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Evolution Characteristics of Overburden Strata Structure for Ultra-Thick Coal Seam Multi-Layer Mining in Xinjiang East Junggar Basin

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Abstract: The efficient and safe extraction of ultra-thick coal seam in the Xinjiang East Junggar Basin has been a major focus in the future of mining in China. This paper systematically studied the overburden strata fracturing process and the structure evolution characteristics based on a typical ultra-thick coal seam condition in Xinjiang, using both physical and numerical modeling studies. The interactions between shields and the roof strata were also examined, from the perspective of ground support. The results indicated that roof structure was mainly in the form of voussoir beam at the early mining stage, where overburden stability was affected by the rock mass properties and mining parameters. The support load mainly included top coal and immediate roof gravity load and the load caused by main roof rotary consolidation. As a result of mining disturbance and strata movement, the overlying strata re-fractured in the later mining stage. The roof structure changed from beam to arch gradually and propagates upwards with the increase of multi-layer mining times. The support load was mainly the gravity load of the friable rock mass within compression arch. The results will provide a guideline for the improvement of roof stability under similar mining conditions in Xinjiang.

Keywords: ultra-thick coal seam; multi-layer mining; overlying strata structure; shield and surrounding rock interaction

1. Introduction

Coal mining in China has recently rapidly expended from eastern to western regions, where the environment is significantly more sensitive to mining. Xinjiang is one of the 14 coal regions in China, which has been prioritised for the explorations with reserves nearly billion tonnes respectively, and it has four major coalfields within the area, being East Junggar, Ili, Turpan-Harmi and Kuqa-Bay Coalfields. The presence of thick coal seams, which are usually more than 20 m thick, is an important feature in these coalfields [1]. For example, in East Junggar Coalfield, a single seam with thickness more than 80 m has been reported, and there is a ultra-thick coal seam in Shaerhu Coalfield, with thickness more than 200 m. Therefore, in the future of Chinese coal mining, the efficient and safe extraction of ultra-thick coal seam has been a major focus.

It is generally believed that the formation of ultra-thick coal seam has experienced multiple sedimentary discontinuities, and it is an integration of multiple coal seams [2]. In recent years, a large amount of researches have been conducted focusing on the stress redistribution characteristics [3,4] and mining-induced movement of overlying strata [5,6], and safe mining techniques [7,8] associated with ultra-thick coal seam mining. It has resulted in an improvement in the understanding of ultra-thick coal seam mining, and the relevant results are mainly categorised into two aspects:

(1) The stress redistribution within the overburden strata and the associated strata instability characteristics induced by ultra-thick coal seam mining based on practical experience. Jeromel et al. [9] and Jakob et al. [10] studied the stress redistribution characteristics in multi-slice longwall top coal caving and quantified the vertical stress under different mining retreat speed and at varying mining layer thicknesses, which has been successfully used for the determination of reasonable mining parameters in ultra-thick coal seam mining. Islam et al. [11] examined the stress redistribution law and the strata failure characteristics under different rock mechanics parameters and total mining thicknesses in the multi-slice mining of ultra-thick coal seams, and concluded that the stress redistribution induced by ultra-thick coal seam extraction can result in the deformation of the geological structure, leading to the fracture network development as groundwater flow pathways. Deng et al. [12] studied the roof displacement and vertical stress changes during the upward mining of ultra-thick coal seam with backfilling. It was found that the overburden subsidence and the vertical stress gradually decreased with the increase of the number of mining layers as the extraction of the first seam has greater impact on the stability of the surrounding rock. Zarlin et al. [13,14] studied the vertical displacement and elasto-plastic zone distribution characteristics of the surrounding strata, using multi-slice room and pillar methods for ultra-thick coal seam mining. They suggested that when the coal seam is relatively weak, the multi-slice room and pillar methods can effectively control the surface subsidence.
(2) The characteristics of overburden strata and the ground control techniques for thick and competent roof strata in thick seam mining. Kang et al. [15] analyzed the characteristics of mining-induced fracture propagation in the repeated mining of thick coal seam and proposed the prediction method for the "two zones" height within the overburden, summarizing the relationship between the crack height of overburden and the seam thickness. They concluded that the increase of seam extraction layers can improve the roof control. Zhang et al. [16] studied the main characteristics of the multi-seam mining fissure field and found that the overburden failure zone of the cover rock at the coal face is shown to be saddle-like in shape, high on both sides and low at the middle, the number and width of small cracks increases with continued mining. Zhu et al. [17] analyzed overburden movement characteristics of top-coal caving mining in multi-seam areas by simulation experiment and microseismic monitoring. It is believed that coal pillars left over from upper coal seam would cause further development of overburden fractures, and that design of small coal pillars and hydraulic fracturing should be used to improve overburden stress environment. Xu et al. [18] studied the characteristics of overlying strata instability under the multi-layer mining of ultra-thick coal seam using physical modelling. It is believed that the increase of mining volume is likely to cause large-scale instability of the overlying strata, and the fracture development is mainly controlled by the key strata structure. Yu et al. [19,20] and Wang W. et al. [21] focused on the strong mine pressure in thick coal seam mining based on cases studies in Datong Mine, and revealed the relationship between the height of fracture zone in the overburden and the seam thickness. They established an empirical model for the overlying strata movements in the caving of ultra-thick coal seam; and developed an effective roof control strategy combining the use of hydraulic fracturing [22] from surface drilling and pre-conditioning of roof strata.

To date, there have been improvements in the theoretical studies and engineering practices for the characteristics of overburden failure and stress behavior in ultra-thick coal seams. However, the studies are mainly focus on the two areas as mentioned above. There are still knowledge gaps in understanding the evolution of overlying strata structure considering both timing and location, and the associated roof control technology in the multi-layer mining ultra-thick coal seams. The ground stability under the condition of large scale extraction volume of ultra-thick coal seam and the multi-mining disturbance will be a significant issue for the future mining regions in areas such as East Junggar and Turpan-Harmi.

