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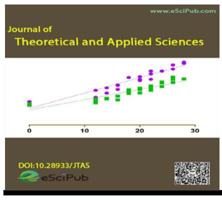

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Risk assessment of Ordovician limestone water inrush in No.9 coal seam of Yangdong coal mine and its prevention and control measures

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ABSTRACT

With the increasing of mining depth, intensity, scale and speed, Ordovician limestone water has become the biggest threat to the safety production of the low group seam. Based on the existing geological data, the hydrogeological characteristics of Ordovician limestone water are analyzed; the risk of Ordovician limestone water inrush is evaluated by using the method of “five maps and double coefficients” and considering the importance of effective protective thickness of floor protective layer in the evaluation results. The results show that there are no non straight through relative safety area (Area I) and non straight type relative risk area (Area II), only non straight type water inrush risk area (Area III) and straight through water inrush risk area (Area IV). According to the evaluation results, the floor grouting reinforcement is directly adopted in Area IV, and the Ordovician limestone may need to be modified in the strong water rich area; in Area III, the grouting transformation of the floor is carried out after the area with water inrush is identified first, but the Ordovician limestone is not needed. Other prevention and control measures should be subsidiary.

Keywords: Water inrush from Ordovician limestone; Risk assessment; “five figures and double coefficients” method; Prevention and control measures

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Introduction

With the continuous increase of coal mining depth, intensity, scale and speed, mine water hazards have become the second largest disaster in the process of coal mine safety production in my country. Among them, the Ordovician floor water damage is a serious threat to the safe mining of the Carboniferous Permian coalfields in North my country due to its strong suddenness, high water pressure, strong catastrophe and strong replenishment [1-5]. For the evaluation of water inrush from coal seam floor, the Water Inrush Coefficient Method, Vulnerability Index Method and "Five Graphs-Double Coefficient" method are recommended in the "Regulations on Coal Mine Water Prevention and Control" [6]. In the water inrush evaluation of coal mines in my country, the water inrush coefficient method is still the most widely used method, but as the depth of coal mining increases, its limitations are exposed [7]. The vulnerability index method can not only comprehensively consider and analyze the water inrush factors, but also reflect the complex water inrush process; but it needs enough relevant data in the early stage of the study area [8], and there is subjectivity in the establishment of weights. The "Five-Picture-Double Coefficient" method is more comprehensive than the water inrush coefficient method in terms of evaluation content and results, and requires less relevant data and more objectivity in the evaluation process than the vulnerability index method; The "coefficient" method is more suitable for evaluating the risk of water inrush in areas with large mining depths and less or incomplete relevant data.

Yi Weixin modified the water inrush coefficient method considering factors such as faults, Ordovician water-rich areas, mine pressure, etc., and applied the "five maps-double coefficient" method to evaluate the water inrush from the floor of Daping Coal Mine, and obtained prediction results that are more consistent with the actual situation [9]. Zhang Yi used the vulnerability index method and the "five graph-double coefficient" method to evaluate the water inrush from floor karst water of a coal mine in Zuozhushan Coal Field, Inner Mongolia, and compared the two evaluation results [10]. However, the importance of the effective protective thickness of the bottom water barrier in the evaluation results was not considered. Using existing geological data and data, using multiple parameters to superimpose and synthesize, analyze the hydrogeological characteristics of the Ordovician aquifer; apply the "five-map double-coefficient" method, and consider the importance of the effective protection thickness of the floor protection layer in the evaluation results It evaluates the risk of water inrush from Ordovician ash in the bottom of the 9# coal seam of the Xia Group of Yangdong Mine, and proposes prevention and control measures, which has an important guiding role in mine safety mining under pressure.

Survey of research area

Yangdong Mine is located in the east of Fengfeng Mine, 30 km northeast of Handan City, where Fengfeng Group is located, and is a typical North China coal field (Fig.1). The strata of each age within the minefield range from new to old are Quaternary, Triassic, Permian, Upper and Middle Carboniferous, and Middle Ordovician.

