Hydraulic and Civil Engineering Technology VII
M. Yang et al. (Eds.)

doi:10.3233/ATDE220899

Study on the Development Law of Downward Cracks with Multi Seam Superimposed Mining

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Abstract. Coal mining has produced a large number of shallow cracks ("downward cracks"), which cause water and soil loss and ecological degradation. Coal mining has a huge impact on the ecological environment. This phenomenon is further aggravated by the superimposed mining of multiple coal seams. This study takes the two geomorphic conditions of wind beach and loess ridge as the research background. Based on the selection of typical working faces, the development law of downward fractures in multi coal seam superimposed mining has been studied by means of field geological survey, statistical analysis, numerical simulation and borehole logging. The results show that the downward cracks development laws of wind beach landform and loess landform are different when a single coal seam is mined. The depth and width of downward cracks produced by coal mining in wind beach landform are smaller, the cracks spacing is more stable, and there is no hidden cracks development. As the downward cracks of coal mining under the loess landform is more complex, the development law of downward fissure of multi coal seam superimposed mining under the loess landform has been further studied. There is no significant change in surface cracks in multi seam superimposed mining compared with single seam mining, but the density of hidden cracks is higher in multi seam superimposed mining. After the superimposed mining of coal, the density of hidden cracks increased by 100%, and the average height of hidden cracks increased by 60.95%. The research results provide key parameters for the treatment of multi seam superimposed mining subsidence areas under different geomorphic conditions.

Keywords. Coal mining, downward cracks, loess, windy beach, superimposed mining

1. Introduction

Northern Shaanxi is one of the main coal mining areas in China, at the junction of the Loess Plateau and the Mu Us Desert [1]. Coal mining here has a close relationship with water resources, land resources and ecological environment, especially the downward cracks of coal mining is the key element [2-4]. At present, the coal mining areas in Northern Shaanxi include Shenbei mining area, Shennan mining area, Shenfu mining area, Yushen mining area and Yuheng mining area. Among them, Shenbei mining area

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is dominated by wind beach landform, and the mined areas such as Yushen mining area and Shenfu mining area are dominated by loess ridge landform. Shennan mining area spans two landforms, and is the area with the strongest geomorphic contrast among the mining areas at present. The comparative study of the disturbance of coal mining on the surface under different landforms is of great significance.

Domestic research on coal mining downward cracks (ground fissures) is very rich, and the methods include field geological survey, remote sensing, UAV observation, numerical simulation, physical simulation and theoretical research [5-7]. In terms of research content, there are research on the ground fissures of single coal seam mining, research on the ground fissures of multi coal seam superposition mining, research on the geometric characteristics of surface fissures, research on the geometric characteristics of hidden underground fissures, research on the impact of ground fissures on soil, research on the impact of ground fissures on the ecological environment, research on the development mechanism of coal mining ground fissures, and Research on the development characteristics of ground fissures under a single landform [8-10]. However, under different geomorphic conditions, there is no report on the study of downward cracks (including hidden cracks) in the superimposed mining of coal seams.

Taking Ningtiaota Coal Mine in Northern Shaanxi as the research background, this paper carries out the research on the development law of downward cracks in different landforms in single coal seam mining. Aiming at the more complex loess landform, this paper studies the further development law of downward cracks during multi coal seam superimposed mining.

2. Overview of the Study Area

2.1. Overview of Ningtiaota Coal Mine

The study area is Ningtiaota Coal Mine in Jurassic coal field in Northern Shaanxi, which is located in the northwest of Shenmu city in Northern Shaanxi. The northern part is Shenbei mining area, and the southern part is Yushen mining area. Along the central part of the mining area, kaokaowusu gully is divided into two types of geomorphic units, namely, loess gully landform in the north and sandy beach landform in the South (as shown in figure 1).

There are 11 minable coal seams in the mine, but at present, 1-2 coal and 2-2 coal are mainly mined, which are the two layers of coal mined in this superposition. The existing research and practice have proved that the surface cracks of coal mining are restricted by many factors, among which the influence of landform is the key factor. Therefore, first of all, similar working faces are selected for comparative study.

Figure 1. Typical Landforms in the study area.

