Prediction Of Mining-induced Fracture In North China Coal Field Based On Orthogonal Test

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Abstract

The floor failure depth has an important influence on the mining of Carboniferous-Permian coal seam. In view of the characteristics of the above-mentioned seam floor, this paper analyses the main controlling factors affecting the floor failure depth, and design orthogonal experiment to simulate fracture development under mining conditions. Through the analysis of the experimental results, the influence of different floor lithology combination and floor shear strength on the failure depth of coal seam floor is determined, and the mathematical model for predicting the failure depth of coal seam floor is established. The model is proved to be reliable by the measured data.

Keywords: floor failure depth, orthogonal test, lithological combination , numerical simulation, linear regression model

Introduction

In the process of coal seam mining, the destruction of seam floor will produce fracturing, and we call it 'floor failure depth'(Shi 2000). If the floor failure depth reaches to communicate with underlying aquifer, water inrush from floor will easily occur, causing serious safety accidents.

Coal in North China type coalfields was mainly produced in the late Carboniferous-early Permian coal-accumulating period (Qiu 2017). Most of the coal was formed in a marine sedimentary environment. Therefore,the north China coal field has a remarkable feature that coal measure strata are mainly composed of sandstone, mudstone and carbonate rock. Under the same mining conditions, different mechanical properties of floor rocks and different combinations of fracture mechanism among different rocks have a decisive influence on floor failure depth. For this reason, it is necessary to make a reasonable prediction of the floor damage depth of North China type coal field according to the characteristics of North China type coal, so as to ensure the safety of coal production.

Analysis of the Main Control Factors of Mining Floor Failure Depth

There are many factors affecting the floor failure depth, which mainly depend on the influence of two major factors: one is the damage resistance ability of underlying strata, the other is the force that causes floor failure. In this paper, 6 major factors, such as mining thickness, mining depth, slope length of working face, coal seam inclination, lithological association of floor and shear strength of floor, are selected to model and analyze the main control factors affecting the floor failure depth. The changes of six main controlling factors have a strong influence on the failure depth of the floor. The mining thickness, the mining depth, the slope length of the working face and the inclination angle of the coal seam together determine the mine pressure, the lithologic combination of the second floor and the shear strength of the floor(Wei 2018). The lithological association of floor and shear strength of floor affects the damage resistance ability of the floor rock mass.

Orthogonal test design

Considering the general characteristics of

Table 1 The level values of the main control factors of floor failure depth

Main control factors	Level 1	Level 2	Level 3	Level 4	Level 5
Shear strength	5	4	3	2	1
Mining thickness/m	1	3	5	7	9
Lithologic combination of floor	4:0	3:1	2:2	1:3	0:4
Mining depth/m	200	300	400	500	600
Slope length of working face/m	80	100	120	140	160
Dip angle of coal seam/(°)	5	10	15	20	25

Remarks: Floor lithology assemblage is expressed by sand-mud ratio

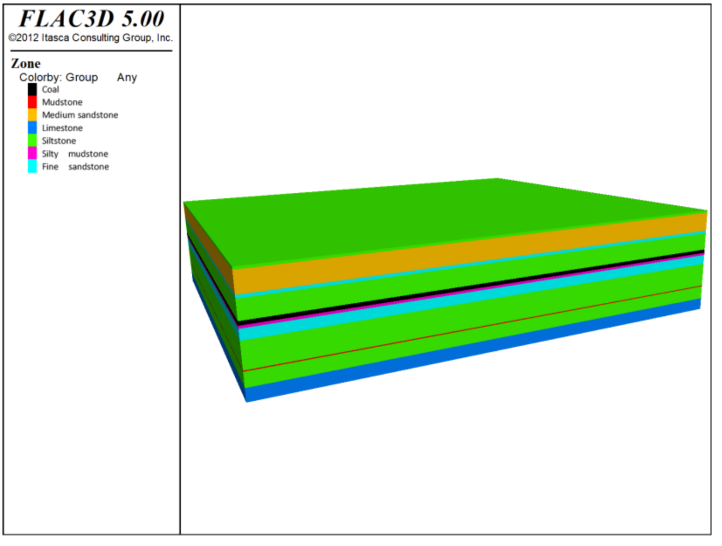

Figure 1 Three-dimensiona *numerical calculation model*

coal production in China and the process and characteristics of floor rock mass failure, in the simulation test, six factors including the thickness of stope, floor lithology combination, floor shear strength, mining depth, working face inclined length and coal seam inclined Angle were selected as the test parameters, as shown in table 1.

Establishment of computational models

In order to determine the influence of lithologic difference of floor on the floor failure depth, the finite element difference method is used to set different parameters for numerical simulation.

