

Research on Simulation and Field Measurement Technology of Floor Mining Failure Depth

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Abstract - Aiming at the detection problem of floor mining failure zone after mining, in order to grasp the failure law of floor strata caused by mining and ensure the safe mining on confined water, in this paper, the methods of the theoretical prediction and FLAC^{3D} numerical simulation was adopted to study floor mining failure depth of the 41303 working face in Huafeng coal mine, and then the system of double ends borehole plugging device in measuring leakage was applied to the field measurement to verify the theoretical prediction and numerical simulation results, and the results of the three methods were compared. The research shows that: (1) the prediction depth of floor mining failure depth is 16.89~21.24mm, and the numerical simulation results are 15m, and the measured depth is 13.15m; (2) Through comparison, it can be seen that the numerical simulation result is basically close to the field measured result. The result of empirical formula is expected to be conservative. In summary, the maximum floor mining failure depth of the 41303 working face is 13.15m. It provides scientific basis for the safe mining of coal resources under the pressure of the confined water; (3) With the advancing of the 41303 working face, the plastic zone of the bottom plate is increasing. When the working surface reaches 90m, the depth of the floor mining failure reaches the maximum value of 15m, and the depth is no longer increased and its shape is a straight line which is approximately parallel to the floor. the change trend of plastic zone is consistent with the maximum principal stress.

Keywords - Floor Mining Failure Zone; Double Ends Borehole Plugging Device; Theoretical Prediction; FLAC^{3D}; Field Measurement.

I. INTRODUCTION

After the coal seam mining, deformation and damage occurred in the floor strata because of the pressure of mine. And three damage zones which are similar to that in overlying strata are formed in floor strata. It is called "Three Underlying Belts". According to the extent of damage and fracture conductivity of three underlying belt from top to bottom, it were as follows: floor mining failure zone, complete rock zone and confined water conduction zone zone[1]. The study on the floor failure depth can not only reflect the characteristics of floor rock mass destruction caused by mining but also provide basic data for safety mining on confined water. It is of great

importance to the prevention of mine water inrush disaster, reasonable arrangement of protective coal pillar, safety mining evaluation of coal resources. Many scholars have used theoretical analysis, similar material simulation, numerical analysis and field measurement to study the failure depth of floor rock mass and the development law of mining fracture, and have achieved fruitful results.

In the aspect of theory, Zuoyu Wang and Baiying Li put forward to the theory of "three zones", "in situ tension crack and zero position failure" and "thin plate", and study the damage depth and water inrush mechanism of floor rock mass[2-5]. According to the key strata theory of KS, Liangjie Li and Jian Sun discussed and analyzed the mechanism of water inrush from mine floor strata[6-7]. Aiming at the problem of floor mining failure, Longqing Shi put forward to the linear regression and nonlinear regression formula and used a large number of measured data to verify the formula, which has been proved to be of high value[8]. Considering the anisotropy of the floor rock mass deformation and strength, he studied the distribution law of mining stress and the failure depth of the floor rock mass [9].

In the aspect of similar material simulation, Jinan Wang used the full stress strain test and single crack permeability test on floor rock to study the fracture characteristics and seepage characteristics of rock mass, and further reveals the mechanism of fluid solid coupling in rock mass[10]. Taking floor rock mass on high confined water in Jiulong coal mine as back ground, Yaodong Jiang adopted the floor simulation device designed by himself to carry out the simulation experiment of similar materials to further explore the law of floor failure[11].

In the aspect of numerical analysis, Weitao Liu adopted the numerical software FLAC^{3D} to further study the main control factors of the stability and failure depth of the floor[12-14]. Rui Zhang used FLAC^{3D} to carry on the comprehensive test and the numerical simulation to the coal seam floor mining destruction characteristic[15].

In the aspect of field measurement, taking the actual

project as the background, Weitao Liu applied double ends borehole plugging device to field measurement of floor failure depth[16]. After that, some scholars carried out the failure depth of floor detection research using microseismic monitoring technology[17] and acoustic wave CT technology[18-19].

