Study on "Two Zone" Development Height of Overburden Rock in Fully Mechanized Face with Large Mining Height

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Abstract. In terms of the problems of the development height of the "two zones" of overburden in the fully mechanized mining face was difficult to predict, taking the 31303 working face in Chahasu coal mine as an example, methods of empirical formula, leakage of drilling fluid and borehole colour TV were used for prediction and exploration. On the basis, the concept of empirical formula error was proposed, and the error rate predicted by slicing mining and fully mechanized caving mining in thick seam was analysed. The results showed that the fracture-mining ratio and caving-mining ratio of 31303 working face were 23.67 and 5.6 respectively, that is, the development height of water-conducting fracture zone and caving zone were 106.50 m and 25.20 m respectively. The "two zones" empirical formula of thick seam slicing mining and fully mechanized caving mining deviated greatly from the predicted results of fully mechanized mining face with large mining height. The formula for calculating the error rate of empirical formula was proposed. The error rates of the empirical formulas for layered mining and fully mechanized caving mining were quantitatively analysed, which were 50\% and ± 28\%, respectively, indicating that the traditional empirical formula was not universal in the prediction of "two zones" of fully mechanized mining with slicing mining.

1. Introduction

There are abundant coal resources, complex hydrogeological conditions in mines in China, water inrush accident is the second of the five major disasters\cite{1}. In recent years, with the increase in the depth of coal resource extraction and the popularity of comprehensive mechanization, the degree of water inrush will become more prominent, the frequency and intensity of water inrush will continue to increase, and the prevention and control of the disaster of water inrush is also facing great challenges. In particular, the high-intensity mining of thick coal seams and extra-thick coal seams in the western mining region in China has made the roof of coal seam more severely damaged, the mine pressure appears more serious, and the water-conducting fissure zone can easily lead to overlying aquifers, which causes the disaster of water inrush\cite{2-4}.

At present, some progress has been made on the developmental height of the "two zones". However, most of the research results focus on the general mining and slice mining of thick coal seams, and the thickness of a single slice is less than 3 m. The development height of the "two zones" of overburden
rock in fully mechanized or fully mechanized mining is not yet mature. Although the "Three Under" Mining Guide (2017 Edition) added the prediction formula of "two zones" for large mining height of thick coal seam or fully mechanized caving in mining regions, due to the complexity of geological conditions, the number of samples is relatively small, and the discrete type of "two zones" development height in different mining regions is large, resulting in the large mining height of thick coal seam or fully mechanized caving mining development formula has not reached consensus.

In view of this, many scholars have made a study on the development height of "two zones" of overburden in different mining regions, and achieved some results. Xu Yanchun et al.[5] based on the measured data of the "two zones" in more than 40 fully mechanized top coal mining working faces, and obtained the "two zones" prediction formula under the condition of medium hard and soft overburden, and carried out applicability analysis. Sun Qingxian et al.[6] took the 1121 working face of Hongliu Coal Mine of Shenhua Ning Coal Group as an example, three technical methods of surface drilling drilling fluid leakage observation, borehole color TV observation and underground transient electromagnetic geophysical exploration were to study the "two zones" height of the full height working face in the comprehensive mining of soft overburden. Shu Zongyun[7] took the 14.8 m thick coal seam mined in 1305 fully mechanized top coal caving face of Guojiahe coal mine as an example, using the methods of field measurement and numerical simulation, studied the "two zones" height under the condition of fully mechanized top coal caving in extra thick coal seam. Li Xiaojian et al.[8] took the 2601 working face of Gangou coal mine as an example to study the development height of the "two zones" of the working face, and determined the reasonable mining height of the coal seam under the water-rich and extra-thick sandy conglomerate. Wang Changming et al.[9] took the B8 coal seam fully mechanized working face in the Xiaogou sub-mine of Nanshan coal mine as the research object, and studied the pressure law of the mining face and the characteristics of the "two zones" overburden. Liu Jun et al.[10] used the parallel electrical method to detect the distribution of "vertical three zones" in a high gas inclined thick coal seam comprehensive mining face in Xinjiang, and divided the development height of "three zones". Yang Junze[11], Ding Xinpin[12], Liu Zhigang[13], Li Jingjing[14] have all studied the damage and development height of overburden in fully mechanized or fully mechanized mining of thick coal seams, and have carried out certain applications. Chahassu coal mine is located at the junction of Yulin, Inner Mongolia, Ordos and Shuozhou, Shanxi. It is the "Golden Triangle" region with the most abundant coal resources in China. It belongs to Xinjie mining region in the Dongsheng coalfield, and is adjacent to Bulianta and Shangwan coal mines in the Shendong company in the East. According to the relevant literature[8, 15], the height of the water conducting fracture zone of 1-2 coal (mining depth 265 m, mining height 4.5 m) in Bulianta coal mine is 105.96 m, and that of 1-2 coal (mining depth 208 m, mining height 4.85 m) in Shangwan Coal Mine is 53.10 m. If we use the data of adjacent mines for work guidance, there will be great blindness and pertinence, which will definitely bring hidden safety hazards to the mine's safe production and water inrush control. Therefore, taking the 31303 working face in the Chahasu coal mine as an example, it is of great significance to study the development height of "two zones" of overburden in the Chahasu coal mine for the prevention and control of the disaster of water inrush.