The parameters of the whole model, such as size, mining thickness, dip angle, thickness of coal seam and lithological association, are determined respectively according to orthogonal test schedule. Taking into account the larger range of calculations, horizontal and vertical displacements are constrained by lateral and lower boundaries on both sides of the model, and the vertical load (where, above, the gravity of the rock mass on the surface) is applied. (0.025 MN/m^3 is the average bulk density of overlying strata, H is mining depth and p/13MPa is stress). There are 69782 elements and 64800 nodes in the model. The 3-D numerical model is shown in figure 1.

Orthogonal test scheme design

In order to study the sensitivity of the factors determining the floor failure depth,the orthogonal experimental design method was adopted,this method can effectively reduce the amount of calculation.The orthogonal design method was used to design the orthogonal test table of 6 factors and 5 horizontal values, as shown in Table 2.

According to this design scheme,the 3D numerical model is simulated and tested, and the failure depth of the floor under different experimental schemes is obtained.

Analysis of Simulation results of orthogonal experiment

Based on the orthogonal test theory, the failure depth of the simulated floor was analyzed by variance and range analysis.Variance analysis and range analysis was used to determine the sensitivity of each main controlling factor and the influence of the main control factors on the experimental results.

According to the variance analysis and range Analysis, it can be concluded that the sensitivity of the main factors affecting the failure depth of the floor from $R_E > R_D > R_C > R_A > R_B > R_F$, is the slope length of the working face, the mining depth, the lithologic combination of the floor, the shear strength of the strata, the mining thickness and the dip angle of the coal seam in the order of strong to weak.

Comparing the average deviation of each factor, it can be seen that the shear strength

Table 2 The orthogonal simulate test scheme of floor failure depth

Test number	Main control factors						Floor failure depth(m)
	Shear strength	Mining thickness/m	Lithologic combination of floor	Mining depth/m	Working face slanting length/m	Coal seam dip angle (°)	
1	1(5)	1(1)	1(4:0)	1(200)	1(80)	1(5)	2.42
2	5	2(3)	2(3:1)	2(300)	2(100)	2(10)	5.31
3	5	3(5)	3(2:2)	3(400)	3(120)	3(15)	9.62
4	5	4(7)	4(1:3)	4(500)	4(140)	4(20)	10.14
5	5	5(9)	5(0:4)	5(600)	5(160)	5(25)	19.28
6	2(4)	1	3:1	400	140	25	10.81
7	4	3	2:2	500	160	5	11.73
8	4	5	1:3	600	80	10	9.96
9	4	7	0:4	200	100	15	4.08
10	4	9	4:0	300	120	20	10.63
11	3(3)	1	2:2	600	100	20	8.35
12	3	3	1:3	200	120	25	5.36
13	3	5	0:4	300	140	5	10.83
14	3	7	4:0	400	160	10	14.7
15	3	9	3:1	500	80	15	8.23
16	4(2)	1	1:3	300	160	15	8.86
17	2	3	0:4	400	80	20	7.7
18	2	5	4:0	500	100	25	8.2
19	2	7	3:1	600	120	5	12.94
20	2	9	2:2	200	140	10	4.72
21	5(1)	1	0:4	500	120	10	11.61
22	1	3	4:0	600	140	15	17.75
23	1	5	3:1	200	160	20	14.74
24	1	7	2:2	300	80	25	4.5
25	1	9	1:3	400	100	5	6.73

Table 4 *Orthogonal Test Variance Analysis Table of influencing factors of floor failure depth*

Main control factor	Deviation squared sum	Free degree	*F* ratio	Significance
Rock shear strength (A)	27.431	4	5.748	medium
Mining thickness (B)	13.827	4	2.973	
Lithologic combination of floor (C)	41.920	4	9.013	medium
Mining depth (D)	151.478	4	32.567	high
Face slope length (E)	192.692	4	41.428	high
Coal bed pitch (F)	5.394	4	1.411	

Table 5 *Range Analysis Table of orthogonal Test for influencing factors of floor failure depth*

Main control factor	Average deviation					*Range*
	K_1	K_2	K_3	K_4	K_5	
Rock shear strength (A)	10.866	9.694	7.884	9.442	10.154	1.982
Mining thickness (B)	8.01	9.57	10.07	10.072	10.318	2.06
Lithologic combination of floor (C)	11.74	9.606	7.184	9.01	10.9	3.556
Mining depth (D)	6.624	8.226	9.912	10.782	12.656	6.392
Face slope length (E)	6.562	6.734	10.032	12.25	13.862	7.3
Coal bed pitch (F)	9.13	9.66	9.708	10.512	9.63	1.382
Remarks	K_1-K_5 are the average deviation					