In summary, the research methods of floor mining failure depth is varied, which has experienced the different stages of theoretical analysis, numerical simulation, similar material test and field test. By contrast, the field test results are the most reliable. The method of field measurement represented by "double ends borehole plugging device" has the advantages of simple operation, high accuracy and so on. Based on this, in the paper, taking the 41303 working face in Huafeng coal mine as background, the author has applied the theory prediction, numerical simulation FLAC^{3D} and the

field measurement to study the failure depth of floor mining. The theoretical and numerical simulation results are consistent with the field measurement results, and it has achieved good application.

II. ENGINEERING BACKGROUND

The lower group coal in Huafeng coal mine is mainly mined by 13, 15 and 16 coal seams. Its 41303 working face is located in the No.13 coal seam, the mining level is -520m. The dip angle in this coal seam is 25 degrees ~35 degrees, its average dip angle is 30 degrees, and the thickness of coal seam is 0~1.91m, its average thickness is 0.94m. The direct roof of the coal seam is fine sandstone, its average thickness is 5m, and the direct floor is medium sandstone, its average thickness is 2m. The composition and thickness of the roof and floor of the coal seam are shown in Figure 1.

Column	Rock (coal) layer name	Thickness (m)	Characterization of rock strata
.....	Fine sandstone	19	Gray white, fine - grained structure, the development of the top cracks, mainly quartz, feldspar.
.....	Mmedium sandstone	4.2	Gray white, fracture is not developed, local mudstone
.....	Silty sandstone	13	Deep grey silty structure, middle and lower part of mud
.....	Sandy mudstone	2.5	Deep gray, layered structure, the upper visible calcite veins, the bottom joint development, more broken
.....	Fine sandstone	5	Light grey, fine grained structure, medium thin layer, calcareous cementation, joint and fissure development
.....	No.13 Coal Seam	0.94	Simple structure, average thickness of coal seam 0.94m
.....	Mmedium sandstone	2	Grey white, medium coarse grained structure, calcareous ementation
.....	Fine sandstone	4.5	Deep grey sandy structure, locally with stone
.....	Silty sandstone	25.5	Gray, dark gray siltstone, layered core
.....	Mmedium sandstone	25	Gray white, medium coarse grained structure, medium and thick layered structure of calcareous cementation, mainly contain quartz stone, feldspar
.....	Mudstone	8	Contains Brown calcite gray component, containing mud and rock joints is broken

Fig.1 Strata comprehensive histogram

The method of longwall mining on strike was adopted to manage the roof in the working face. The strike and inclined length of the working face is 400m and 150m, respectively. Its surrounding areas were not mining. Within the scope of the work face, there is no obvious fault and structure. Six small faults between 0.6~1.6m were revealed in the tunneling process of the mining roadway. Near the top of the roof was broken, the coal seam was soft and easy to fall.

The Calculation index of physical and mechanical properties of rock strata selected by rock mechanical property test are shown in Table 1.

III. THEORETICAL PREDICTION

Referring to the geological conditions of the 41303 working face in Huafeng coal mine, according to the empirical formula of regulations of buildings, water, railway and main well lane leaving coal pillar and press coal mining, it can be expressed as follows:

If considering the mining depth, angle and inclined length of working face, the prediction formula for the depth of floor water-conductive fissure zone is that:

$$h_1 = 0.0085H + 0.1665\alpha + 0.1079L - 4.3579 \quad (1)$$

In the type: h_1 stands for the depth of floor water-conductive fissure zone, its representative unit is meter; H is mining depth; α is the dip angle of coal seam, its unit is angle; L is inclined length of long wall working face.

If only considering the inclined length of the working face, the prediction formula for the depth of floor water-conductive fissure zone is that:

$$h_1 = 0.7007 + 0.1079L \quad (2)$$

In the type: h_1 stands for the depth of floor water-conductive fissure zone, its representative unit is meter; L is inclined length of long wall working face.

