Research on Destroyed Floor Depth —The Example of the 51302 Working Face in the Liangzhuang Coal

xiaoge yu (✉ yuxioage2010@163.com)

Shandong University of Science and Technology

Yifei Liu

Shandong University of Science and Technology

Haibin Fan

Shandong institute of Geological and Mineral Survey

Research Article

Keywords: floor depth, damage variable, rock damage, effect factors

Posted Date: May 5th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-458999/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Research on Destroyed Floor Depth

---the example of the 51302 working face in the Liangzhuang coal

Xiaoge yu^{1,2,3}, Yifei Liu⁴, Haibin Fan⁵

1. Department of Resource and Civil Engineering, Shandong University of Science and Technology,
Taian 271019, China;

2. National Engineering Laboratory for Coalmine Backfilling Mining, Shandong University of
Science and Technology, Tai'an Shandong 271019, China;

3. Department of Resource and Civil Engineering, Shandong University of Science and
Technology, Tai'an Shandong 271019, China;

4. College of Earth Science and Engineering, Shandong University of Science and Technology,
Qingdao Shandong 266590, China;

5. Shandong Provincial Institute of Geological and Mineral Survey, Weifang Shandong 261021,
China;

* Corresponding author

E-mail address: haibinfan2021@163.com (Haibin Fan)

Abstract: Based on the analysis on factors affecting floor depth, mining depth, dip angle of coal seam, mining thickness, dip length of working face, damage variable of floor strata and whether there are faults and crushed zones in the working face are defined as main influence factors. The classical Down Three Zone Theory, Down Four Zone Theory based on damage mechanics, formula written in the national standard, BP (Back Propagation) neural network algorithm considering various influencing factors and Numerical Simulation Method were applied for predicting floor depth of the 51302 working face. A double-side seal borehole water injection

1 device was used to determine the actual floor depth of the 51302 working face. By comparing the
2 prediction results with the actual measurement results, the prediction results obtained by
3 considering rock damage are closer to reality.

4 **Keywords:** floor depth; damage variable; rock damage; effect factors

5

6 The prediction of destroyed floor depth of coal seams is important for the
7 research on floor water disasters (Miao et al. [2011](#); Wu et al. [2013](#)). With mining
8 depth increasing, the actual destroyed floor depth is far beyond the calculated value
9 obtained by empirical formulas of shallow coal seam mining. For example, the mining
10 depth of the 1237(2) working face in Zhaogezhuang Coal Mine is 1000 m and its
11 destroyed floor depth is up to 38 m (Meng et al. [2009](#)), additionally, the mining depth
12 of 32031(2) working face in Wucun Coal Mine is 640 m, and its destroyed floor depth
13 is up to 26.40 m (Shi et al. [2013](#)). Deep coal seam mining is seriously influenced by
14 the high confined water, so it is obviously important to predict destroyed floor depth.
15 More and more scholars have predicted the destroyed floor depth by various methods,
16 based on the factors influencing destroyed floor depth of coal seams, but most of these
17 scholars assumed that the coal seam floor is complete without considering the floor
18 rock damage (Chang et al. [2016](#); Gao et al. [2017](#); Jin et al. [2011](#); Kang et al. [2017](#); Li
19 et al. [2013](#)). In fact, after going through the long-term geologic process and
20 tectonization, there are many fracture planes in the interior of coal seam floor strata.
21 With coal seam mining, mine pressure and in situ stress have further influence on
22 floor strata, and floor strata is damaged more seriously, which is especially evident in

1 deep coal seam mining(Li et al. 2003; Liu et al. 2017; Liu et al. 2017; Lu et al. 2017;
2 Lu et al. 2013; Ma et al. 2016). The damage of floor strata is of great importance
3 when considering whether the predicted value of the destroyed floor depth can guide.
4 (Wang et al. 2014; Yu et al. 2008; Yu et al. 2011; Yu et al. 2017; Zhang et al. 2011;
5 Zhang et al. 2016; Zhu et al. 2014) Based on the factors influencing destroyed floor
6 depth, this paper mainly studies the influence of floor damage on the floor depth of
7 coal seams. Combining the classical Down Three Zone Theory, Down Four Zone
8 Theory based on damage mechanics, formula written in the national standard, BP
9 neural network algorithm considering various influencing factors and Numerical
10 Simulation Method, this paper calculates the destroyed floor depth of the 51302
11 working face in Liangzhuang Coal Mine, makes a comparison between the predicted
12 value and measured value and probes into the influence of floor damage on damaged
13 floor depth.