Therefore, this paper systematically studies the structure and evolution characteristics of the overlying strata in the mining process of ultra-thick coal seam, based on the geological and mining conditions at East Junggar coalfield, Xinjiang. The results will provide a guideline for the improvement of roof stability under similar mining conditions.

2. Geological Condition at East Junggar Coalfield

The East Junggar coalfield has a forecasted resource reservation of 409.5 billion tons, including Wucaiwan, Dajing, Jiangjunmiao, Xiheishan and Laojunmiao mining regions. The locations of coal mines in the coalfield are shown in Figure 1. Currently, longwall top coal caving is mainly used mining method for the first layer extraction in the multi-layer mining of ultra-thick coal seam.

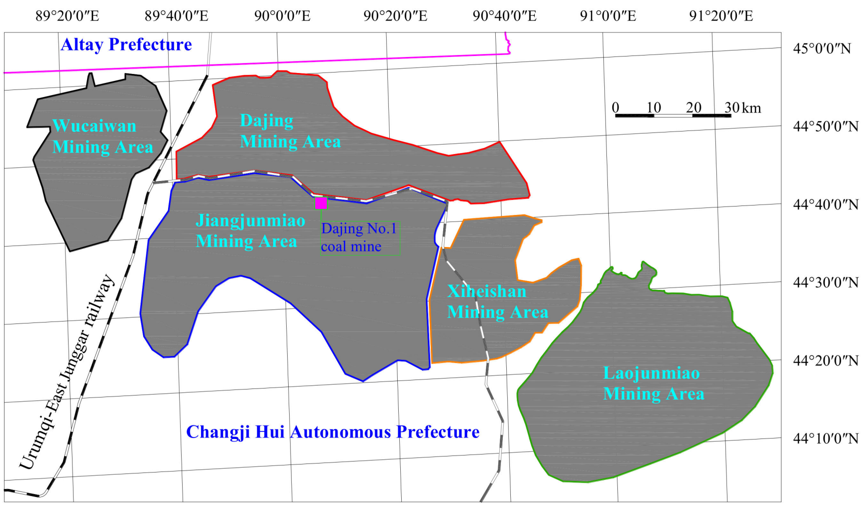


Figure 1. Locations of the main coal mines in East Junggar Coalfield.

The main coal-bearing stratums in the East Junggar coalfield are the Lower Jurassic Badaowan Formation (J_1b) and the Middle Jurassic Xishanyao Formation (J_2x). The thickness of single coal seam is 96.44 m at maximum, with an average of 43 m. The Xishanyao Group B formation is a major coal-bearing group in the East Junggar Coalfield, with an average thickness of 70 m and an dipping angle of 5~6°, and contains thin layers of mudstone. The Dajingnan N°. 1 coal mine is located at the junction of the Jiangjunmiao mining area and the Dajing mining area. It is a typical ultra-thick coal seam mine with an average overburden thickness of 310 m, and the main lithology includes siltstone, fine sandstone, and mudstone. The stratigraphy information is shown in Figure 2.

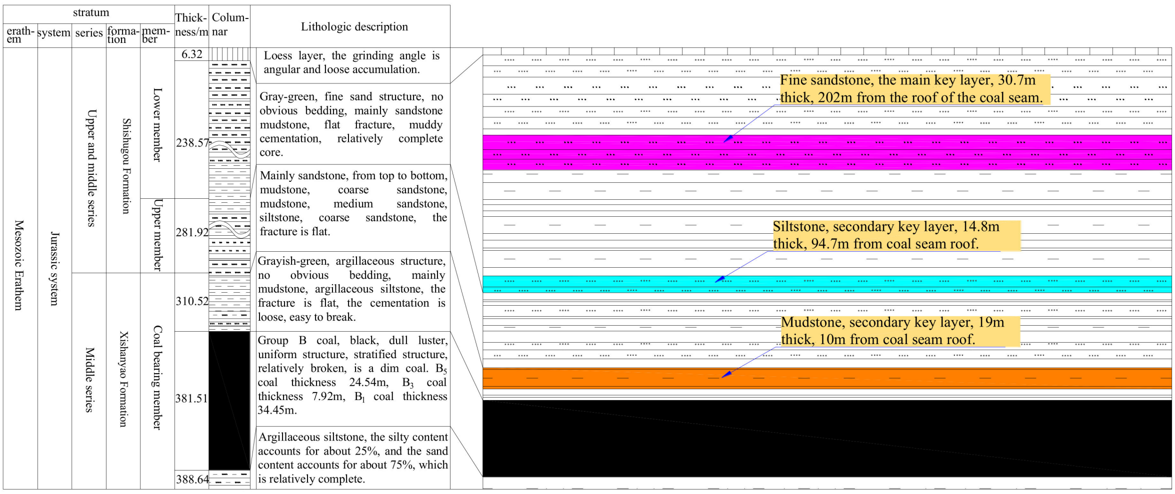


Figure 2. Stratigraphy and lithologies in the studied area.

3. Overview of the Methodology

3.1. Physical Model Setup

The physical model is constructed based on the conditions of the group B coal at the Dajingnan N°. 1 coal mine (B_1, B_3 and B_5, with total thickness 67.5 m). The overall model setup is shown in Figure 3. It has dimensions of 2.5 m (length) by 0.2 m (width) by 1.62 m (height), with the geometric ratio of 1:240 (model to in situ). There are 92.5 m boundary pillars at both ends of the model to minimize the boundary effects. The length of the simulated coal seam is 415 m and the overburden thickness is 310 m. The overburden lithology is dominated by fine sandstone and mudstone. The uniaxial compressive strength of fine sandstone is 17.46 MPa, the cohesive is 1.81 MPa, and the uniaxial compressive strength of mudstone is 14.21 MPa, and the cohesive force is 1.41 MPa.

