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Research Article

Study on the Evolution Characteristics of Two-Zone Failure Mode of the Overburden Strata under Shallow Buried Thick Seam Mining

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There are risks of water burst and sand inrush in the working face of the Northwest Mining Area in China. Based on the 22407 working face of Halagou coal mine, the evolution characteristics and mechanism of a two-zone failure mode of the overburden strata in shallow buried thick seam mining were thoroughly analysed using physical modelling, theoretical analysis, on-site observation, and other research methods. A method to calculate the overburden fissure width was also proposed. The analysis results indicated that the evolution of a two-zone failure mode of the overburden strata mainly includes four stages: gestation, formation, transformation, and stabilization. In the transformation stage, a fracture zone is transformed into a caving zone. The caving zone and fracture zone are separately transferred to the working face direction based on the structure type of key strata of voussoir beam and cantilever beam after the heights of the two zones stabilize, and the "two-belt" cracks are mainly composed of inclined and horizontal fissures. Based on this study, the mechanism of the two-zone failure mode of overburden strata development was analysed according to the mining height and overburden strata key layer structure. This paper serves as a guide for safe and green mining on shallow buried thick seams.

1. Introduction

Northwestern China has become an energy supply center in recent years [1]. In this region, the main characteristics of coal reserves include their simple geological conditions, shallow burial, thin bedrock, and thick seams, while working faces are also characterized by the high-intensity mining features of large mine height, fully mechanized, and fast advancement [2]. The ground surface of northwest China mainly comprises grassland and desert (including the Gobi Desert) and is characterized by low vegetation coverage and a fragile ecological environment. Thus, as cracks caused by shallow thick coal seam mining are sometimes transmitted straight to the surface, a "two-zone" failure mode including caving zone and fracture zone can form in overlying strata. There are also a number of hidden dangers associated with shallow thick coal seam mining, including water bursting, sand inrush, and air leakage, which can seriously threaten the safety of coal mine production and destroy the ecological environment of the mining area [3, 4]. It is therefore extremely important to study the characteristics underlying the evolution of two-zone failure mode of overburden strata under shallow buried thick seam mining for coal mine safety, efficiency, environmentally friendly mining, and to protect the ecological environment of the Northwest Mining Area, China.

A significant amount of research has been carried out in recent years on two-zone failure mode of overburden strata and associated fissures in shallow thick coal seam mine working face [5–8]. Xu et al., for example, employed statistical regression analysis to obtain an empirical formula for the calculation of two-zone failure mode height under different overburden conditions for thick coal seam top coal caving faces [9]. While Xu et al. proposed that the location of the key strata exerts a significant effect on the height of a two-zone failure mode. Xu et al. also further proposed a method for estimating the height of the two-zone failure mode based on the location of the key strata. On the basis of this analysis [10, 11], Wang et al. determined the height of the caving zone by analysing the gob space, the immediate roof thickness, and its expansion in order to determine the height of the fracture zone based on the stable articulated structure formed by the key strata [12]. Wang then studied the time effect on fissure development following coal mining and provided the basis for predicting overburden failure height under repeated mining [13]. Fu et al. simulated the evolution characteristics of roof strata due to large mining height of a shallow coal seam, finding that main roof is difficult to form an articulated structure subsequently [14]. Huang was then able to reveal that a water flowing fracture in overburden strata was mainly comprised of upward crack (upward crack is formed by subsidence due to the roof caving from bottom to top and bed separation subsidence during mining) and downward crack (downward crack is the downward development of tensile fracture due to strata subsidence on the surface) on the basis of a physical model of shallow coal seam mining in Northern Shanxi Province as well as actual measurements [15]. On this basis, he proposed a mechanism for the closure of the impermeable layer downward fissure [16], which was then developed by Guo et al. in a further analysis of the upstream and downstream fissure transfixion of overburden into the thin bedrock filling face as part of a study on the safety of water-preserved mining under a thick loose aquifer [17]. All of these studies demonstrate that a good deal of progress has been made in terms of height prediction of two-zone failure mode and the characteristics of overburden fissure under high-intensity mining of a shallow thick coal seam. However, little research has been carried out on the evolution characteristics of two-zone failure mode. In this paper, a physical model experiment is presented that was aimed at determining the evolution characteristics of the two-zone failure mode given the high-intensity mining of a shallow thick coal seam. Thus, a mechanistic model of two-zone failure is established, and the evolutionary mechanisms are analysed. The results of this study have clear significance for the safe and environmentally friendly mining of shallow buried but thick coal seams.

