

Height Prediction of Water Flowing Fractured Zone and Thickness Effect of Long Wall Caving in Thick Loose Seam with Weak Cementation

Yao Lu

Corresponding author

*State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology
Shandong University of Science and Technology
Qingdao, China
723262355@qq.com*

Chuanping Sun

*State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology
Shandong University of Science and Technology
Qingdao, China
545236818@qq.com*

Changxiang Wang*

Corresponding author

*State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology
Shandong University of Science and Technology
Qingdao, China
1554624100@qq.com*

Buchu Zhang

*State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology
Shandong University of Science and Technology
Qingdao, China
525047249@qq.com*

Wenbo Wang

*State Key Laboratory of Mining Disaster Prevention and Control Co-founded by Shandong Province and the Ministry of Science and Technology
Shandong University of Science and Technology
Qingdao, China
wangwenbo5211314@qq.com*

Abstract—Based on the transfer rock beam theory and the mining overburden movement theory, the height prediction methods of collapse zone and fracture zone under different lithologic conditions are deduced according to the characteristics of rock mass dilatation and rock strata combined motion. Furthermore, the predicted height of water-conducting fracture zone of a shallow soft rock thick coal seam is 10-12.5 times of mining height. The mechanical parameters of each rock layer are obtained by field coring and laboratory mechanical tests. The mechanical properties of different rock layers are tested by configuring similar simulated materials according to different ratios. The rock mixture ratio is selected by similarity criterion, and the similarity simulation experiment is carried out. The relationship between the height of the water-conducting fissure zone and the mining thickness is obtained by simulating the development of the height of the water-conducting fissure zone with different mining thickness, and the accuracy of the predicted height is verified. In this paper, the mining thickness effect of the water-conducting fractured zone in thick coal seam mining is further analyzed, and the three stages of the collapse zone, which increase with the mining thickness, namely, the waiting stage, the increasing stage and the stable stage, are obtained under the specific geological conditions. The fracture zone shows linear growth and the collapse zone presents a step growth pattern.

Keywords—transfer rock beam theory, water-conducting fractured zone, ratio test, mining thickness effect

I. INTRODUCTION

The prediction of the height of the water-conducting fractured zone is the key to the prevention and control of disasters in the mine and the third mining. When the water-conducting fractured zone forms a passage with the surface, it may lead to the accumulation of carbon monoxide spills in the old goaf and the spontaneous combustion of the residual coal, etc. Causing casualties and property damage. Water inrush and gas outburst occur from time to time when the water-conducting fractured zone is connected with the overlying aquifer or the gas accumulating area near the old goaf. Many scholars at home and abroad have done a lot of theoretical and practical work in order to explore the development law of the water-conducting fracture zone. The research results show that there are many factors affecting the development height of the water-conducting fracture zone, such as mining and roof management methods, mining strength, overburden mechanical properties and structural characteristics, repeated mining, tectonic stress and time.

Academician Liu Tianquan[1-2] obtained statistical calculation formulas for the development height of water-conducting fractured zones through a large number of actual measurements and theoretical analysis, which meets the requirements of coal mining design under water body of most mines in the early stage of China. However, under the background of new mining technology, the error of the calculation method is getting bigger and bigger. It is an

important research topic for mining workers to find a method for predicting the development height of the water-conducting fractured zone that is in line with the existing mining technology and process and is easy to operate. Professor Xu Jialin et al.[3-4] proposed a new method for predicting the height of water-conducting fractured zone by the location of the key strata of overburden rock, but the height of water-conducting fractured zone is expected to be based on sandstone in overlying strata. The influence of lithology on the height of water-conducting fracture zone is neglected. Prof. Wang Lianguo et al.[5] proposed to use ultimate tensile strength and ultimate tensile strain as indicators for judging the fracture and hydraulic conductivity of hard rock formations and soft rock formations from the characteristics of rock failures in different lithologies, thereby establishing an expected shallow depth and thinness. The mechanical model of the height of the water-conducting fractured zone under the characteristics of bedrock and aeolian sand accumulation (abundant water content). Shi Longqing et al.[6] based on the practical mine pressure control theory, deduced that the work surface span (oblique length) is the most important factor affecting the development height of the water-conducting fractured zone, but it is only applicable to large-depth mining face.

Solid backfill mining has been applied to excavate coal seams under aquifers in China; however, the control effects of the water-conducting fractured zone (WCFZ) require further study. Therefore, based on the mechanical properties of the compacted backfill materials, a method for simulating these materials has been proposed, and the compaction of backfill materials subject to the effects of overlying strata has been simulated[7].

A new numerical model is presented to simulate fracture initiation and propagation in geological structures. This model is based on the recent amalgamation of established failure and fracture mechanics theory, which has been implemented to the finite difference FLAC code as a constitutive FISH userdefined- model[8].