2.2. Overview of Coal Faces

(1) Mining face of single coal seam in loess landform

The selected working face is N1209 working face, which is located in the north wing of Ningtiaota Coal Mine. The dip length of the working face is 295m, the strike length is 1316m, and the dip angle is 0.3 °. Coal seam 2-2 is mined in the working face, with an average thickness of 5.87m. The coal seam is generally close to the level, and the structure is simple. The surface of the coal mining face is loess gully area, with high middle and low east-west. The coal seam is 86-175m away from the surface, the thickness of the overlying loess layer is 33-95m, the gully area is thin, the ridge area is thick, and the bedrock thickness is 84~120m. The thickness change is roughly equivalent to that of the soil layer.

The mining of N1209 working face began in December 2011 and was completed in May 2012, with an average mining height of 4.02m. The first pressure step distance of the main roof of the working face is 45.5m. The step distance of periodic pressure on the upper part of the working face is 13.0-14.0m, and the average step distance is 13.5m; The middle part is 9.0-14.0m, with an average step distance of 12.0m. The lower part is 8.0-14.0m, and the average step distance is 11.8m. The maximum step distance of the main roof periodic pressure of the whole working face is 14m, the minimum is 9m, and the average is 13.41m.

(2) Mining face of single coal seam in wind beach landform

The selected working face is S1207 working face, which is located in the south wing of Ningtiaota Coal Mine. The coal seam 2-2 is mined in this working face. The thickness of the coal seam is 4.8-6.8m, with an average thickness of 5.9m. The coal seam is nearly horizontal, and the burial depth is 85-120m. The coal seam occurrence in the working face is stable. The bedrock of the roof is 30.48-35.86m thick. The ground of the working face is aeolian sand landform, which is high in the West and South and low in the East and North. The terrain is relatively flat, and the ground elevation is +1227-+1262m.

S1207 fully mechanized mining face started mining in June 2013 and finished mining in July 2014, with a mining height of about 5.4m. The direct roof collapse step distance of the working face is 7.3-9.8m, the average value is 9.3m, and the incoming pressure strength is 14.7-28.5 MPa, the average value is 18.2 Mpa. The first pressure step distance of the main roof of the working face is 34-103.3m, with an average of 64.8m. The initial pressure strength is 23.2-43.3MPa, with an average of 27.3 Mpa. The periodic pressure step distance of the main roof of the working face is 8.9-18.9m, and the average pressure step distance is 14.8m; The periodic incoming pressure strength of the main roof is 17.2-42.5 MPa, with an average of 31.7 MPa.

(3) Multi coal seam superimposed mining faces in loess landform

The selected superimposed working face is the intersection of N1114 working face and N1206 working face, which is located in the north wing of Ningtiaota Coal Mine. The mining thickness of 1-2 coal is 1.8m, and the buried depth is about 140.5m. The mining thickness of 2-2 coal is 4.8m, and the buried depth is about 195.1m. The surface of the coal mining face is loess gully area.

3. Development Law of Surface Cracks with Single Coal Seam Mining

This field geological survey adopts manual mapping to carry out the investigation of coal mining ground cracks. Due to the large range of coal mining face, one section of it is mapped. The spatial distribution and geometric characteristics of coal mining ground cracks are mainly observed.

3.1. Characteristics of Surface Cracks in Coal Mining with different Landforms

The relevant numerical statistics of coal mining ground cracks in different landforms are shown in table 1. Table 1 shows the different characteristics of different landforms:

(1) The continuity rate of coal mining ground cracks under loess ridge landform is lower.

(2) Under the Loess ridge landform, the spacing of coal mining ground cracks changes more.

(3) The average width and fall of coal mining ground cracks under loess ridge landform are larger than that of sandy beach landform.

(4) The filling property of coal mining ground cracks under loess ridge landform is worse.

Table 1. Statistical table of ground cracks difference in different landforms.

Type of crack	Landform	Average line continuity	Variance of spacing	Average width /m	Average drop /m	Average filling rate
Parallel cracks	Wind beach landform	0.97	3.21	0.07	0.12	0.96
	Loess landform	0.88	17.14	0.26	0.27	0.14
Boundary cracks	Wind beach landform	0.94	-	0.10	0.17	0.92
	Loess landform	0.92	-	0.21	0.23	0.14

3.2. Results Analysis of Surface Cracks in Coal Mining with different Landforms

(1) The maximum and minimum altitude points in the study area are located in the loess hilly area, which indicates that the elevation difference of the Loess Hilly landform is larger, the stability of the loose layer in the mountain area is worse, and a large number of loess collapses are developed, resulting in the larger geometric size of the coal mining ground cracks under the Loess Hilly landform.