2. Simulated Evolution of "Two-Zone" Failure Mode of Overburden Strata

2.1. Experiment Design. The fully mechanized high-intensity 22407 coal mining face within the Halagou mine inside the Shendong mining area was selected as a suitable example as a physical model. The working face of this mine is about 284.3 m wide, while the advance length is 3,224.1 m, the average coal thickness is 5.39 m, and the depth is about 163 m. The thickness of overburden bedrock ranges between 35 m and 98.5 m (average: 88.94 m), while the thickness of the unconsolidated formation ranges between 40 m and 69 m (average: 42 m). The bedrock within this mine is mainly sandstone, fine sandstone, and siltstone, while the overburden comprises three inferior key strata and a primary key stratum. The inferior key strata refer to the strata which control the upper part of strata above it, and the primary key strata are the strata which control all the strata above it, which constitute a multiple key strata structure [18]. The drilling column and key strata positions are shown in Figure 1.

A two-dimensional physical simulation test bed was used for experiment. The model dimensions are 4.0 m (width) × 1.50 m (height) × 0.3 m (thickness), as shown in Figure 2. On the basis of the characteristics of this physical model, the size of the test bed, and site-specific geological conditions, the design geometry was determined to be 0.01 (100-fold reduction in the size of the site-specific geological conditions). River sand and mica were used as aggregate materials in the simulation, while gypsum and calcium carbonate were used as cement. Because of the specific nature of this rock formation in the field, a large number of compressive strength tests using differently proportioned specimens were carried out in order to select a reasonable ratio of strength and the mechanical properties of materials. Physical and mechanical parameters of working face strata are shown in Table 1.

2.2. Analysis of Experimental Results. The physical model mining speed was set at 15 cm/2.4 h according to the actual mining speed (15 m/d) of the 22407 working face. However, for ease of analysis, actual sizes following application of the geometric similitude ratio are used in this description.

Simulations show that when the working face was set as shown in Figure 3(a), the caving zone is below the lower key strata. There was no obvious bed separation above the caving zone, and the initial caving interval was 60 m. However, when the working face was advanced to 90 m (Figure 3(b)), periodic weighting was apparent and there was obvious bed separation over the top of the roof. Thus, simulations show that, as the working surface advanced, a fracture zone developed in the overburden; indeed, when the working face was advanced to 125 m, a fracture zone developed to the top of the inferior key strata 3, but when it was advanced to 135 m (Figure 3(c)), the immediate roof cantilever beam reached the maximum overhang space. At this time, the caving zone developed to the bottom of inferior key strata 1 and the fracture zone developed to the top of inferior key strata 3; after ten minutes, the immediate roof cantilever beam broke (Figure 3(d)), rock block 1 collapsed along with inferior key strata 1, and rock block 2 turned toward the advancing direction of the working face and collapsed directly in gob. Subsequently, rock block 3 broke and turned through a small angle in the direction of the gob to contact the lower collapse rock block, forming an articulated structure and achieving a temporarily stable state. At the same time, a caving zone developed to the bottom of inferior key strata 2; inferior key strata 1 and its bearing bed were transformed into the caving zone from the fracture zone, and the fracture zone continued to develop to the basement bed carried by the upper part of inferior key strata 3. These developments ensured that the fissures of overburden strata were comprised mainly of inclined fissure and horizontal fissure. When the working face advanced to 150 m (Figure 3(e)), the immediate roof cantilever beam fractured and also turned in the direction of the gob to form an unstable articulated structure with the gob collapse rock. The

Number	Thickness (m)	Depth (m)	Lithology	Remark
20	15.66	15.66	Aeolian sand	
19	26.34	42.00	Clay	
18	13.47	55.47	Gritstone	Primary key stratum
17	4.89	60.36	Sandy mudstone	
16	5.35	65.71	Siltstone	
15	6.67	72.38	Mean-grained sandstone	
14	4.57	76.95	Fine-grained sandstone	
13	4.88	81.83	Siltstone	
12	13.89	95.72	Sandy mudstone	Inferior key stratum 3
11	2.02	97.74	Siltstone	
10	6.87	104.61	Fine-grained sandstone	Inferior key stratum 2
9	3.64	108.25	Fine-grained sandstone	
8	4.42	112.67	Mean-grained sandstone	
7	5.66	118.33	Fine-grained sandstone	Inferior key stratum 1
6	3.29	121.62	Sandy mudstone	
5	2.84	124.46	Mean-grained sandstone	
4	6.68	131.14	Siltstone	
3	5.39	136.53	Coal seam 2-1	
2	5.8	142.33	Siltstone	
1	7.87	150.2	Fine-grained sandstone	

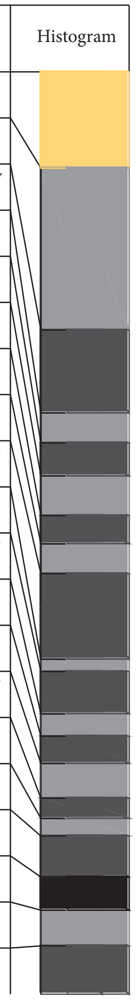

Figure 1: Drilling columnar diagram and position of key strata.