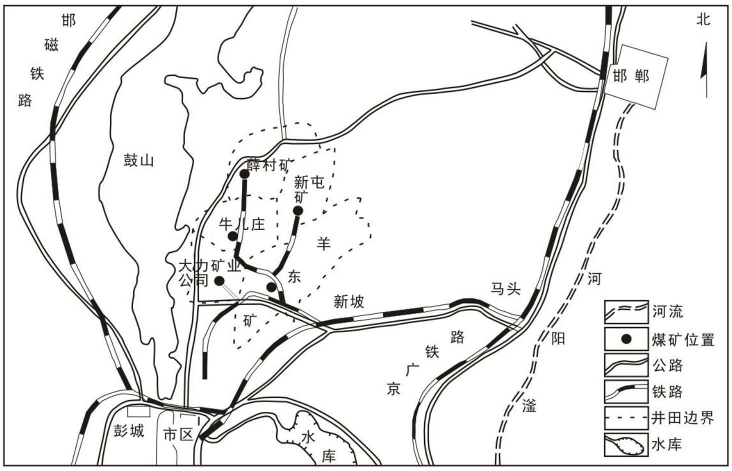

Fig.1 Schematic diagram of regional location

The geological structure of the Yangdong Mine is very complex. The basic structure is a monoclinic structure, which strikes NNE and tends to SEE. The faults are very developed, 91 faults have a drop of more than 5 m, and more than 160 faults have a drop of less than 5 m. The controlled faults are normal faults except the F32 fault, which is a reverse fault; the overall strike is mainly in the direction of NNE and NEE , The inclination is NW or SE, and the dip angle is generally 60-70°; it is mainly distributed in the north and southwest, and it is a complex horst block. Folds and collapsed columns are relatively developed.

Yangdong Minefield is located in the weak runoff zone in the eastern part of Gushan Mountain, the southern unit of Hanxing Hydrogeological Unit (Fengfeng Hydrogeological Unit). The replenishment source of Ordovician lime karst fissure water is mainly atmospheric precipitation infiltration replenishment. It is located in karst-developed limestone exposed areas such as Jiushan and Gushan outcrops. In addition to receiving rainfall infiltration and replenishment, there are also fissure karsts in the western and northwestern mountains Partial lateral recharge of groundwater. The Ordovician aquifer is karst and developed with fissures and strong water richness, but the water richness is extremely uneven, and the recharge is sufficient, and the water level is between +110 m and +130 m. With the continuous extension of the mining level, the pressure of O2f3+2 limestone groundwater on the coal seam floor gradually increases, and the threat to the mining of the lower coal (8#, 9# coal) is increasing, so the O2f3+2 aquifer becomes the main treatment Object.

There are 5 layers of stable mineable coal seams in Yangdong Mine, namely 2#, 4#, 6#, 8#, 9# coal. With the continuous mining of coal seams, the depth of the working face continues to increase, and the possibility of water inrush from the Ordovician floor water is also increasing. The water level of the Ordovician Ash is between +110 -- +130 m; the average distance between the 9# coal floor and the roof of the Ordovician Peak Formation is only 25 m, all of which are below the Ordovician Water Level. Evaluate the risk of water inrush from the Ordovician ash from the floor, and propose prevention and control measures to provide a basis for safe production in coal mines.

"Five Pictures-Double Coefficients" Method for Risk Assessment of Floor Water Inrush

The "five maps-double coefficients" method is a method for evaluating water damage in coal seam floors in the "Regulations on Water

Prevention and Control in Coal Mines". The five maps refer to the contour map of the damage depth of the floor protective layer, the contour map of the thickness of the floor protective layer, the contour map of the water head above the coal seam floor, the contour map of the effective protective layer thickness, and the evaluation map of mining under pressure. Double coefficient refers to the coefficient of pressure and water inrush coefficient [11].

