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Study on Overlying Rock Movement in Mining of Thin Bedrock Face with Thick Unconsolidated Strata

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Abstract: China as a big country of coal production and consumption, coal strategic position is key. The condition of thick loose layer and thin bedrock is often encountered in mining. This special geological structure causes the mechanical behavior of coal seam after mining and the deformation and failure law of overlying rock to be different from the conventional condition. Taking the 21106 working face of Xinqiao Coal Mine as the research object, this paper conducts an in-depth study on the overburden fracture law of the working face with thick unconsolidated layer and thin bedrock, and obtains the following results:(1) The mining engineering geological conditions of 21106 face were analyzed, the mining conditions of the face were mastered, the changes in bedrock thickness were revealed, the heights of caving zone and water-conducting fracture zone of the face were calculated, and the bedrock thickness of the face was classified as follows: The area with a bedrock thickness less than 51.7m is divided into thin bedrock area, the area with a bedrock thickness greater than 51.7m and less than 54.7m is divided into a transition area of bedrock thickening, and the area with a bedrock thickness greater than 54.7m is divided into a thick bedrock area, and the thin bedrock research area of the working face is determined.(2) The numerical model of the working face is established and the overlying rock breaking characteristics are mastered. The overlying rock breaking of the working face can be divided into four stages: basic roof breaking stage I, pseudoplastic rock beam forming stage II, loose layer caving arch forming stage III and loose layer caving arch transverse development stage IV. The characteristics of stress arch evolution in the working face are understood: the stress arch structure gradually expands from the direct top to the loose layer, and the compaction area of caving rock continuously increases, which causes the fractal migration of stress arch and forms an asymmetric double arch structure on both sides of the goaf.

Keywords: Thin Bedrock; Thick Loose Layer; Overburden Movement; Water Conduction Fracture Zone.

1. Introduction

Coal is not only the basic fuel in China, but also an important industrial raw material, which will remain the main source of energy consumption in China for a long time in the future [1]. As the ballast of China's energy security and the stabilizer supporting the adjustment of energy structure, coal will continue to play an extremely important strategic role [2].

Professor Jiang Fuxing[3,4] further explored the dynamic relationship between the spatial structure and stress field of mining overlying rock by means of measurement, experiment and numerical calculation. Kang Jianrong [5] analyzed the mechanical model and fracture failure conditions of mining overburden rock. Wang Yuehan[6,7] established a dynamic mechanical model of mining rock mass. Ren Fenhua[8] conducted monitoring and analysis of overlying rock failure height in goaf. Wu Kan [9] studied the application of dynamic mechanical model of overlying strata movement failure in goaf.

Under the mining geological condition of thick loose layer and thin bedrock, the mechanical behavior and deformation and failure law of overburden after coal seam mining are different from that of normal overburden thickness. In the mining of coal seams with special geological conditions, serious accidents such as roof step cutting, pressure frame collapsing sand, flooding and burying people often occur on the working face, which bring huge economic losses and casualties to the state and enterprises. Therefore, it has become a key scientific problem that must be solved urgently to clarify the characteristics of ore pressure and master the overburden movement law of mining in thin bedrock working face of thick unconsolidated layer.

2. Project Overview

2.1. Overview of the Working Face

21106 fully mechanized mining face is located in the South Xi Mining area, the ground elevation is +31.52 ~ +32.29m. The surface position of the working face is located in the territory of Dazengzhuang and Li Lou in Maqiao Township, and it is distributed between the exploration line 15 and 18. The coal pillar is protected by the wind oxidation zone near the dome structure in the north, by the east main lane of the south wing belt transport in the south, by the F8 fault in the west, and by the DXF37 fault and F9 fault in the east. The recoverable area is 293,580 m2. 21106 face mining No.2 coal seam, the thickness of coal seam 0.5 ~ 5.1m, the average thickness of 3.97m; The dip Angle of coal seam is 0°~30°, the average is 14°, the strike length of working face is 932m, and the dip length is 315m. 21106 working face plane diagram is shown in Figure 1.

2.2. Research Area Division

2.2.1. The Thickness of The Bedrock of the Working Face

From the coal seam contour map of the working face, it can be seen that the buried depth of the coal seam is significantly different in different positions of the whole working face. Starting from the position of the cut hole, the buried depth of the coal seam shows a trend of increasing gradually with the stoping of the working face. The coal seam contour of the working face is shown in Figure 2.

