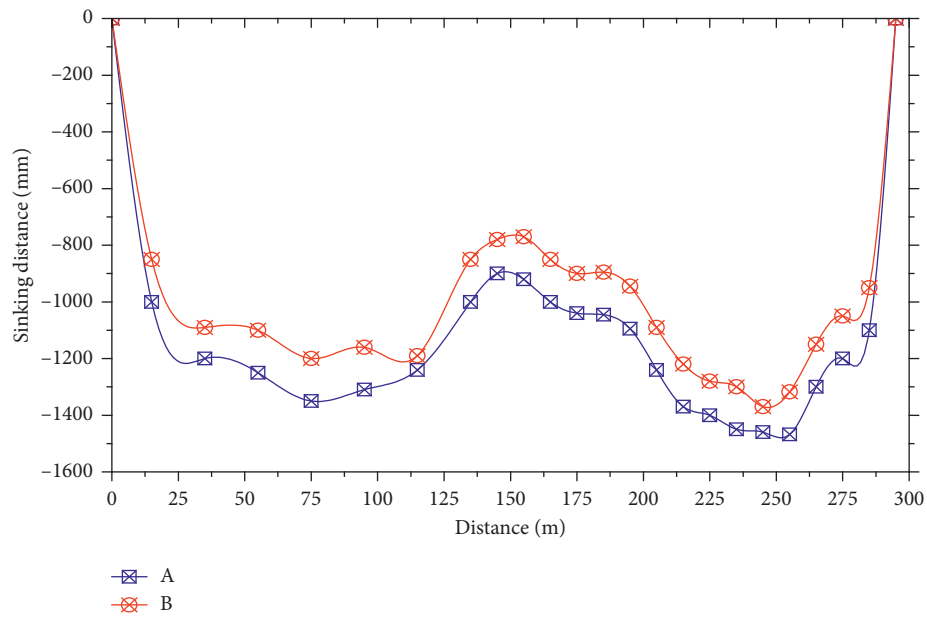

Figure 6: Surface subsidence data.

weight stress of the overlying strata is greater than the friction force, the overlying strata will undergo bar-type full-thickness cutting off as the basic roof break after working face stopping. The actual pressure of the bedrock bearing structure is the difference between the weight and the friction force on both sides of the overlying strata. If the weighting interval of the basic roof is taken as the limit span of the bearing structure, when the working face is mined in the gully, the mechanical model of surrounding rock is formed under the action of overlying strata, as shown in Figure 7.

In this study, in order to facilitate the calculation of load bearing structure, the following assumptions are made: ① it is assumed that the development angle of mining-induced fractures is a right-angle and ② the self-weight of bedrock is negligible.

Taking $ABCD$ as the sliding overlying strata, it can be known from the static balance equation of the beam that

$$\begin{cases} F_{RA}L + F_{AC}L - \gamma L\dfrac{a+b}{2}\cdot\left[L - \dfrac{2a+b}{3(a+b)}L\right] = 0, \\ \gamma L\dfrac{a+b}{2}\cdot\dfrac{2a+b}{3(a+b)}L - F_{RB}L - F_{BD}L = 0, \\ F_{AC} = \dfrac{1}{2}\gamma b^2\tan\phi, \\ F_{BD} = \dfrac{1}{2}\gamma a^2\tan\phi. \end{cases} \tag{1}$$

Then, the magnitude of the bearing reaction at both ends of the nonuniformly distributed load beam is

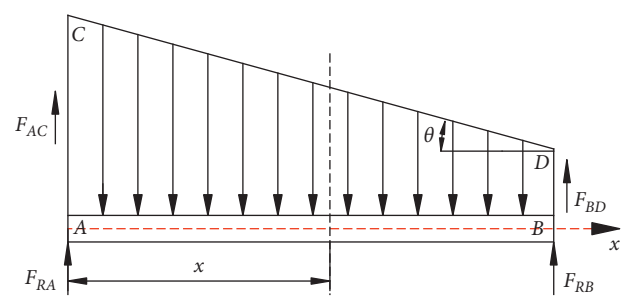

Figure 7: Mechanical model of the beam with nonuniform load.