Depth of underfloor protection layer damage

The coal seam floor rock layer is destroyed due to factors such as mining stress and mineral pressure during the coal seam mining process, resulting in fissures. The fissures between the coal seam and the aquifer become a good water channel, which increases the possibility of water inrush from the coal seam floor. The destruction depth of the coal seam floor refers to the maximum depth that the fissures can penetrate each other under the action of the mine pressure [12, 13]. The depth of the coal seam floor failure zone is calculated using the empirical formula (1).

$$h = 0.0085H + 0.1665\alpha + 0.1079L - 4.3579 \quad (1)$$

where:

h--Thickness of floor failure zone in mining coal seam (m)

H--Coal seam mining depth (m)

A--Stratum dip (°), Take 15°

L--Slope length of mining face (m), Take 160m

According to the data of geological boreholes, hydrogeological boreholes, and mining slope length in the study area, the above formula is used to calculate the protection layer damage depth of each borehole floor in the study area (Table 1), and draw the Yangdong Mine 9# coal seam floor Contour map of the damage depth of the protective layer (Fig.2).

Table 1 Thickness of failure zone of floor protective layer in No.9 coal seam

Number	9# Coal seam floor protection layer failure zone thickness (m)	Number	9# Coal seam floor protection layer failure zone thickness (m)	Number	9# Coal seam floor protection layer failure zone thickness (m)
121	21.43	羊 12	20.99	910	21.87
126	24.02	55	23.23	1003	23.28
134	21.78	71	21.77	羊 18	20.19
151	20.57	99	22.79	801	17.28
1109	23.29	611	21.71	825	17.37

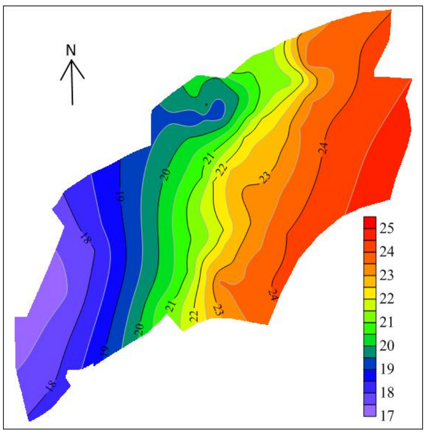

Fig.2 Contour map of failure depth of floor protective layer in No.9 coal seam

It can be seen from Fig.2 that the damage depth of the floor protection layer in the Yangdong Mine 9# coal increases from west to east. The minimum damage depth of the floor protection layer in the west is 17.28 m, and the maximum damage depth of the floor protection layer in the southwest is 24.85 m.

Thickness of bottom protection layer

The thickness of the floor protection layer is the thickness of the rock layer between the coal seam floor and the top slab of the confined aquifer, which is the thickness of the floor water-proof layer. The thickness of the 9# coal floor protection layer is calculated (Table 2), and the Yangdong Mine 9# coal seam floor protection is drawn Contour plot of layer thickness (Fig.3).

Table 2 Thickness of floor protection layer of No.9 coal seam

Number	9# Coal seam floor protection layer thickness (m)	Number	9# Coal seam floor protection layer thickness (m)	Number	9# Coal seam floor protection layer thickness (m)
121	24.05	羊 12	20.63	910	49.36
126	7.00	55	19.77	1003	24.17
134	23.90	71	19.34	羊 18	35.33
151	27.75	99	23.20	801	10.55
1109	3.07	611	21.70	825	29.99

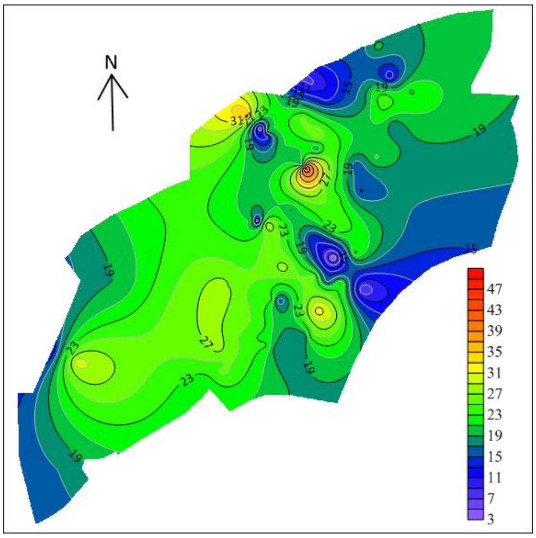

Fig.3 Contour map of protective layer thickness of No.9 coal seam floor

It can be seen from Fig.3 that the thickness of the protective layer of the 9# coal seam floor in the study area fluctuates greatly, ranging from 3.07 to 49.36 m. Among them, the thickness of the central and western regions did not change much, all around the average value of 25 m. The thickness of the inner north, southeast, and southwest regions was less than 17 m; combined with Fig.2, after coal seam mining, most of the cracks generated under the floor communicate with each other. Lower aquifer.