As the focus of China's coal mining gradually shifts to the west, the study of the overlying strata movement law in the western coal mining has gradually become the focus of China's mining research[9-12]. Similar simulation test is one of the effective methods to study the movement law of overlying strata in coal mining. The choice of proportioning is the key to the success of similar simulation experiments[13-14]. Some scholars in China have already made sufficient research on the matching of similar materials[15-16], but the western coal mines generally have the characteristics of shallow depth and low intensity. In order to realistically simulate the law of overburden rock failure in the exploitation of soft rock coal seams in the west, before the simulation, the ratio test of real rock mechanics tests and similar material tests must be conducted.

In this paper, based on the theory of mining overburden rock[17], combined with the theory of rock-girder transmission[18], from the perspective of the disintegration characteristics and rock formations of different lithologic rock masses, the water-conducting fractured zone are derived when the long-wall sag mining method is used to produce different thicknesses. With developmental height. The ratio tests of real rock mechanics tests and similar material tests were conducted to select the optimum proportions of similar materials. Finally, similar simulation

tests were conducted to verify the effect of mining thickness on the water-conducting fractured zone.

II. HEIGHT PREDICTION METHOD FOR WATER-CONDUCTING FRACTURED ZONE

After the mining of the long wall caving method, the overlying rock formed the caving zone, the fracture zone and the bend subsidence belt from bottom to top, and the caving zone and the fracture zone formed the water-conducting fractured zone, as shown in Figure 1.

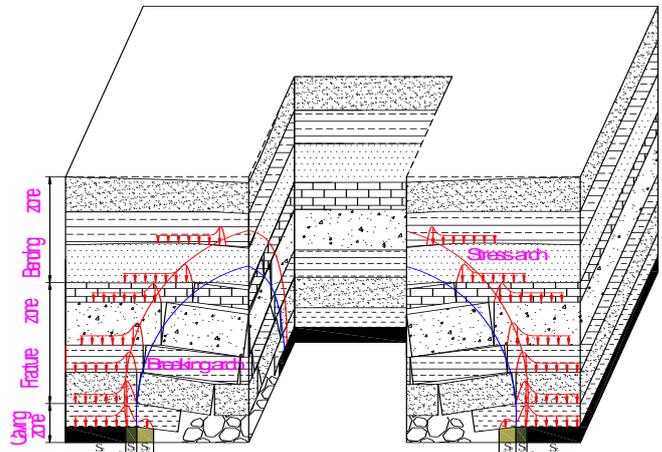


Figure 1 Overburden destruction "three zones"

According to the theory of transfer rock beam[18], the main influencing factors affecting the height of the collapse belt are mining height h , allowable settlement value of rock beam S_0 , actual settlement value of rock beam S_A , and the coefficient K_A of collapse of the caving rock.

1) When $S_A \geq S_0$, the rock layer collapses. The relationship between the actual settlement value and the mining height of rock strata during rock collapse is studied by field measurement.

$$S_A = K_S h \quad (1)$$

Where: h -the mining height, m; K_S -The scale factor of the actual settlement and mining height in the case of unsloped rock formations and shear failures are shown in Table I.

TABLE I. THE RATIO BETWEEN CAVING ZONE, FRACTURE ZONE AND MINING HEIGHT OF DIFFERENT LITHOLOGY

Lithology name of rock formation	K_S	m_k / h	$\sum h_1 / h$
High-strength sandy mudstone	0.10-0.15	2.8~3	2~3
Medium or fine sand hard sandstone	0.15~0.25	2.5~2.8	3~5
General sandstone and sandy shale	0.25~0.40	2~2.5	5~8
Siltstone and marlite	0.40~0.50	1.7~2	8~10

2) The size of the broken expansion coefficient of rock-bearing rock stratum below the contact rock is affected by many factors, mainly including:

(1) The rock mechanics properties and structure of the rock. When the sandstone or hard sandstone with high strength and joint fissure development is forced to top, $K_A = 1.33 \sim 1.35$, general rock layers (siltstone, shale, etc.) with relatively low strength, $K_A = 1.25 \sim 1.28$. According to the results of existing experiments, it is proved that lithology has little effect on the broken coefficient of broken rock

mass[18-19]. Therefore, in this paper, K_A is taken as a certain value, ie $K_A = 1.3$, to simplify calculation.

(2) The destruction of rock formations. For example, if the strata of a stratum is developed from a curved subsidence, the above values can be used; if the whole strata are cut off, K_A is 1. This article discusses the limitations of bending settlement.

(3) In summary, Equation 2 can be used to calculate the relationship between the caving height and the mining height when the K_A value is 1.3 under different lithologic conditions.

$$m_k = \frac{h - S_A}{K_A - 1} \quad (2)$$

Where: m_k - the height of the caving zone.