14 **1 Overview of research area**

15 The Liangzhuang Coal Mine is located in the northwest region of Xinwen coal
16 field, in Shandong province, eastern China (Fig. 1). The main workable coal seam are
17 the No. 2 coal seam, No. 4 coal seam and No. 6 coal seam in Taiyuan Formation and
18 the No. 11 coal seam, No. 13 coal seam and No. 15 coal seam in Shanxi Formation.
19 The 51302 working face is located in the east of 5 mining area at the level of -580 m,
20 and its trend length is 690 m, dip length is 165 m and the placing depth is 640 m. The
21 working face is a monoclinic structure, and there are folds in some parts of it and 13
22 faults were exposed. The trend of the coal seam is NW, the tendency is NE and its dip

1 angle is 12° . The basal water influencing No. 13 coal seam mining are NO.4
 2 limestone aquifer in the roof and Xujiashuang limestone aquifer and Ordovician
 3 limestone aquifer in the floor. NO.4 limestone aquifer is the immediate roof of No. 13
 4 coal seam and it is nearly anhydrous. So, 51302 working face mining is influenced
 5 most by Xujiashuang limestone water and Ordovician limestone water. The distance
 6 of the 51302 working face from Xujiashuang limestone aquifer and Ordovician
 7 limestone aquifer is 40 m and 79 m respectively. (Fig. 2) The destroyed floor depth
 8 has a great influence on floor water burst.

Fig. 1 Geographic location of the Liangzhuang Coal Mine in China

Fig. 2 Strata of columnar section of the Liangzhuang Coal Mine

2. Effect factors of floor depth

There are many factors influencing mining damage depth of coal seam floor, and the main factors (Liu et al. 2015; Duan, 2014; Yu et al. 2009) are as follows. (1) Mining depth: The influence exerted by mining depth plays a basic role, and the difference in depth of mining causes the change of the self weight of the overlying strata and changes the base pressure of the floor. The deeper the mining is, the larger the stress of primary rock and hydraulic pressure are, and the more serious the degree of destroyed floor is. (2) Dip angle of coal seam: The change of dip angle of the coal seam makes the degree and area of stress concentration change, and thus, the damage depth of the coal seam floor changes. (3) Mining thickness: The greater the mining thickness of the coal seam is, the greater the ground pressure is, the stronger strata behavior is, and the more serious the degree of destroyed floor is. (4) Dip length of working face: With the dip length of the working face increasing, the damage depth of

1 the coal seam floor increases; (5) Damage variables of floor strata: These variables
2 include rock strength, strata combination and the developmental situation of original
3 fractures. It is the inherent property of the coal seam floor, reflected in the anti-failure
4 ability of the floor rock layer. It can be analyzed from three factors in rock mechanics
5 parameters: tensile strength, cohesion and internal friction angle. (6) Whether or not
6 there are faults and crushed zones in the working face: The destroyed floor depth near
7 faults or crushed zones is 0.5~1 times larger than that of normal strata.

8 **3 Computing method of destroyed floor depth**

9 **3.1 Calculating destroyed floor depth based on the Down Three Zone Theory and** 10 **Down Four Zone Theory**

11 The Down Three Zone Theory (Li, [1999](#)) is put forward from the field practice.
12 Based on elastic mechanics and assuming that rock is continuous, perfectly elastic and
13 homogeneous, this theory divides the coal seam floor into three zones: floor damage
14 zone or “diversion zone” (h_1); intact strata zone or “water-blocking zone” (h_2);
15 confined water flowing crevice zone or original water flowing crevice zone (h_3), as is
16 shown in Fig. [3](#). Longqing Shi (Shi et al. [2005](#)) assumes that the rock is damaged.
17 Based on damage mechanics and fracture mechanics theory, he divides the coal seam
18 floor into four zones: broken zone caused by underground pressure; new damage zone;
19 original damage zone; original water flowing crevice zone (Fig. [4](#)).