With reference to the current mining methods in the area, multi-layer extractions are simulated in seven layers. The first six layers are mined with a thickness of 10 m, and the seventh layer is 7.5 m thick.

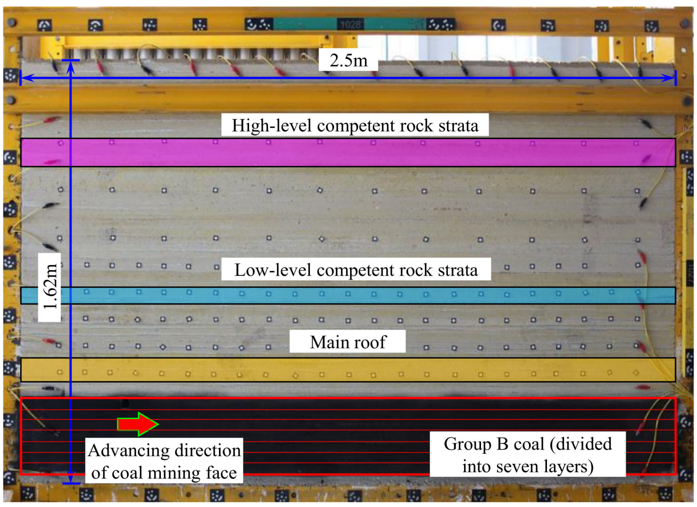


Figure 3. The physical model built for the analyses of ultra-thick coal seam mining.

3.2. Numerical Model Setup

The 2D Discrete Element Modeling (DEM) code Universal Distinct Element Code (UDEC, Itasca Consulting Group, Inc., Minneapolis, Minnesota, USA) is used for the numerical modelling analysis to analyze the characteristics of overburden activities and stress changes in the mining process, due to its capability in representing the behavior of discrete rock mass in the overburden strata. The model size is 800 m by 382 m, with coal seam thickness being 67.5 m. The boundary conditions are shown in Figure 4, where the side and bottom boundary displacement are constrained, and the upper boundary is representing the free surface. Mechanical parameters of coal and rock are shown in Table 1. There are 100 m wide barrier pillar left to minimize the boundary effects. Stress monitoring line is placed in the competent strata layers at 19 m, 102 m and 216 m above the seam, with 61 monitoring points on each line at an interval of 10m. A total of 600 m of each multi-layer is extracted, and after each excavation is completed, the corresponding data is exported for processing. The model is calibrated according to the surface subsidence range and maximum subsidence value after the first layer mining

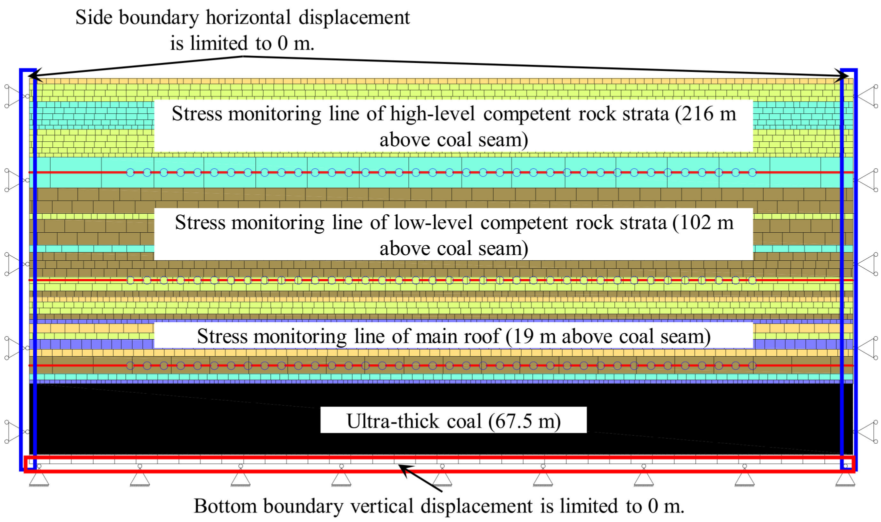


Figure 4. The UDEC model for ultra-thick seam coal mining.

Table 1. Mechanical parameters of coal and rock mass.