Assume that the thickness of the fractured zone is $\sum h_i = xh$, and h is the seam height. It is assumed that the coefficient of heaving expansion is K'_A , the rock layers in the fracture zone are layered up and down, left and right cracking, there is no rock turnover, broken expansion is not obvious, generally 1.02 to 1.15[20], and the weighted average can be calculated according to the thickness of each rock layer, generally 1.05 calculation. The height of the residual separation space can be considered as 0, after the fracture zone rock fracture dilatation filling the goaf, then the relationship between the height of the fractured zone and the mining height can be calculated from formula 3 under different lithological conditions:

$$\sum h_i + S_A = \sum h_i \cdot K'_A \quad (3)$$

The final determination of the development height of the water-conducting fractured zone is controlled by the combined strata. When the water-conducting fracture zone is expected to develop to a certain rock layer above and below, if the rock layer and its lower strata are of "upper soft and lower hard type", then during the overlying rock movement, the rock layer and the lower rock layer are combined motion of soft rock formation. The water-conducting fracture zone will break through the weak rock layer and stop at the upper group of hard rock, and the height of the water-conducting fractured zone will increase, that is to say, the thickness of the weak rock layer H_R will be increased. If the strata and the lower strata are of "upper

hard and lower soft type", the strata belong to the upper hard rock formation and the lower soft rock formation separately during the overlying rock movement, and the water-conducting fractured zone will stop below the hard rock layer.

Thus, the predicted height formulas (4) and (5) for the water-conducting fractured zone under different lithology and rock assemblage can be obtained.

1) "Upper soft and lower hard type"

$$H_D = m_k + \sum h_i + H_R \quad (4)$$

2) "Upper hard and lower soft type"

$$H_D = m_k + \sum h_i \quad (5)$$

III. VERIFICATION OF HEIGHT SIMULATION OF WATER-CONDUCTING FRACTURED ZONE

A. Geological overview

The 2-2 coal seam of a certain mine is shallow, with a maximum depth of 270 m, near horizontal, and a thickness of 12m. The surface is 18m aeolian sand, under the eolian sand is the Quaternary yellow soil layer of 15 m, and the red clay layer is 15 m. The geological structure is relatively simple. Coal-bearing formations have poor cementation, and low rock strength, large coal seam thickness, fine-grained sandstone and siltstone in the top and bottom rock formations. See Table II for the occurrence of specific strata.

According to the method described in this paper, the height of the water-conducting fractured zone is calculated as follows. The caving zone is sandstone and argillaceous sandstone. Therefore, the height of the caving zone is 2~2.5 times of the mining height, and the basic top is alternating sandstone and mudstone, so the height of the fracture zone is 8 ~10 times of the mining height. In summary, the height of the water-conducting fractured zone is 10~12.5 times of the mining height. According to the occurrence of strata, the harder siltstone is located at a height of 10 to 12.5 times the mining height above the working face. Therefore, the upper and lower rock formations belong to the "upper hard and lower soft type", so the height of the water-conducting fracture zone will stop at the lower part of the rock, that is, the height of the water-conducting fracture zone is 10~12.5 times of the mining height and will not break through the rock formation.

TABLE II. OCCURRENCE OF STRATA

Order number	Name	Thickness/m	Order number	Name	Thickness/m
1	Aeolian sand	18	11	Mudston	5
2	Loess	15	12	Fine	15
3	Laterite	15	13	Sandsto	12
4	Siltstone	18	14	Fine	4
5	Coarse sandstone	12	15	Sandsto	6
6	Mudstone	18	16	Argillac	4
7	Fine sandstone	56	17	2 coal	12
8	Mudstone	6	18	Siltstone	2
9	Middle sandstone	12	19	2 lower	2
10	Siltstone	32	20	Mudston	5

B. Similar material ratio test

1) *Determination of mechanical parameters of 2-2 coal and its overlying strata in a shallow soft rock coal mine.*

According to the coal column diagram and the previous mechanical experiments, the mechanical parameters of the

coal seam and the overlying rock layers can be obtained. Taking the 2-2 coal seam and its roof and floor as examples, the compressive strength limit and the compressive strength limit are shown in Table III below. The model size similarity ratio is 1:200 and the gravity similarity ratio is 1:1.5, so the intensity similarity ratio is 1:300.