(2) The continuous discontinuous interval in the loess hilly area is mainly concentrated in the gully area, which is the main channel of water and soil movement in the Loess Plateau and is prone to fracture healing. Therefore, the continuity of cracks under the Loess Hilly landform is worse.

(3) Through the underground mine pressure observation, it can be found that the variance of the pressure step in the loess hilly area is larger than that in the wind beach area due to the heterogeneity of the overlying load, and the research has shown that the parallel cracks are mainly caused by the mine pressure, so the variation range of the ground crack spacing of coal mining in the Loess Hilly landform is larger.

(4) Existing studies have proved that the deposition rate of aeolian sand in the wind beach area is much higher than that in the loess hilly area, so the coal mining ground fissures in the wind beach area generally have the characteristics of high filling rate.

4. Development Law of Downward Cracks in Superimposed Mining of Loess Landform

Due to the fluidity of aeolian sand, the downward cracks of aeolian sand beach landform are similar to the surface cracks. However, under the condition of loess landform, they become different. The downward cracks of loess landform refer to the cracks above the upward fissures (water conducting fissure zone), which include surface cracks and hidden cracks in loess.

Therefore, this study will study the surface cracks, upward cracks and hidden cracks respectively. Among them, the development law of surface cracks continues to be obtained by field geological survey. The upward fracture development law is obtained by numerical simulation. Hidden cracks are obtained through borehole logging (micro resistivity scanning imaging logging).

4.1. Comparison of Surface Cracks Development in Superimposed Mining Area

The relevant numerical statistics of surface cracks in single and multi seam mining are shown in table 2. Table 2 shows the difference between single coal seam and multi coal seam mining surface cracks: surface cracks are stronger in the superimposed mining area as a whole, but the increase is relatively limited.

Table 2. Comparison of surface cracks between single coal seam and superimposed coal seam mining.

Type of crack	Coal seam	Average line continuity	Variance of spacing	Average width /m	Average drop /m	Average filling rate
Parallel cracks	Single coal seam	0.88	17.14	0.26	0.27	0.14
	Multiple coal seams	0.79	19.45	0.32	0.28	0.16
Boundary cracks	Single coal seam	0.92	-	0.21	0.23	0.14
	Multiple coal seams	0.90	-	0.29	0.26	0.16

4.2. Development Law of Water Conducting Fracture Zone in Superimposed Mining Area

Taking the columnar borehole of Ningtiaota Coal Mine as the engineering prototype, the fracture development law of water conducting fracture zone in the mining process of 1-2 coal seam and 2-2 coal seam is studied by using UDEC software. According to the overburden composition and rock mechanics parameters in the comprehensive columnar table 3, a strike model with a length of 500m and a height of 214.3m is established. The model mines 1-2 coal seams first, and then 2-2 coal seams. Each excavation step is 5m. 100m boundary coal pillars are set on the left and right sides of the model.

Table 3. Comprehensive columnar overburden composition and rock mechanical properties.

No.	Rock stratum	Thickness/m	Buried depth/m	Density/g/cm^3	Uniaxial compressive strength/ MPa	Modulus of elasticity/ MPa	Tensile strength/ MPa	Cohesion/ MPa	internal friction angle/°
1	Lishi loess	31	31	1620	700	600	0.2	0.32	20
2	Baode loess	60	91	1620	700	600	0.2	0.32	20
3	Sandy mudstone	8.2	99.2	2400	4000	3200	1.2	1.6	20
4	Fine grained sandstone	4.4	103.6	2500	4500	3800	1.5	1.8	25
5	Sandy mudstone	1.8	105.4	2400	4000	3200	1.2	1.6	20
6	Fine grained sandstone	3.3	108.7	2500	4500	3800	1.4	1.8	28