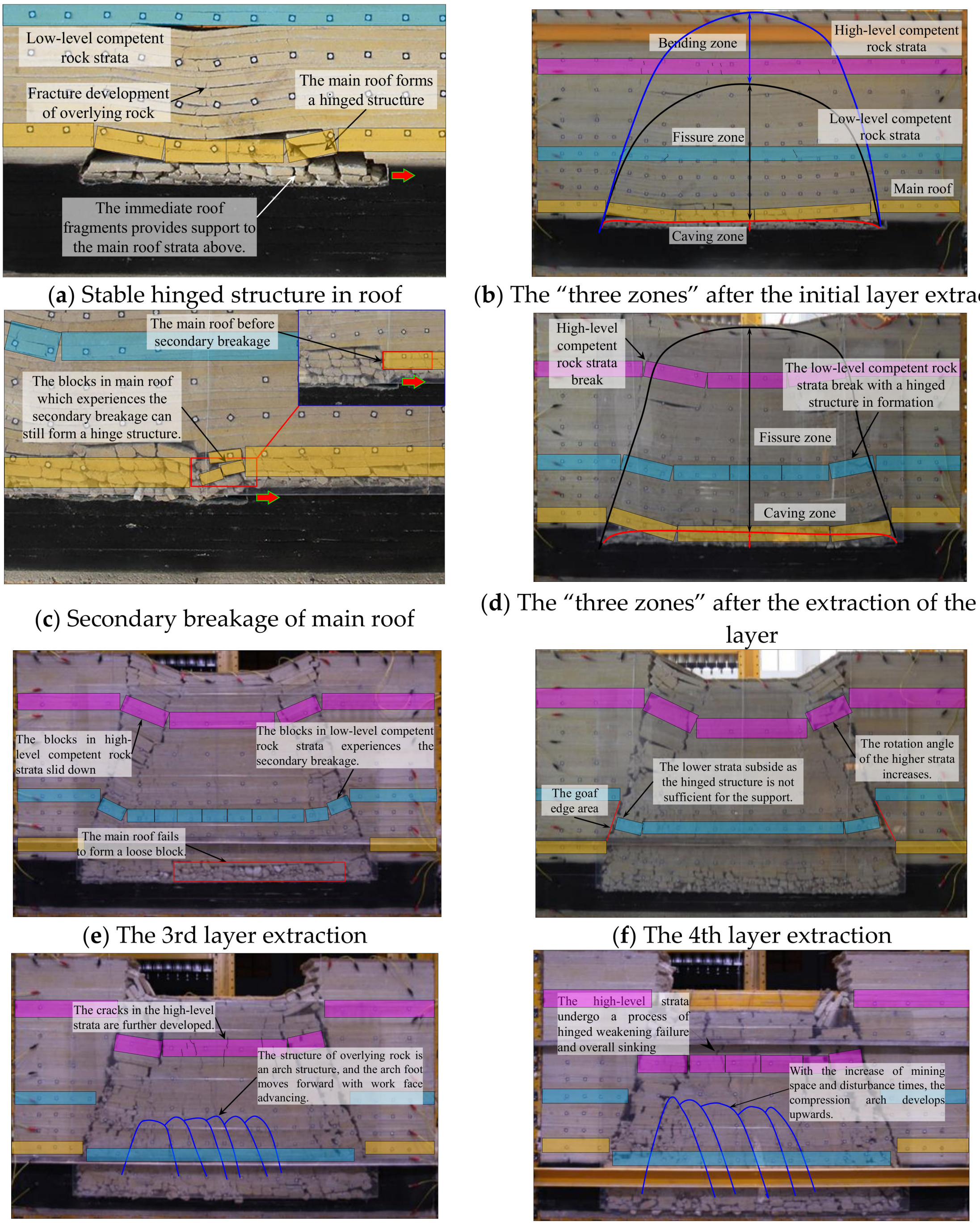
Item	Volumetric Weight/kN·m^{-3}	Tensile Strength/MPa	Compressive Strength/MPa	Internal Friction Angle/°	Cohesion/MPa
fine sandstone	2.19	0.95	17.46	36.44	1.81
gritstone	2.10	0.81	14.14	39.21	1.13
siltstone	2.22	1.02	17.58	37.91	1.76
coal	1.21	0.67	6.38	39.86	0.8
mudstone	2.28	0.70	14.21	37.73	1.41
medium sandstone	2.08	0.83	11.12	39.14	1.06

3.3. The Failure Features of Overburden

3.3.1. Strata Failure Process

The process of fracture development within the overlying strata in ultra-thick coal seam mining is shown in Figure 5. In the first layer extraction process, the immediate roof fragments provides support to the main roof strata above, and the main roof forms a hinged structure, which limits the movement space of the overlying rock formation further up to a certain extent (as shown in Figure 5a); The distribution of overlying rock "three zone" (caving zone, fissure zone and bending zone) is shown in Figure 5b. During the second layer mining process, the blocks in main roof rotates back to the goaf and the secondary breakage occurs, where the broken rock can still form a hinge structure (as shown in Figure 5c). The low-level competent rock strata break with a hinged structure in formation, and the fractured network propagates upwards to the surface (as shown in Figure 5d). In the third layer mining process, the main roof which experiences the secondary breakage fragments further and the articulation weakens and fails to form loose blocks. The rotation angle of the lower strata increases thus the secondary fracture occurs. The main roof in higher position slid down (as shown in Figure 5e).

During the fourth layer mining process, the main roof collapses during the mining process. The lower strata subside as the hinged structure is not sufficient for the support, in the goaf edge area; similarly, the rotation angle of the higher strata increases (as shown in Figure 5f). During the extraction of the fifth layer and the remaining seam, the cracks in the low-level strata are further developed, and the high-level strata undergo a process of hinged weakening failure and overall sinking (Figure 5g,h). In summary, in the process of ultra-thick coal seam mining, the fracture characteristics of the competent rock strata have an obvious pattern of "first breakage with hinged beam structure—second breakage with hinge weakening—multiple disturbance leading to structural instability".

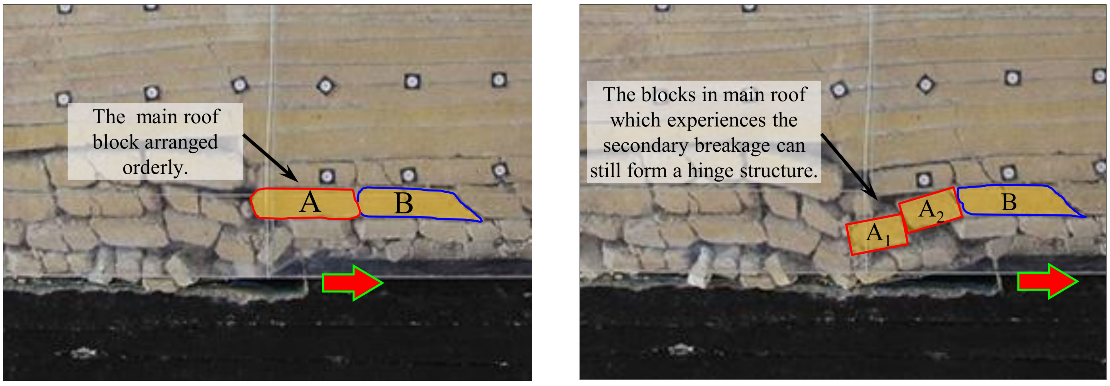


(**a**) Stable hinged structure in roof
(**b**) The "three zones" after the initial layer extraction
(**c**) Secondary breakage of main roof
(**d**) The "three zones" after the extraction of the 2nd layer
(**e**) The 3rd layer extraction
(**f**) The 4th layer extraction
(**g**) The 5th layer extraction
(**h**) The 7th layer extraction

Figure 5. Overburden rock mass failure at different mining stages.