Fig.3 Down Three Zone model of mining coal seam floor

Fig.4 Down Four Zone model of mining coal seam floor

The formula provided by the Down Three Zone Theory is a practical formula summarized by field scientific and technical personnel in practice (State Coal Industry Bureau 2000). It is the following empirical formula of destroyed floor depth according to the single factor—working face dip length (L) of single factor in the 1980s:

$$h_1 = 1.86 + 0.11L \quad (1)$$

Based on damage mechanics and combined with the Mine Pressure Theory, the Down Four Zone Theory elicited the theoretical calculating formula of damage depth (h_1) of mining coal seam floor:

$$h_1 = 59.88 \ln \frac{K_{\max} \gamma H}{\sigma_1} \quad (2)$$

where, $K_{\max}$ is the maximum concentration coefficient of mine pressure, γ is the average unit weight of overlying strata, and H is the mining depth.

The dip length of the 51302 working face is 165 m. According to Ground Pressure Control Theory, Rock Mechanics Theory and mechanical testing data analysis of relative strata in Xinwen Coal Mine, the calculation of the 51302 working face damage depth can be based on the following values: $K_{\max} = 2.8$,

1 $\gamma = 0.028 \text{ MN} / \text{m}^3$, $H = 640 \text{ m}$, $\sigma_1 = 27 \text{ Mpa}$. The destroyed floor depth is 20.0 m and
2 37.1 m, respectively, according to Formula (1) and (2).

3 **3.2 Calculating destroyed floor depth according to Regulation and BP neural** 4 **network**

5 *Calculating destroyed floor depth according to Regulation*

6 According to Regulations on Buildings, Water Bodies and Railways and
7 Unexploited Main Coal Pillar and Coal Mining (State Coal Industry Bureau 2000), the
8 placing depth, dip length of working face and dip angle of coal seam (α) are three
9 easily obtained parameters selected to calculate the destroyed floor depth:

$$10 \quad h = 0.0085H + 0.1079L_x + 0.1665\alpha - 4.3579 \quad (3)$$

11 The destroyed floor depth is determined to be 20.88 m by putting the relative
12 parameters $H = 640$, $\alpha = 12$, $L = 165$ into Formula (3).

13 *Calculating destroyed floor depth according to BP neural network computing*

14 Most of factors influencing destroyed floor depth are together with noise which
15 affects the prediction of destroyed floor depth directly. Based on BP neural network
16 computing, the establishment of destroyed floor depth prediction model can reduce
17 effectively reduce or eliminate the influence of these noises.

18 *Acquisition of samples*

19 Actual field data of 26 mined working faces are were chosen to be the training
20 samples and testing samples of BP neural network computing (Table 1). Samples
21 1~22 are set as learning samples to conduct training to the network, and samples
22 23~26 as checking samples to test the network performance.

17	Liangzhuang mine 51101W working face	640	15	1.5	165	0.7	0	20.1
18	Xinji mine the first working face	650	10	4.5	150	0.8	0	19.17
19	Zhaogu mine 11011 working face	710	3	3.6	180	0.7	0	25.8
20	Huafeng mine 41303 working face	721	30	0.94	120	0.6	0	11.95
21	Zhaolou mine 1304(2) working face	984.5	4	4.81	205	0.7	0	22.6
22	Zhaogezhuang mine 1237(2) working face	1000	30	2	200	0.5	0	38
23	Xinzhuangzi mine 4303(1) working face	310	26	1.8	128	0.6	0	16.8
24	Ningmei mine 213 working face	416	18	1.5	115	0.6	0	16.5
25	Pansan mine 37(1) working face	590	15	3	205	0.6	0	14.6
26	Zhaogezhuang mine 1237 working face	1056	26	10	200	0.2	1	35

- 1 (1,2 from Xu et al. 2015; 3,4,11,12,14,19,24 from Xu and Yang 2013;
- 2 5,6,8,10,16,21 from Yu 2011; 13,17,20,22,23 from Shi et al. 2013; 7,15,25 from Chen
- 3 et al. 2012; 18 from Fan et al. 2012; 9,26 from regulation, 2000)

Fig. 5 Scatter points diagram of error between goal output and real output about double

hidden-layer

Fig. 6 Training processes curve

The destroyed floor depth of the 51302 working face is 35.2 m obtained by putting the parameters of the 51302 working face (Table 2) into the BP neural network prediction model.