Effective protective layer thickness

The effective protective layer thickness, also known as the effective water barrier thickness.

According to the aforementioned floor mining failure depth and protective layer thickness, the effective protective layer thickness of the 9# coal seam floor in the study area can be calculated, as shown in Table 3, draw the effective protective layer thickness contour map of the 9# coal seam floor in the study area. As shown in Fig.4.

Table 3 Effective protective layer thickness of No.9 coal seam floor

Number	9# Effective protection layer thickness of coal seam floor (m)	Number	9# Effective protection layer thickness of coal seam floor (m)	Number	9# Effective protection layer thickness of coal seam floor (m)
121	2.62	羊 12	0.00	910	27.49
126	0.00	55	0.00	1003	0.89
134	2.12	71	0.00	羊 18	15.14
151	7.18	99	0.41	801	0.00
1109	0.00	611	0.00	825	12.62

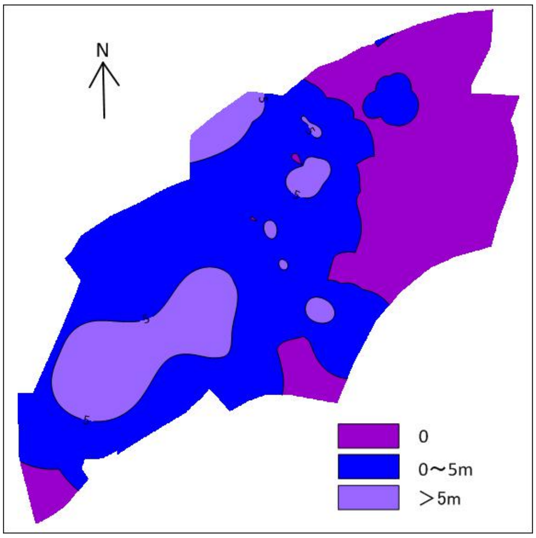

Fig.4 Contour map of effective protective layer thickness of No.9 coal seam floor

It can be seen from Fig.4 that the overall trend of the effective protective layer thickness of the 9# coal seam floor in the study area is thick in the west and thin in the east. The possible reason for this feature is that the east is buried deep, and the damage caused by coal mining is even greater. Large, which invalidates the water barrier in the east. In the eastern, northeastern, southern, and southwestern regions of the figure, the effective water barrier thickness of the floor is 0 m, and water inrush is prone to occur in this area; the effective protective layer thickness of the floor in other areas in the figure is greater than 0 m.

Pressure coefficient

In the "five-figure-double coefficient" method, the pressure coefficient refers to the maximum water pressure that the rock layer can resist per meter; the overall compressive strength is calculated by the equivalent coefficient of the bottom water-proof layer, and the value obtained by subtracting the actual water pressure. That is the pressure coefficient. When the pressure coefficient is less than 0, it is a dangerous zone, otherwise it is a safe zone [11]. According to the conversion table [14, 15] (Table 4) of equivalent water resistance coefficient and compressive strength of the rock formation, the equivalent water resistance layer thickness and pressure coefficient of each drilling point are obtained (Table 5), and 9# coal seam The isoline map of the water pressure of the bottom water-proof layer (Fig.5) and the isoline map of the pressure coefficient (Fig.6).

Table 4 Rock equivalent water coefficient and compressive strength conversion

Lithology	Equivalent water barrier coefficient	Test compressive strength ($MPa\cdot m^{-1}$)
Mudstone, marl, shale	1.0	0.05
Non-karst melting limestone, dolomite	1.3	0.10
Sand shale	0.8	0.07
lignite	0.7	-
sandstone	0.4	0.10
Siltstone	0.8	0.07
Sand, gravel, gravel, karst limestone, caving fracture zone	0	-

Table 5 Equivalent thickness of water resisting layer and coefficient of bearing pressure of each drilling point