3.3.2. The Secondary Break

The experiment results indicate that during the multi-layer mining of ultra-thick coal seam, the competent rock mass strata breaks twice under the effect of large-scale mining volume and repeated disturbances. The secondary fracture process of the main roof during the second layer mining is shown in Figure 6. The main roof block A is in close contact with the blocks on both sides when the longwall is retreated underneath, as shown in Figure 6a. When the longwall face is advanced away from block A, it gradually rotates towards the goaf and breaks into sub-blocks A_1 and A_2, which still form a hinged structure with rock block B, as shown in Figure 6b. As the longwall retreat further ahead, blocks A_1 and A_2 consolidates in the goaf.



(**a**) Before the secondary breakage of main roof (**b**) After the secondary breakage of main roof

Figure 6. The secondary breakage process of the main roof.

3.4. The Structural Evolution of the Overburden Strata

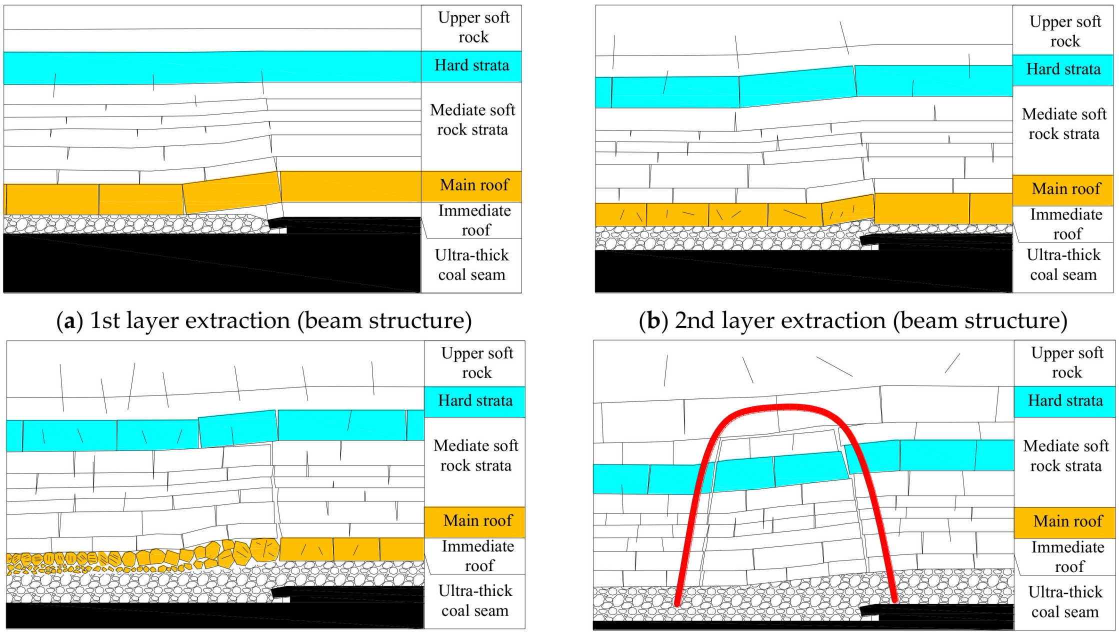
The physical modelling shows that in the process of multi-layer mining of ultra-thick coal seam, the overburden strata evolved from a voussoir beam structure to an arched structure, and the evolution process is shown in Figure 7.

During the extraction of the first and second layer, the overlying structure of the working face forms a voussoir beam structure. As the first layer is extracted, the main roof breaks and rotates to form a voussoir beam structure to bear the overburden with the rock masses at the front and rear ends; after the working face is retreated passing the structure, the main roof blocks arranged closely in the goaf. During the second layer extraction, the main roof rock mass breaks twice and the rock within the bending zone breaks and the fractured zone develops up to the surface.

During the third and fourth layer mining, a beam structure forms at the higher part of the overburden. For the third layer mining process, the detached rock blocks in the main roof are further fractured and the hinges are weakened. After the collapse of the main roof, loose blocks were formed as results of further fragmentation. In the fourth layer mining process, the competent rock formation near the fracture line of the overburden failed with weakening hinged structure, but it still has a certain bearing capacity.

In the fifth and the rest of the layers mining, an arched structure is formed within the overburden. When the rest of the seam layers are mined, the broken rock blocks of the competent rock strata no longer provides support, and they collapse as the mining continues; however, the strata above form an arch structure under the compression effect from the adjacent blocks.

In the process of these multi-layers mining of ultra-thick coal seam, the overlying strata structure shows the evolution process of "beam structure-higher beam structure-arch structure". The induced stress on the face changes as the presence of these varying overburden structures. Therefore, it is necessary to clear understand the mechanism of the overlying structure evolution, prior to the implementation of ground support in the ultra-thick coal seam.



