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Failure Characteristic and Fracture Evolution Law of Overburden of Thick Coal in Fully Mechanized Sub-level Caving Mining

(Pencirian Kegagalan dan Evolusi Retakan Hukum Beban Atas Arang Batu Padat dalam Perlombongan Perampakan Subparas Berjentera Penuh)

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ABSTRACT

In mining process, the height of water flowing fractured zone is important significance to prevent mine of water and gas, in order to further research the failure characteristic of the overlying strata. Taking certain coal mine with 5.82 m mining height as the experimental face, by using the equipment which is sealed two ends by capsules in borehole, affused measurable water between the two capsules and borehole televiewer system, ground penetrating radar, microseismic monitoring system in underground coal mine, the height of water flowing fractured zone of fully-mechanized top caving are monitored, a numerical simulation experiment on the failure process was conducted, a similarity simulation experiment on the cracks evolution was conducted, at the same time, empirical formula of traditional was modified, The results showed that the height of caving and fractured zones were respectively 43.1 and 86.7 m in fully mechanized sub-level caving mining. The data difference of each test method of caving, fractured and water flowing fractured zones were respectively less than 4.5%, 7.1% and 9.0%. The degree of fracture development was low before mining, the number of fissures was obviously increased after mining, the degree of fracture development increased. The fractures cluster region mainly focuses near the coal wall. The fractures density distribution curves of overlying strata like sanke-shapes. The new and adapt to certain coal mine geological conditions empirical formula of water flowing fractured zone height is proposed.

Keywords: Cracks evolution; empirical formula; ground penetrating radar; microseismic monitoring system; overburden failure

ABSTRAK

Dalam proses perlombongan, zon retak ketinggian air mengalir adalah keertian penting untuk mengelakkan lombong daripada air dan gas untuk kajian lanjut tentang ciri kegagalan strata atas. Dengan mengambil lombong arang batu tertentu pada ketinggian lombong 5.82 m sebagai muka uji kaji, menggunakan peralatan yang ditutup kedua-dua hujung dengan kapsul dalam lubang gerek, pelakuran air boleh ukur antara dua kapsul tersebut dan sistem petelelihat lubang gerek, radar menembusi tanah, sistem pemantauan mikroseismos lombong arang batu bawah tanah, zon retak ketinggian air mengalir perampakan atas berjentera penuh adalah dipantau, uji kaji simulasi berangka ke atas proses kegagalan telah dijalankan, uji kaji simulasi keserupaan pada evolusi retak telah dijalankan dan pada masa yang sama formula empirik tradisi telah diubah suai. Keputusan kajian menunjukkan bahawa ketinggian zon perampakan dan retak masing-masing adalah 43.1 dan 86.7 m dalam perlombongan perampakan subparas berjentera penuh. Perbezaan data untuk setiap kaedah ujian zon perampakan, zon retak dan zon retak air mengalir masing-masing kurang daripada 4.5%, 7.1% dan 9.0%. Tahap pembangunan retak adalah rendah sebelum perlombongan, bilangan rekahan jelas meningkat selepas perlombongan serta darjah pembangunan retak juga meningkat. Rantau kelompok retak tertumpu berhampiran dinding arang batu. Lengkung taburan kepadatan retak atas strata berbentuk seperti sanke. Kaedah baru dan sesuai dengan formula empirik keadaan geologi lombong arang batu tertentu zon retak ketinggian air mengalir adalah dicadangkan.

Kata kunci: Evolusi retak; formula empirik; kegagalan beban atas; radar menembusi tanah; sistem pemantauan mikroseismos

Introduction

After coal mining, the overlying strata deformation and rock breaking would happen, at last, the overlying strata were divided into three bands from top to bottom (caving, fault and bending zones) and at the same time, generated mining fracture. Research of height of caving zone and fault zone were important significance to prevent mine water resource and control of water disaster from data prepared by Gao et al. (2012). Mining induced fissure was not only thoroughfare of gas flow but key of gas drainage layout of grouting borehole, therefore, research of failure characteristic and fracture evolution law of overburden were important significance to prevent mine water and gas from data prepared by Loke et al. (2013) and Poulsen et al. (2014).