TABLE III. SOFT ROCK STRENGTH LIMIT TABLE

Rock formation	Compressive strength	Compressive strength of the model	Tensile strength	Tensile strength of the model	σ_c/σ_t
	limit/MPa	model/MPa	limit/MPa	model/MPa	
Mudstone	7.796	0.02599	1.225	0.00408	6.364
Coarse sandstone	15.622	0.05207	1.960	0.00653	7.970
Middle sandstone	16.847	0.05616	1.507	0.00502	11.179
Fine sandstone	16.234	0.05411	1.564	0.00521	10.379
Siltstone	13.221	0.04407	1.641	0.00547	8.056
Sandstone	9.159	0.03053	1.108	0.00369	8.266
Argillaceous sandstone	11.932	0.03977	0.841	0.0028	14.187
coal	10.061	0.03354	1.939	0.00646	5.188

2) Determination of the strength of similar materials with different proportions

The selection of similar materials and the determination of the composition ratios of the constituents of similar materials have become one of the most important factors in simulation experiments. The similar materials selected for this experiment were sand, calcium carbonate, gypsum, mica powder and water. According to the results of uniaxial compression tests of 2-2 coal and its roof in shallow soft rock coal mines, it is known that the western coal rocks belong to weak rock formations. The smaller the cement

content (ie, calcium carbonate, gypsum) in the test piece, the lower the strength of the test piece, and the greater the calcium carbonate content in the cement, the lower the tensile strength. Therefore, when configuring the specimens with different proportioning numbers, the proportion of cement should be small, and the proportion of calcium carbonate is greater than that of gypsum and the moisture content is 10%. A standard test piece was prepared by arranging similar materials with different proportions. After drying for 2 days, uniaxial compressive strength tests were performed.

TABLE IV. SPECIMEN STRENGTH PARAMETERS OF DIFFERENT PROPORTIONS

Specimen labels	Sand: Calcium carbonate: Gypsum: Water	σ_c (MPa)	σ_t (MPa)	σ_c/σ_t
1-1	6:0.6:0.4:0.7	0.05633	0.00514	10.959
1-2	6:0.7:0.3:0.7	0.05047	0.00987	5.114
1-3	6:0.8:0.2:0.7	0.04307	0.00747	5.767
2-1	7:0.6:0.4:0.8	0.04653	0.00673	6.910
2-2	7:0.7:0.3:0.8	0.04453	0.00653	6.816
2-3	7:0.8:0.2:0.8	0.03833	0.00607	6.318
3-1	8:0.6:0.4:0.9	0.04447	0.00593	7.021
3-2	8:0.7:0.4:0.9	0.03653	0.00453	8.058
3-3	8:0.8:0.4:0.9	0.0296	0.00353	8.377
4-1	9:0.6:0.4:1	0.03853	0.00267	14.450
4-2	9:0.7:0.3:1	0.03033	0.002	15.166
4-3	9:0.8:0.2:1	0.02433	0.00173	14.038

In the room temperature, 15 cm×15 cm×15 cm concrete standard molds were used to make 4 blocks and 12 groups of 60 blocks according to the following table ratios. The specimen was demoulded one day after molding and maintained at room temperature for 4 days. Then the uniaxial compressive strength test of the test piece was performed on a Shimadzu AX-G250 tester. The compressive strength parameters of the test piece are shown in Table IV.

When the specimen is subjected to axial tensile stress, the specimen is destroyed, and the pressure per unit area is the tensile strength of the specimen. Due to the direct tensile tests, the specimens and loading requirements are high, and the point load test results are discrete. However, the splitting

test specimens are easy to process and the test is simple. Therefore, the splitting method is used to determine the tensile strength of the specimens. The height-to-diameter ratio of the test piece is 2:1, the diameter is 5cm, and the height is 10cm. Tensile strength parameters are shown in Table IV.