$$\begin{cases} F_{RA} = \dfrac{a+2b}{6}\gamma L - \dfrac{1}{2}\gamma b^2\tan\phi, \\ F_{RB} = \dfrac{2a+b}{6}\gamma L - \dfrac{1}{2}\gamma a^2\tan\phi, \end{cases} \tag{2}$$

in which F_{RA}, F_{RB} are the bearing reaction at both ends of the nonuniformly distributed load beam, kN; a and b are the buried depth of the shallow and deep ends of the overlying strata above the nonuniform load beam, respectively, m; γ is the average volume force of the overlying strata, kN/m^3; L is the ultimate span of the bearing structure, m; $\tan\varphi$ is the friction coefficient of the slipping surface of the overlying strata, which is generally 0.3 [3].

According to equation (2), the difference of the bearing reaction at both ends of the nonuniformly distributed load beam is

$$F_{R(A-B)} = \frac{1}{2}\gamma(b-a)\left[\frac{1}{3}L - (a+b)\tan\phi\right]. \tag{3}$$

Therefore, when the limit span $L < 0.9(a+b)$, the difference between the two ends of the nonuniformly

distributed load beam is less than zero. In other words, the nonuniformly distributed load beam is subjected to greater pressure at the shallow-buried end, where it is more likely to cause the fracture development of the surrounding rock. When $a = b$, the bearing reaction at both ends of the load beam are equal, and the fracture development is basically synchronous.

In the AB section of the nonuniformly distributed load beam, for any section with a distance of x from the origin, the shear force is

$$\begin{cases} F_S(x) = F_{RA} + F_{AC} - \dfrac{2b - x\tan\theta}{2}\gamma x, \\ \tan\theta = \dfrac{b-a}{L}, \end{cases} \tag{4}$$

where $F_S(x)$ is the shear force on the section at x from the origin, kN, and $\tan\theta$ is the surface slope of the overlying strata.

The shear force on the bedrock plane on this section is

$$F_S(x) = \frac{b-a}{2L}\gamma x^2 - b\gamma x + \frac{a+2b}{6}\gamma L. \tag{5}$$

According to equation (5), the shear force on each section of the nonuniformly distributed load beam changes with x. In order to see how it works, take the derivative of x and make it equal to zero. Thus, it can be known that the nonuniformly distributed load beam simply decreases in the interval (0, L), and the extreme value of the shear force is

$$\begin{cases} F_S(0) = \dfrac{a+2b}{6}\gamma L, \\ F_S(L) = -\dfrac{2a+b}{6}\gamma L, \\ F_S\left(b\gamma - \dfrac{L\sqrt{a^2+ab+b^2}}{\sqrt{3}\,(b-a)}\right) = 0. \end{cases} \tag{6}$$

4.2. Theoretical Analysis Results

(1) If the working face advances in the uphill direction, the maximum shear stress of the nonuniformly distributed load beam is located at the coal wall of the working face. When the shear stress of the basic roof is greater than its shear strength, the shear failure will occur along the coal wall, which will result in full-thickness cutting off in the overlying strata and cause the surface step-subsidence. If the working face advances along the downhill direction, the nonuniformly distributed load beam will break under the maximum shear stress behind the working face, resulting in the tensile shear failure near the coal wall of the basic roof.

(2) The ratio of the shear stress on the deep and shallow ends of the nonuniformly distributed load beam is $F_S(0)/F_S(L) = -(a + 2b/2a + b)$. Its value is only related to the buried depth of the loose overlying strata at the left and right ends of the nonuniformly distributed load beam, which has nothing with other parameters and the direction of the shear force on both ends is opposite.