For the research on the failure features of overburden strata, many scholars, both at home and abroad, have made lots of studies, put forward the distribution of overburden failure and overburden looks like a saddle type distribution after coal mining. Chi and Li (2013) discovered that summed up height of caving and fault zones in the case of different roof lithologic character according to lots of measured data and written to relevant regulation, laid the groundwork for the coal mining under water body and buildings and railway; on the basis of three zones theory, put forward four zones theory, gave a loose alluvium zone according to van Schoor (2005); the overlying strata structure and fracture distribution were studied, put forward O-ring theory of mining-induced fractures according to Kidybinski and Babcock (1973) and Palchik (2003); discovered that, in mining process, failure features of overburden strata were affected by geological characteristics, the effect characteristics differ according to lithology, shear motion characteristic was researched by displacement sensor from data prepared by Mills et al. (2016). For test method of failure height of the overlying strata, there were mainly borehole flushing fluid method, underground upward slant hole zonal water injection method, from data prepared by Cheng et al. (2001) and Iannacchione and Tadolini (2016), the application of these methods has played an important role for safe mining.

The paper certain coal mine as the experimental face, by using the equipment which is sealed two ends by capsules in borehole, affused measurable water between the two capsules and borehole televiewer system, ground penetrating radar, microseismic monitoring system in underground coal mine, the height of water flowing fractured zone of fully-mechanized top caving are monitored, a numerical simulation experiment on the failure process was conducted, a similarity simulation experiment on the cracks evolution was conducted, at the same time, empirical formula of traditional was modified Roslee et al. (2017).

ENGINEERING SITUATION

Certain coal mine production capacity was 5.2 Mt/a, the main coal seam of colliery was 3# coal seam with a thickness of 1.5 m and a mining depth of 428 m, flat seam, the coal mining technology was sub-level caving mining, gas content was 7.65 m^3/t, the immediate roof was sandy mudstone with a thickness of 3.2 m and basic roof was poststone with a thickness of 12.6 m.

Analysis of failure features of overburden strata after mining

ZONAL WATER INJECTION EXPERIMENT LAYOUT OF DRILL HOLE

Zonal water injection experiment was a traditional way of test height, because the overlying strata present division layer character and the crack growth degree were different from top to bottom, therefore, water injection rate were different, the height of cover rock destruction were determined according to different water injection rate, taking 3302 coal face as the experimental face, arrange three bores in 3302 intake airway with a longness of 190 m and with a dip angle of 45°, specific arrangement as shown in Figure 1.

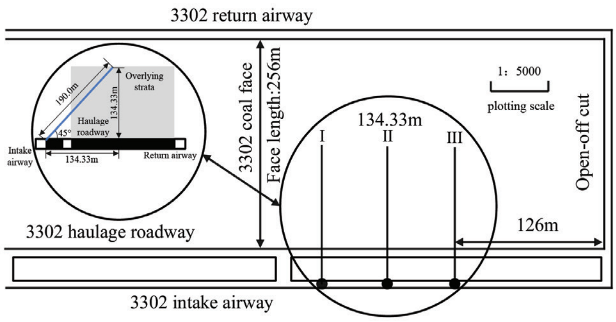
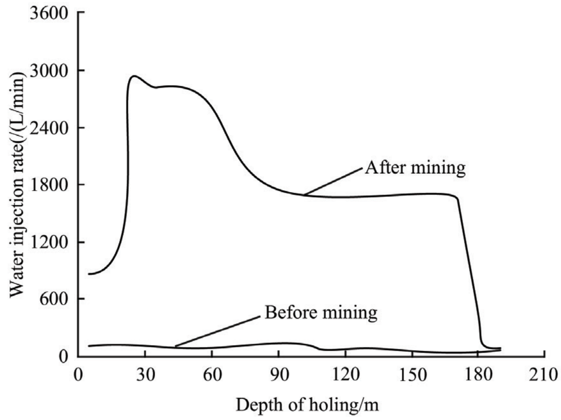