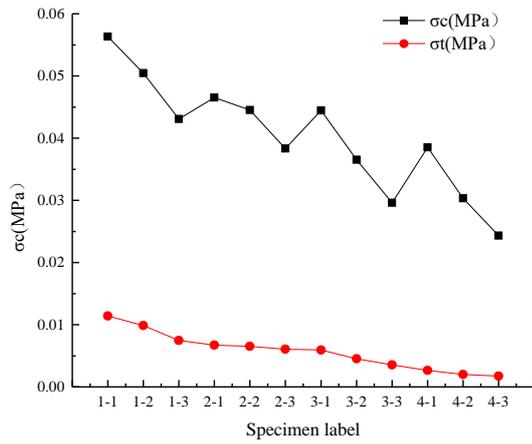


Fig.2 Strength of specimens with different proportioning

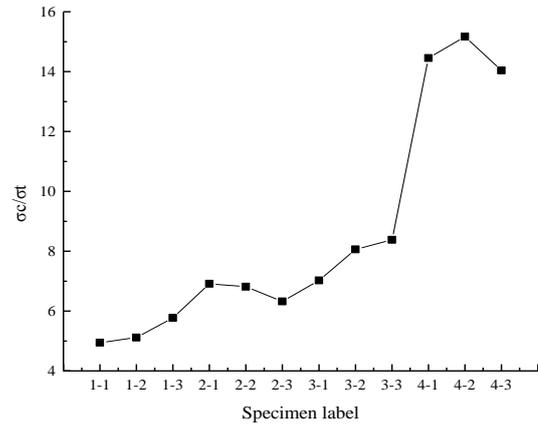


Fig.3 Ratio of σ_c/σ_t

From Figures 2, 3 and Table 4, it can be seen that with the increase of the ratio of sand to rubber, the strength of the test piece is gradually decreasing, and the ratio of compressive strength and tensile strength of the test piece is gradually increasing. According to the compressive strength, tensile strength, etc. of the real rock layer in Table 3, the proportioning number is selected by the intensity similarity ratio, and the matching results are shown in Table V.

TABLE V. MATCHING RESULT OF ROCK MATCHING NUMBER

Serial number	Name	Matching ratio	Serial number	Name	Matching ratio
1	Aeolian sand	--	11	Mudstone	8:0.8:0.4:0.9
2	Loess	--	12	Fine sandstone	6:0.6:0.4:0.7
3	Laterite	--	13	Sandstone	8:0.7:0.4:0.9
4	Siltstone	8:0.6:0.4:0.9	14	Fine sandstone	6:0.6:0.4:0.7
5	Coarse sandstone	8:0.6:0.4:0.9	15	Sandstone	8:0.7:0.4:0.9
6	Mudstone	8:0.8:0.4:0.9	16	Argillaceous sandstone	9:0.6:0.4:1
7	Fine sandstone	6:0.6:0.4:0.7	17	2 coal	7:0.8:0.2:0.8
8	Mudstone	8:0.8:0.4:0.9	18	Siltstone	8:0.6:0.4:0.9
9	Middle sandstone	6:0.6:0.4:0.7	19	Under 2 coal	7:0.8:0.2:0.8
10	Siltstone	8:0.6:0.4:0.9	20	Mudstone	8:0.8:0.4:0.9

C. Similar simulated test development of water-conducting fracture zones

Following the three laws of similar conditions, a simulation test was planned, in which the size-similarity ratio was 1:200, the design model size was 190cm×22cm, and the height was 134.5cm. Left and right sides of the left 15cm coal pillar mining, model mining results shown in Figure 4,5,6.