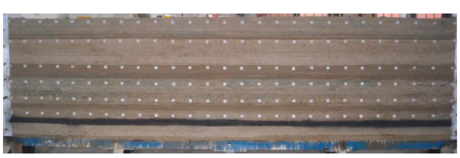

Figure 2: The image of the whole model.

width of the inclined fissure in the caving zone and the fracture zone increased in size. The caving zone developed to inferior key strata 3 and reached its maximum height, while the fracture zone developed into the bedrock carried by inferior key strata 3. Thus, when the working face was advanced to 165 m (Figure 3(f)), the immediate roof reversed and instability occurred; the inclined fissure width of the gob boundary reached its maximum extent, and both inclined and horizontal fissures closed completely. When the working face advanced to 180 m (Figure 3(g)), the fissures developed to the top of the bedrock, and the two-zone failure mode reached its maximum height. At this time, the key strata in the caving zone formed a cantilever beam and formed a voussoir beam structure in the fracture zone. During the continuous working face process, the key strata within these "two-zone" failure modes were passed up with a cantilever beam.

3. Evolution and Development of Two-Zone Failure Mode

3.1. Analysis of Evolution Characteristics of Two-Zone Failure Mode. The results of simulations test reveal that division between the two zones is determined by the structure of the key strata. However, because of the large mining space and thin bedrock, the low key strata of the cantilever beam broke. Because of the large rotation angle, the low key strata could not form a stable structure under the mining conditions of the shallow buried thick coal seam and ultimately collapsed in the gob, which formed the caving zone. In contrast, the high key strata developed into a fracture zone; the collapse of the high key strata of voussoir beam structure meant that fissures were also transformed into the caving zone. Figure 4 shows the evolution process of the two-zone failure mode with the advancement of the working face; according to this test process, this process can be subdivided into four stages, as follows:

(1) The two-zone failure mode gestation stage: at the start of the mining, the immediate roof collapses and forms a caving zone. There is no obvious fracture zone in the overburden; at this time, the height of the two-zone failure mode is roughly equal to the height of the caving zone.

(2) The two-zone failure mode formation stage: when the working face further advances and the mining range increases, there are two obvious zones in the overburden strata and the height of the caving zone does not significantly change, but the fracture zone increases obviously. The two zones do not reach the maximum height because the working face has not reached critical mining.

(3) The two-zone failure mode transformation stage: with the working face advancement, the key strata of the fracture zone voussoir beam structure are unstable and collapse, and the fracture zone becomes the caving zone. The height of the fracture zone sharply increases during the transformation period. In the last stage of the two-zone transformation, the caving zone height is basically stable, and the height of the fracture zone rapidly increases and exceeds its previous period height. Throughout the period, the height of the two-zone failure mode linearly increases.

(4) The two-zone failure mode stabilization stage: when critical mining is achieved, the caving zone and fracture zone reach the maximum height and remain stable. The two-zone failure mode develops to the surface. When the face continues to advance, the cantilever beam and voussoir beam structures in the caving zone and fracture zone periodically move toward the working face.

Table 1: Physical and mechanical parameters of the model.

No.	Histogram	Compressive strength (MPa)	Modulus of elasticity (GPa)	Poisson's ratio	Compressive strength of model (kPa)
1	Aeolian sand	11.6	12	0.30	69.6
2	Clay	15.3	20	0.30	91.8
3	Gritstone	36.6	35	0.25	219.6
4	Sandy mudstone	22.8	23	0.28	219.6
5	Siltstone	40.6	35	0.25	243.6
6	Mean-grained sandstone	45.3	33	0.28	271.8
7	Fine-grained sandstone	44.6	32	0.28	267.6
8	Coal seam	10.5	15	0.35	63