(3) When $x = b\gamma - (\sqrt{a^2+ab+b^2}/\sqrt{3}\tan\theta)$, the shear stress of the nonuniformly distributed load beam is zero. The determination of this position provides an important theoretical basis for the determination of the coal pillar in the working face of shallow-buried and thin bedrock coal seam, the filling mining of goaf, and the retracting position of the working face. Meanwhile, it shows that the greater the slope of the overlying strata, the closer the position, where the shear stress is zero, to the deeper buried end, and the smaller the fracture spacing.

Based on the mechanical properties of the basic roof and the stress environment, the study on the stability of the working face during mining is the basis of mechanical research to predict the weighting interval of shallow-buried thin bedrock in the gully. Under the maximum shear force, when the nonuniformly distributed load beam breaks, its maximum shear stress is

$$\tau_{\max} = \frac{a+2b}{4h}\gamma L, \tag{7}$$

where $\tau_{\max}$ is the maximum shear stress of the nonuniformly distributed load beam, MPa, and h is the thickness of the nonuniformly distributed load beam, m.

As a result, when the maximum shear stress of the nonuniformly distributed load beam reaches its shear strength, its ultimate span is

$$L_S = \frac{4h[\tau]}{(a+2b)\gamma}, \tag{8}$$

in which $[\tau]$ is the ultimate shear strength of the nonuniformly distributed load beam, MPa.

The above relationship shows the following:

(1) The limit span of nonuniformly distributed load beam is $L_S \in [4h[\tau]/3b\gamma, 4h[\tau]/3a\gamma]$. It is obviously different from the limit span of the basic roof calculated according to the uniformly distributed load beam. The larger the difference between a and b, that is, the larger the slope, the larger the error of the limit span of basic roof calculated according to the uniformly distributed load beam. When calculated by the average of the sum of the buried depth at both ends, the error may reach 25%.

(2) Under the limit span of the nonuniformly distributed load beam, the magnitude of the bearing reaction on both ends is shown in equation (9). It lays

an important theoretical foundation for the selection of support resistance in working face:

$$\begin{cases} F_{RA}(L_S) = \dfrac{2h[\tau]}{3} - \dfrac{1}{2}\gamma b^2 \tan\phi, \\ F_{RB}(L_S) = \dfrac{2h[\tau](2a+b)}{3(a+2b)} - \dfrac{1}{2}\gamma a^2 \tan\phi. \end{cases} \tag{9}$$

5. Field Investigation and Management Discussion

5.1. Field Investigation. This study investigated the development characteristics of surface mining-induced fractures in the shallow-buried coal mining face of Anshan Coal Mine. According to the development morphology and scale characteristics of mining-induced fractures, it can be known that two types of typical mining-induced fractures are easily formed in the upper and lower mining stages of the working face, namely, collapsed and stepped mining fractures. The horizontal opening or vertical misalignment of stepped fractures is large, but the opening of the two wings of the collapsed fractures is small. In gentle areas, parallel fractures with small misalignment and small opening are easy to form, as shown in Figure 8. However, fractures develop periodically with the advance of the working face. That is, the bedrock fracture causes the overlying strata to slip, thus resulting in the surface fractures, and with the advance of the working face and the rear surface fractures gradually closed.

5.2. Management Discussion. The development of surface fractures above the working face will form a good water-air leakage channel, which seriously threatens safe mining. Therefore, the treatment of mining-induced fractures should fully consider the landform and occurrence conditions, optimize the layout of the working face, and formulate scientific prevention measures according to local conditions. In engineering application, the following measures are suggested for the treatment of mining-induced fractures:

(1) Technical control measures: ① for the working face with a direct water source or confined aquifer, reasonable filling materials and techniques should be selected according to the stress distribution characteristics of the working face. The purpose is to prevent the mining from directly connecting the mine water source and causing air leakage at the working face. ② For the working face without the above-mentioned water source conditions, scientific treatment measures should be formulated according to the topographic conditions. For example, filling mining is not necessary in gentle areas. After the overall subsidence, the ground fissure sealing technology can be used for landfill and repair and ecological management. For the gully, according to the amount of surface water, it should be decided whether to adopt backfilling mining to prevent it.