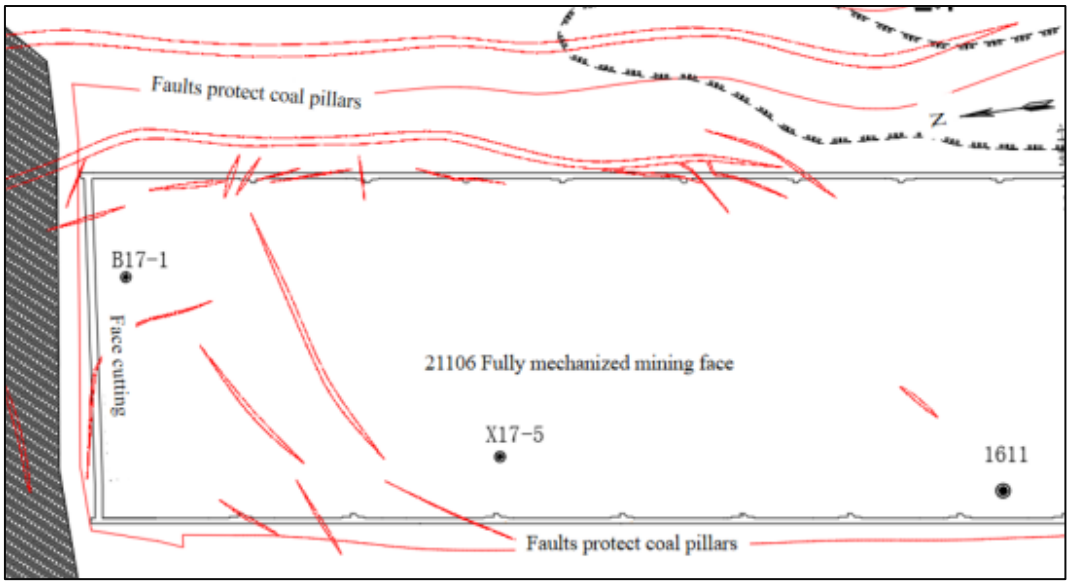


Fig 1. Workface plan

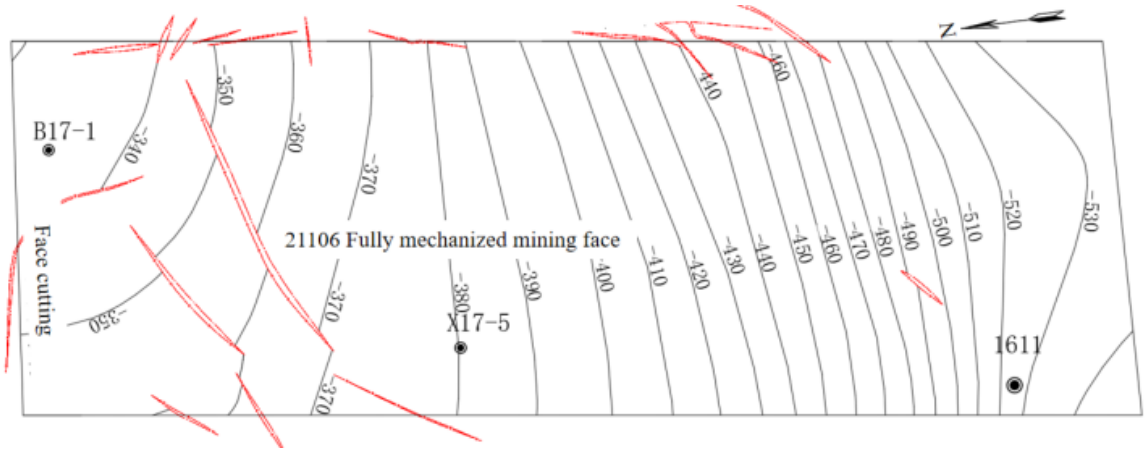


Fig 2. Coal seam contour of working face

B17-1 supplementary drilling hole (see Figure 3) is 25m away from the cutting hole, borehole X17-5 is 380m away from the cutting hole, and the column chart of borehole 1611 is 845m away from the cutting hole. According to the thickness of loose layer, bedrock, coal seam and floor in the borehole, the variation chart of bedrock thickness in the working face is drawn, as shown in Figure 4.