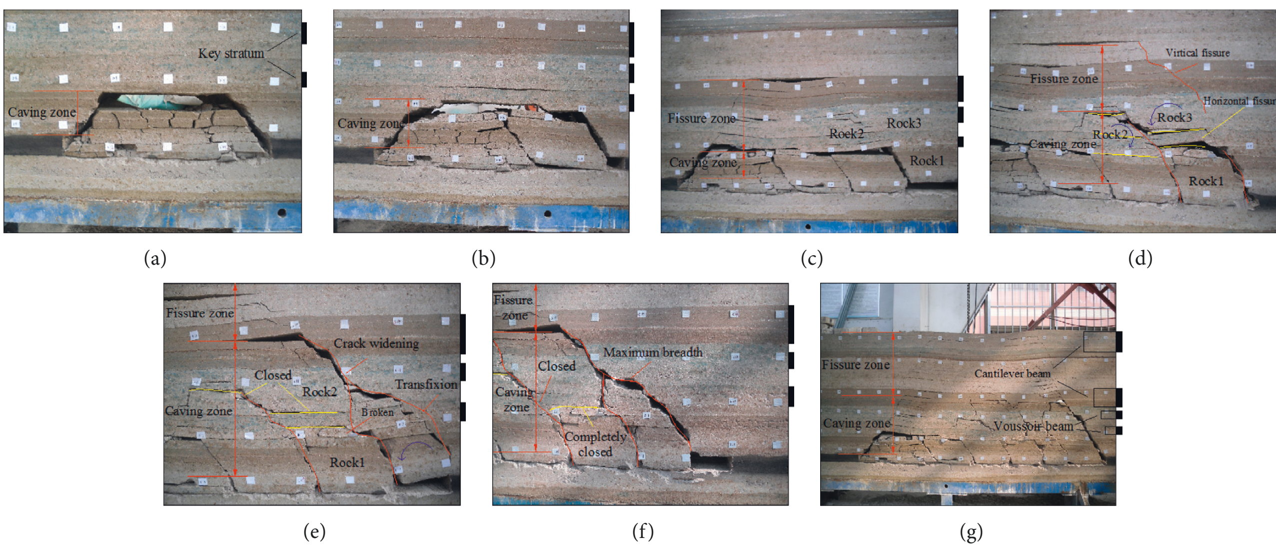

Figure 3: The evolution process of "two zone." (a) 60 m. (b) 90 m. (c) 135 m. (d) 135 m, after 10 minutes. (e) 50 m. (f) 165 m. (g) 180 m

3.2. Evolutionary Characteristics of Overburden Fissures. The fissures in the two-zone failure mode of overburden strata are mainly horizontal fissures and inclined fissures (Figure 4). These cracks separate the fracture zone from the caving zone. When the key strata of voussoir beam achieve achieves critical instability, the fissure width is the largest, and the cracks begin to close after the collapse. When the face continues to advance, the rock in the caving zone is further compacted, and the fissures are connected. According to the formation location and reasons, the inclined fissures can be divided into inclined fissures in the caving zone and those in the fracture zone. The inclined fissure of the fracture zone belongs to the voussoir beam structure fissure, and the inclined fissure of the caving zone refers to the fissure between the caving rock and the working coal wall. This has maximum aperture when it forms and closes after periodic weighting. The inclined fracture of the caving zone and fracture zone in the gob boundary is a permanent fissure and penetrates to the surface, which is the main channel of water bursting and sand inrush in the working face and requires artificial filling.

3.3. Field Observations of Overburden Fissures. The rock movement deformation and failure in the two-zone failure mode of the 22407 working face in Halagou Coal Mine were not directly observed, but the evolution characteristics of two-zone failure mode was obtained from the development characteristics of surface fractures. In the field investigation, there were many tensile fractures on the ground surface above the gob of 22407 working face, which was caused by the bedrock fracture and different deformations of the surface loose layer. There were notably few subsidence cracks on the ground surface above the working face, which indicates that the caving zone did not develop to the surface. As shown in Figure 5(a), such fractures mainly develop in the working face direction. Some cracks were sliding cracks because of the effect of topography, which mainly developed on the slopes with larger slopes in the surface, as shown in Figure 5(b). When the working face advances, the downhole workers found that aeolian sand had broken into the mine working face, and the ventilation rate at the working face increased, which showed that the inclined fissures in the fracture zone and caving zone propagated to the surface. Through multiple observations of multiple cracks, it was found that the crack in the gob area eventually closes itself, and the gob area boundary was a persistent fracture. The observed results of the surface cracks were consistent with the experimental results.