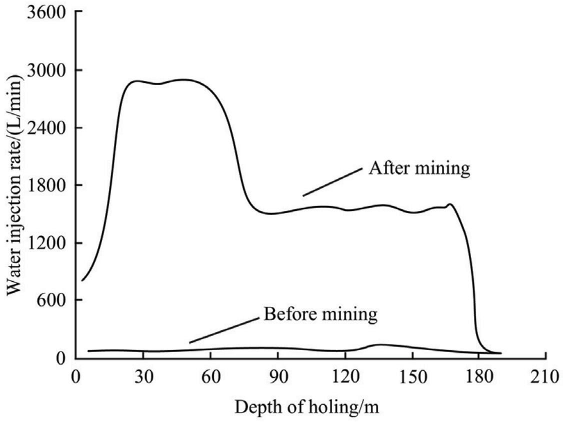
FIGURE 1. Sketch of boreholes layout

Test results and Analysis

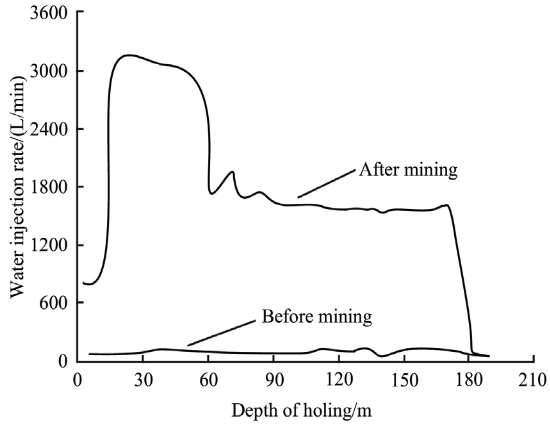
With reference to Figure 2, we can see that water injection rate were less than 100 L/min before mining, on the whole, water flooding curve looked linear distribution, therefore, low number of initial fissure and low fracture development degree; water flooding curve looked like step distribution after mining, when drilling depth was about 180 m, the water injection rate returned to before mining levels, water injection rate of first stage were from 2700 to 3200 L/min, their levels were 27-32 times as water injection rate as before mining, water injection rate of second stage were from 1600 to 1900 L/min, their levels were 16-29 times as water injection rate as before mining, according to water injection rate we can see that first stage was caving zone and second stage was fault zone, caving zone height of three holing were as follows: 41.0, 43.1, 42.4 m and water conducted zone height were as follows: 126.6, 126.6, 127.3 m, in brief, caving zone height was from 41 to 43.1 m and fault zone height was from 83.5 to 85.5 m.



(a)No. I borehole



(b)No. II borehole



(c)No. III borehole

FIGURE 2. Water injection rate graphs before and after mining

BOREHOLE TELEVIEWER DETECTED FRACTURE DEVELOPMENT AND FAILURE HEIGHT

By using borehole televiewer detected fracture development, fracture development characteristic were showed by unfolded picture, according to picture we can see that fracture development and demarcation point of three zones Lindang et al. (2017).

With reference to Figure 3 we can see that number of cracks of overlying strata were few, degree of fracture development of overlying strata was low before mining, after mining the number of cracks of overlying strata obvious increased, degree of fracture development of overlying strata enlarged.

According to distribution of overlying strata of three zones after mining, detected height of caving zone and height of fault zone, data picture as shown in Figure 4.

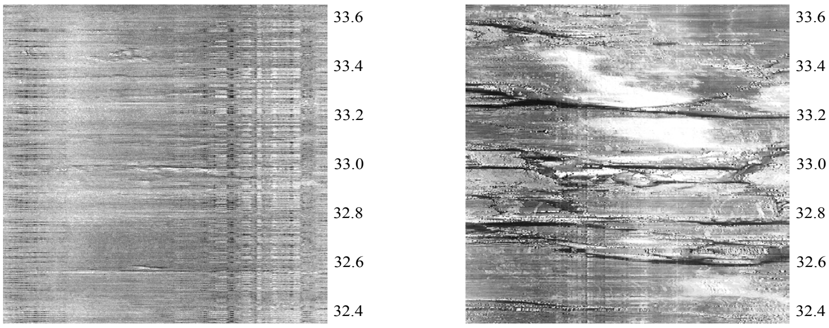
With reference to Figure 4(a) we could obviously see characteristic of caving zone top, at the same time, according to other two drilling holes, the height of the caving zone was from 37.6 to 42.3 m.