2. Engineering situation

2.1. Geological conditions

The Chahasu coal mine is located in the middle and deep area of the southern margin of the Dongsheng coalfield. The strata in the region are as follows: the upper Triassic Yanchang Formation (T3y), the middle and lower Jurassic Yan'an formation (J1-2y), the Middle Jurassic Zhiluo Formation (J2z), the lower Cretaceous Zhidan group (K1zh), and the Quaternary System (Q).

Except for the Quaternary alluvial aquifer, which directly receives atmospheric rainfall, the remaining aquifers can be divided into three relative aquifers and two relative aquifuges based on factors such as water inflow and permeability, which are the first aquifer group (Cretaceous Zhidan Group (K1zh) clastic rock pores, fractured aquifers), Jurassic Middle Ages Zhiluo Formation (J2z)
aquifer, No. 2 Aquifer Formation (from Jurassic Middle Ages Luo Formation (J2z) to the 3rd coal seam), 3rd coal bottom water barrier, No. 3 aquifer group (from No. 3 coal bottom mudstone bottom boundary to 6th coal group aquifer).

2.2. Working face situation
The 31303 working face is located in the west of the 31 mining area, with the coal seam strike of 165° southeast, dip of 225° southwest, dip angle of 1-3°, buried depth of 350-450 m and average mining thickness of 5.87 m. The coal seam roof is mainly composed of mudstone, sandy mudstone and sandstone with different particle sizes. The working face adopts double-lane driving, and the width of the coal pillar is 18 m, and the roadway is arranged along the strike direction, which is the second working face after trial production. The northwest direction of the working face is a horizontal east wing transportation, main Return Way and other main lanes, the northeast and southeast faces are unexcavated areas and the border of the minefield, and the southwest direction is close to the 31301 working face. The strike of working face 31301 is about 3000 m long and 300 m wide. At present, the mining has been completed, and the mining process is mainly affected by roof water.

3. Experience prediction of "two zones" in fully mechanized face with large mining height

3.1. Lithology analysis of roof and floor of coal seam
Core sampling was carried out in two boreholes X3-3 and X5-4 near 31303 working face, the sampling range was 30 m above the roof to 20 m below the floor of coal seam, and rock mechanics test was carried out, and the test results were shown in Table 1.

| Layer of No.3 coal seam | Lithology       | Compressive strength (MPa) | Water absorption state | Natural state | Platts coefficient Rf | Softening coefficient | Modulus of elasticity Ei | Poisson's ratio β |
|-------------------------|-----------------|-----------------------------|------------------------|---------------|-----------------------|-----------------------|-------------------------|-----------------|
| coarse sandstone        | 3.4-34.8        | 10.0-42.4                   | 1.02-4.32              | 0.35-4.32     | 1.39×104              | 0.17-0.81             |
| medium grain sandstone  | 6.3-33.6        | 3.4-53.8                    | 0.34-5.49              | 0.17-0.93     | 8.16×103              | 0.09-0.83             |
| fine sandstone          | 11.6-42.6       | 1.3-48.1                    | 0.14-4.91              | 0.41-0.89     | 5.48×103              | 0.11-0.26             |
| siltstone               | 8.9-30.5        | 18.1-81.4                   | 1.84-8.30              | 0.32-0.88     | 1.09×104              | 0.06-0.30             |
| sandy mudstone          | 3.6-40.3        | 15.8-54.6                   | 1.61-5.57              | 0.07-0.97     | 9.32×103              | 0.09-0.29             |
| mudstone                | 2.5-18.9        | 11.5-38.8                   | 1.18-3.96              | 0.08-0.91     | 8.55×103              | 0.26                  |

