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Overburden fracture evolution laws and water-controlling technologies in mining very thick coal seam under water-rich roof

Zhang Youxi [a,b], Tu Shihao [a], Bai Qingsheng [a,*], Li Jianjun [b]

[a] School of Mines, Key Laboratory of Deep Coal Resource, Ministry of Education of China, China University of Mining & Technology, Xuzhou 221116, China
[b] Datong Coal Mine Group Co. Ltd., Datong 037003, China

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ABSTRACT

Considering the danger of water inrush in mining very thick coal seam under water-rich roof in Majialiang Coal Mine, the universal discrete element (UDEC) software was used to simulate the overburden fracture evolution laws when mining 4# coal seam. Besides, this study researched on the influence of face advancing length, speed and mining height on the height of the water flowing fractured zones (HWFFZ), and analyzed the correlation of face advancing length and change rules of aquifer water levels and goaf water inflow. Based on those mentioned above, this research proposed the following water-controlling technologies: draining the roof water before mining, draining goaf water, reasonable advancing speed and mining thickness. These water-controlling technologies were successfully used in the field, thus ensured safely mining the very thick coal seam under water-rich roof.

1. Introduction

According to statistics, the direct economic losses caused by mine water accidents have been the greatest one among all coal mine accidents. Since 2000, more than 500 water damage accidents have happened in China, killing more than 2800 people, and the direct economic losses amounted to multibillion RMB Yuan [1]. Water sources and water inrush channel are two main factors of water inrush disaster. Overburden fractures are the main reason of forming water inrush. Therefore, studying the development and evolution laws of mining induced fractures is the basis for predicting water inrush and preventing water accidents [2]. It has been widely recognized in the world that coal mining causes overburden deformation, breaking, thus formes water flowing fractures. Scholars at home and abroad have done a lot of studies in this area, and summarized the empirical formula for calculating the HWFFZ [3–7]. At present, based on the borehole flushing fluid leakage, radon gas, surface borehole observations, isotopes, ultrasound, electrometric imaging, etc., some scholars observed the laws of overburden fractures distribution, as well as the impacts of mining on roof aquifers [1,8–12]. Guo et al. analyzed the relationship between longwall mining and water level of the aquifer, compared the observed HWFFZ(s) with the calculated values in the use of traditional empirical formulas, and found that the calculated values from empirical formulas were smaller than the actual results, so strongly recommended that a larger safety factor should be considered [13]. Combining with numerical simulations, physical simulations and field observations, some scholars used the fractal theory to study the fractal evolution laws of the overburden fractures, and investigated the correlation of fracture fractal dimension to face width, advancing length, ground pressure, overlying strata subsidence, upper three zones and burial depth [14–18]. Numerical methods have also been widely used to research on the distribution of overburden fractures induced by mining activities and how the roof aquifers affect the mining [2,4,14,19,20].

Based on the practical conditions of 14101 face in Majialiang Coal Mine, this paper used the discrete element software (UDEC) to simulate the evolution laws of overburden fractures with an increase in the length of face advancing. The emphasis was put on the relationships between face advancing speed, mining thickness and the HWFFZ. Combining with field observation, this paper also analyzed the correlations of longwall mining to water levels of aquifers and goaf water inflow, and then proposed the water controlling mining technologies and successfully applied in the field to ensure safely mining the very thick coal seam under the water-rich roof.

2. Geological conditions

Majialiang Coal Mine is located in the south of Shuozhou city, Shanxi province, which is the first productive mine of Shuonan mining area in Ningwu Coalfield. 4# coal seam was mined in 14101 mining face. The seam has a thickness of 4.0–11.0 m, and

* Corresponding author. Tel.: +86 13852489517.
E-mail address: bqshcumt2008@126.com (Q. Bai).

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9.1 m on average. The dip angle of the seam is 3–8°, with an average of 5°. The width of the mining face is 250 m, and the advancing length is 2700 m. The fully mechanized top coal caving method is used in the face. The designed production is 6 million t/year in the face.

The average cover depth of 4# coal seam in 14101 mining face is 600.4 m, with average thickness of bedrock 340.2 m and unconsolidated layer 260.2 m. There are a few aquifers in the roof strata. The total thickness of the water-bearing section in unconsolidated layer is 84.5 m. This aquifer is rich in water. The unconsolidated aquifer has strong lateral recharge, as this section is the discharge area of Shentou Spring. If the unconsolidated aquifer is connected to the mining induced fractures, it is easily to cause water inrush, even inundation. The aquifer mentioned above is the main water source that threatens the safety of mining operation. The average thickness of the sandstone aquifer group in upper and lower Shihezi Group is 272.8 m, and the units-inflow is 0.0164 L/s·m with weak water abundance. The average thickness of lower fissured aquifer in the early Permian is 72.39 m, which mainly distributes at the bottom of K5 sandstone. The distribution of the fissured aquifer is very uneven with units-inflow of 0.0164 L/s·m. The aquifer is a weak fissured aquifer group, mainly including static water. There is a sandstone intercalated with mudstone aquiclude below the unconsolidated aquifer, which has a thickness of 50 m. Another one is in the middle of the Shihezhi Group with a thickness of 18.6 m. Table 1 shows the roof and floor lithology in mining face, including aquifers and aquicludes. The aquifer and aquiclude are numbered for easy analysis.