With reference to Figure 4(b) we could see that no cracks above 179.8 m, it was similar to the characteristics of borehole fissure before mining, based on this, here was the top of the fault zone, at the same time, according to other two drilling holes, the height of the fault zone was from 80.7 to 86.4 m.

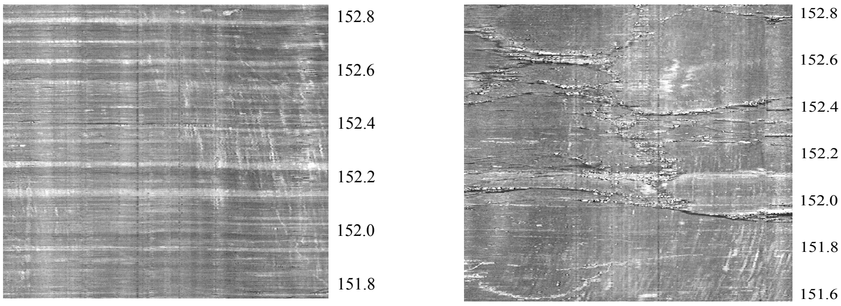
GROUND PENETRATING RADAR DETECTED FRACTURE DEVELOPMENT AND FAILURE HEIGHT

By using GV7 ground penetrating radar, trigger mode was GPS and transmission mode was Bluetooth data, the maximum depth of the detection was 80 m, detecting inclination angle was 45° in intake airway, detected coal seam roof, detected data as shown in Figure 5.

With reference to Figure 5 we could obviously see that there was no black stripes in overlying strata, because of this, the overlying strata were complete and it had cracks little before mining, after mining, appeared multi-term black stripes in overlying strata, because of this, the overlying strata appeared cracks by mining effect, roof broken, fracture development degree increased, at 58.0 m created the boundaries, height of fault zone was 41.0 m.