It can be seen from Table 1 that the roof of No. 3 coal seam is mainly composed of mudstone, sandy mudstone and sandstone with different particle sizes. The average compressive strength of mudstone and sandy mudstone is 21.00 MPa and 32.89 MPa, respectively. The average tensile strength of sandstone is between 24.93 MPa and 36.63 MPa, most of them are less than 30 MPa. Referring to the lithology classification of overburden in "Three Under" Mining Guide, it can be seen that the lithology of overburden of No. 3 coal seam belongs to medium hard.
3.2. Lithology analysis of roof and floor of coal seam

3.2.1. Height prediction of "two zones" in slice mining of thick coal seam

Empirical formula for height of collapse zone:

\[ H_k = \frac{100 \sum M}{4.7 \sum M + 19} \pm 2.2 \]  

Empirical formula for the height of the water-conducting fracture zone:

\[ H_{\text{li}} = \frac{100 \sum M}{1.6 \sum M + 3.6} \pm 5.6 \]  

3.2.2. Height prediction of "two zones" in fully mechanized top coal caving in thick seams

Empirical formula for height of collapse zone:

\[ H_k = 6M + 5 \]  

Empirical formula for the height of the water-conducting fracture zone:

\[ H_{\text{li}} = \frac{100M}{0.23M + 6.10} \pm 10.42 \]  

In the formula, \( H_k \), \( H_{\text{li}} \)—the maximum height of the collapse zone and the water-conducting fracture zone, m; \( M \), \( \sum M \)—the mining thickness and the cumulative mining thickness, m.

According to the formula for slice mining of thick coal seams, it was estimated that the heights of the collapse zone and water-conducting fracture zone in the Chahasu coal mine were 14.80 m and 50.78 m, respectively. According to the formula of fully mechanized top coal caving in thick coal seams, it was estimated that the development heights of the collapse zone and water-conducting fracture zone in the Chahasu coal mine were 40.22 m and 89.21 m, respectively.

4. Measurement of "two zones" in fully mechanized face with large mining height

4.1. Observation method of "two zones" for leakage of drilling washing fluid

4.1.1. Drilling arrangement

According to the actual conditions of overlying rock lithology and strength of the top and bottom of 31303 working face in the Chahasu coal mine, the maximum value of the water-conducting fracture zone was estimated. In order to prevent abnormal conditions such as excessive crack height, the 10-20 m hole section was extended as the observation drilling height so as to measure the watertight hole section of a certain length. As a basis for determining the top boundary of the fracture zone, the actual maximum control height was 90-110 m.

According to the industry "Observation Method for Leakage of Drilling Flushing Fluid at the Height of Water-Conducting Fracture Zone", \( D_1 \) is arranged 75 m away from the belt transport chute of working face 31303 and drilled below the coal seam floor. \( D_2 \) was arranged 73 m away from the belt transport lane of working face 31303 and drilled below the coal seam floor, and the drilling layout was shown in Figure 1.

![Figure 1. 31303 drilling layout diagram.](image-url)
4.1.2. Analysis of the observation results of leakage of drilling and flushing fluid

D1 and D2 holes leakage per unit time and unit footage loss per unit time were shown in Figure 2.