TABLE 1 Physical and mechanical properties calculation index of rock group

Serial number	Lithology	Bulk density/kN·m ⁻³	Elastic modulus/MPa	Poisson ratio	Cohesive force/MPa	Friction angle/(°)	Tensile strength/MPa
1	Fine sandstone	25.7	11000	0.17	7.38	29.9	1.06
2	Medium sand	25	10000	0.2	6.28	28	1.04
3	Silty sandstone	25.5	11000	0.2	1.26	28.5	0.84
4	Sandy mudstone	25.1	10000	0.18	6.93	31	1.04
5	Fine sandstone	26.2	10000	0.18	7.23	30.1	1.08
6	No.13 Coal Seam	14	1300	0.24	1.04	23	0.04
7	Medium sand	25.7	11000	0.21	6.32	29.8	1.03
8	Fine sandstone	23	9900	0.19	5.85	28	1.06
9	Silty sandstone	25.9	11000	0.19	6.25	32	0.82
10	Medium sand	25.7	10000	0.21	6.27	29.5	0.97
11	Mudstone	24.8	4000	0.25	1.22	31	0.41

The depth of the mining induced damage zone based on the above formula (1) and (2) is 16.89~21.24m. Taking the possible abnormal situation such as local large floor mining failure depth into account, the maximum failure depth of the floor rock mass is predicted to be 21.24m.

Therefore, the extension height of the observation hole must be more than this value, and also need to extend the length of the drill hole 5 ~10m in order to measure the non leaking hole section, regard it as the maximum boundary of

controlling the depth of mining damage.

IV. NUMERICAL SIMULATION

Model construction

41303 working face mining geological model constructed according to the mining geological conditions, strata comprehensive histogram and physical and mechanical parameters of rock strata of research area in Huafeng coal mine is as shown in Figure 2.

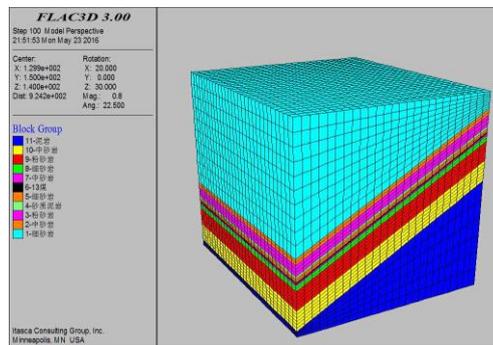


Fig.2 FLAC^{3D} numerical model

Model size: Length is 260m, Width is 300m, Height is 280m;

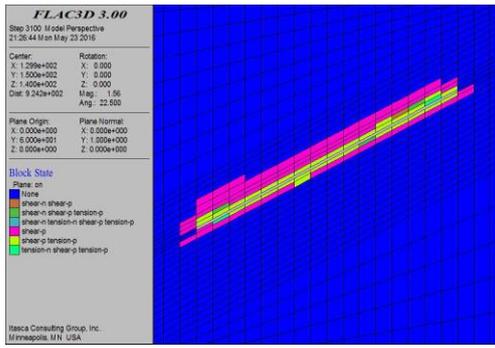
Model boundary: The front and back boundaries and the left and right boundary of the model are constrained by the horizontal direction displacement; The upper boundary layer is simplified to 13 MPa uniform load, and the bottom boundary is imposed with full constraint.

Mining area: From the direction of the working face length is 200m, inclined length is 150 m, and the excavation height of the coal seam is 0.94m, excavation length along the strike of the coal seam at every step is 10 m. Considering the boundary effect, mining start and stop line of working face

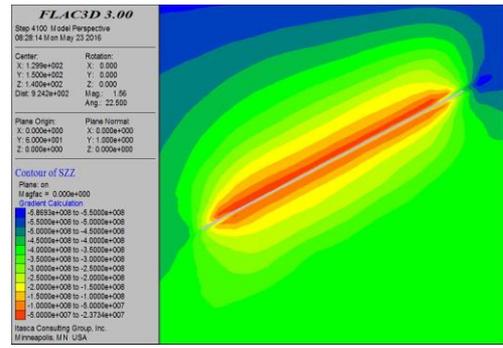
from the left and right boundaries of the model is 75 m; The width of roadway protection pillar before and after the model boundaries is respectively 50 m.

Simulation results and analysis

With the working face mining, due to the influence of mining, deformation and cracks appear in the floor rock mass, and then the floor mining failure zone is formed. When the working face is pushed to the 40m, 60m, 80m and 120m, the plastic zone and the maximum principal stress of floor rock mass affected by the mining along the inclined direction of the working face is shown in figure 3 to figure 6.