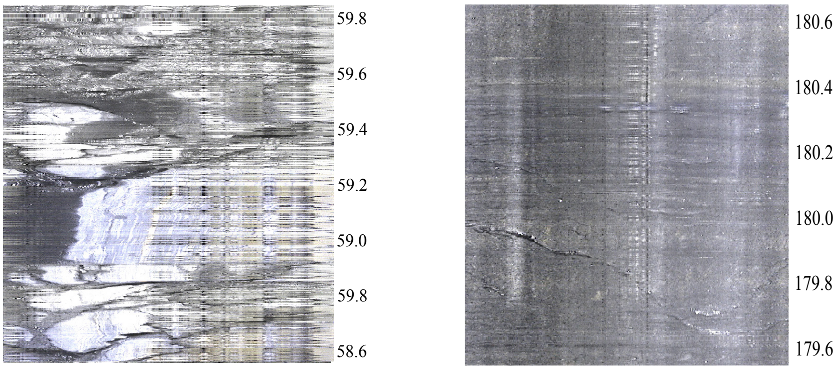


(a) Before mining (b) After mining



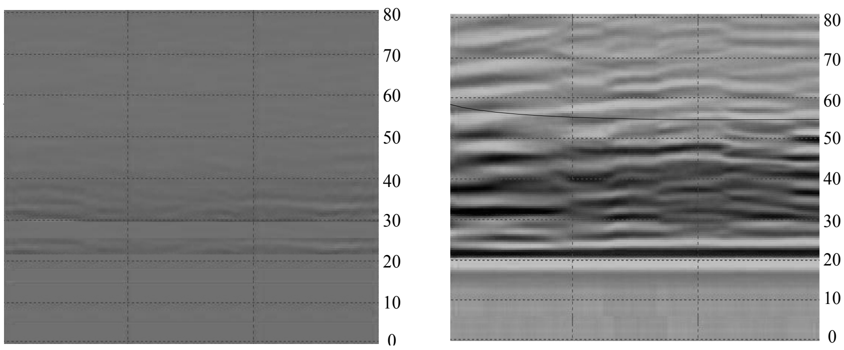
(a) Before mining (b) After mining

FIGURE 3. Fracture characteristic of boreholes after mining



(a) Characteristic of caving zone top (b) Characteristic of fault zone top

FIGURE 4. Characteristic of caving zone top and fault zone top



(a) Before mining (b) After mining

FIGURE 5. Fracture characteristics of geological radar

MICROSEISMIC MONITORING TECHNOLOGY DETECTED FAILURE HEIGHT

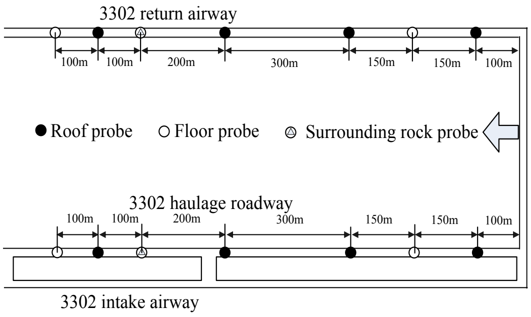
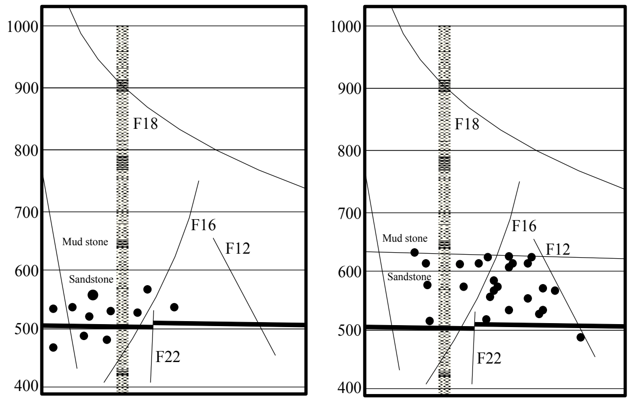


FIGURE 6. Sketch of microseismic monitoring

Microseismic monitoring technology could monitor by four-dimensional, according to characteristic of evenment and energies, analysed characteristic of overburden failure, set up ten sensors in coal face by ARAMIS M/E microseismic monitoring system with a sampling rate of 50, 100 and with a positioning accuracy of (±50) m, probe as shown in Figure 6.

With reference to Figure 7(a), we could see that height of overburden fault was 98 m and it was located in upper part of sandstone when advancing distance was 200~260 m.

With reference to Figure 7(b), we could see that height of overburden fault was from 124 to 128 m, it was located in sandstone and mudstone boundary points, lower sandstone were fully faulted and parts of top mudstone were faulted when advancing distance was 1020~1100 m.



(a) Advancing distance : 200~260m

(b) Advancing distance : 1020~1100

FIGURE 7. Damage of overburden in panel 3302 caving (energies were greater than 10000)

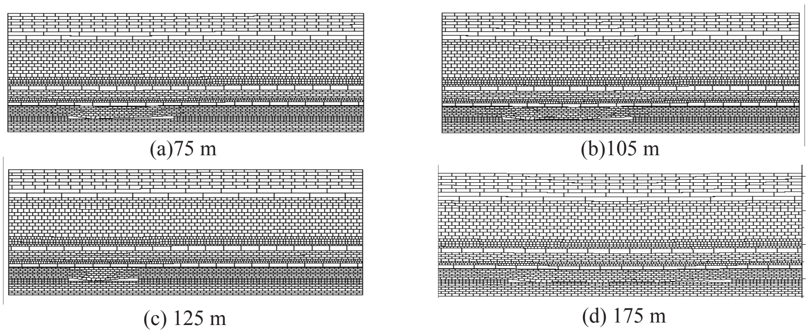
With the mining of working face, the goaf and overlying strata failure height gradually increased, when overlying strata failure height tended to reach a limit, it was no increasing with the mining of working face, maximum failure height was 130 m.