According to Fig. 2 (a) and field drilling observation, the flushing fluid circulates well between 275.4 m and 283.4 m at the depth in the D1 hole, and the flushing fluid leakage between the depth of 275.4 m and 279.4 m did not change much, generally tended to rise gently. At a depth of 285.3 m, the circulation of the washing solution was interrupted, and no water was lost in the hole, and no water returned. When the depth of the hole was 374.6 m, it dropped about 0.2 m, and when the depth of the hole was 375.1 m, the air suction in the hole was obvious after lifting. After the hole depth exceeded 376.20 m, the number of dropped drills increased. At the same time, there will be jamming, and the integrity of the core taken out is poor. There is obvious suction inside the hole. According to Fig. 2 (b) and field drilling observation, the flushing fluid circulates well between 255.2 m and 271.2 m at the depth in the D2 hole, and the flushing fluid leakage between the depth of 255.2 m and 271.2 m did not change much, and the overall tends to be gentle. When the hole depth was 273.2 m, the leakage of flushing fluid began to change, with a sudden increase trend. When the circulation of flushing fluid was interrupted at the depth of 278.4 m, all the liquid were lost, and no water was returned after the water injection test. After the hole depth exceeded 359.7 m, the number of dropped drills increased. At the same time, stuck drills may occur, and the integrity of the removed core was poor. There was obvious suction inside the hole.

![Figure 2](image)

(a) D1  
(b) D2

Figure 2. Loses curves of drilling fluid with hole depth.

4.2. "Two zones" observation method of borehole color TV

Because there were many primary fissures in the observation sections in the D1 and D2 holes, in order to obtain the height of the water-conducting fissure zone and the collapse zone more accurately, based on the leakage measurement, the auxiliary judgment was made by combining the water level change rate and ultra-high definition full intelligent borehole TV (GD3Q-GA type).

The curve of water level in the D1 hole with drilling depth was shown in Figure 3. According to the observation results in Figure 3, it can be seen that the water level in the hole decreased with the increase of the drilling depth, and cannot be measured until the depth of 285.30 m.

![Figure 3](image)

Figure 3. Variation curve of water level in the D1 hole with drilling depth.
Figure 4 showed the results of color TV peeping at the depth of 285.30 m and 361.20 m in the D1 borehole. According to Figure 4 (a), the hole wall was relatively smooth at 285.30 m, and there were micro-cracks in the hole wall. The fracture trace of the hole wall was obvious at 361.20 m.

(a) Observation at a hole depth of 285.30 m           (b) Observation at a hole depth of 361.20 m

Figure 4. Color TV peek in the D1 hole.

The water level variations in the D2 hole with drilling depth was shown in Figure 5. It can be known from the observation results in Figure 5 that the water level in the hole decreased with the increase in the depth in the hole, and cannot be measured until 278.40 m. The results of the D2 borehole color TV peep were similar to the hole of the D1, which would not be explained here.

![Variation curve of water level in the D2 hole with drilling depth.](image)

The water level variations in the D2 hole with drilling depth was shown in Figure 5. It can be known from the observation results in Figure 5 that the water level in the hole decreased with the increase in the depth in the hole, and cannot be measured until 278.40 m. The results of the D2 borehole color TV peep were similar to the hole of the D1, which would not be explained here.

Figure 5. Variation curve of water level in the D2 hole with drilling depth.

4.3. Determination of the height of the "two zones" in the Chahasu coal mine

4.3.1. Determination of the height of the "two zones" in the D1 hole

Based on the observation of the leakage and the color television peeping results of the drilling, the vertex of the water-conducting fissure zone in the D1 hole was 285.30 m, and the vertex of the collapse zone was 361.20 m. The calculation formulas of the water-conducting fracture zone and the collapse zone were shown in equations (5) and (6).

The formula for calculating the height of water conducting fracture zone was:

\[
H_{li} = H - h_{li} + W
\]

(5)

\[
H_{k} = H - h_{k} + W
\]

(6)

In the formula, \(H\)—the vertical depth of coal seam roof from the orifice, m; \(h_{li}\), \(h_{k}\)—the vertical depth of apex of fracture zone and collapse zone from the orifice, m; \(W\)—the compression value of fracture zone rock during drilling observation, m.

4.3.2. Determination of the height of the "two zones" in the D2 hole

Based on the results of the leakage measurement and color television peeping, the apex of the water-conducting zone in the D2 hole was 278.40 m, and the apex of the collapse zone was 359.70 m.
The distance between the D2 hole and the coal seam floor was 388.5 m, and the mining thickness of the coal seam at this hole was 4.50 m. According to formulas (5) and (6), the height of the water-conducting fracture zone and the collapse zone in the D2 hole were 106.50 m and 25.20 m.