According to the analysis of the above figure, with the advancement of the mining process of the working face, the thickness of the overlying bedrock of the coal seam presents a trend of increasing, that is, the thickness of the working face bedrock presents a transition form of "thin bedrock to thick bedrock", and the change range of the bedrock surface is small, and the basic level remains. The depth of the coal seam near the cutting hole of the working face is 364.70m, the coal thickness is 4.94m, the bottom of the Cenozoic is 322.1m, and the overlying bedrock is 47.54m. In the middle of the working face, the depth of coal seam is 408.06m, the thickness of coal is 4.5m, the depth of Cenozoic bottom is 326.0m, and the overlying bedrock is 82.06m. The buried depth of the coal seam near the stop-mining line of the working face is 556.45m, the buried depth of the Cenozoic bottom boundary is 333.5m, and the overlying bedrock of the coal seam is 222.95m.

The research of this paper focuses on the overlying rock movement of the working face in the thin bedrock region, so it is necessary to divide the thin bedrock region of the working face according to the key parameter of bedrock thickness.

2.2.2. Failure Height Calculation of Mining Overburden

According to the lithology characteristics of coal overlying rock of working face, the relevant calculation formulas provided in Code for Coal pillar Retention and coal Pressure Mining in Buildings, water Heads, Railways and Main Shafts and Lanes (2017) are selected to calculate the height of caving zone and water-channeling fracture zone respectively.

$$H_k = \frac{100\sum M}{4.7\sum M + 19} \pm 2.2 \quad (1)$$

$$H_{li} = \frac{100\sum M}{1.6\sum M + 3.6} \pm 5.6 \quad (2)$$

$$H_{li} = 20\sqrt{\sum M} + 10 \quad (3)$$

Where: Hk - maximum caving zone height, m; Hli - the maximum height of the fracture zone with the maximum water conductivity, m; - Cumulative thickness, m.

Under the condition that the mining thickness of No. 2 coal seam is 5m, the height of caving zone and water-conducting fracture zone are calculated according to the above rock mechanics parameters and related calculation formulas. The height range of caving zone is 9.6 ~ 14.0m, and the maximum height of caving zone is 14.0m. The calculated height of the fracture zone is 37.5 ~ 48.7m and 54.7m. Since the height of

the water-conducting fracture zone is the range value calculated by the empirical formula, the average value of the maximum value calculated by the empirical formula is 51.7m as the height of the water-conducting fracture zone.

Floor number	Layer thickness/m	Burial depth /m	Lithology	Bearing horizon	Columnar
11	118.64	322.10	Clay	Thick loose layer	
10	1.49	323.59	Fine grained sandstone	Pseudoplastic rock beam	
9	2.58	326.17	Sandy mudstone		
8	0.77	326.94	Fine grained sandstone		
7	3.40	330.34	Siltstone		
6	0.70	331.04	Fine grained sandstone		
5	4.80	335.84	Medium grained sandstone	Basic roof	
4	16.38	352.22	Sandy mudstone	Thin bedrock	
3	3.02	355.24	Fine grained sandstone		
2	9.46	364.70	Medium grained sandstone	Immediate roof	
1	4.94	369.64	Coal seam		