NUMERICAL SIMULATION OF OVERBURDEN FAILURE MODEL

By using UDEC numerical simulation software, modeled overburden failure characteristic, mechanical parameters were shown in TABLE 1.

TABLE 1. Mechanical parameters

Lithology	Density /(kg/m³)	compressive strength /MPa	Elastic modulus /MPa	Adhesion / MPa	Internal friction angle /(°)	Poisson ratio
Siltstone	2540	87.60	3385	1.7	21	0.14
Coarse sandstone	2420	59.80	7232	5.0	36	0.17
Medium sandstone	2380	80.10	2215	1.9	32	0.21
Mudstone	2450	49.30	4205	3.5	38	0.23
Fine sandstone	2650	136.8	9305	4.3	27	0.14
Coal	1280	23.40	2392	1.3	32	0.28
Conglomerate	2660	35.20	2150	1.1	34	0.19
Sandy mudstone	2581	60.40	2130	4.7	32	0.18



(a)75 m (b)105 m

(c) 125 m (d) 175 m

FIGURE 8. Deformation characteristic of overburden during panel caving

SIMULAIN RESULTS AND ANALYSIS

With reference to Figure 8 we could obviously see that with goaf increased, the overburden ceaseless faulted, when advancing distance was 75 m, the roof caved, just like arch-shapes, with the mining of working face, overlying strata failure height gradually increased, when advancing distance was 125 m, height was not increasing, at the same time, the middle goat were compacted by overlying strata, caving zone height was 37.5 m, when advancing distance was 145 m, engendered bed separated fissures and a large number broken fissures for tension action, when advancing distance was 175 m, the middle goat were fully compacted, mining-induced fractures closed, with the mining of working face, overlying strata failure height no increased, the water conducted zone height was 120.8 m.

SIMILAR SIMULATION OF OVERBURDEN FAILURE MODEL DESIGN

Taking 3302 coal face as the experimental face, the moulded dimension were 3000×2000×200 mm (length×width×height), by using stress test bench, aggregate was silver sand, cementing materials were lime and oulopholite, retarder was borax, by using proportioning test, prepared structure material were tested, achieved mechanical requirements of similar simulation, the geometric similarity ratio was 1:200, bulk density ratio was 1.6, time ratio was 14.1.

ANALYSIS OF CRACK DEVELOPMENT OF FAILURE

In mining process, set up 60 m protective coal pillar on the left and set up 100 m protective coal pillar on the right, eliminated the influence of boundary.

With reference to FIGURE 9 we could knew that the caving zone height was 37 m and the water conducted zone height was 118 m (Idris et al. (2009).

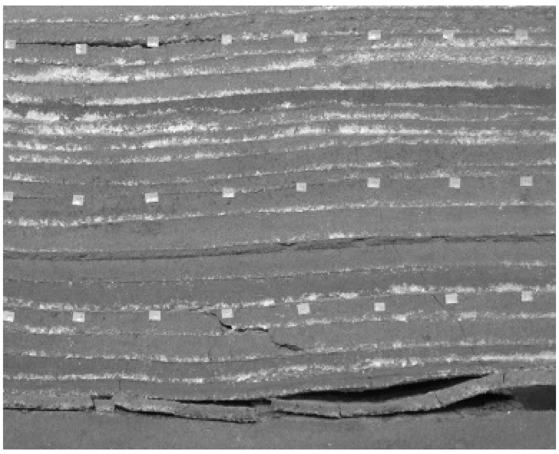


FIGURE 9. Characteristics of overburden rock fracture

In order to describe overburden failure characteristics, the fracture density was used as the index, aggregate analysed fracture characteristics.