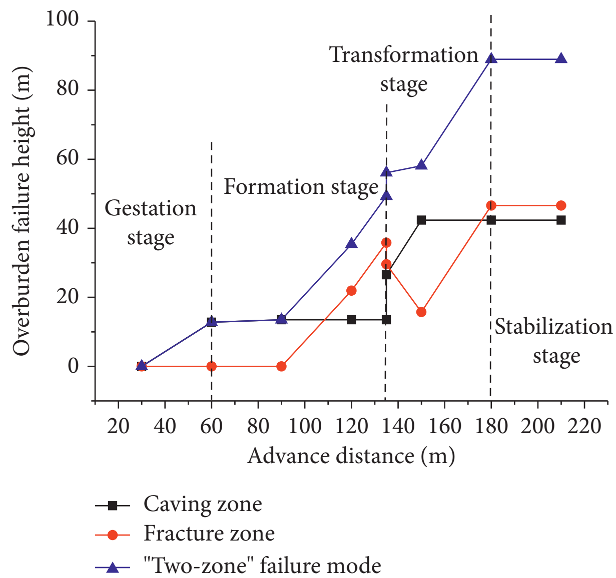

FIGURE 4: The evolution process of the two-zone failure mode with working face moving.

(a) (b) (c)

FIGURE 5: The surface cracks of 22407 working face and physical model.

4. Mechanical Analysis of the Evolutionary Process of Two-Zone Failure Mode

4.1. Mechanical Analysis. The physical simulation process shows that, under the high-intensity mining conditions of the shallow thick coal seam, the cantilever beam is formed in the low key strata after the working face breaks in the initial stage; then, the caving zone is formed. Because of the expansibility of the rock mass, the high key strata can break down to form the voussoir beam structure. With the advance of the working face, if the voussoir beam structure breaks, the fracture zone is transformed into the caving zone; otherwise, the fracture zone continues to exist. Thus, the mechanical model of the two-zone failure mode in shallow thick coal seam high-intensity mining was established.

The cantilever beam structure forms in the low key strata in the caving zone above the coal seam, and voussoir structure is observed in the high-level key strata in the fracture zone, as shown in Figure 6.

Thus, when the maximum stress of the lower key strata is greater than allowable stress, the total rock mass becomes unstable, as follows:

$$\begin{aligned} &\sigma_{O_1\,\max} \geq [\sigma], \\ &\text{or } \tau_{O_2\,\max} \geq [\tau], \end{aligned} \tag{1}$$

where $\sigma_{O_1\,\max}$ (kPa) was the bending tensile stress of lower key layer behind the fixed end of the O_1 point and $\tau_{O_2\,\max}$ was the bending shear stress of the O_2 point on the neutral axis of the critical section:

$$\begin{aligned} \sigma_{O_1\,\max} &= \frac{M_{O_1}}{W_z} = \frac{3(q+k_1)l_1^2}{bh^2}, \\ \tau_{O_2\,\max} &= \frac{F_S S_z^*}{I_z b} = \frac{3(q+k_1)l_1}{2hb}, \end{aligned} \tag{2}$$

where M_{O_1} (kN/m) refers to the constraint moment at the O_1 point, while W_z is the flexural section coefficient, F_S (kN) the cross-sectional shear force, S_z^* (m) denotes the static

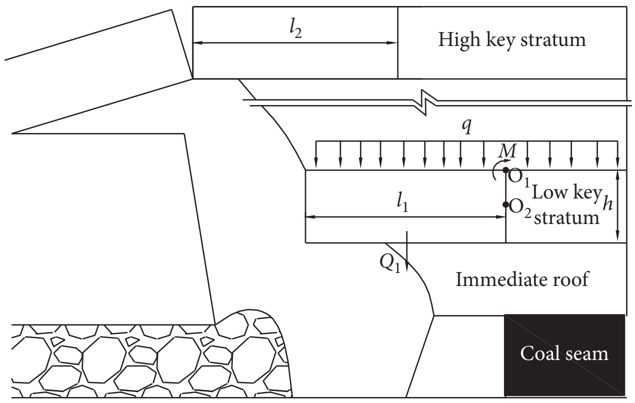

FIGURE 6: Mechanical model of “two-zone” failure mode evolution (I).

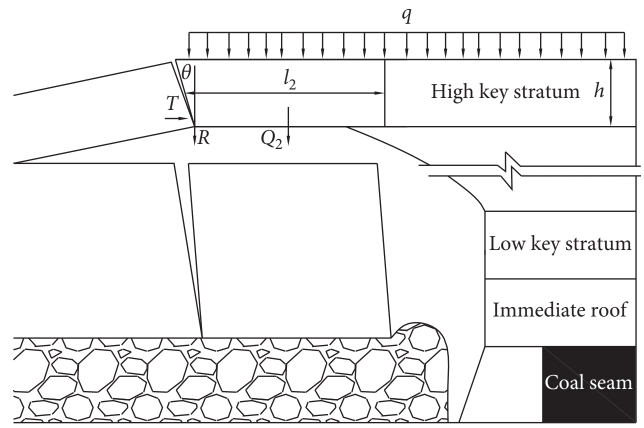

FIGURE 7: Mechanical model of “two-zone” failure mode evolution (II).