(**a**) 1st layer extraction (beam structure) (**b**) 2nd layer extraction (beam structure)

(**c**) 3rd layer extraction (higher beam structure) (**d**) 5th layer extraction (arch structure)

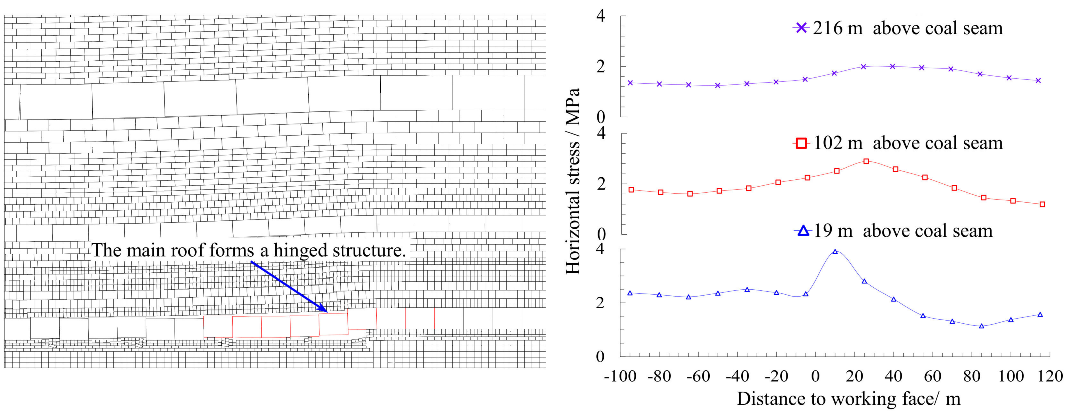
Figure 7. Change of structures in the overburden at different mining stages.

3.5. Mechanisms Contributing to the Change of the Overburden Structure

This section focuses on the causing mechanisms contributing the failure pattern as descried in the previous section, through stress analysis and the stability assessment of the overburden strata.

3.5.1. Stress Redistribution Characteristics in the Roof

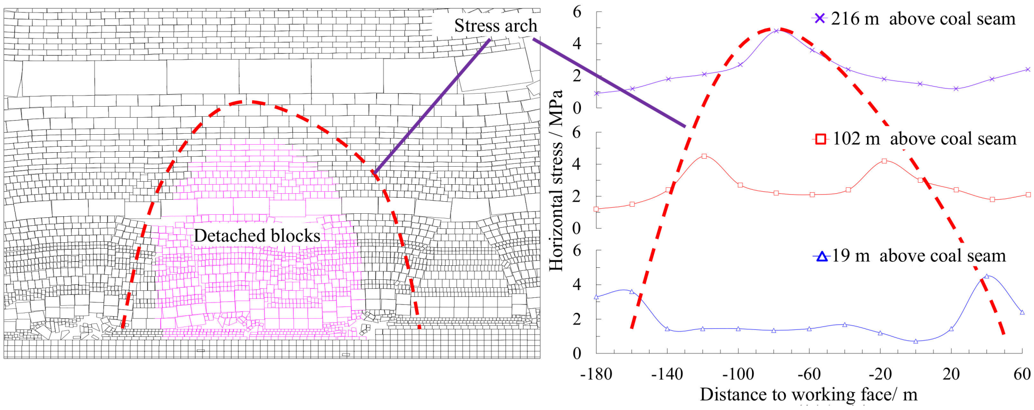
According to the results of numerical simulation, during the early mining stage (the first layer extraction) of the ultra-thick coal seam, the rock blocks in the main roof are subjected to the overburden loading, and the horizontal stress redistribution characteristics are the same as other thick coal seams (Figure 8). There is a horizontal stress concentration in the main roof 10 m in front of the longwall face, with peak value is 3.91 MPa, which is 170% of the in site horizontal stress (2.3 MPa). As the height of the roof increases, the horizontal stress value and the magnitude of change gradually decrease.



(**a**) Strata structure (**b**) Horizontal stress distribution

Figure 8. The failure pattern and stress measurements for the overburden after the 1st layer extraction.

The overlying strata structure and horizontal stress curve at the later mining stage (the fifth layer extraction) is shown in Figure 9. At this time, the overlying strata in the overburden are changed from a beam structure to an arch structure, and the weight of the overlying strata is transferred to the arch feet, forming stress arches in the overburden. The rock mass in the arch is in forms of detached blocks, and the horizontal stress is reduced to 1.2–1.5 MPa, which is 52.17%–65.22% of the initial horizontal stress. The rock mass at the foot of the arch extrude to each other, inducing more horizontal stress with the peak value of 4.8 MPa, which is 2.09 times of the initial horizontal stress. Similarly, with the increase of the height of the roof strata, the arch width gradually decreases.



(**a**) Strata structure (**b**) Horizontal stress distribution

Figure 9. The failure pattern and stress measurements for the overburden after the 5th layer extraction.

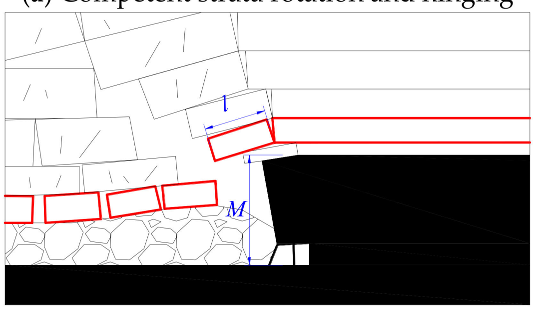
3.5.2. Beam structure stability analysis

Based on the key strata theory and voussoir beam theory, the influencing factors of structural stability of overlying strata of thick coal seams are studied in this section.

(a) Rotation angle

During the first layer extraction of an ultra-thick coal seam, the rotation of roof fractured strata is shown in Figure 10.

(**a**) Competent strata rotation and hinging



(**b**) Competent strata rotation

Figure 10. Rock block rotation after the 1st layer extraction.

The rotation angle of the fracture rock block can be derived from Figure 10 as

$$\sin\beta = \frac{1}{l}\left[M - \sum h\left(K_p - 1\right)\right] \quad (1)$$

where K_p is the expansion coefficient of the collapse zone; l is the length of the failed block; M is the extraction seam thickness at each mining stage; $\sum h$ is the height of the collapsed zones in overburden.