Number	Thick-ness (m)	Combination of rigid rock and flexible rock						Equivalent water barrier thickness (m)	Overall compres-sive strength (MPa)	Actually bear water pressure /MPa	Can resist
		Mudstone thickness (m)		Siltstone thickness (m)		Limestone thickness (m)					
		Thick-ness (m)	Propor-tion	Thick-ness (m)	Propor-tion	Thick-ness (m)	Propor-tion				
121	24.05	13.23	0.55	10.82	0.45			21.886	1.4189	7.01	no
126	7.00	4.55	0.65	2.45	0.35			6.51	0.399	9.95	no
134	23.90	15.26	0.638	8.64	0.362			22.172	1.3678	7.45	no
151	27.75	18.43	0.664	9.32	0.336			25.886	1.5739	5.97	no
1109	3.07	2.15	0,70	0.92	0.3			2.886	0.1719	9.01	no
羊 12	20.63	12.58	0.61	8.05	0.39			19.02	1.1925	6.36	no
55	19.77	11.81	0.597	7.96	0.403			18.178	1.1477	8.84	no
71	19.34	11.42	0.59	7.92	0.41			17.756	1.1254	7.26	no
99	23.20	14.85	0.64	8.35	0.36			21.53	1.327	8.56	no
611	21.70	13.44	0.619	8.26	0.381			20.048	1.2502	7.18	no
910	49.36	19.74	0.4	24.68	0.5	4.94	0.1	45.906	3.2086	7.68	no

1003	24.17	15.27	0.632	8.9	0.368			22.39	1.3865	9.18	no
羊 18	35.33	14.17	0.401	18.64	0.528	2.52	0.071	32.358	2.2653	5.44	no
801	10.55	5.59	0.53	4.96	0.47			9.558	0.6267	1.72	no
825	29.99	13.91	0.464	14.62	0.487	1.46	0.049	27.504	1.8649	2.19	no

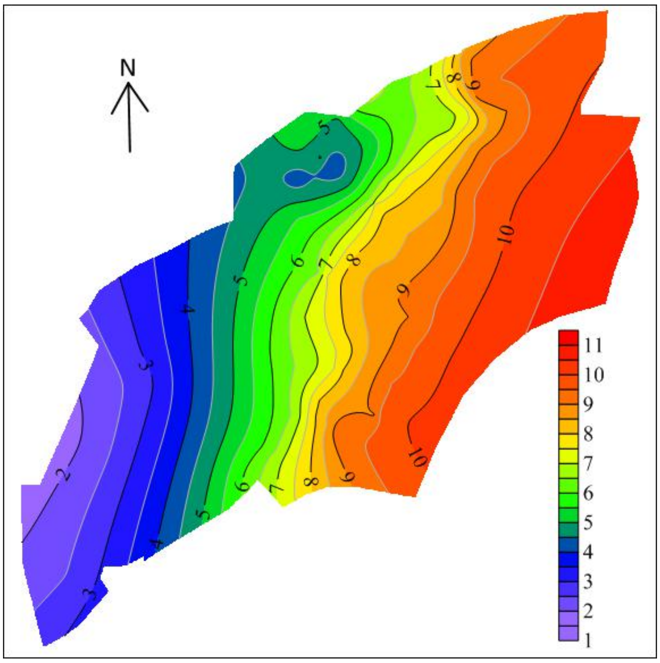

Fig.3-5 Contour map of water pressure bearing capacity of No.9 coal seam floor aquiclude