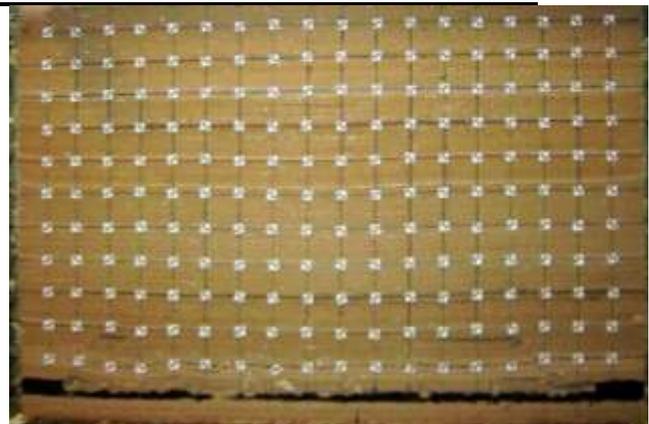


Fig. 4 The model of mining 6m

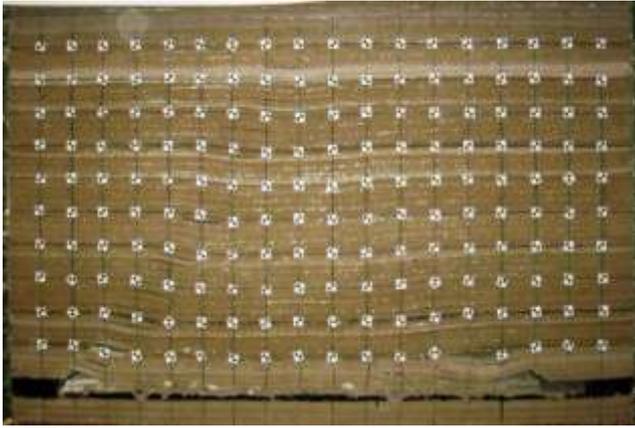


Fig. 5 The model of mining 8m

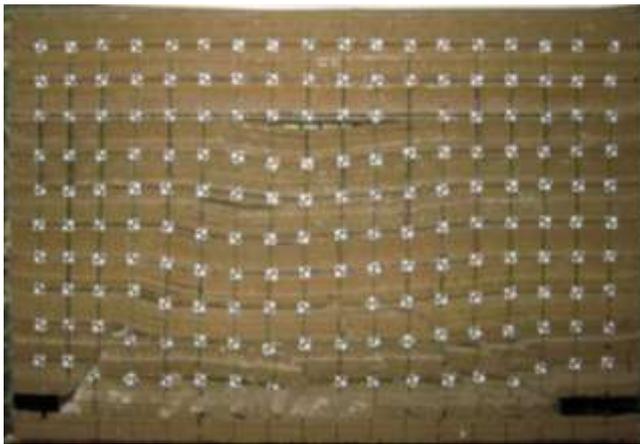


Fig. 6 The model of mining 12m

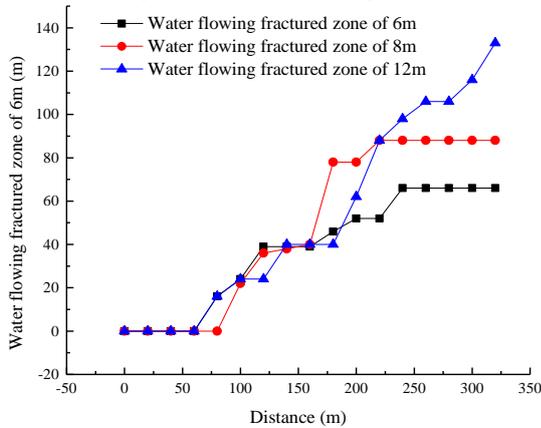


Fig 7 Development of the water-conducting fracture zone

During the excavation process, the development of the height of the water-conducting fracture zone was recorded. The statistics are shown in Fig. 7. After the excavation is over, the final height of the water-conducting fracture zone is calculated and plotted. From Fig.8, it can be seen that with the increase of mining thickness, the height of the mining water-conducting fracture zone increases linearly. The linear relationship between fitting the water-conducting fracture zone and the mining thickness is: $y = 11.178x - 1.2142$. The simulation results are basically consistent with the prediction methods of this paper.

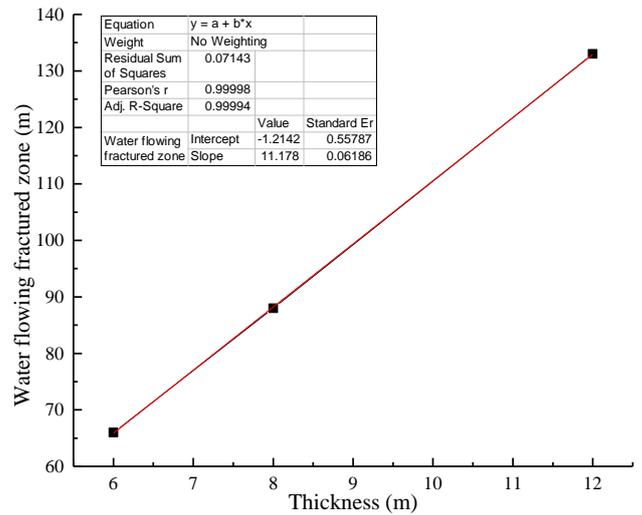


Fig 8 Height of the water-conducting fracture zone

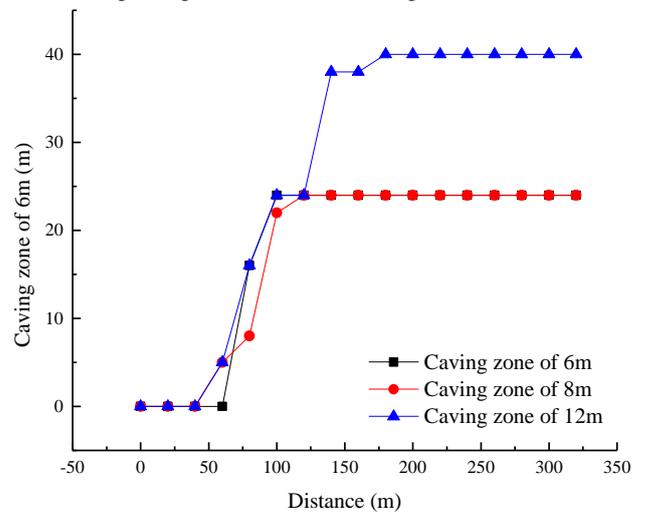


Fig 9 Development of the Caving zone

IV. ANALYSIS OF HIGH MINING THICKNESS EFFECT IN WATER-CONDUCTING FRACTURE ZONE

A. The thickness effect of the caving zone

It can be clearly seen from Fig. 9 and 10 that the development of the caving zone can be divided into three phases: waiting phase, growth phase, and stabilization phase. The formation speed of the caving zone is high, but as the thickness increases, the caved height increases and the forming speed slows down. The caving zone quickly enters a stable phase and will remain stable for a long period of time. When the thickness is 6m and 8m, the height of the caving zone is unchanged. When the thickness is 12m, the caved height suddenly increases to about 40m.