Fig 3. Bar diagram of drilling B17-1

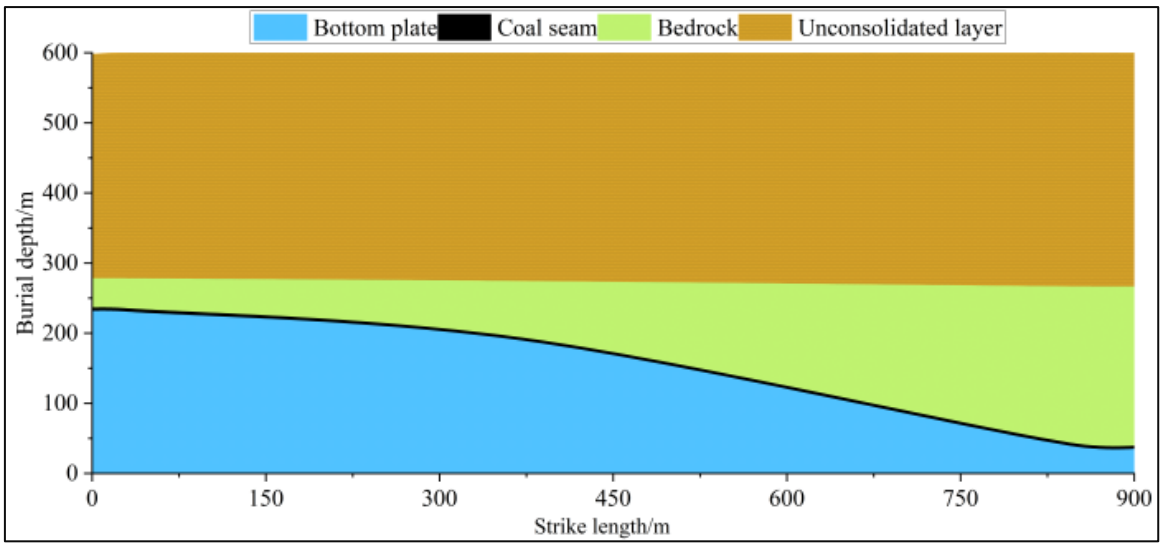


Fig 4. Schematic diagram of variation of bedrock thickness in working face

2.2.3. Thin Bedrock Regional Division

On the basis of previous studies, combined with the actual engineering conditions of this paper, the 21106 working face bedrock is classified as follows: the area with a thickness of less than 51.7m is divided into thin bedrock area; The region with the thickness of the bedrock greater than 51.7m and less than 54.7m is divided into the transition region of the bedrock thickening. The area where the thickness of the bedrock is greater than 54.7m is divided into thick bedrock area. Therefore, the working face is divided into thin bedrock

working face in the range of 0~180m with the opening hole as the starting point. In the range of 180-235m, it is divided into a transition face of bedrock thickening. The range of 235 ~ 1000m is divided into thick bedrock working face. The classification results of the bedrock of the working face are shown in Figure 5.

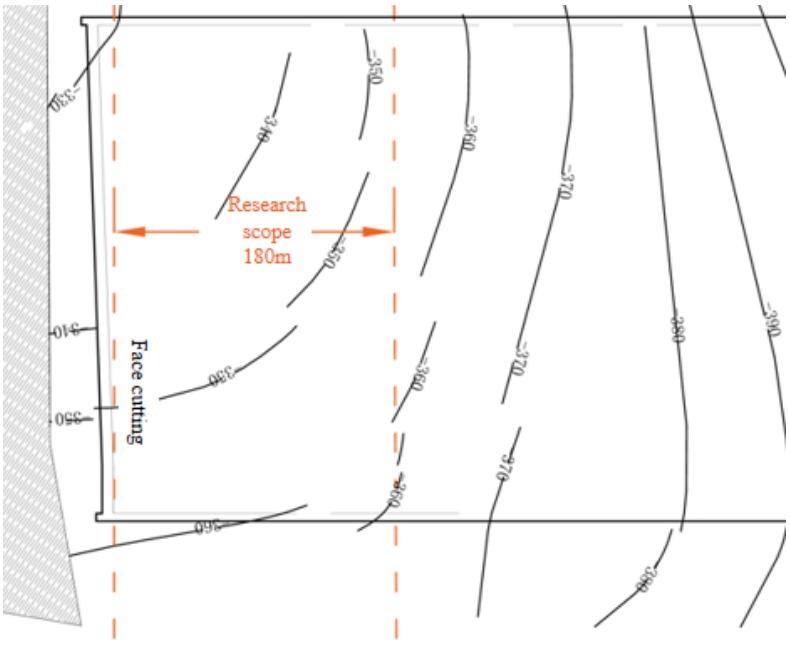


Fig 5. Classification results of bedrock of working face

3. Numerical Simulation of Overburden Movement

3.1. Numerical Modeling

The numerical model is established based on the real geological conditions of 21106 working face. Considering the small inclination of coal seam in thin bedrock area, the coal seam is assumed to be horizontal in order to simplify the calculation. The model size is set to 300×130m (length × height), the basic top height is 42.5m, the height of the loose layer is 83.5m, and the boundary coal pillar is 60m at each end. The model excavated 5m each time from left to right, and excavated 180m in total. The constitutive relation of the model is set as the elastic-plastic constitutive model, namely the Moore-Coulomb constitutive model and the Moore-Coulomb yield relation. The established UDEC numerical model is shown in Figure 6.