Table 2 Factors influencing the destroyed floor depth of the 7105 working face

based on a statistical analysis

Name of working face	H/m	$\alpha/^\circ$	M/m	L/m	D	F	H_1/m
51302	640	12	1.0	165	0.42	1	35.2

3.3 Simulating destroyed floor depth by RFPA numerical simulation

RFPA software can consider the heterogeneity of materials and randomness of defect distribution and simulate the progressive failure of materials combining the statistical distribution of material properties and the numerical computation method.

This paper sets the floor of the 51302 working face as complete type and damaged

1 type (damaged variable is 0.42) and simulates the destroyed floor depth accordingly.

2 *Establishment of numerical model*

3 According to the mechanical parameters (Table 3) of the coal seam (21 seam)
 4 floor of the 51302 working face in Liangzhuang Coal Mine, the striking length of the
 5 model is 600 m and the height is 200 m. The model includes 120,000 elements
 6 (200×600). The calculating capacity and operating rate of the model are limited, so
 7 the 10-m-thick overlying stratum is put at the top of model with a unit weight is 20
 8 times heavier than that of loose weathered strata. The higher head pressure is
 9 transferred to the lower aquifer of strata through the boundary, and rock mass only
 10 bears its own weight and hydraulic pressure. The boundary conditions are set as
 11 follows: both ends are restricted level and they can move vertically; the bottom is
 12 fixed, and the bottom and top of it are confining boundaries; the 550-m-high water
 13 boundary is set to simulate the high-pressure water value (5.5 Mpa) of Ordovician
 14 limestone water. (Fig. 7)

15 Table 3 Table of rock mechanics parameters

NO.	lithology	thickness (m)	Elastic modulus (MPa)	Compressiv e strength (MPa)	Poisso n ratio	Internal friction angle (°)	Bulk density (N/mm ³)	Perme ability coeffi cient (m/d)	Pore pressure coefficient
1	Equivalent rock stratum	10	8000	200	0.12	50	5.2e-4	0.1	0.01
2	sandstone	15	9500	102	0.23	37	2.52e-5	2	0.1
3	medium sand	25	9200	98	0.212	35	2.62e-5	1	0.1
4	NO.11 coal seam	2	2600	20	0.27	40	1.3e-5	0.1	0.01
5	Clay rock	6	3200	45	0.19	42	2.56e-5	0.1	0.01
6	sandstone	8	8600	99	0.18	50	2.53e-5	2	0.1
7	siltstone	25	2002	67	0.173	45	2.63e-5	0.1	0.01

8	NO.4 limestone	7	9266	65	0.217	56	2.64e-5	10	0.5
9	No.13 coal seam	1	2700	19	0.26	40	1.4e-5	0.1	0.01
10	siltstone	10	1034	14	0.316	50	2.64e-5	0.1	0.01
11	Fine sandstone	3	6647	35	0.212	52	2.59e-5	0.5	0.03
12	siltstone (black)	4	1133	10	0.284	54	2.66e-5	0.1	0.01
13	siltstone (gray)	13	5419	28	0.199	48	2.66e-5	0.1	0.01
14	Fine sandstone	10	12323	32	0.192	48	2.64e-5	0.3	0.02
15	Medium sand	9	8923	34	0.213	50	2.63e-5	1	0.1
16	siltstone	4	6512	25	0.231	48	2.67e-5	0.1	0.01
17	Xujiazhuang limestone	10	5209	22	0.242	48	2.65e-5	10	0.5
18	mudstone	4	4500	23	0.213	33	2.61e-5	0.1	0.01
19	Caobugou limestone	9	9326	54	0.155	37	2.67e-5	10	0.01
20	mudstone	4	6800	36	0.226	36	2.63e-5	0.1	0.01
21	Ordovician limestone	21	11207	55	0.167	40	2.66e-5	100	1

1 ***The process and results analysis of numerical simulation***

2 The simulation process is conducted step by step (Fig. 8). The simulation mining
3 length is 160 m and each step is 10 m, so there are a total of 16 steps. The excavation
4 is conducted from the open-off cut 200 m far from the left of the figure, and the
5 destroyed floor depth of complete floor and damaged floor are obtained.