distance, and k_1 is the constant. Thus, $k_1 = Q_1/l_1$, b (m) is the length of the mine working face (m) as follows:

$$l_1 \geq \sqrt{\frac{bh^2}{3(q+k_1)}[\sigma]},$$
$$\text{or } l_1 \geq \frac{2hb}{3(q+k_1)}[\tau]. \tag{3}$$

Note that the low key strata cantilever beam will break and fall when it reaches breaking distance.

In this model, the high key strata forms a voussoir beam structure. Thus, as shown in Figure 7, the slipping instability condition can be expressed in this case as follows:

$$\frac{R}{T} \geq \tan(\varphi + \theta), \tag{4}$$

where R (kN) is the shear force at the occlusal point, $R = ((q + k_2)l_2)/2$, T (kN) is the horizontal force, $T = ((q + k_2)l_2^2)/8h$, φ is the internal friction angle, and θ is the fracture angle:

$$\frac{h}{l_2} \geq \frac{\tan(\varphi + \theta)}{4}. \tag{5}$$

Thus, when the ratio of length to height in a high key strata suspended rock mass conforms with equation (5), it would become unstable and collapse. The key strata will therefore be transformed into a cantilever beam structure, while the fracture zone will transform into the caving zone.

4.2. Overburden Fissure Width Calculation. In shallow thick coal mining, the overburden failure mode cracks sometimes penetrate into the surface. These cracks are the channels of water in flow and sand inrush, which endanger the working face. To calculate the failure mode of fracture aperture, a calculation model was established, as shown in Figure 8.

A horizontal fissure within the two-zone failure mode refers to cracks between articulated blocks and the collapse rock. Thus, the maximum width of a fracture, x, will be approximately equal to the amount of articulated rock block subsidence as follows:

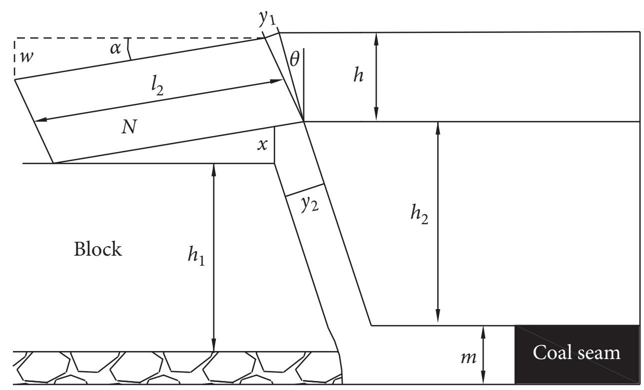

FIGURE 8: The calculation of overburden strata fissure width.

$$x = w = m - (K-1)\sum h, \tag{6}$$

where $\sum h$ denotes the thickness of a caving stratum, while m (m) is the mining height, and K is the bulking factor of the rock.

y_1 (m) refers to the width of inclined fissure. The articulated point is therefore located at the lower end of the fracture between the two rocks and conforms to the geometric relationship of the voussoir beam structure in the key strata as follows:

$$y_1 = \frac{\sqrt{2}h}{\cos\theta}\sqrt{1-\cos\alpha}, \tag{7}$$

where α (degree) denotes the maximum rotation angle of rock mass, $\sin\alpha = w/l_2 \cdot y_2$ (m) refers to the inclined fissure aperture of the caving zone. Therefore, the geometric contact relationship of rock mass rotation will be as follows:

$$y_2 = w\sin\theta = \left[m - \left(K_p - 1\right)\sum h\right]\sin\theta. \tag{8}$$

5. Analysis of Factors Underlying the Evolution of Two-Zone Failure Mode

5.1. Underlying Factors. On the basis of the physical simulation experiment presented in this paper, it is clear that mining height determines the size of the turning space. In other words, the height of the caving zone is higher in large mining height working faces, while in the case of a more general mining height, a key strata of articulated balance structure could form. Similarly, in the case of large mining height, a stable voussoir beam structure would be unable to form because of large rotation instead developed as a cantilever beam structure and immediately collapsed. A thicker key stratum can form a stable voussoir beam structure [19].