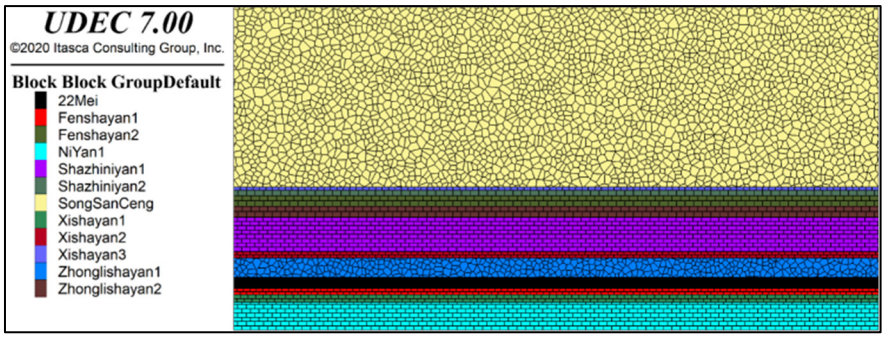
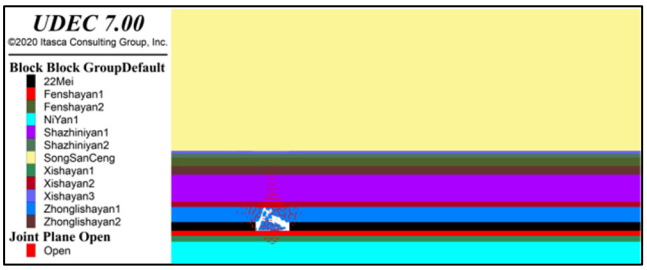


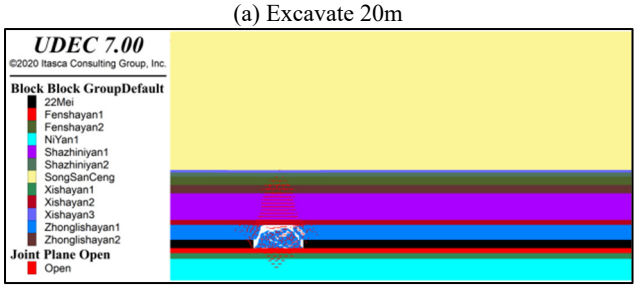
Fig 6. Numerical model diagram

3.2. Overburden Fracture Characteristics

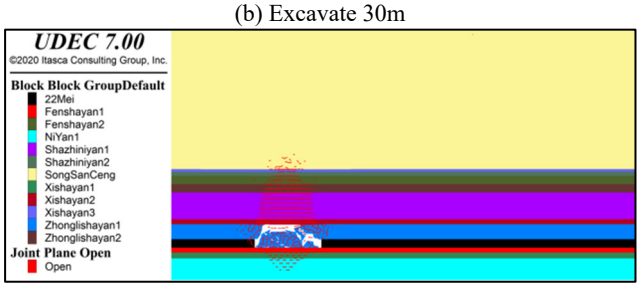
According to the analysis in FIG. 7, it can be seen that when the working face is advanced to 20m, the direct roof will collapse under the influence of mining, and the caving height is 10m. The mining will lead to stress redistribution, causing the joint crack to expand upward and on both sides of the goaf, and the joint crack developing height from the basic top to the top is 17m. The development range of the internal joint crack of the direct roof in front of the working face is 6m, indicating that the direct roof behind the cutting hole is more affected by stress redistribution and the damage is more serious than that in front of the working face. At this time, there are no obvious separation cracks in the basic roof above the goaf. When the working face is advanced to 30m, the collapse range of the direct roof increases, resulting in intensified internal damage of the basic roof, and the joint crack of the basic roof increases and extends upward, reaching a height of 26m. When the working face advances to 40m, the caving range of the direct roof continues to increase, and the joint crack range of the direct roof in front of the working face reaches 10m. At this time, the joint crack develops upward to the loose layer. When the working face is advanced to 45m, the basic roof is broken, the first pressure occurs in the working face, the separation fissure appears at 12m above the coal seam, and the range of irregular joint fissure in the loose layer expands.