Fig. 7 Sketch of numerical model

Fig.8 full rock and damage rock elastic modulus distribution

It is known from the simulated results that:

1 Before the excavation, the strata are in a state of three-dimensional stress
2 equilibrium. With the coal seam mining, the stress is redistributed. The rapid change
3 of stress causes the floor damage.

4 (1) When the mining width is 20 m, the surrounding rock stress of goaf is
5 redistributed, and the floor is damaged sporadically.

6 (2) When the mining width is 60 m, the degree of stress concentration of the
7 open-off cut and supporting coal wall increases. The rock mass failure modes of the
8 coal seam floor mainly consist of tension failure, tension-shear failure and
9 shear-tension failure. Moreover, the coal wall appears to suffer tension-shear failure,
10 and the coal seam floor appears evident destroyed floor depth. The damage depth of
11 the complete floor is up to 5.3 m and that of the damaged floor is approximately 18.9
12 m.

13 (3) When the mining width is 100 m, the main failure mode of floor rock mass is
14 tension failure, and the secondary failure mode is shear-tension failure. Under the
15 influence of periodic weighting, the destroyed floor range moves forward with the
16 mining face advancing. The damage depth of the complete floor is up to 12.6 m and
17 that of the damaged floor is up to 25.5 m.

18 (4) When the mining width is 140 m, the overlying caving strata is contacted
19 with floor, supporting stress reduces and the destroyed floor depth increases
20 continuously. The destroyed floor depth of the complete floor and the damaged floor
21 is 18.2 m and 33.8 m respectively.

22 (5) When the mining width is 160 m, there is obvious damage depth in the strata

1 of the coal seam floor, which does not develop downwards just horizontally. The
 2 destroyed floor depth of the complete floor and the damaged floor stabilize to 18.2 m
 3 and 33.8 m respectively.

4 According to the numerical simulation results, the destroyed floor depth of the
 5 complete floor and the damaged floor is finally defined to 18.2 m and 33.8 m
 6 respectively.

7 **3.4 Actual measurement of destroyed floor depth of 51302 working face**

8 Double side seal borehole water injection devices can conduct water injection
 9 and draining tests to the boreholes of the floor in any direction and angle using
 10 differential mode. According to the water leakage value at different depths, the
 11 fractures in rock mass or surrounding rock failure situation can be defined. (Fig. 9)

12
 13 Fig.9 Double Side Seal Borehole Water Injection Device

14 *Setting of observation points*

15 According to roadway conditions of working face (Fig. 10), the observation
 16 points are placed near the level coal pillar on the 51302 working face. No. 1 borehole
 17 is in the place which is 40 m from the open-off cut of the 51302 working face. No. 2

1 borehole is in the centre of the working face, 80 m from the open-off cut. No. 3
2 borehole is near the terminal mining line. No. 1 borehole is set as a pre-mining
3 observation pore and post-mining observation pore and No. 2 and 3 boreholes are set
4 as post-mining observation pores. The pre-mining observation pore is used to observe
5 the original fracture state of the coal seam floor strata uninfluenced by mining, and is
6 the foundation of post-mining observation pores. And the post-mining observation
7 pore are used to predict the most development depth of the mining failure zone in
8 floor strata. The drilling construction elements and requirements are shown in Table 4.

Table 4 Drilling construction elements

Number	Name	Pore diameter/mm	Angle/(°)	Hole depth/m
1	Pre-mining observation pore (Post-mining observation pore)	89	50	70
2	Post-mining observation pore	89	50	70
3	Post-mining observation pore	89	50	70

Fig. 10 Drilling plan layout and cross section of working face floor

(a)

(b)

(c)

(d)

(a) drill-leakage at NO.1 drill hole (2015.8.23) (b) drill-leakage at NO.2 drill hole (2015.10.2)

(c) drill-leakage at NO.3 drill hole (2016.2.6) **Fig.11** Drill-leakage

Measured results

According to the measured data of the three boreholes before and after mining, the observation results figure of the water injection and seepage value of the floor are obtained by analyzing the changing law of water injection and seepage value, as the borehole depth changes.