The key strata types of overburden in Northwest Mining Area are mainly multiple key strata structure and composite single key strata structure [20]. When compared with the overburden strata with multiple key strata, the composite single key strata structure is thicker. The overburden generally has two obvious zones after coal mining. When the overburden strata are with multiple key strata structures, the inferior key strata near the coal seam tend to collapse and form a cantilever beam after forming a voussoir beam structure during the upward transition of the caving zone. This process is a two-zone failure mode conversion transformation. When the overburden stratum is a composite single key layer structure, the breakage of the key layer near the coal seam will make all rock break. Whether there is a transformation in the process of two-zone failure mode depends on whether the structure is a stable voussoir beam structure.

In summary, the mining height and key strata structure are two main factors that affect the evolution of the two-zone failure mode of overburden strata.

5.2. Influence of Mining Height and Key Strata Structure on the Evolution of Two-Zone Failure Mode. To further study the effects of the mining height and key strata structure on the evolution mechanism of the two-zone failure mode, based on the stratum data of the 22407 working face of Halagou coal mine and the 1203 working face of Daliuta coal mine [20], the UDEC numerical simulation software was used to analyse the two-zone failure mode with the unit tensile failure as the overburden fissure judgement criterion. The 22407 working face was a multiple key strata structure, and the 1203 working face was a composite single key strata structure. The height of two-zone failure mode was determined for different advancing distances of 2 types of different key strata structure and mining height (5.3 m and 3 m).

When the overburden was a multiple key strata structure and the mining heights were 5.3 m and 3.0 m (Figures 9(a), and 9(b)), the evolutionary processes of the two-zone failure mode were similar. When the working face was advanced to 90 m, the two-zone failure mode was formed. When the working face was advanced to 120~180 m, the two-zone failure mode was transformed. When the mining height was 5.3 m, inferior key strata 1 of the fracture zone fell to inferior key strata 3, which was converted into the caving zone. When the mining height was 3.0 m, inferior key strata 1 in the fracture zone and its following layer were converted into the caving zone. When the working surface was advanced to 180 m, the two-zone failure mode height was stable. When the overburden strata were a composite single-layer structure and the mining heights were 5.3 m and 3.0 m (Figures 9(c), and 9(d)), the evolutionary process of the two-zone failure mode was obviously different. When the working face was advanced to 30 m, the two-zone failure mode was formed. When the working face was advanced to 60 m and the mining height was 5.3 m, the primary key strata and their overburden strata formed a fracture zone. When the mining height was 3.0 m, the primary key strata did not break, so there was a two-zone failure mode below the primary key strata. When the mining height was 5.3 m, the primary key strata were unstable, and the caving zone developed to the surface. When the mining height was 3.0 m, the primary key strata broke and formed a stable voussoir beam structure, the primary key strata broke below the formed caving zone, and the primary key strata broke and their superficial follower layer formed the fracture zone.

There was great difference between the evolution processes of the two-zone failure mode when the mining height was identical but the overburden strata key layer structure was different (Figure 9). In the transformation process, the height of the two-zone failure mode basically linearly increased in the multiple key strata structure. However, the height of the caving zone and fracture zone discontinuously increased or decreased in the structure of composite single key strata structure. The reasons are that some inferior key strata near the coal seam in the multiple key strata structure were independently broken. The overburden in the caving zone and fracture zone developed orderly as the cantilever beam and voussoir beam structure, respectively. In the composite single key strata structure, the primary key strata near the coal seam broke first, and the overburden follower layer subsequently broke. When the mining height was higher, the primary key strata could not form a stable cantilever beam structure after breaking. The primary key strata and its bearing strata were transformed into the caving zone, and the caving zone was developed to the surface. In contrast, when the mining height was lower, the primary key strata layer could form a stable cantilever beam structure. The main key layer and its overburden strata did not experience a two-zone failure mode transformation, and the caving zone developed to the lower part of the primary key strata.

In summary, the mining height and key strata structure are important factors that affect the overburden strata two-zone failure mode evolution. In addition, the the evolution process of the two-zone failure mode of overburden strata varies with different key strata numbers, positions, and mining heights, but the evolution form and mechanism of the two-zone failure mode are similar, which is not presented in this paper because of limited space.