(2) Management and prevention measures: specialized personnel shall be arranged to carry out fine exploration in the mining area, and gullies and the places where obvious subsidence or fractures have been formed shall be recorded one by one. The basic data is supplemented and improved timely, and the areas with the threat of water-air leakage are circled. Targeted prevention and control measures should be formulated, and forces are efficiently organized for timely governance.

Because the "nonuniform load beam" seriously impacts the support when the working face passes through the valley, the ordinary working face can not effectively prevent the occurrence of dynamic load mine pressure. When the working face passes through the valley, the advancing direction of the working face and the direction of the valley can be adopted to advance at a 15° angle, that is, the advancing speed of the upper and lower ends of the working face can be adjusted, so as to avoid the roof accident caused by the large-area hanging roof in the goaf.

At the same time, in order to accurately predict the pressure law of the working face and the pressure position of the working face, an online KJ513 mine pressure monitoring system is used to monitor the mine pressure of the working face in real time when the working face passes through the valley. Three measuring lines are arranged at the upper, middle, and lower parts of the working face, respectively. The monitoring range is 50 m before and after the trench bottom; that is, the working face is 45 m away from the open cut, and the observation is 100 m. Until the working face advances to the position 145 m away from the open cut, the working resistance curve of the upper, middle, and lower supports of the working face with the advancing of the working face is shown in Figure 9. In this process, there are 6 times of periodic weighting, and the maximum weighting is at the bottom of the ditch. At this time, the working resistance of the upper, middle, and lower supports of the working face is 41 MPa, 40 MPa, and 42 MPa, respectively, with an average of 41 MPa. The dynamic load coefficient is 1.37, 1.33, and 1.4, respectively, with an average of 1.37. The weighting strength is not very large. The rated working resistance of ZY8000/14/28 shield type hydraulic support selected in 20304 working face is 8000 kN, which can meet the requirements and realize the safe mining of working face. At the same time, the moving frame with pressure in the process of advancing can speed up the advancing speed of the working face, so as to reduce the movement range of the overlying strata and reduce the mine pressure behavior strength.

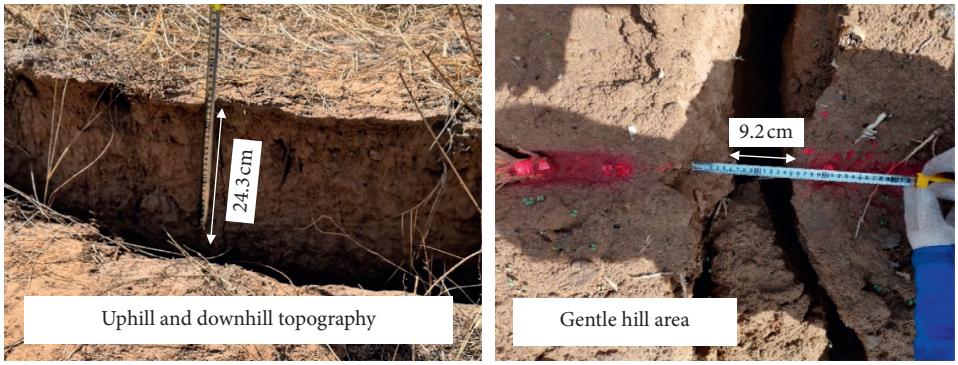

Figure 8: Morphological development of surface fissures in shallow seam mining.