(1) It is shown (Fig. 11(a)) from the observation results before mining of No.1 borehole that there is obvious water leakage 3 m from the hole depth and the water leakage rate is 1.2 L/min. This leaking occurs because the shallow surrounding rock near the aperture is damaged and the broken rock zone is formed when the borehole is constructed. When the hole depth is 21~33 m, the water leakage value increases obviously up to 1.6 L/min. According to the analysis of water leakage value and floor

1 strata, it may be caused by partial original fracture development or roadway
2 construction. When the hole depth is 33 m, the water leakage value approaches to 0
3 L/min, which shows that the deep strata is basically in a continuously complete state
4 and the fractures do not develop.

5 (2) Because the No.1 borehole is complete, it is set as post-mining observation
6 pore to be tested. It is shown (Fig. 11(b)) from the data that after mining, the water
7 injection and leakage of No.1 borehole are both increase, and the water leakage value
8 of shallow surrounding rock near the aperture increases to 1.8 L/min from 1.2 L/min,
9 and original cracks develop and extend to form the new cracks. When the hole depth
10 is 21~33 m, water leakage increases to 2.0 L/min. There is just a little water leakage
11 in deeper hole section and the whole remains intact.

12 Therefore, the measurement boundary of destroyed floor depth of post-mining
13 No.1 borehole is 33 m, assuming that the dip angle of borehole is 50° , and the
14 destroyed floor depth is 25.28 m.

15 (3) It is known (Fig. 11(c)) from the observation results of No.2 borehole that the
16 all 35~40 m hole sections have 8~12 L/min water leakage rate. Compared with the
17 water injection and leakage of pre-mining pore of No.1 borehole, this section is a new
18 crack. There is minimal water leakage deeper from the place where the hole depth is
19 40 m, and it is not regarded as the connected fracture development area.

20 Therefore, the measurement boundary of destroyed floor depth of post-mining
21 No.2 borehole is 40 m, assuming that the dip angle of borehole is 50° , and the
22 destroyed floor depth is 30.64 m.

(4) No.3 borehole is affected most obviously by mining influence in the ground pressure behavior area. It can be seen (Fig. 11(d)) that when the hole depth is within 45 m, the water leakage rate increases greatly, and the average water leakage is 14 L/min, and the internal cracks are connected completely. The water leakage rate approaches to 0 L/min deeper from the place where the hole depth is 45 m.

Therefore, the measurement boundary of destroyed floor depth of post-mining No.3 borehole is 45 m, assuming that the dip angle of borehole is 50° , and the destroyed floor depth is 34.47 m.

It is known from the comprehensive analysis that the measured greatest depth of destroyed floor of the No.51302 working face is 34.47 m.

4 Comparison between calculated and measured results

Using the method of calculating absolute error and relative error, the prediction results are compared with the measured values. The comparison results are shown in Table 5.

Table 5 Comparison between calculated and measured results of destroyed floor depth

Computing method			Calculated value (m)	Measured value(m)	Comparison between calculated and measured values	
					absolute error/m	relative error/%
1	“Down Three Zone”		20	34.47	14.47	41.9
	“Down Four Zone”		37.1		-2.63	7.6
2	Regulation		20.88		13.59	39.4
	BP neural network		35.2		-0.73	2.1
3	RFPA simulation	Complete type	18.2		16.27	47.2
		Damaged type	33.8		0.67	1.9

5 Conclusion

(1) By comparing the calculated and the measured results of the complete type and

1 damaged type simulated by Down Three Zone Theory, Down Four Zone Theory,
2 Regulation, BP neural network and RFPA software, it is found that the calculated
3 value markedly differs from measured value a lot without considering the damage of
4 floor strata and the calculated value does not conform to the reality. When considering
5 the damage of floor strata, calculated value is very close to the measured value, which
6 conforms to the reality.

7 (2) During the coal seam mining, especially the mining of deep coal seam, the
8 strata damage is the important factors influencing the destroyed floor depth among
9 various influencing factors.