5. Error analysis of height prediction of "two zones" in empirical formula

When empirical formulas were used to estimate the height of the "two zones" of the overlying strata in the 31303 working face, the mining height was 5.87 m, which is the average mining height. However, the coal thickness exposed by the drill hole in the D1 and D2 holes were regarded as mining height in the actual measurement. The "two zones" were compared at the height, and the error of empirical calculation was not suitable. Therefore, in order to reduce the error, it was considered to compare the crack-to-mine ratio and the collapse-to-mine ratio, and then the error rate of the empirical formula was more reasonable.

The error rate of the empirical formula was defined as the difference between the actual measured fracture (collapse)-mining ratio and the expected fracture (collapse)-mining ratio divided by the measured fracture (collapse)-mining ratio as the empirical formula error rate, that was:

$$
\eta = \frac{\xi - \xi'}{\xi}
$$

In the formula, $\eta$ was error rate of predicted heights, $\xi$ was the fracture (collapse)-mining ratio obtained from field measurements, $\xi'$ was the fracture (collapse)-mining obtained from the empirical formula. A positive $\eta$ value indicated that the value of the predicted water-permeable fracture zone (collapse zone) was small; a negative $\eta$ value indicates that the value of the predicted water-conducting fracture zone (collapse zone) was large.

The measured fracture-mining ratio and collapse-mining ratio in the D1 hole were 21.39 and 5.24 respectively. The measured fracture-mining ratio and collapse-mining ratio in the D2 hole were 23.67 and 5.6, respectively. The slice mining formula for thick coal seams predicted fracture-mining ratio and collapse-mining ratio were 8.65 and 2.52, respectively while the formula for fully mechanized caving mining predicted fracture-mining ratio and collapse-mining ratios were 15.20 and 6.85, respectively. Substituting the value into equation (7), the error rates of the water-conducting fracture zone and the collapse zone predicted by the empirical formula of slice mining formula for thick coal seams for D1 hole were 59.56% and 51.91%, respectively while the error rates of the water-conducting fracture zone and the collapse zone of fully mechanized caving mining were 28.94% and -30.73%, respectively. The error rates of the water-conducting fracture zone and the collapse zone predicted by the empirical formula of slice mining formula for thick coal seams for D2 hole were 63.46% and 55%, respectively while the error rates of the water-conducting fracture zone and the collapse zone of fully mechanized caving mining were 35.78% and -22.32%, respectively.

In summary, the existing empirical prediction formulas for thick coal seams have deviations in the "two zones" development heights of large mining heights in different mining regions. The empirical formulas for thick seam slice mining have large deviations, with an error rate of more than 50%. The slice mining formula for thick coal seams prediction was no longer applicable to the prediction of "two zones" development in high-mining working face. The error rate of the empirical formula for fully mechanized caving mining was close to ± 30%, which has certain reference significance.

To ensure the safety of coal mine production, the fracture-mining ratio and collapse-mining ratio of 31303 working face in the Chahasu coal mine were determined to be the maximum values in the actual measurement, which were 23.67 and 5.6, respectively. The height of the water-conducting fracture zone and the collapse zone were determined to be 106.50 m and 25.20 m.

6. Conclusions

(1) Through the observations of the leakage of the washing fluid and the color television in the holes, the fracture-mining ratio and collapse-mining ratio of D1 and D2 holes in the 31303 working face in the Chahasu coal mine were obtained, which were 21.39, 5.24 and 23.67, 5.6, respectively. Through
comparative analysis, the development heights of water-conducting fracture zone and collapse zone in the 31303 working face in the Chahasu coal mine were determined, which were 106.50 m and 25.20 m, respectively.

(2) The empirical formula of "two zones" for thick seam slice mining and fully mechanized caving mining were used to predict the development height of "two zones" in 31303 working face in the Chahasu coal mine, it is concluded that the predicted results of the two formulas have certain deviation, and the predicted value of "two zones" of fully mechanized caving mining was closer to the measured value than the predicted value of thick coal seam slice mining.

(3) The concept of error rate of empirical formula was put forward, and a quantitative analysis of the error rate predicted by the empirical formula of thick seam slice mining and fully mechanized caving mining in working face 31303 was made. The error rates of the empirical formulas for layered mining and fully mechanized caving mining were quantitatively analysed, which were 50% and ±28%, respectively, indicating that the traditional empirical formula was not universal in the prediction of "two zones" of fully mechanized mining with slicing mining.

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