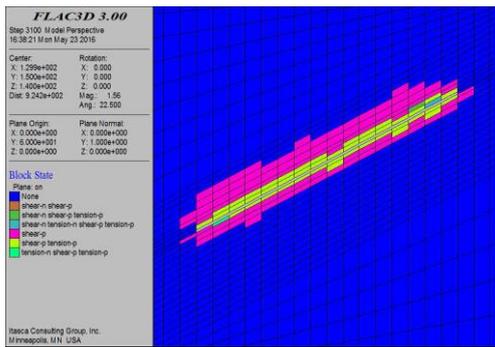


(a) The floor plastic zone

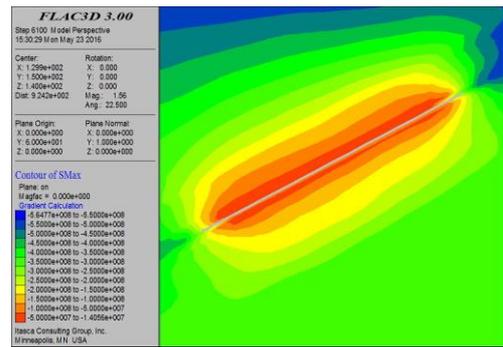


(b) The maximum principal stress

Fig.3 Distribution of plastic zone and maximum principal stress when mining 40m

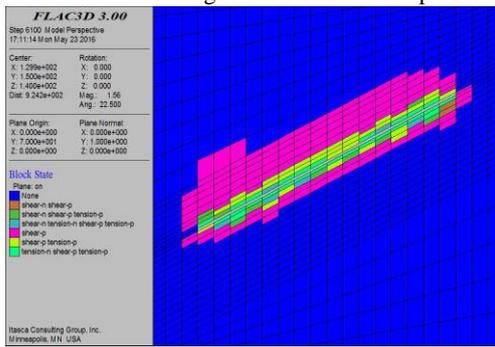


(a) The floor plastic zone

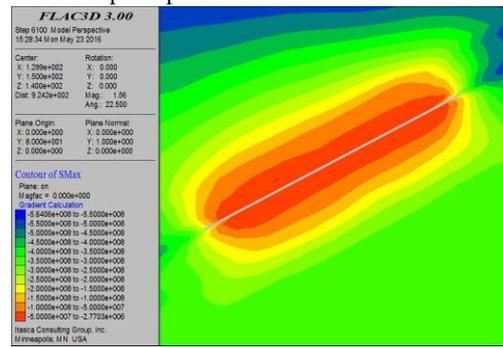


(b) The maximum principal stress

Fig.4 Distribution of plastic zone and maximum principal stress at 60m

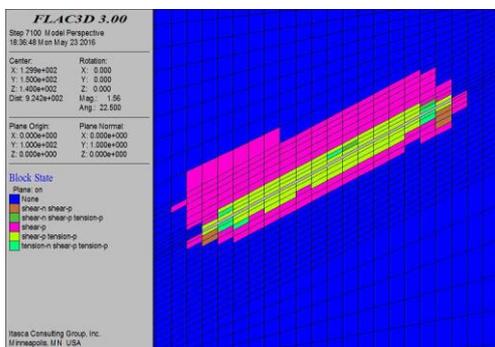


(a) The floor plastic zone

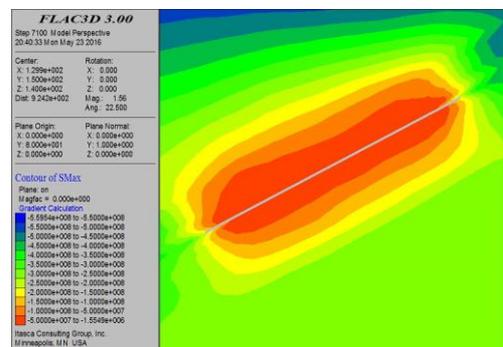


(b) The maximum principal stress

Fig.5 Distribution of plastic zone and maximum principal stress at 80m



(a) The floor plastic zone



(b) The maximum principal stress

Fig.6 Distribution of plastic zone and maximum principal stress at 120m

From the slices of plastic zone and maximum principal stress of floor rock mass along 41303 working face when advancing 40m, 60m, 80m, and 120m, it can be seen:

With the working face advancing, the depth of floor damage is increasing continuously. When the working surface is pushed to 40m, the maximum damage depth of the floor is 4.25m; When the working surface is pushed to 60m, the maximum damage depth of the floor is 6.5m; When the

working surface is pushed to 80m, the maximum damage depth of the floor is 10.75m; When the working surface is pushed to 120m, the maximum damage depth of the floor is 15m. The change trend of the maximum principal stress and the failure depth of the plastic zone in floor rock mass are roughly the same.