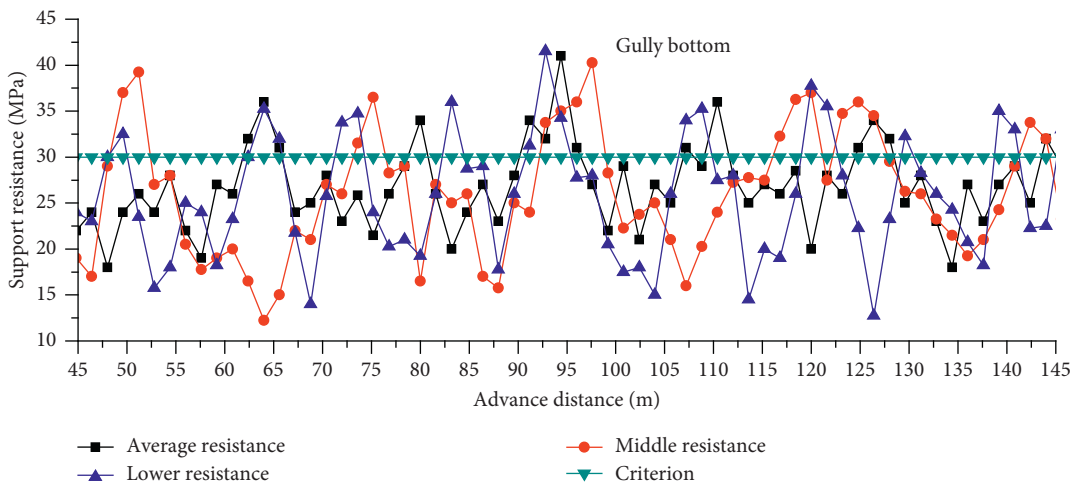

Figure 9: Support working resistance curves as the working face advances.

6. Conclusion

(1) During the mining in the gully, mining-induced fractures in the weak overlying strata show the characteristics of periodic dynamic development with the failure and instability of bedrock. The overlying strata slide with the bedrock instability, and collapsed and stepped mining fractures are relatively developed. In the uphill stage, the fracture opening is larger than that in the downhill stage. The fractures in the deep gully are gradually closed under the action of rotation, and the surface is uplifted.

(2) Based on the structural characteristics of surrounding rock in shallow-buried thin bedrock gully terrain, a structural mechanics model of surrounding rock with nonuniformly distributed load beam is established. The discriminant conditions for the stability of the surrounding rock structure are derived, and the calculation of the parameters such as the pressure at both ends of the basic roof, the shear force, and the ultimate span is determined.

(3) The slope of overlying strata above the nonuniformly distributed load beam has little effect on the weighting interval, while the buried depth has a great effect on the weighting interval. When the sum of buried depth at both ends is equal, the smaller the surface slope is, the larger the interval between the mining fractures will be. Surface fractures are basically equidistant and parallel development under gentle terrain conditions.

Data Availability

All data generated or analyzed during this study are included within this article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

T. Y. and J. Z. conceived and designed the experiments; Y. Y. and T. L. conducted data analysis; and T. Y. and S. G. wrote the paper.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (nos. 52004200 and 51774229) and China

Postdoctoral Science Foundation (no. 2020M673609XB). The agencies' funding is gratefully acknowledged.

References

[1] T. Yang and J. Zhang, "Experimental research on simulation material for water-resisting soil layer in mining physical simulation," *Advances in Materials Science and Engineering*, vol. 2020, Article ID 3456913, 8 pages, 2020.

[2] M. Qian, X. Miao, and J. Xu, "Theoretical study of key stratum in ground control," *Journal of China Coal Society*, vol. 21, no. 3, pp. 2–7, 1996.

[3] Z. Hou, "Analysis of combinatorial key strata stability in shallow coal seam with thick loose bed," *Journal of China Coal Society*, vol. 25, no. 2, pp. 127–131, 2000.

[4] J. Xu, W. Zhu, X. Wang et al., "Influencing mechanism of gully terrain on ground pressure behaviors in shallow seam longwall mining," *Journal of China Coal Society*, vol. 37, no. 2, pp. 179–185, 2012.

[5] Y. Fu, X. Song, P. Xing et al., "Study on simulation of caving and evolution law of roof strata of large mining height workface in shallow thick coal seam," *Journal of China Coal Society*, vol. 37, no. 3, pp. 366–371, 2012.

[6] Y. Fu, X. Song, and P. Xing, "Study of the mining height of caving zone in large mining height and super-long face of shallow seam," *Journal of Mining & Safety Engineering*, vol. 27, no. 2, pp. 190–194, 2010.