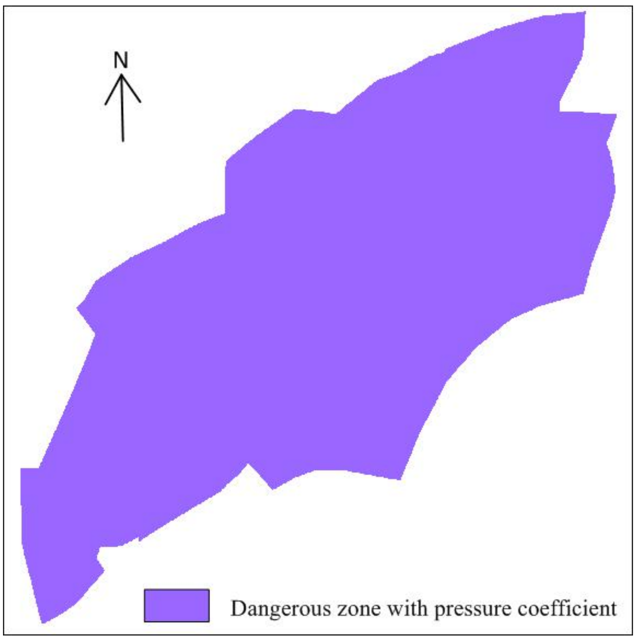

Fig.6 Contour map of pressure coefficient in floor of No.9 coal seam

It can be seen from Figure 5 that the water pressure of the 9# coal seam floor water-proof layer is 1.72-10.65 MPa, which gradually increases from west to east in the shape of a strip.

It can be seen from Figure 6 that the pressure coefficients in the study area are all less than 0 Mpa. The thickness of the 9# coal seam floor water-insulating layer is small, of which mud-stone accounts for more than 50%, so the overall compressive strength that can be with-stood is small, while the 9# coal seam floor water-isolating layer actually bears greater water pressure, forming a uniform area in the study area. It is a dangerous zone with pressure coefficient.

Water inrush coefficient

The water inrush coefficient is the water pressure that the coal seam floor per unit of water-proof layer is subjected to, and it is an important index to evaluate the water inrush risk of the coal seam floor in mining under pressure. The water inrush coefficient is calculated using the modified formula (2).

$$T_s = \frac{P}{H_{有效}} \quad (2)$$

where:

T_S—water inrush coefficient after the water barrier is destroyed(Mpa/m)

P—Water pressure on the bottom of the water barrier(Mpa)

$H_{有效}$—thickness of the effective water barrier of the bottom plate(m)

Table 6 Water inrush coefficient of No.9 coal seam floor

Number	9# Coal seam floor protection layer failure zone thickness (m)	Number	9# Coal seam floor protection layer failure zone thickness (m)	Number	9# Coal seam floor protection layer failure zone thickness (m)
121	2.67	羊 12	>0.1	910	0.28
126	>0.1	55	>0.1	1003	10.34
134	3.51	71	>0.1	羊 18	0.36
151	0.83	99	21.03	801	>0.1
1109	>0.1	611	>0.1	825	0.17

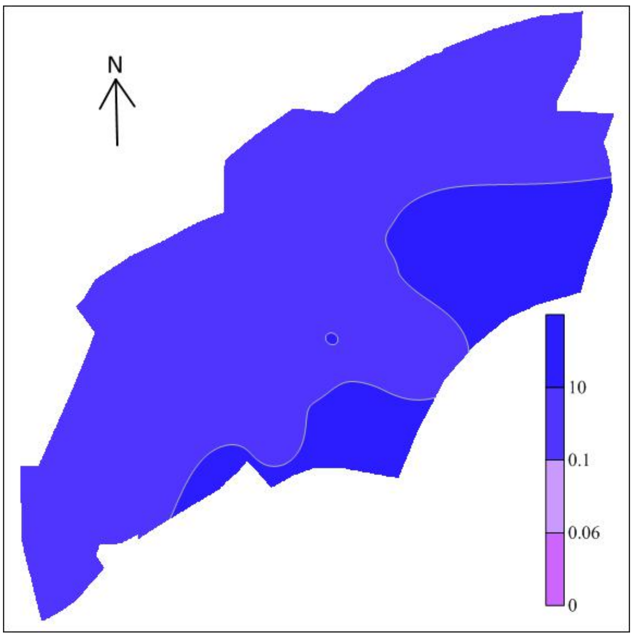

Fig.6 Contour map of floor water inrush coefficient in No.9 coal seam

It can be seen from Fig.7 that the water inrush coefficients of the 9# coal seam floor are all greater than 0.1 MPa, and some areas are even greater than 10 MPa. The thickness of the effective water-resistant layer of the 9# coal seam floor is relatively small, but the actual water pressure of the 9# coal seam floor is relatively large. So the entire study area is a water inrush danger zone.