The plastic zone information of other slices in the model is summarized, as shown in figure 7. As

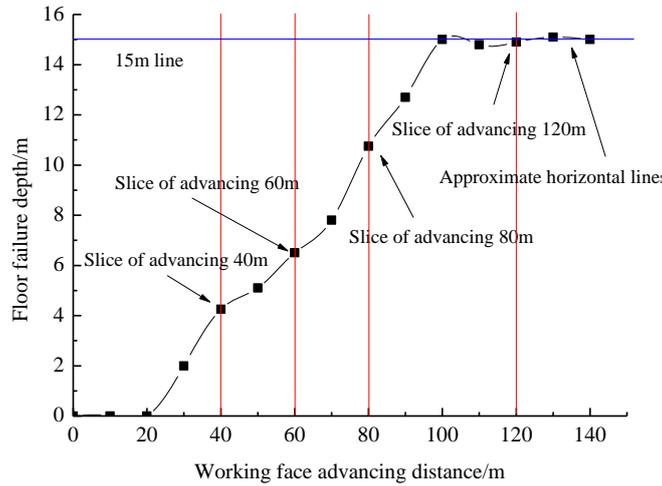


Fig.7 Floor damage depth trends

can be seen, when the working advancing 100m, floor damage depth has reached 15m. As the working face continues to advance, the maximum damage depth is no longer increased and becomes a straight line which is approximately parallel to the bottom of the coal seam. Therefore, according to the FLAC^{3D} numerical simulation, it can be obtained that the failure depth of floor mining is 15m.

V.FIELD MEASUREMENT

Measuring equipment and function

Double ends borehole plugging device belongs to test device for drilling permeability of rock mass in mine. It can be used for the water differential injection testing of drilling hole in floor rock mass at arbitrary azimuth and dip angle. According to the measurement of the water leakage in the hole section of different depth, the fracture development or surrounding rock failure condition is determined. Subsection water injection observation system mainly consists of four parts such as inner hole plugging water injection pipe, connecting pipe, external control valve and observation instruments, as shown in figure 8. The inner hole plugging water injection pipe is a water injection probe with a double end sealing capsule, which is used for sealing the two ends of the test hole; The external control valve and observation instruments mainly include flow meter, pressure gauge and the

corresponding valve, used to control the water injection pressure, sealing pressure and water injection flow rate.; The external control valve, instrument and water injection probe are connected with the high-pressure rubber hose and the pressure hose.

VI.OBSERVATION SCHEME DESIGN

The construction elements and requirements of the drilling hole design in the observation section are shown in table 2. According to construction elements and roadway conditions around the coal face, observation roadway and section was built near the lower coal pillar of 41303 haulageway. Before mining drilling is used to observe the original fracture state of floor rock mas which is the basis of comparative observation after the mining; After mining drilling is used to control maximum development depth of the mining failure zone of the floor strata. The layout of the borehole observation section is shown in Figure 9.

VII.OBSERVATION RESULTS AND ANALYSIS

According to the four measured data collected by before and after mining drill holes, making comparison and analysis of the leakage loss of drilling water injection changes with the drilling depth , and draw out the leakage loss diagram, as shown in Figure 10.