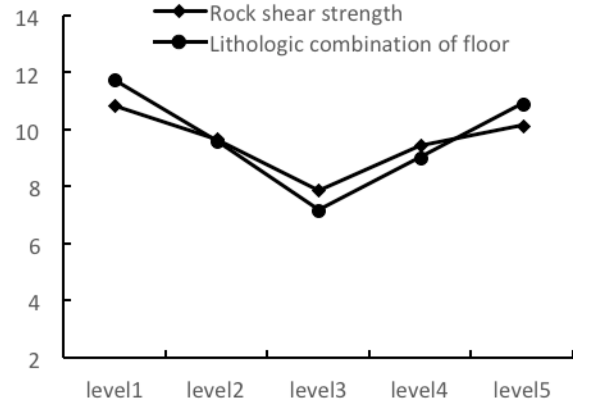

Figure2 Trend *chart of influence of rock shear strength and floor lithology combination on failure depth*

of the strata increases, the failure depth of the floor decreases first and then increases, which is closely related to the lithology of the floor. When the lithologic combination of coal seam floor is sand-mudstone interaction, the floor failure depth is the smallest; when the floor is a single lithology, the failure depth is larger; when the floor is sandstone, the floor failure depth is the largest(figure 2) .

SPSS linear regression analysis

Based on the above-mentioned simulation tests, it can be found that the lithologic combination and shear strength of coal floor have obvious influence on the failure depth of coal floor except for the slope length and mining depth of the coal seam, which accord with the characteristics of North China coalfield. Therefore, in this paper, the linear

Table 6 List of results of regression calculations

Constant	Regression coefficient						Statistical parameter		
	a0	a1	a2	a3	a4	a5	U	F	Significance
-5.338	0.156	0.19	0.087	0.02	0.07	0.01	311.129	4.294	0.006

Remarks:U--regression sum of squares represents the increment of dependent variable generated by the change of independent variable. F--ratio of regression mean square to residual mean square, used for regression significance test.

Table7 Practical data of North China Coal Mine

Number	Shear strength	Mining thickness/m	Sand-mud ratio	Mining depth/m	Working faceslanting length/m	Dip angle (°)	Floor failure depth(m)		Absolute error(m)
							Actual	Simulate	
BZ 7409	4	1.9	2:02	225	130	14	9.75	10	0.25
SG 1208	2	1	2:02	287	130	10	9.5	10.42	0.92
HF 41303	3	0.94	4:00	721	120	30	19	19.11	0.11
YC 3710	2	1.1	2:02	259	75	12	5.5	6.37	0.6
TZ 11703	3	0.9	1:03	205	192	4	12.8	13.37	0.57

regression method is used to analyze the test results, and a reasonable prediction model for the failure depth of the coal floor in North China type coalfield is established.

Construction of the model

Based on the above-mentioned orthogonal numerical simulation test results and correlation analysis, the linear regression analysis method is adopted by using SPSS software. The prediction model of failure depth of mining floor is established:

$$h=x+a_0A+a_1B+a_2C+a_3D+a_4E+a_5F \quad (1)$$

H is the failure depth of the mining floor, x is the constant term of the regression equation, a_0,a_1,a_2,a_3,a_4,a_5 are the regression coefficients.

Regression significance test

Regression analysis is carried out on the prediction model of floor failure depth.and the results are shown in Table 6.

Check the F distribution table: $F^{0.100}_{4.4}$=2.28,$F^{0.010}_{4.4}$=4.46, $F^{0.001}_{4.4}$=7.44. It can be seen from the F values in Table 6 that for the linear equation,$F^{0.100}_{4.4}<F<F^{0.010}_{4.4}$, the regression is highly significant.

Based on the results of significance test, it can be concluded that the regression calculation results obtained from orthogonal test simulation and linear analysis are more reliable. Get the formula:

$$h= -5.338+0.156A+0.190B+0.087C+0.020D+0.070E+0.010F \quad (2)$$

Analysis and inspection

Formula(2) is obtained by analyzing 25 orthogonal tests. In order to verify whether the model is feasible in practical application, verification analysis is carried out through the actual measured case data of 8 groups of north China type coal mines (table 7). Table 8 shows the comparison between the measured and calculated failure depths of the floor of each working face.

According to the analysis of calculation results in table 7, the maximum error of the failure depth of coal seam floor calculated by the model is 0.92. The prediction result of the model is close to the reality, with high precision and small error, which can basically meet the engineering needs. It is proved that the model is feasible to predict the failure depth of coal seam floor in north China type coal field.

Conclusions

1. Through orthogonal test simulation, it is concluded that floor lithology combination and rock shear strength have great influence on floor failure depth,

especially in the north China type coal field, the roof and floor lithology of coal seam should be paid attention to.

2. Through the analysis of the experimental results, it is known that the shear strength of rock strata increases, and the failure depth of floor decreases first and then increases;When the lithological combination of floor is sand-mudstone interaction, the failure depth of floor is the minimum, while the failure depth of single lithological floor is large. When the coal floor is sandstone, the failure depth of floor is the maximum.
3. By establishing a linear model, a relatively reliable prediction formula of floor failure depth was obtained, and the calculated value of the model was compared with the calculated value and measured value of the three procedures to analyze its accuracy, proving that the prediction model has applicability.

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