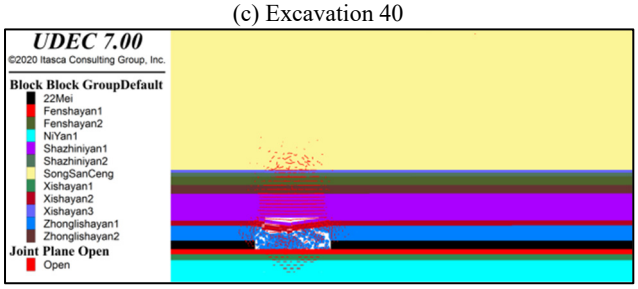
(a) Excavate 20m



(b) Excavate 30m

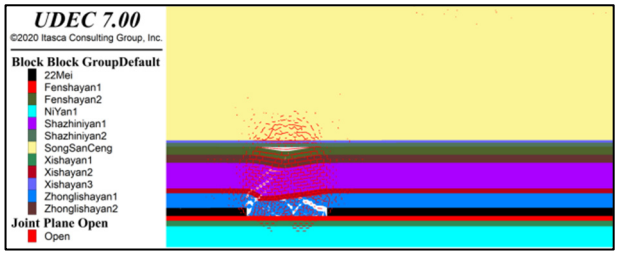


(c) Excavation 40

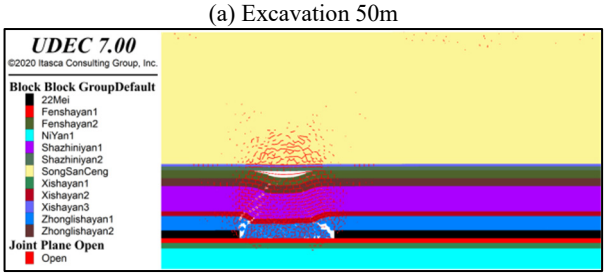


(d) Excavation 45m

Fig 7. Basic toppling stage I



(a) Excavation 50m

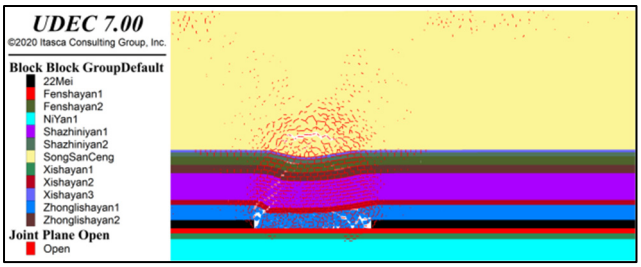


(b) Excavate 60m

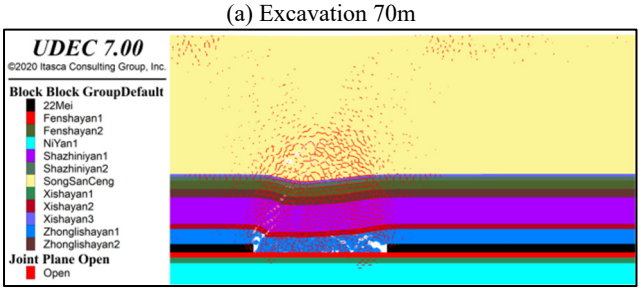
Fig 8. Formation stage of pseudoplastic rock beam II

As can be seen from the analysis of FIG. 8, when the working face is advanced to 50m, the basic top is broken in a large extent, and a large separation crack appears at 40m above the coal seam. At this time, the load of the loose layer is carried by pseudoplastic rock beams, and more irregular joint cracks appear in the loose layer with an arch distribution, indicating that the internal failure of the loose layer is gradually serious under the influence of mining. When the working face advances to 60m, the direct roof continues to fall with the advancing of the working face, the separation space expands, the pseudoplastic rock beam bends and deforms, the internal damage of the loose layer worsens, and the internal arch joint cracks increase further.

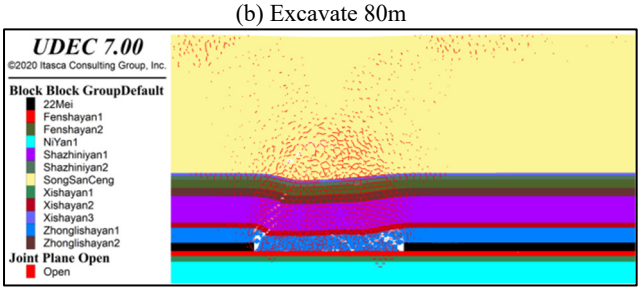
According to the analysis in FIG. 9, when the working face is advanced to 70m, the pseudo-plastic rock beam will bend and sink obviously, the separation space will be compressed, and the loose layer will collapse irregularly and synchronously to form a loose layer caving arch with an arch height of 11m. When the working face is advanced to 80m, the arch height of the caving arch of the unconsolidated layer increases to 19m, the caving rock above the goaf is compacted, and the range of arch joint cracks in the unconsolidated layer continues to expand. When the working face advances to 90m, the internal joint fissure of bedrock and unconsolidated layer expands further, and the arch height of caving arch of unconsolidated layer increases to 26m.