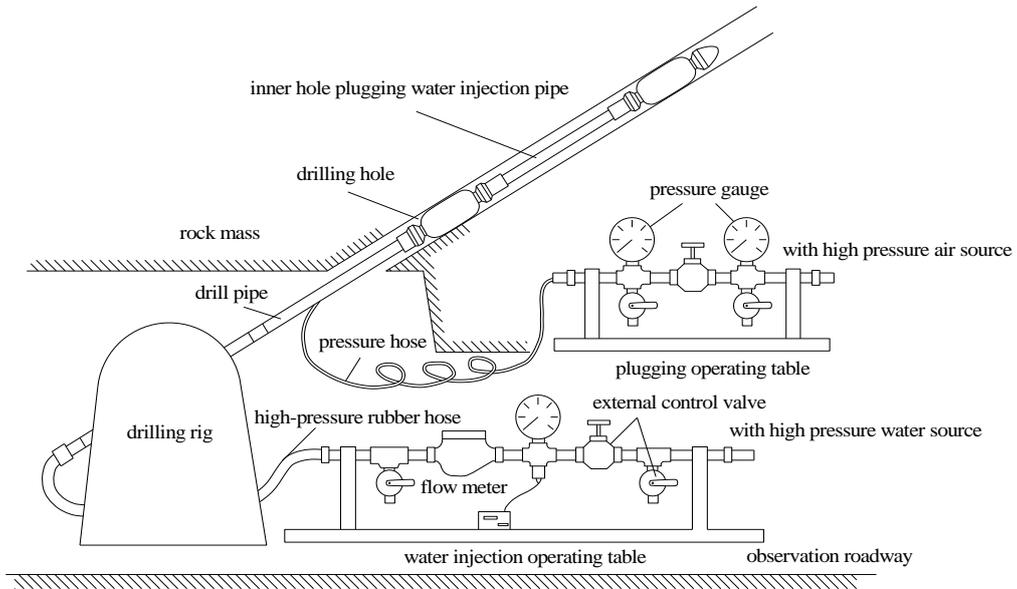


Fig.8 Double ends borehole plugging device in measuring leakage

Table 2 Drilling construction elements

Hole No.	Name	Aperture/mm	Elevation/(°)	Hole depth/m	Complete time
1#	Preharvest hole (Doubles as a post-harvest hole)	89	2°	60	5 days before mining
2#	Post harvest hole	89	8°	60	When advancing 15m
3#	Post harvest hole	89	15°	60	When advancing 25m