[7] Z. Li, X. Ding, and Z. Cheng, "Research on fractal characteristics of overlying strata crack evolution in coal seam with thin bedrock," *Journal of Mining & Safety Engineering*, vol. 27, no. 4, pp. 576–580, 2010.

[8] G. Wang, G. Yu, Y. Yu et al., "Study on cracks fractal evolution laws of mining rock mass," *Journal of Mining & Safety Engineering*, vol. 29, no. 6, pp. 859–863, 2012.

[9] X. Yu and Y. Qiu, "Analysis of subsidence status formation mechanisms in shallow mining seam of ravine cutting area," *Journal of Xi'an University of Science and Technology*, vol. 32, no. 3, pp. 269–274, 2012.

[10] P. Wang, X. Yu, and J. Liu, "Study on cracking failure mechanism of surface ground above underground high cutting ccal mining face in shallow mining depth seam," *Coal Engineering*, vol. 46, no. 5, pp. 84–86, 2014.

[11] L. Fan, X. Zhang, M. Xiang et al., "Characteristics of ground fissure development in high intensity mining area of shallow seam in Yushenfu coal field," *Journal of China Coal Society*, vol. 40, no. 6, pp. 1442–1447, 2015.

[12] L. Fan, "On coal mining intensity and geo-hazard in Yulin-Shen-mu-Fugu mine area," *China Coal*, vol. 40, no. 5, pp. 52–55, 2014.

[13] H. Liu, K. Deng, S. Lei et al., "Dynamic developing law and governance standard of ground fissures caused by underground mining," *Journal of Mining & Safety Engineering*, vol. 34, no. 5, pp. 884–890, 2017.

[14] Z. Hu, X. Wang, and A. He, "Distribution characteristic and development rules of ground fissures due to coal mining in windy and sandy region," *Journal of China Coal Society*, vol. 39, no. 1, pp. 11–18, 2014.

[15] W. Huang, Y. Gao, B. Wang et al., "Evolution rule and development height of permeable fractured zone under combined-strata structure," *Journal of Mining & Safety Engineering*, vol. 34, no. 2, pp. 330–335, 2017.

[16] J. Lou, F. Gao, J. Yang et al., "Characteristics of evolution of mining-induced stress field in the longwall panel: insights from physical modeling," *International Journal of Coal Science & Technology*, vol. 8, no. 1, 2021.

[17] H. Wu, B. Dai, L. Cheng et al., "Experimental study of dynamic mechanical response and energy dissipation of rock having a circular opening under impact loading," *Mining, Metallurgy & Exploration*, vol. 38, no. 2, pp. 1111–1124, 2021.

[18] Z. B. Cheng, L. H. Li, and Y. N. Zhang, "Laboratory investigation of the mechanical properties of coal-rock combined body," *Bulletin of Engineering Geology and the Environment*, vol. 79, no. 5, pp. 1947–1958, 2019.

[19] D. Z. Kong, Z. B. Cheng, and S. S. Zheng, "Study on the failure mechanism and stability control measures in a large-cutting-height coal mining face with a deep-buried seam," *Bulletin of Engineering Geology and the Environment*, vol. 78, no. 2, pp. 6143–6157, 2019.

[20] H. Wu, G. Zhao, and W. Liang, "Mechanical properties and fracture characteristics of pre-holed rocks subjected to uniaxial loading: a comparative analysis of five hole shapes," *Theoretical and Applied Fracture Mechanics*, vol. 105, Article ID 102433, 2020.

[21] X. Kong, S. Li, E. Wang et al., "Dynamics behaviour of gas-bearing coal subjected to SHPB tests," *Composite Structures*, vol. 256, Article ID 113088, 2021.

[22] X. Kong, S. Li, E. Wang et al., "Experimental and numerical investigations on dynamic mechanical responses and failure process of gas-bearing coal under impact load," *Soil Dynamics and Earthquake Engineering*, vol. 142, Article ID 106579, 2021.