10 **Acknowledgements**

11 This research was financially supported by the National Science Foundation
12 (42002282) ;National Science Foundation (41572244); National Natural Science Foundation of
13 China(NSFC) (51778351); the Ministry of Education Research Fund for the Doctoral Program
14 (20133718110004); the Shandong Province Nature Science Fund (ZR2015DM013); Shandong
15 Province key research and development plan of China (2016GGX102029);Taishan Scholars
16 Construction Projects Funded by Special Funds (2016GX0038). SDUST Research Fund. The
17 authors would like to thank workers of the Department of Geology in the Liangzhuang coal mine
18 for their field test and data collection.

19 **References**

20 Miao Xiexing, Bai Haibo (2011), Water-resisting characteristics and distribution rule of carbonate
21 strata in the top of Ordovician in North China. Journal of China Coal Society, 36(2):185-193
22 Wu Q, Cui FP, Zhao SQ, Liu SQ, Zeng YF, Gu YW (2013). Type classification and main

1 characteristics of mine water disasters, Journal of China Coal Society, 38(4):561-565

2 Meng ZP, Yi W, Lan H, Wang M (2009), Water inrush characteristics of Fangezhuang coal mine

3 field in Kailuan and its geological condition analysis of water inrush from coal seam floor,

4 Chinese Journal of Rock Mechanics and Engineering, 28(2):228-237

5 Shi LQ, Xu DJ, Qiu M, Jing X, Sun HH. Improved on the formula about the depth of damaged

6 floor in working area[J]. Journal of China Coal Society. 2013, 38 (Supp2): 299-303.

7 Chang QL, Tang WJ, Li XS. Study on field measurement and floor failure law of paste filling fully

8 mechanized mining [J]. Journal of Mining & Safety Engineering. 2016, 33 (1): 96-101.

9 Gao WF, Shi LQ, Yu XG, Zhai PH, Ma ZH. Study on detection sealed bad drilling using mine 3D

10 DC method [J]. Journal of Hunan University of Science & Technology (Natural Science

11 Edition). 2017, 32 (3): 6-9.

12 Jin JF, Li XB, Yin ZQ, et al. Study on the definition of rock damage variables under cyclic shock

13 wave impedance[J]. Rock and Soil Mechanics. 2011, 32 (5): 1385-1393.

14 Kang J. Risk Assessment and Control Measures for Ordovician Limestone Water Inrush in Baode

15 Mine [J]. Safety in Coal Mines. 2017, 48 (S1): 99-103.

16 Li SY, Li WS. Comprehensive geophysical exploration technology for early warning in

17 Ordovician Limestone water inrush [J]. Journal of Henan Polytechnic University (Natural

18 Science). 2013, 32 (5): 552-555.

19 Li XG, Gao YF. Destruction and damage analysis of stope floor[J]. Chinese Journal of Rock

20 Mechanics and Engineering. 2003, 22 (1): 35-39.

21 Liu HY, Li JF. Study on calculation method of non - penetrating jointed rock mass damage

22 variables [J]. Rock and Soil Mechanics. 2016, 37 (S1): 95-100

- 1 Liu WT, Mu DR, Yang L, Li LY, Shi CH. Calculation method and main factor sensitivity analysis
2 of inclined coal floor damage depth[J]. Journal of China Coal Society. 2017, 42 (4): 849-859.
- 3 Lu HF, Yao DX, Hu YB, Sun J. Elasticity solution for failure depth of mining floor under water
4 pressure [J]. Journal of Mining & Safety Engineering. 2017, 34 (3): 452-458.
- 5 Lu YL, Wang LG. Numerical simulation and microseismic monitoring of the damage of bottom
6 plate with fault coal seam[J]. Journal of Mining & Safety Engineering. 2013, 22 (1): 35-39.
- 7 Ma GS, Sun SQ, Zheng KG, Li C, L WC, Chen DD. Numerical Simulation of Deformation Failure
8 Characteristics of Coal Seam Floor in Mining Process[J]. Safety in Coal Mines. 2016, 47 (9):
9 202-205.
- 10 Wang ZH, Yang SL, Kong DZ, et al. Research on floor failure depth of working face mining on
11 confined water[J]. Safety in Coal Mines. 2014, 45 (1): 17-20.
- 12 Yu HY, Wu JH, Li Q. A reasonable definition method for one-dimensional damage variables[J].
13 Journal of Chongqing University. 2008, 31 (11) :1261-1266.
- 14 Yu XG. Study on broken depth of Damage Floor[D], Doctor of Philosophy, Shandong University
15 of Science and Technology. 2011.
- 16 Yu XG, Han J, Wang Y, Shi LQ. Application of Fisher discriminant model in coal floor water
17 inrush [J]. China Science Paper, 2017, 12 (15): 1770-1773.
- 18 Zhang HL, Wang LG. Computation of mining induced floor additional stress and its application [J].
19 Journal of Mining & Safety Engineering. 2011, 28 (2): 288-293.
- 20 Zhang PS, Yan W, Zhang WQ, et al. The study on the mechanism of the induced bottom plate
21 damage and the fault activated water inrush mechanism under the solid state coupling model[J].
22 Chinese Journal of Geotechnical Engineering. 2016, 38 (5): 877-889.