(a) Excavation 70m

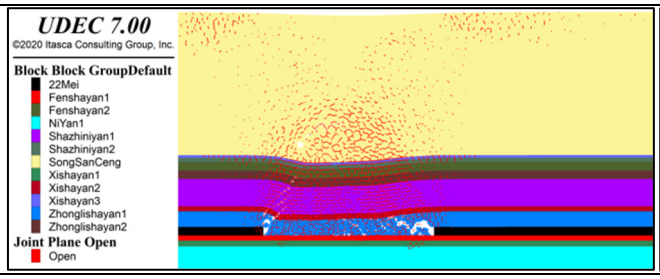


(b) Excavate 80m

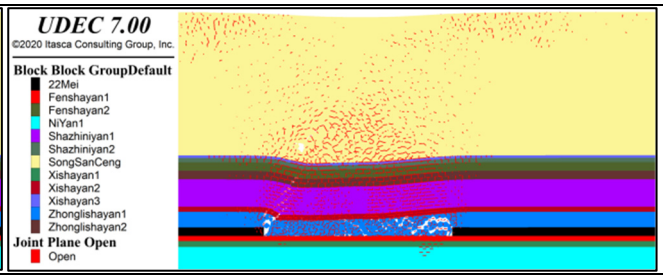


(c) Excavate 90m

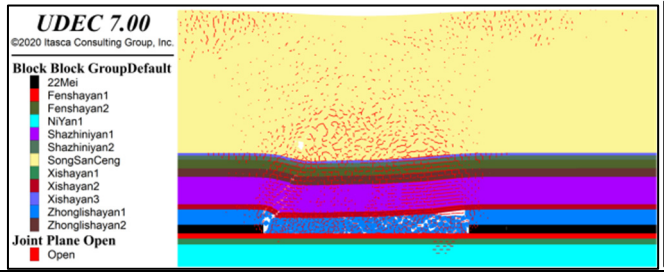
Fig 9. Caving arch of unconsolidated layer formed stage III