With reference to FIGURE 9 we could knew that: In mining process, with overburden caved, engendered fractures, with the mining of working face, amount and width of fracture gradually increased. When the working face advanced to a certain position, with the mining of working face, the height of overburden failure no increased, at the same time, the goaf were compacted by overlying strata, amount of fracture reduced. The fractures cluster region mainly focuses near the coal wall and the distribution curves of fractures density in overlying strata presents snake-shapes (Lindang et al. 2017).

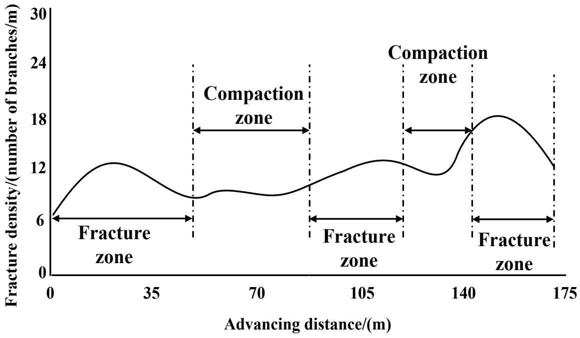


FIGURE 10. Distribution law of overlying fissure density

ANALYSIS OF THE HEIGHT OF OVERBURDEN FAILURE AND FORMULA MODIFICATION

ANALYSIS OF CRACK DEVELOPMENT OF FAILURE

Comprehensive analyse the height of overburden failure of each method.

FORMULA MODIFICATION

According to 'three zones' modification, combine to geological conditions, selected modification of water conducted zone (1).

where: is the height of water conducted zone(m); and

$$H_f = \frac{100\sum M}{1.6\sum M + 3.6} \pm 5.6 \qquad (1)$$

is the cumulative exploiting thickness(m).

The mining height was 5.82 m, brought it into (1), obtained the maximum height of water conducted zone was 50.7 m, the maximum height of measured and simulation were 128.7 m, a contrastive analysis of measured result and modification result, specific value was 2.538 and obtained new modification (2).

TABLE 2. Material mixture ratio

Lithology	Model compressive strength /MPa	Fine sand:Calcium carbonate:Gypsum (kg)
Siltstone	0.270	8.54:0.34:0.76
Coarse sandstone	0.190	8.40:0.26:0.34
Medium sandstone	0.250	8.40:0.36:0.84
Mudstone	0.150	8.52:0.22:0.74
Fine sandstone	0.430	8.40:0.48:0.72
Coal	0.073	4.30:0.10:0.30
Conglomerate	0.110	8.40:0.38:0.84
Sandy mudstone	0.188	8.34:0.70:0.70

TABLE 3. Comparison for determining the height of overburden failure

Method	Height of caving zone/m	Height of fault zone/m	Height of water conducted zone/m
Zonal water injection experiment	41.0~43.1	83.5~85.5	126.6~127.3
Borehole televiewer	37.6~42.3	80.7~86.4	118.3~128.7
Ground penetrating radar	41.0	/	/
Microseismic monitoring technology	/	/	124.0~128.0
Numerical simulation	37.5	83.3	120.8
Similar simulation	37.0	81.0	118.0
Comparative analysis	Less than 4.5%	Less than 7.1%	Less than 9.0%

$$H_f = \frac{253.8\sum M}{1.6\sum M + 3.6} \pm 5.6 \tag{2}$$

Comparative analysed new modification and measured result of height of water conducted zone we could knew that the error was less than 5.6%.

Conclusion

Caving zone height was 43.1 m and fault zone height was 86.7 m. The data difference of each test method of caving, fractured and water flowing fractured zones were respectively less than 4.5%, 7.1%, 9.0%. Zonal water injection experiment and borehole televiewer test and ground penetrating radar signed that the fracture development degree was low before mining and after mining, the fracture development degree increased. In mining process, with overburden caved, engendered fractures, with the mining of working face, amount and width of fracture gradually increased, when the working face advanced to a certain position, with the mining of working face, the height of overburden failure no increased, the goaf were compacted by overlying strata, amount of fracture reduced. The fractures cluster region mainly focuses near the coal wall and the distribution curves of fractures density in overlying strata presents snake-shapes.

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