Evaluation standard

The "five maps-double coefficients" method to evaluate the risk of water inrush from coal seam floor often uses a combination of three-level discrimination and double coefficients to determine whether floor water inrush occurs, the form of floor water inrush, and the amount of water inrush. The third level of three-level discrimination is The indicators are:

①I-level discrimination index (straight-through water inrush)

The equivalent thickness of the effective water barrier of the 9# coal seam is 0 m～27.49 m. Among them, the effective protective layer thickness of the floor in the east, northeast, south and southwest is 0 m, and other areas in the mining area are pressure zones, indicating that the effective water-proof layer of the coal seam floor in this area bears a greater water pressure on the Ordovician aquifer. In addition, the effective thickness of the water barrier is small, which is prone to direct water inrush.

②Class II discrimination index (non-straight-through water inrush possibility and its water inrush form)

The water inrush coefficient of the 9# coal floor of Yangdong Mine is all greater than the critical water inrush coefficient of 0.06 MPa/m. Therefore, the 9# coal seam is more likely to have non-through water inrush in the mining area. During the mining process, the 9# coal seam floor will form a conduction zone, fault activation fissures and floor failure fissures. Ordovician lime water occurs in these three channels. Water burst.

③Class III discriminant index (change status of water inrush amount)

According to the analysis of regional hydrogeological conditions, the Yangdong Mine is located in the weak runoff zone in the eastern part of Gushan, the southern unit of the Hanxing Hydrogeological Unit (Fengfeng Hydrogeological Unit). The replenishment source of the Ordovician karst fissure water in the Yangdong Mine is mainly the replenishment of atmospheric precipitation infiltration. It is located in the exposed areas of karst developed limestone such as Jiushan and Gushan outcrops. In addition to receiving regional rainfall infiltration and replenishment, in the western and northwestern mountainous areas, Partial lateral recharge of fractured karst groundwater. According to previous exploration data, it can be known that the water richness of Ordovician lime water is strong in the western and central parts of Yangdong Mine, and the water richness of other parts is medium. The water pressure of the Ordovician water in the western and central parts of Yangdong Mine is greater than 1.7 MPa, and the area is close to the replenishment area. It has the characteristics of adequate replenishment, large water volume, and high water pressure. Once a water inrush accident occurs, it will be extremely harmful.

Evaluation result

Taking the pressure coefficient, the water inrush coefficient and the effective protective layer thickness as the main evaluation indicators, the "five-map double-coefficient method" is used to evaluate the water inrush zone map of the ordovician rock in the No. 9 coal seam of

Yangdong Mine (Fig.8).

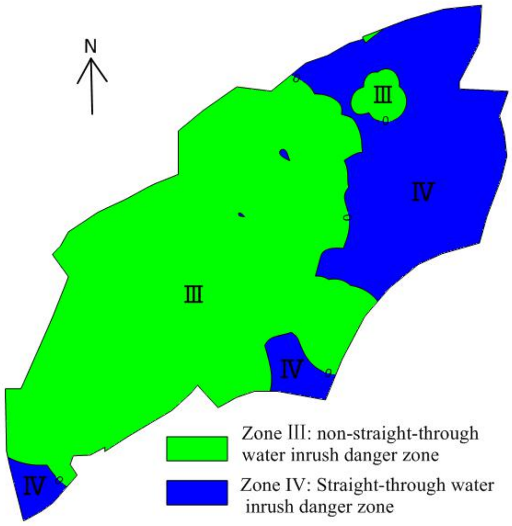

Fig.8 Evaluation zoning map of Ordovician limestone water inrush from floor of No.9 coal seam by "five diagrams double coefficient" method

① Zone Ⅰ: When the pressure coefficient is greater than 0 MPa/m, the water inrush coefficient is less than 0.06 MPa/m, and the effective protection layer of the bottom plate is greater than 0 m, it is a non-straight-through relatively safe zone. After evaluation, there is no non-straight-through relatively safe area in the study area.

②Zone Ⅱ: When the pressure coefficient is less than 0 MPa/m, the water inrush coefficient is greater than 0.06 MPa/m and less than 0.1 MPa/m, and the effective protection layer of the floor is greater than 0 m, the working surface is a non-straight-through relatively dangerous area, and there is a floor The possibility of water inrush, especially in the vicinity of faults. After evaluation, the study area has no non-straight-through water inrush relatively dangerous area.