7	Sandy mudstone	10.2	118.9	2400	4000	3200	1.2	1.6	20
8	Fine grained sandstone	1	119.9	2400	4000	3000	1.3	1.6	20
9	Sandy mudstone	6.6	126.5	2400	4000	3200	1.4	1.7	24
10	Medium grained sandstone	1	127.5	2500	4500	3500	1.5	1.8	25
11	Sandy mudstone	3.6	131.1	2400	4000	3200	1.4	1.7	24
12	Marl	1	132.1	2400	4000	3200	1.2	1.6	20
13	Medium grained sandstone	5	137.1	2500	4500	3500	1.5	1.8	25
14	Siltstone	1.5	138.6	2400	4000	3000	1.3	1.6	20
15	1^{-2} coal seam	1.8	140.5	1420	2000	1800	1.0	1.0	15
16	Siltstone	8.5	149	2400	4000	3000	1.3	1.6	20
17	Medium grained sandstone	6.8	155.8	2500	4500	3500	1.5	1.8	25
18	Fine grained sandstone	14.5	170.3	2400	4000	3800	1.3	1.6	20
19	Medium grained sandstone	1	171.3	2500	4500	3500	1.5	1.8	25
20	Siltstone	6	177.3	2400	4000	3000	1.3	1.6	20
21	Medium grained sandstone	13	190.3	2500	4500	3500	1.5	1.8	25
22	2^{-2} coal seam	4.8	195.1	1420	2000	1800	1.0	1.0	15
23	Floor	20	215.1	2400	4000	3200	1.2	1.6	20

(1) Development law of water conducting fractured zone with 1-2 coal mining

The working face of coal seam 1-2 has been advanced for a total of 300 m. The initial pressure step distance of the basic roof is 40 m, the periodic pressure step distance is 10-15 m, the height of the caving zone is 8.5 m, which is 4.7 times the mining height. After the overburden is stabilized, the height of the water diversion fracture zone is 51 m, which is 28.3 times the mining height. The development process of water conducting fracture zone is shown in figure 2.

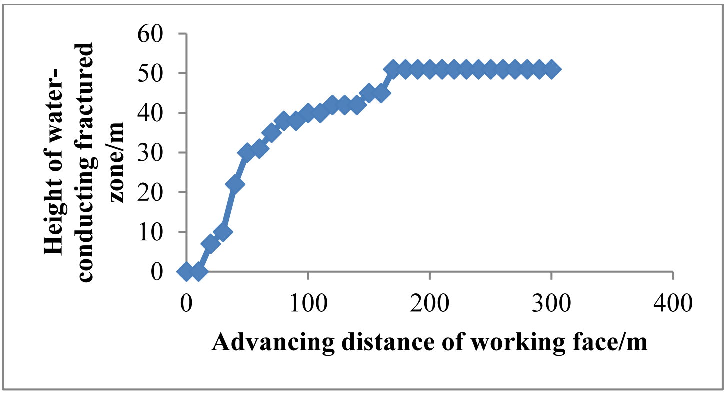

Figure 2. Height development curve of water conducting fractured zone with 1-2 coal seam mining.

(2) 2-2 development law of water conducting fractured zone with coal mining

The working face of coal seam 2-2 has been advanced for a total of 300 m. The initial pressure step distance of the basic roof is 65m, the periodic pressure step distance is 10~15 m, and the height of the caving zone is 21 m, which is 4.4 times the mining height. After the overburden is stabilized, the height of the water diversion fracture zone is 147m, which is 30.6 times the mining height. The development process of water conducting fracture zone is shown in figure 3.

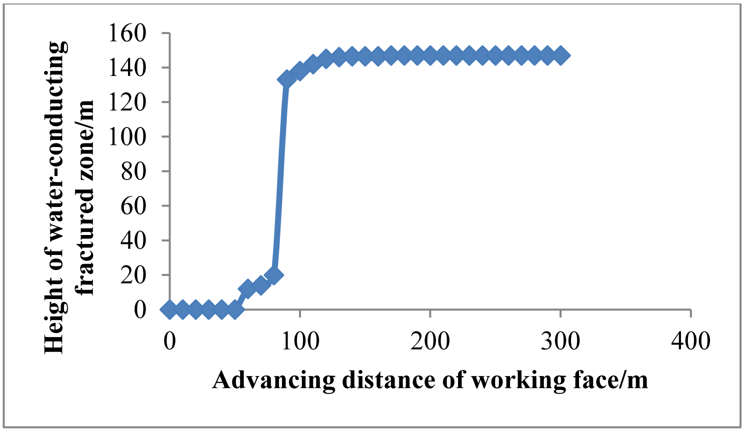

Figure 3. Height development curve of water conducting fractured zone with 2-2 coal seam mining.