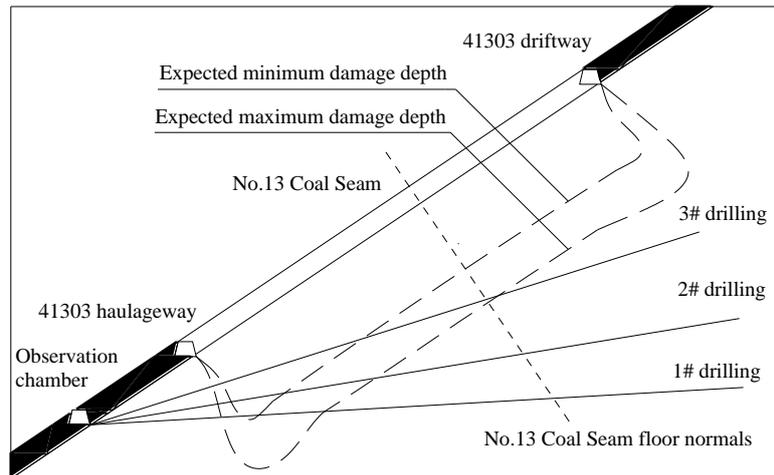


Fig.9 Drilling construction layout schematic diagram

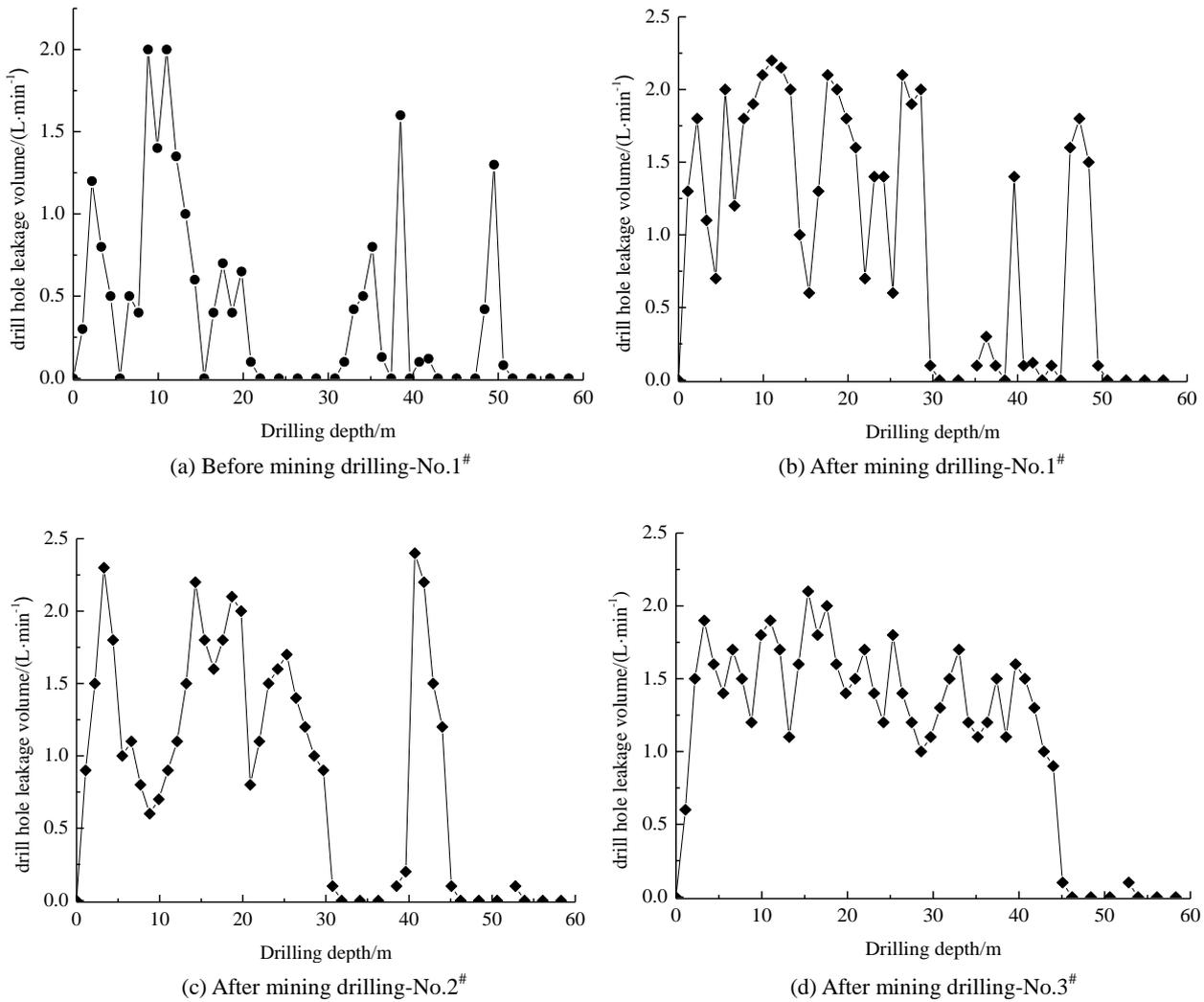


Fig.10 Injected water leakage of drilling hole

(1) Through the before mining drilling No.1[#], it can be seen that there is a clear water leakage point at the depth of 3m, and the leakage volume is about 1.2L / min⁻¹. That is caused by the rock destruction of the shallow hole and the formation of the loose circle during drilling construction. At the depth 8~14m and 17~20m, the leakage volume is significantly increased, 1.4~2.0L/min⁻¹ and 0.5~0.8L/min⁻¹, respectively. According to the numerical analysis of the leakage volume and floor lithology, it may be caused by the influence of tunnel excavation or the development of local primary fissures. At the depth 34m, 39m and 50m, the leakage volume is about 0.6~1.7L min⁻¹, and the leakage volume of the other position of the hole tends to be close to 0. It shows that the fracture of deep layer is not developed, and it is in a continuous and complete state.

(2) Because of the before mining hole No.1[#] remaining in good condition, the field measurement using that as after mining hole were observed again. Through measured data, it can be seen that the original leakage volume of after mining

hole is increased, and the leakage volume at shallow hole rock is increased from 1.2L/ min⁻¹ to 1.7L/min⁻¹. Affected by mining, the original shallow primary fracture is further developed, and the corresponding leakage volume is also increased. At the depth of the hole 8~14m, 17~20m and 21~33m, the maximum leakage volume is increased from 2.0L /min⁻¹ to 2.2L/min⁻¹, 0.8L /min⁻¹ to 2.3L/min⁻¹ and 2.2L·min⁻¹, respectively. At the depth of 21~33m, the original crack is further expanded into a new crack. The result shows that although there are few high value point of leakage volume at the deep position of the hole, the rock mass is generally kept intact.