3. Numerical analysis of fracture evolution laws in overburden strata

The UDEC was used to analyze the correlation of overburden fractures evolution laws with the increase in the length of face advancing, speed and mining thickness.

3.1. Relationship between advancing length and overburden fracture

The designed production of 14101 face is 6 million t/year. When the mining face reaches the designed production, the face advancing speed is 8 m/d. The evolution laws of the overburden fractures with face advancing are simulated at this advancing speed. The maximum value of face advancing length is 400 m.

Fractures in the overburden strata dynamically varied with the mining face advancing. The fracture zones extended in height and breadth, but closed at some local region at the same time, as shown in Fig. 1. As 4# aquifer was in the immediate roof, it caved with the face advancing. The aquifer became the directly charge source of the mining face. When the face advanced to 100 m, overburden strata fractures developed to the bottom of 2# aquiclude, and connected with the 3# aquifer. When advancing to 140 m, overburden fractures passed through 2# aquiclude, and extended to the bottom of the 2# aquifer. When advancing to 200 m, overburden fractures extended to the bottom of 1# aquiclude. When advancing to 260 m, fractures developed at the bottom of 1# aquiclude, but within a small scale. At this advancing length, the HWFFZ reached its maximum value of about 225 m. Since then, as the face continued to advance, the fractures above 2# aquiclude gradually closed. The scope of fractured zones in the central of the advancing length shrank beneath 2# aquifer, while near the open-off cut, it shrank beneath 1# aquiclude.

Owing to the low strength, poor cementation and weak ability to resist the deformation of unconsolidated layer, the fractures appeared at the bottom of the unconsolidated layer when advancing to 200 m. Fractures extended to the surface when the face advanced to 260 m. As the advancing length increased, the scope of the fractured zones in the unconsolidated layer spread, and the density of fractures increased in the upper part, but relatively decreased in the bottom part. The fractures only spread in the unconsolidated layer other than the below 1# aquiclude. These phenomena indicated that water in the unconsolidated layer was insulated by 1# aquiclude and did not seep to the mining face through mining induced fractures.

When advancing to 340 m, fractures near the open-off cut began to close, and the HWFFZ decreased to about 262 m, but increased rapidly in the central of advancing length. When advancing to 400 m, fractures began to close in the central of advance length, and HWFFZ reduced from 276 to 187 m.

From those analysis, the following conclusion can be drawn: when the face advancing speed was 8 m/d, the fracture zones developed to the bottom of 1# aquiclude; in general, 1# aquifer would not be connected, since there was a bedrock of 60 m between 1# aquifer and the overburden fractures.

Table 1
Roof and floor lithology in mining face including aquifers and aquicludes.

No.	Lithology	Layer thickness (m)	Depth (m)	Notation	No.	Lithology	Layer thickness (m)	Depth (m)	Notation
1	Loose bed	260.2	260.2	1# aquifer,☆	14	Packsand	28.6	541.3	
2	Sandstone intercalated with mudstone	50.0	310.2	1# aquiclude	15	Mudstone	13.3	554.6	
3	Packsand & mudstone	10.5	320.7		16	Siltstone & packsand	9.1	563.7	☆
4	Mudstone & conglomerate	68.2	388.9		17	Sandstone	10.8	574.5	
5	Sandstone	8.6	397.5	2# aquifer	18	Mudstone	7.7	582.2	
6	Argillaceous siltstone	6.3	403.8		19	K5 sandstone	7.2	589.4	4# aquifer
7	Sandstone	18.6	422.4		20	Siltstone	11.2	600.6	
8	Sandy mudstone	9.5	431.9		21	4# coal	9.2	609.8	
9	Mudstone intercalated with sandy mudstone	18.6	450.5	2# aquiclude	22	K4 sandstone	2.3	612.1	
10	Conglomerate	26.8	477.3		23	Mudstone	8.3	620.4	
11	Packsand	6.3	483.6		24	Packsand	5.3	625.7	
12	Mudstone & sandy mudstone	13.6	497.2		25	Mudstone	2.5	628.2	
13	Sandstone	15.5	512.7	3# aquifer	26	Sandstone	6.8	635.0	

Note: ☆ is the bottom position of the observation boreholes.