When the exposed rock layer reaches the limit collapse distance, and reaches the limit bending subsidence value, the rock layer collapses. When the mining thickness increases by 2m, there is no increase in the caving height, which means that the sinking space with correspondingly increased mining thickness is still not enough to make the upper rock formation fall. When the mining thickness is increased to 12m, the corresponding sinking space increased by the increase in mining thickness causes the upper rock formation to fall.

Based on this, it can be concluded that due to the existence of rock fragmentation, with the increase of the mining thickness, there will be no linear growth in of the

caving zone, but a step growth pattern. In general rock conditions, that is, mining thick medium-thick coal seams, direct top general sandstone, S_A value is $(0.35\sim 0.5)h$ at

this time, the formula $m_z = \frac{h-S_A}{K_A - 1}$ shows that the rock

dilatancy is obvious, so the mining thickness increases from 6m to 8m, the caving height is not increased, mining thickness increased from 6m to 12m, a sudden increase in the caving height to fall. Through Figures 10, it is found that with the increase of the mining thickness, the caving zone is a step-like increase.

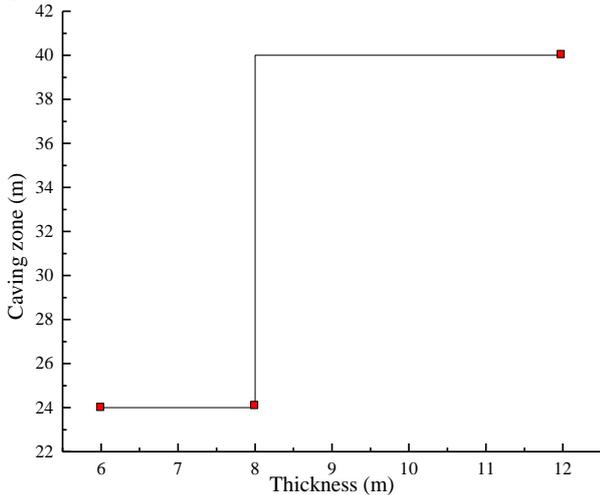


Fig 10 Caving zone of different thick

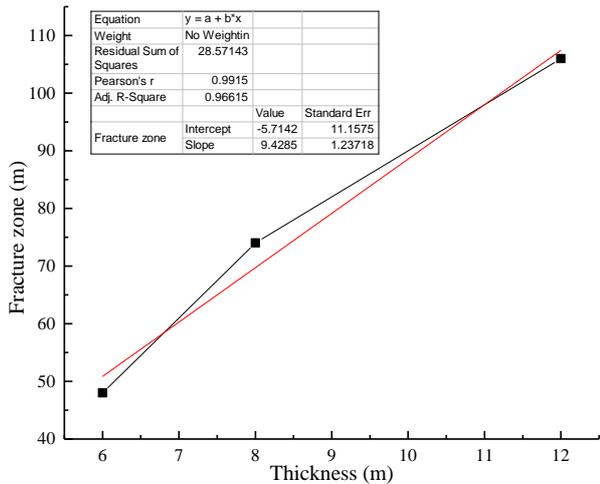


Fig 11 Fracture zone development thick

B. Thickness effect of fracture zone

The development process of the fracture zone is consistent with the development of water-conducting fracture zone. The development height is the height of water-conducting fracture zone minus the height of the collapse zone. Figure 11 shows that with the increase in mining thickness, the fracture zone grows linearly, and the linear relationship between the fracture zone and the mining thickness is: $y = 9.4285x - 5.7142$.

The subsidence space required for the formation of the fracture zone is much smaller than that of the caving zone, and the crushing expansion in the rock fractures is much smaller than that in the caving zone. Therefore, the mining thickness increases from 6m to 8m and increases to 12m. The height of the fracture zone will be obviously increase.

V. CONCLUSION

1) The heights of the caving zone and fracture zone under different conditions are derived based on the rock-swelling characteristics, so that the predicted height of the water-conducting fractured zone under any combination of lithology conditions can be obtained. The water-conducting fractured zone can be finally determined in combination with the rock-beam combined movement. Combining the actual rock layer properties of the coal mine to predict the height of water-conducting fractured zone instead of giving a statistical formula in general, the method is simple and the result is more accurate.

2) Through similar simulation experiments, the height of the water-conducting fractured zone under the condition of thick and loose layers of extra-thick coal seam was verified. It is expected that the height of the water-conducting fractured zone will be 10~12.5 times of the mining height, and the thickness will be obtained under the condition of thick and loose coal seam. With the linear relationship between the height of the water-conducting fractured zone and the predicted height range, the reasonableness and accuracy of the predicted water-conducting fractured zone height are verified.