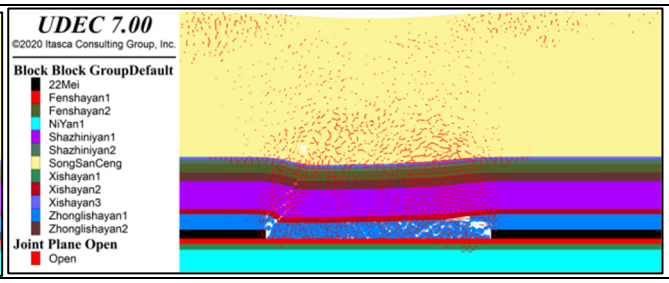
(a) Excavate 100m



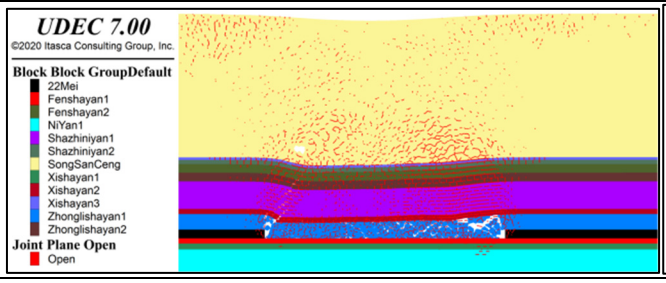
(b) Excavation 110m



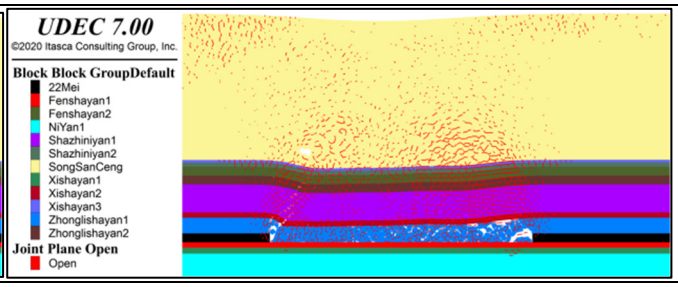
(c) Excavate 120m



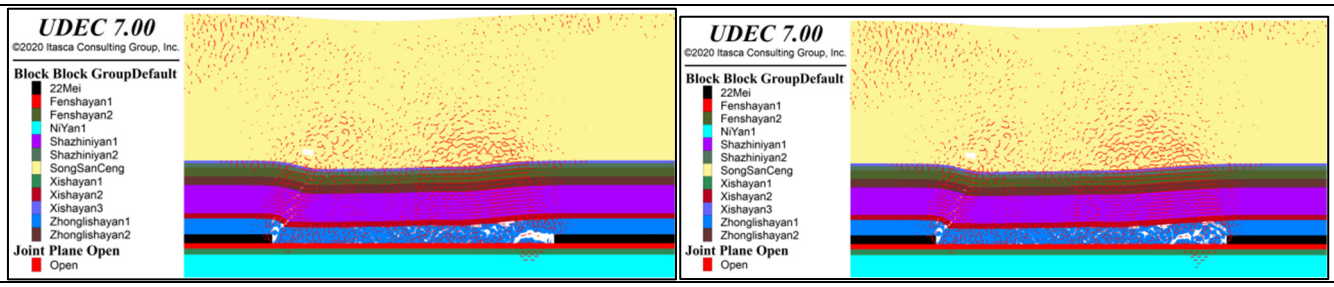
(d) Excavation 130m



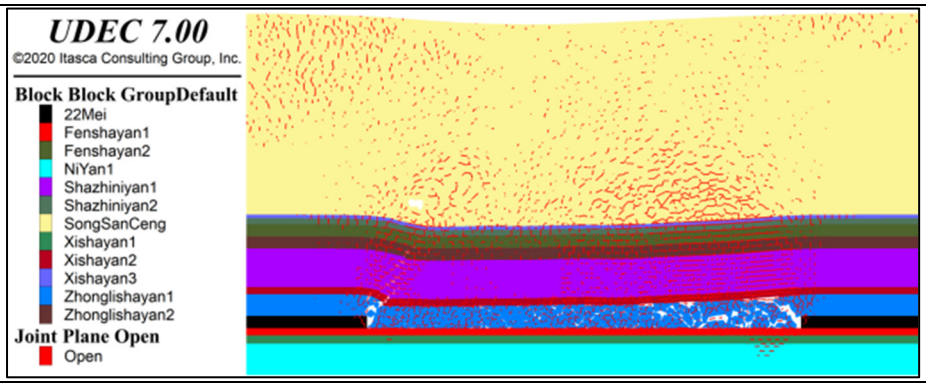
(e) Excavate 140m



(f) Excavation 150m



(g) Excavation 160m (h) Excavation 170m



(i) Excavation 180m

Fig 10. Lateral development stage of caving arch of unconsolidated layer IV

According to the analysis in FIG. 10, when the working face is advanced to 100m, the direct roof continues to collapse with the mining of the working face, the joint crack range of the unconsolidated layer continues to expand, the caving rock above the goaf is compacted, and the joint crack disappears. When the working face continues to advance from 110m to 130m, the caving rock above the goaf is gradually compacted, and the disappearance range of internal joints and cracks in caving rock expands, the range of internal joints and cracks in unconsolidated layer appears transverse expansion, and the caving arch appears transverse development. When the working face continues to advance from 140m to 180m, the caving arch of the unconsolidated layer continuously develops laterally, and the joint crack range of the unconsolidated layer gradually shows a bimodal shape, and the joint crack range of the unconsolidated layer above the right side of the goaf is larger.

4. Conclusion

(1) The height of the caving zone is 14.0m and the height of the water-conducting fracture zone is 51.7m. According to the relationship between the thickness of the bedrock and the height of the water-conducting fracture zone, the working face is divided into thin bedrock zone (0~180m), transition zone of the bedrock thickened (180 ~ 235m) and thick bedrock zone (235 ~ 1000m). This partition provides a quantitative benchmark for subsequent research.

(2) Through numerical simulation tests, the overburden fracture characteristics during the mining process of thin bedrock face with thick loose layer are studied. The results show that the overburden fracture process induced by mining can be divided into four stages: basic roof fracture, formation of pseudoplastic rock beam, collapse arch of loose layer and its lateral development.

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