4.3. Development Law of Hidden Cracks in Superimposed Mining Area

A borehole is arranged in the single coal seam mining area (the separate mining area of N1114 working face) and the superimposed mining area (the intersection of N1114 working face and N1206 working face). In the loess section of each borehole, micro resistivity scanning imaging logging is used to detect the hidden fractures in the exposed area of the borehole. The detection results are shown in table 4. It can be seen from table 4 that the density of hidden cracks increased by 100% and the average height of hidden cracks increased by 60.95% after coal superposition mining.

Table 4. Hidden cracks measured by borehole logging.

Coal seam	Borehole Number	Depth of hidden cracks /m	Density of hidden cracks/strip/m	Average height of single hidden crack /m
Single coal seam	1	0-83.0	0.11	2.10
Multiple coal seams	2	0-54.4	0.22	3.38

5. Conclusion

(1) Under the condition of single coal seam mining, the cracks in loess landform has larger scale, worse filling, greater impact on the environment and more complex development mechanism than the cracks in wind beach landform.

(2) In the case of superimposed mining of multiple coal seams in loess landform, the downward cracks include surface cracks and shallow hidden cracks. Compared with single coal seam mining, the development scale of surface cracks changes limited. However, after the superimposed mining of coal, the density of hidden cracks increased by 100%, and the average height of hidden cracks increased by 60.95%.

Funding

This paper was funded by the Natural Science projects of Liupanshui Normal University (LPSSYYBZK202208),the Science and Technology Foundation of Guizhou Province (QIANKEHEJICHU-ZK [2022]YIBAN529), Guizhou Provincial Education Department Fund(QianjiaoheKYzi [2022]45, QianjiaoheKYzi [2020]050, QianjiaoheKYzi [2020]119, QianjiaoheKYzi [2018]386), by Fund project of Liupanshui science and Technology Bureau (52020-2019-05-03), by Liupanshui Normal University Innovation Team Project (lpssykjtd201902), by Fund of Guizhou science and Technology Department(Qiankehepingtairencai [2021] 001).

Competing Interests

The authors declare that they have no conflicts of interest.

References

[1] Li T, Wang S, Han L, et al. Reasonable thickness of protected loess under loose aquifer in ecologically fragile mining area. Journal of China Coal Society. 2017; 42(1): 98-105.

[2] Ma L, Du X, Wang F, et al. Water-preserved mining technology for shallow buried coal seam in ecologically-vulnerable coal field: A case study in the Shendong coal field of China. Disaster Advances. 2013; 6: 268-278.

[3] Palchik V. Experimental investigation of apertures of mining-induced horizontal fractures. International Journal of Rock Mechanics and Mining Sciences. 2010; 47(3): 502-508.

[4] Zhang S, Liu Y. A simple and efficient way to detect the mining induced water-conducting fractured zone in overlying strata. Energy Procedia. 2012; 16: 70-75.
[5] Palchik V. Localization of mining-induced horizontal fractures along rock layer interfaces inoverburden: Field measurements and prediction. Environmental Geology. 2005; 48(1): 48, 68-80.
[6] Li J and Liu C. Formation mechanism and reduction technology of mining-induced fissures in shallow thick coal seam mining. Shock and Vibration. 2017; 2017(6): 1-14.
[7] Li T, Zhang J, Gao Y, et al. Hydrological characteristics of ordovician karst top in a deep region and evaluation of its threat to coal mining: A case study for the Weibei Coalfield in Shaanxi Province, China. Geofluids. 2020; 6: 1-17.
[8] Fan G. and Zhang D. Mechanisms of aquifer protection in underground coal mining. Mine Water and the Environment. 2014; 34: 95-104.
[9] Zhang D, Fan G, Ma L, et al. Aquifer protection during longwall mining of shallow coal seams: A case study in the Shendong coalfield of China. International Journal of Coal Geology. 2011; 86:190-196.
[10] Tang M, Qiu J, Zhang H, et al. Numerical simulation of ground air leakage into the gob based on surface cracks observation: a case study in Shendong coalfield of China. Arabian Journal of Geosciences. 2021; 14:1-10.