3) The similar simulation experiment simulates the effect of mining thickness on the water-conducting fractured zone under thick coal seam conditions. With the increase of mining thickness, the caving zone shows a step growth pattern, and the fracture zone shows a linear growth. This provides a theoretical basis for the safety of mining operations, the prevention and control of mining disasters, and the environmental protection of mining areas.

REFERENCES

- [1] L. Tianquan, "Safe mining of near loose layer under thick unconsolidated aquifer," Coal science and technolog, vol. 13, pp. 14-18, 1986.
- [2] State Bureau of Coal Industry. "Standard Practice for the construction of coal pillars and coal pillars for buildings, water bodies, railways and main wells," Beijing:China Coal Industry Publishing House, 2000,pp.38-43.
- [3] X. Jialin,Z. Weibing,W. Xiaozhen."A method for predicting the height of water-conducting fracture zone based on key layer location,"vol.37. Journal of China Coal Society,2012,pp.762-769.
- [4] X. Jialin,W. Xiaozhen,L. Wentao,W." Zhigang.Influence of the position of key stratum of overlying strata on the height of water-conducting fracture zone,"vol.28.Chinese Journal of Rock Mechanics and Engineering,2009,pp.380-385.
- [5] W. Lianguo, W. Zhansheng, H. Jihui, Z. Donglei."Estimation of the height of water-conducting fracture zone of shallow coal seam with thick aeolian sand in thin bedrock,"vol.29.Journal of Mining and Safety Engineering, 2012,pp. 607-612.
- [6] S. Longqing, X. Hengqi, P. Peihe, L. Shouchun, L. Tongbin, Y. Yong, W. Wenxue."Study on height calculation of water-conducting fracture zone under large mining depth conditions,"vol.41.Journal of China University of Mining & Technology, 2012, pp. 37-41 .
- [7] Li M, Zhang J, Deng X."Measurement and numerical analysis of water-conducting fractured zone in solid backfill mining under an aquifer: a case study in China,"vol.50. Quarterly Journal of Engineering Geology and Hydrogeology, 2017,pp.81-87.
- [8] Venticinque, G., J. Nemcik and T. Ren,"A new fracture model for the prediction of longwall caving characteristics,"vol.24.International Journal of Mining Science and Technology,2014. pp. 369-372.
- [9] N. Jianguo, L. Xuesheng, T. Yunliang, W. Jun, Z. Ming, Z. Lisheng."Study on the evaluation method of water conservation in shallow buried sandy mudstone roof coal seam,"vol.32.mining and safety engineering,2015,pp. 814-820.
- [10] L. Bing, W. Bei, J. Ligu, L. Gang, L. Changyu."Study on the dilatancy characteristics of the rock mass in the shallow buried goaf

- area,"vol.38.Journal of China University of Mining and Technology, 2016,pp. 475-482.
- [11] R. Yanfang, Y. NING, and Q. Xinji. "Physical analogous simulation on the characteristics of overburden breakage at shallow longwall coalface,"vol.38.Journal of China Coal Society.2013,pp.61-66.
- [12] W. Jiachen,W. Zhaohui. "Stability of main roof structure during the first weighting in shallow high-intensity mining face with thin bedrock,"vol.32.Journal of Mining & Safety Engineering, 2015,pp.175-181.
- [13] Z. Shutong, D. Linchao, W. Bocao."Simulation study on similar material ratio for simulating coal and gas outburst,"vol.43.coal science and technology, 2015,pp.76-80+145.
- [14] L. Liangliang, W. Hailong, L. Jiangbo, C. Shaojie."Orthogonal ratio test of low intensity similar materials,"vol.33.Journal of Liaoning Technical University , 2014,pp.188-192.
- [15] Y. Xu, S. Dingli, Z. Bin, L. Zhen, Z. Cuiying."Experimental study on the ratio of similar materials in red bed soft rock model test,"vol.37.geotechnical mechanics, 2016,pp.2231-2237.
- [16] H. Qingxiang,H. huoming."Experimental study of stress-strain similar materials and proportioning of clay aquifers,"vol.34.Journal of mining and safety engineering, 2017,pp.1174-1178.
- [17] L. Baiying, G. Weijia ."Mining damage and environmental protection," Beijing: China Coal Industry Press, 2004.
- [18] Song Zhenqi."Practical Mine Pressure Control",Xuzhou: China University of Mining and Technology Press, 1988.
- [19] B. B. Lezhevski ."Fundamentals of petrophysics" translated by He Xiuren. Xuzhou: China University of Mining and Technology Press, 1989.
- [20] He Guoqing."Mine Mining Subsidence." Xuzhou: China University of Mining and Technology Press, 1991.
- [21]