If the layer mining height is relatively large, there is a situation in which rock falls into the goaf, failing to form a three-hinged arch structure, and the bearing layer collapses, as shown in Figure 10b. The rotation angle of the rock block in the remaining stratified extraction process can be calculated by formula (2).

$$\sin\beta = \frac{1}{l}\left[\sum M - \sum h_1\left(K_{p'} - 1\right) - \sum h_2\left(K_{p''} - 1\right)\right] \quad (2)$$

where β is the rotation angle of the detached block; $\sum M$ is the total thickness of coal seam [m]; $\sum h_1$ is the height of the collapse zone below the competent [m]; $K_{p'}$ is the residual expansion coefficient; $\sum h_2$ is the height of the fracture zone below the hard rock [m]; $K_{p''}$ is the expansion coefficient of the fracture zone.

(b) Beam structural stability factors

According to the "S-R" stability theory of voussoir beam structure, when there are no shear slip and deformation on the failed rock block, the structure remains stable.

The fractured block needs to meet the requirements of Equation (3) to avoid shear slip type of failure.

$$h/l \leq \frac{1}{2}\tan\varphi \quad (3)$$

$$l_1 = h\sqrt{\frac{2R_t}{q_1}} \quad (4)$$

$$l_2 = h\sqrt{\frac{R_t}{3q_2}} \quad (5)$$

where h is the thickness of the rock strata [m]; l is the length of the rock strata [m]; φ is the friction angle of the contacts [°]. The length l of the broken rock mass in the first stratified mining and the rest of layer mining can be calculated according to Equations (4) and (5), respectively, where l_1 is weighting distance of the competent roof in the first stratified mining [m]; q_1 is stress acting on the strata [MPa]; R_t is the tensile strength of the rock [MPa]; l_2 is the length of the block fracture [m]; q_2 is stress acting on the rock block [MPa], depends on the hinging effect of the higher strata.

When the fractured block meets the requirements of Equation (6), no deformation instability occurs.

$$\sigma_p/\sigma_c \leq k \quad (6)$$

$$\sigma_p = \frac{2qa^2}{\left(1 - a\sin\beta\right)^2} \quad (7)$$

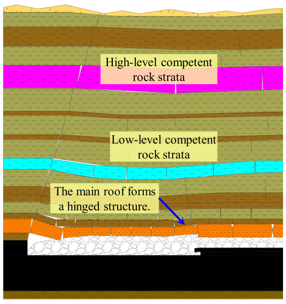
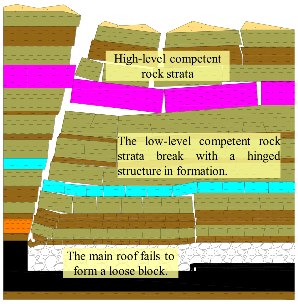
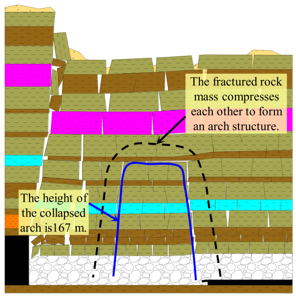
Where σ_p is the compression stress at the contact of the hinged fracture block [MPa]; σ_c is the compressive strength of the rock [MPa]; k is the empirical coefficient as 0.3; q is the stress on the rock block [MPa]; $a = l/h$.

From the above analysis, it can be seen that the stability of the overburden beam structure of ultra-thick coal seam mainly depends on the mining parameters of the thick coal seam ($\sum M$, M) and the physical and mechanical properties of the rock strata (h, φ, R_t, σ_c), and the status of the bearing strata underneath (K_p, q). The mining parameters of the ultra-thick coal seam can be controlled. Therefore, when the conditions for the formation of ultra-thick coal seam are determined, the total thickness of coal seam extraction and the number of multi-layers in the seam can be used as indicators for the overburden structure stability.

(c) Overburden structural evolution mechanism

With the increase of the total extraction thickness of thick coal seam mining, the compressive arch in the overburden rock develops upward. The overburden has experienced the evolution process of "beam structure-higher beam structure-arch structure". To analyze the mechanism of overlying strata structure evolution, the ratio b ($b = H/\sum M$) between overburden thickness H and the total extraction thickness M, is used as an index to analyses the evolution process of overlying strata at Dajingnan N°. 1 coal mine. Table 2 shows the development height and overburden structure of the compressive arch under different conditions.

Table 2. Overburden strata pattern for different overall mining height.

b	$b \geq 15.5$ ($\sum M \leq 20$ m and $H = 310$m)	$7.75 \leq b < 15.5$ (20 m $< \sum M \leq 40$ m and $H = 310$ m)	$b < 7.75$ (40 m $< \sum M$ and $H = 310$ m)
Overburden			
Note	Overall extracted height 20 m, beam structure	Overall extracted height 40 m, higher beam structure	Overall extracted height 70 m, arch structure

According to the physical modelling results, when the thickness of overburden is 310 m, if $b \geq 15.5$ ($\sum M \leq 20$ m), the main roof rock mass blocks are hinged to take the weight of the overlying strata, and it is a beam structure in the overburden; if $7.75 \leq b < 15.5$ (20 m $< \sum M \leq 40$ m), the hinged structure in the main roof fails, and the broken rock of the low-level strata hinges to form a higher beam structure; if $b < 7.75$ (40 m $< \sum M$), the hinged structure in the low level strata fails, and the overburden is in the form of an arched structure. The collapsed arch height finally stabilized at 167 m and was located below the higher and competent rock layers, not affected by the beam structure.

4. Interactions between Shields and Surrounding Rock Mass

In the process of the multi-layer extraction of ultra-thick coal seam, there are two types of interaction state between the main roof, competent rock formations and shield supports: (1) at the early stage, the collapsed rock blocks can effectively support the roof, and the main roof can form a hinge structure; when the main roof rotates and subsides, the stresses on the shields reach the maximum value; (2) at the later period of mining, with the increase of mining volume, the hinged structure within the main roof fails, leading to the roof instability, and the upper rock blocks are compressed together to form an arch structure; in this case, the stress acting on the shields are mainly from the weight of the detached rock blocks within the arch.