6. Conclusions

(1) The results of this study reveal the processes of four evolutionary periods for the two-zone failure mode under shallow thick seam mining, gestation, formation, transformation, and stabilization. During the transformation period, the fracture zone was

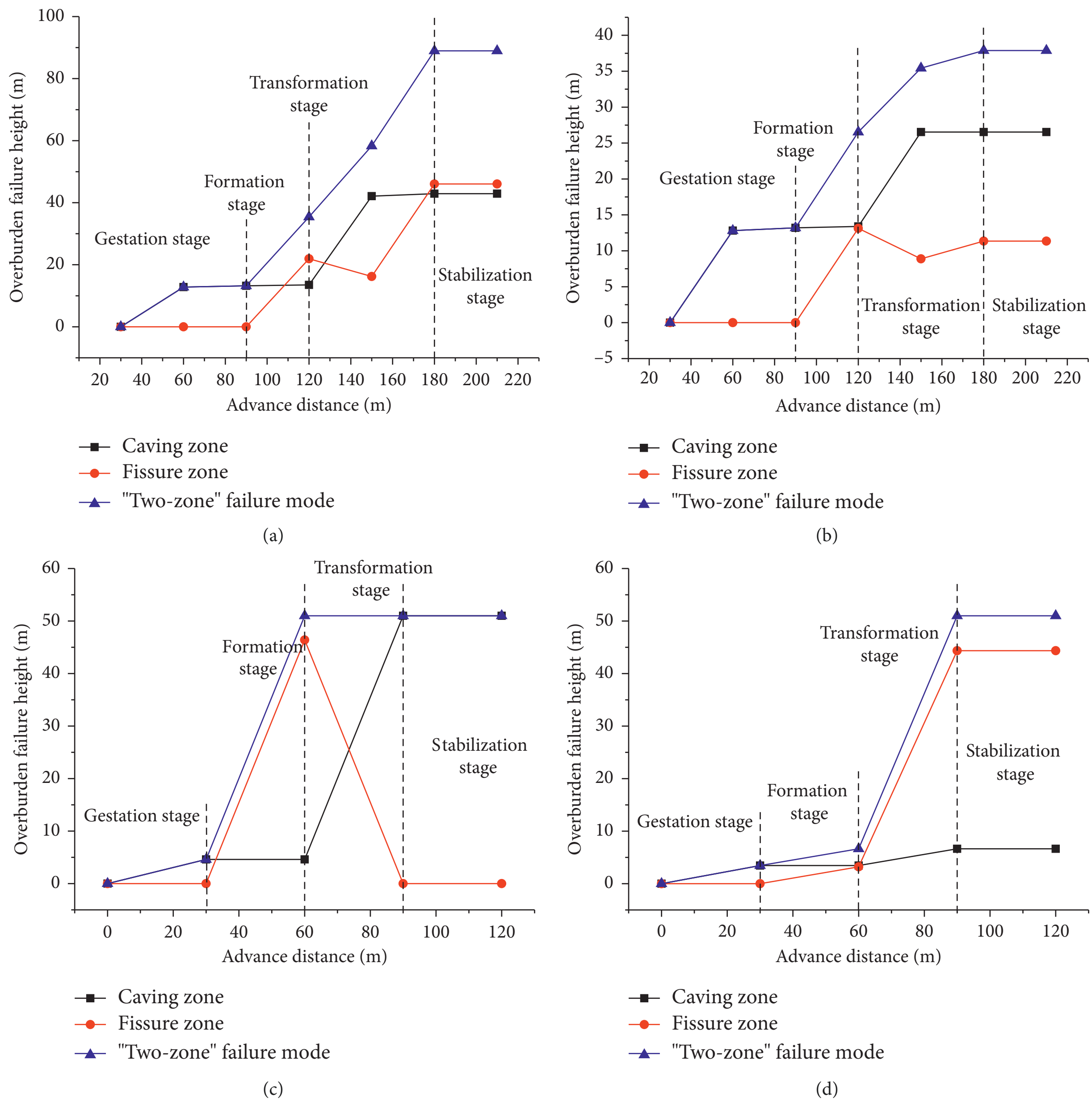

Figure 9: "Two-zone" failure mode evolution process of different key strata structure and mining height. (a) Multiple key strata structure (mining height is 5.3 m). (b) Multiple key strata structure (mining height is 3.0 m). (c) Composite single key strata structure (mining height is 5.3 m). (d) Composite single key strata structure (mining height is 3.0 m).

transformed into the caving zone and its height increased sharply. Cracks in the gob during this period would close eventually, while those in the gob boundary became permanent and provided the main path for water bursting and sand inrush to the working face.

(2) A mechanical model for the evolution of two-zone failure mode overburden strata was established. The conditions of two-zone failure mode transformation were analysed and a calculation method to determine inclined fissure and horizontal fissure width was proposed.

(3) The author introduced the factors that influence the evolution of the two-zone failure mode of overburden strata and analysed the mechanism of the mining height and key strata structure on the two-zone failure mode evolution. The failure law and mechanism of overburden strata obtained from the study are of great significance for ensuring safe mining of shallow and thick coal seam.

Data Availability

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

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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