1 Zhu SY, Cao DT, Zhou HY, Yang CW, Liu JG. Restrictive function of lithology and its composite
2 structure on deformation and failure depth of mining coal seam floor[J]. Journal of Mining &
3 Safety Engineering. 2014, 31 (1): 90-96.

4 Liu WT, Liu SHL, Ji BJ(2015), Sensitivity analysis of controlling factors on failure depth of floor
5 based on orthogonal experiment, Journal of China Coal Society, 40(9):1995-2001

6 Duan HF(2014), Six factors linear prediction model on depth of damage floor, Rock and Soil
7 Mechanics, 35(11):3323-3330

8 Yu XG, Han J, Shi LQ, Wei JCH, Zhu L, Li SHC (2009), Forecast of destroyed floor depth based
9 on BP neural networks, Journal of China Coal Society, 34(6):731-735

10 Li BY (1999), “Down Three Zones” in the prediction of the water inrush from Coalbed Floor
11 aquifer-theory, development and application, Journal of Shandong Institute of Mining and
12 Technology (Nature Science), 18(4):11-18

13 Shi LQ, Han J(2005), Theory and practice of dividing coal mining area floor into fore-zone,
14 Journal of China University of Mining & Technology, 34(1):16-23

15 The professional Standards Compilation Group of People’s Republic of China (2000),
16 Regulations for setting coal pillar and mining under building, water bodies, railways and main
17 roadways. China Coal Industry Publishing House, Beijing.

18 Xu JY, Dai HB (2015) Establishment and application of grey-neural model for forecasting failure
19 depth of coal seam floor. Yinshan Acad J 29(4):9-12

20 Xu YCH, Yang Y (2013) Applicability analysis on statistical formula for failure depth of coal seam
21 floor in deep mine. Coal Sci Technol 41(9):129-132

22 Chen CHL, Yan DX, Zhao K, Yang Q, Cheng G (2012) Floor 10 damage depth of green east coal

- 1 mine based on grey neural network. Coal Technal 31(11):49-51
- 2 Fan SHK, Wu Q, Cui HM, Zeng YF, Ma ZQ, Wei TT, Lei HZ(2012) Simulation study on failure
- 3 depth of NO.1 seam floor in Xinji NO.2 mine. Min Saf Environ Prot 39(4):9-11

Figures

Figure 1

Geographic location of the Liangzhuang Coal Mine in China Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Strata of columnar section of the Liangzhuang Coal Mine

Figure 3

Down Three Zone model of mining coal seam floor

Figure 4

Down Four Zone model of mining coal seam floor

Figure 5

Scatter points diagram of error between goal output and real output about double hidden-layer

Figure 6

Training processes curve

Figure 7

Sketch of numerical model

Figure 8

full rock and damage rock elastic modulus distribution

Figure 9

Double Side Seal Borehole Water Injection Device

Figure 10

Drilling plan layout and cross section of working face floor

(a)

(b)

(c)

(d)

Figure 11

Drill-leakage (a) drill-leakage at NO.1 drill hole 2015.8.23 (b) drill-leakage at NO.2 drill hole 2015.10.2
(c) drill-leakage at NO.3 drill hole 2016.2.6