4.1. The Interaction at Early Stage

At the early stage of extraction, the main roof is hinged to form a voussoir beam structure. The stress redistribution in the roof in ultra-thick coal seam is similar to that of a normal thick coal seam. The stress in the roof is mainly resulted from the gravity load under the main roof and the breakage and rotation of the main roof. The interaction between the shield support and surrounding rock is shown in Figure 11.

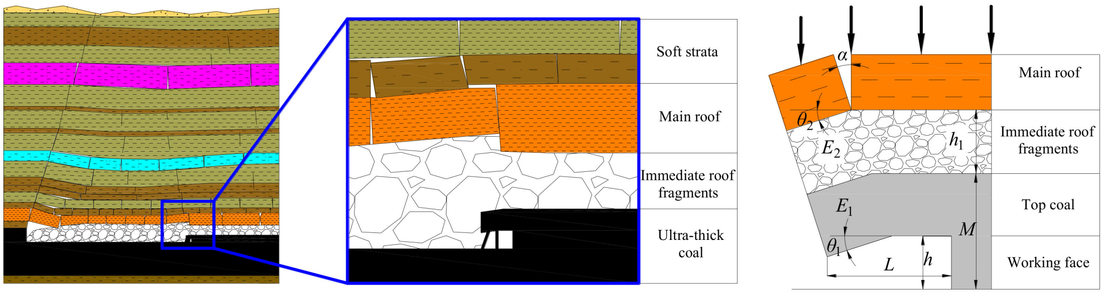


Figure 11. Illustration of the interactions between shields and surrounding rock mass (h—shield height; M—mining height at each multi-layer extraction; h_1—immediate roof thickness; θ_1—top coal rotation angle; θ_2—main roof rotation angle; L—face width; E_1—coal elastic modulus; E_2—elastic modulus of the broken rock mass below the main roof; α—angle of the fracture in the roof.).

4.2. The Interaction at Later Stage

At the later stage of layer mining, as discussed earlier, an arch structure formed in the higher strata, as the rocks of the higher rock strata are under the compression of the adjacent blocks, which contributes to the support of the overburden rock. The evolution of the overburden strata causes a corresponding change in the relationship between the shields support and surrounding rock. The stress on the shields is mainly from the gravity load of loose blocks in the arch. The interaction is shown in Figure 12.

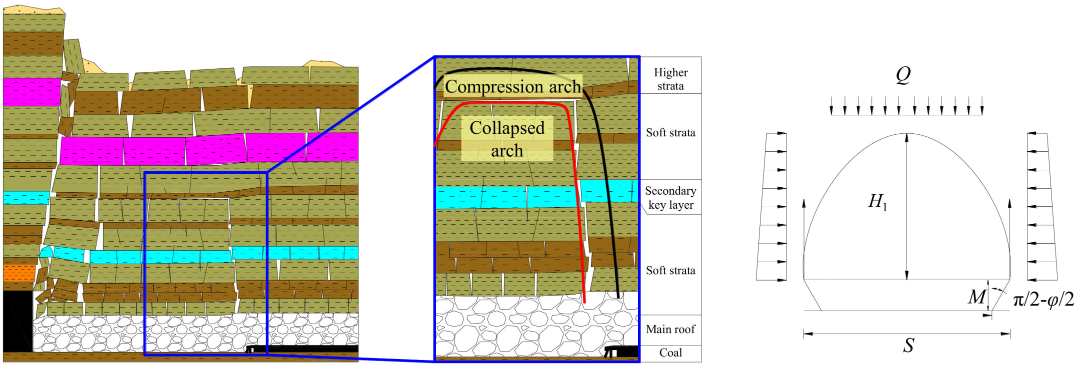


Figure 12. The shields and surrounding rock relationship for a overburden arch structure (H_1—height of the collapsed arch structure; φ—seam breakage angle; S—maximum width of the compression arch; Q—vertical stress redistribution).

5. Conclusions

This paper studied the overburden structural instability based on the case study using the geology and mining conditions of a typical ultra-thick coal seam in Xinjiang area. The failure characteristics include the secondary breakage under the multi-disturbance, as well as the weakening and the sudden change of the roof hinge structure. The factors affecting the stability of the overburden beam structure were determined, and the critical conditions for the evolution of overlying strata were proposed. In the early stage of the extraction of ultra-thick coal seam, if $b \geq 15.5$, the main roof rock mass blocks are hinged to take the weight of the overlying strata, and it is a beam structure in the overburden; if $7.75 \leq b < 15.5$, the hinged structure in the main roof fails, and the broken rock of the low-level strata hinges to form a higher beam structure; if $b < 7.75$ the overburden is in the form of an arched structure.

The interactions between the shields and the surrounding rock mass were also examined, considering the structure of the overlying strata. In the early mining period, the overlying strata can form a voussoir beam structure. The stress in the roof is mainly resulted from the gravity load under the main roof and the breakage and rotation of the main roof. In the later period of mining, the strata gradually transform into an arch structure, and the support is affected, where the load is the gravitational load of the loose blocks above the shields.

As the mining focus in China has rapidly expended from eastern to western regions recently, where the presence of thick seam is a comment feature and environment is significantly more sensitive to mining. The current understanding of the ultra-thick coal seam extraction needs to be improved to achieve a sustainable mining in Xinjiang area. The results of this paper provide insights into the geotechnical challenges associated with ultra-thick coal seam mining from the perspective of ground stability. Future studies are suggested to focus on the quantification of the overburden instability and the associated ground control management for ultra-thick coal seam mining.

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