Therefore, taking the depth 28m of after mining hole No.1[#] as the boundary of the depth of the floor failure depth, in accordance with the drilling angle of 2 degrees, the vertical failure depth of the floor is 13.15m.

(3) Through the after mining drilling No.2[#], it can be seen that there is a continuous leakage volume of 0.7~1.7L/min⁻¹

at the depth 20~30m. Compared with the leakage volume of before mining hole No.1[#], it shows that this section is a new fracture. More than the depth 30m of the hole ,there is only one continuous leakage points, which is not regarded as the development zone of fracture connectivity.

Therefore, taking the depth 30m of after mining hole No.2[#] as the boundary of the depth of the floor failure depth, in accordance with the drilling angle of 8 degrees, the vertical failure depth of the floor is 11.24m.

(4) Therefore, taking the depth 44m of after mining hole No.3[#] as the boundary of the depth of the floor failure depth, in accordance with the drilling angle of 15 degrees, the vertical failure depth of the floor is 11.39m. Due to the vertical distance between the after mining hole No.3[#] and the bottom of the working face, this hole is most strongly affected by mining action. It can be seen from the leakage volume of drill, at the depth 0~44m, the leakage volume of drilling is greatly increased, and the average leakage volume is 1.6L/min⁻¹. The cracks in the rock mass are fully penetrated. at the depth 44m~60m, the leakage volume is almost close to 0.

In summary, the maximum damage depth of the 41303 working face in Huafeng coal mine is 13.15m.

VIII.COMPREHENSIVE COMPARISON AND ANALYSIS OF TEST RESULTS

Based on the geological conditions of 41303 working face in Huafeng coal mine, using the method of empirical formula, numerical simulation and field measurement, the numerical value of the failure depth of the floor is obtained. The theoretical prediction value is 16.89~21.24m, the numerical simulation result is 15m, and the field measured depth is 13.15m. The specific results obtained by comparing different methods and their advantages and disadvantages are shown in Table 3. It can be seen that the field measurement result is consistent with that of numerical simulation. And theoretical prediction is expected to consider the impact of limited factors. The result is conservative, and the expected value is too large. Comprehensive analysis shows that the failure depth of the floor of the 41303 working face is 13.15m, and the result is accurate and reliable.

Table 3 Methods and results analysis

Method	Advantage	Shortcoming	Mining depth destruction
Theoretical predictions	Simple, reliable, easy to quickly calculate	Practical condition limitations, the results too large	16.89~21.24m
FLAC ^{3D} Simulation	Low cost, high efficiency, better reliability, simulate different geological conditions	Model complex process parameters can not be fully representative of the actual conditions	15m
Double ends borehole plugging device in measuring leakage	High accuracy, the most reliable results	Heavy workload, complexity of operations, the presence of measurement error	13.15m

IX.CONCLUSION

(1) According to the geological conditions of 41303 working face in Huafeng coal mine, the theoretical prediction and numerical simulation are used to obtain the failure depth of the floor of the 41301 working face, which is 16.89~21.24m and 15m;

(2) Using double plugging leakage detecting device to measure floor mining damage zones of 41303 working face and the result shows that the maximum failure depth of floor is 13.15m.;

(3) By comparison, it can be seen that the numerical simulation results and are basically close to that of field measured. However, the result of empirical formula is tend to be conservative. After a comprehensive consideration, the

maximum mining failure depth of the floor in41303 working face is 13.15m. It provides scientific basis for the safe mining of coal resources under the pressure of the confined water;

(4) With the advance of the working face, the floor failure range is continuously increasing. When the working face advances to 90m, floor mining failure depth has reached the maximum value of 15m, then the depth is not increased. The maximum depth is a straight line which is approximately parallel to the bottom of the coal seam. The change of plastic zone is consistent with the trend of the maximum principal stress.

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