③Zone Ⅲ: When the pressure coefficient is less than 0 MPa/m, the water inrush coefficient is greater than 0.1 MPa/m and the effective protection layer of the floor is greater than 0 m, the working face is a non-through water inrush danger zone, and water inrush from the floor is likely to occur , Especially in the vicinity of faults, water prevention and control measures must be taken.

④Zone Ⅳ: When the pressure coefficient is less than 0 MPa/m, the water inrush coefficient is also greater than 0.06 MPa/m, and the effective protection layer of the floor is greater than 0 m, it is a straight-through water inrush danger zone; if effective prevention measures are not taken, it is extremely Prone to water inrush accidents.

Prevention

(1) Using the floor directional drilling technology can achieve precise advance grouting to reinforce the cracks of the floor water-resistant rock layer, enhance the tensile and compressive strength of the floor, can effectively overcome the high pressure water of the floor, reduce the risk of water inrush from the floor, and Protecting groundwater resources, and at the same time controlling water-bearing geological anomalies, this technology liberates a large amount of coal resources [16-18]. The through-type water inrush danger zone (Zone Ⅳ) is directly reinforced by floor grouting to increase the thickness of the effective water barrier, enhance the tensile and compressive strength of the floor, and enhance the water blocking capacity of the

water barrier of the coal seam floor, thereby blocking the Olympics. Grey water penetrates into the tunnel of the mining face. For areas with strong water richness, if necessary, ground area treatment technology is used to grouting and reform the Ordovician ash within 40m below the top interface of the Ordovician ash to achieve the purpose of cutting off the water source and reducing the water richness of the aquifer. After the top of the Ordovician ash is treated by grouting, the occurrence of water inrush from Ordovician ash will not cause the mine to be flooded. In the non-straight-through water inrush danger zone (zone Ⅲ), the area where water inrush is likely to be detected first, and then the floor grouting reinforcement transformation is carried out, but there is no need for grouting transformation to Ordovician ash.

(2) For the collapsed columns and faults with large gaps in the straight-through water inrush danger zone (Zone Ⅳ) and the non-through water inrush danger zone (Zone Ⅲ), grouting reinforcement is required or 9# coal seam is required to prevent water resistance. Coal pillars.

(3) Mining from shallow to deep, step by step, and separate mining. Divisional isolation mining is one of the prevention and control measures that can reduce losses in the event of a water inrush accident. Mine divisional isolation is to establish isolation facilities such as waterproof gate walls or waterproof gates in the main roadway of the mine. In the event of a major water inrush accident, immediately use isolation The facilities are isolated to control the water inrush disaster in a small area to prevent the entire mine from being flooded.

(4) Strengthen the measures of "exploration where there is excavation, exploration where there is mining, and drilling where there is doubt" and "physical prospecting first, geochemical exploration follow-up, and drilling verification" [19].

(5) Establish a monitoring and early warning system for the Olympic ash water inrush and increase the drainage capacity of the mine drainage system. The Ordovician lime water has the characteristics of abundant water and strong disaster. Once the Ordovician lime water incurs a water inrush, there is a danger of inundation of the mine. The strong drainage capacity is the last line of defense to avoid flooding in the event of water inrush from Austrian limestone. Therefore, in addition to the horizontal pump drainage system, a submersible pump drainage system was added [20].

Conclusion

Considering the importance of the effective protective thickness of the bottom water-proof layer in the evaluation results, the "five-picture-double-coefficient" method uses the pressure coefficient, the water inrush coefficient and the effective water-resistant layer thickness as the main evaluation indicators, and the evaluation result is under mining conditions. Water inrush may occur in the whole area of the 9# coal seam floor of Yangdong Mine, and even some areas may have direct water inrush. According to the evaluation results of the "five maps-double coefficient" method, water prevention measures such as floor grouting are taken before mining; and during mining, separate mining is adopted, advance detection is strengthened, and a monitoring and early warning system for water inrush from Ordovician limestone is established. And increase the drainage capacity of the mine drainage system and other auxiliary prevention measures.

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