



The Influence of Overburden Structure on Mine Ground Pressure Appearance in Working Face with Super-large Mining Height: a Case Study in Shendong Mining Area

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ABSTRACT

The Shendong mining area where is located in the northwest of China has the highest fully mechanized working face in the world. The purpose of this paper is to understand the causes of abnormal mine ground pressure appearance (MGPA) on the fully mechanized mining working face with super-large height in Shendong mining area. Field monitoring, physical similarity material test and UDEC numerical simulation were used to investigate the influencing factors of abnormal MGPA on the super-large mining height working face. The results show that the simultaneous breaking movement of multiple key strata will transfer more load than that of a single key stratum, which intensifies the MGPA in working face. The distance between primary key stratum and coal seam determines MGPA, but this distance is limited to 115 m above the coal seam. The results of this study are of guiding significance to control the MGPA in Shendong mining area.

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1. INTRODUCTION

China Shendong mining area is located in northern Shaanxi province and southeast of the Inner Mongolia autonomous region, as shown in Figure 1. The geological reserves of coal seams with thickness over 7 m and 8 m are 976 million tons and 350 million tons, respectively. Most of these coal seams are characterized by shallow burial, small dip angle and high hardness [1, 2]. It is suitable for fully mechanized mining with super-large mining height [3].

To improve production and efficiency, the mining height of fully-mechanized working face in Shendong mining area has increased from 7 m in 2009 to 8.8 m in 2019, which is the highest mining face in the world [4-6]. However, an increase in mining height sometimes causes abnormal MGPA in the working face and leads to the dynamic pressure problems such as coal wall caving, roof falling and large shrinkage of hydraulic

support column [7, 8]. In recent years, many experts and scholars have studied the law of MGPA and overburden structure of the super-high working face. Huang et al. [9] studied the roof advanced breaking position and influences of large mining height working face in the shallow coal seam. Their research results can provide early warning for safety problems related to the large height working face of the shallow coal seam, but there is still no clear conclusion for the existence of multiple key strata in overlying strata [9]. Ju et al. [10] summarized the law of MGPA in different mining stages of the world's first 7 m supporting working face and concluded that the distance between a single key stratum and coal seam was the main factor affecting the mining pressure; but did not quantify the factor. By establishing a simplified dynamic model of surrounding rock and support, Pang et al. [11] proposed a two-factor control method to calculate working resistance of hydraulic support, which was successfully applied to working face with super-large mining height of 8 m. However, the mechanism of overburden movement has

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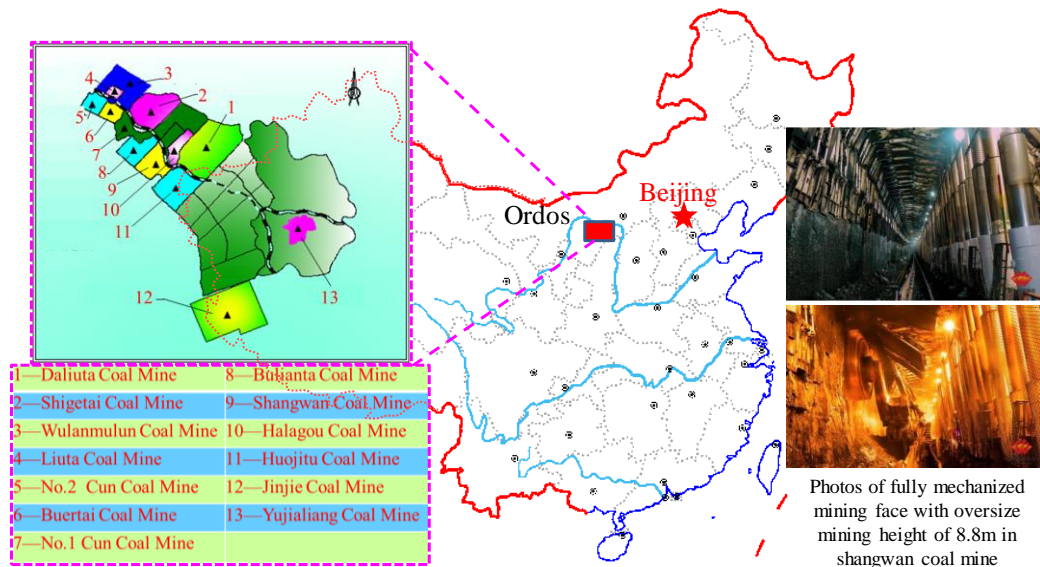


Figure 1. Location of the Shendong mining area and site photos of the Shangwan coal mine

not been studied in depth [11]. Duan [12] obtained the law of weighting interval in the mining period by monitoring the hydraulic support load of working face, but he did not investigate its mechanism. Zhu et al. [13] studies fracture form of the key stratum in the Datong mining area and its influencing mechanism on the stope MGPA, but the difference of geological conditions makes it not applicable to Shendong mining area [14].

The above results provide some references for studying the influence of overburden structure on MGPA in fully mechanized mining face with super-large mining height. However, there is a lack of a unified recognition of the MGPA of several mines in Shendong mining area. In addition, with the gradually entering into deep mining, the roof overburden structure of the coal seam also becomes more complex and the mining pressure law of the working face will be more complicated [15]. This has caused some troubles to Shendong Group's unified management of multiple mines. Therefore, it is necessary to further study the causes of MGPA difference in super-high working face. This paper can guide the actual production and management.

2. MONITORING & ANALYSIS OF MGPA

2.1 Theory of MGPA and its Monitoring Content

Under the action of mine pressure, the phenomenon of mine pressure manifested in the form of surrounding rock movement and support stress is called MGP, such as roadway floor heave, deformation of the two ribs, roof falling, coal wall caving and support stress.

About stope MGPA, Qian Minggao successively proposed "masonry beam theory" and "key strata theory", which can well explain the movement characteristics of overlying rocks in goaf [8, 16-18], as shown in Figure 2. According to the existing theoretical basis, the corresponding data on-site were monitored. The monitoring content and its definition are as follows.

First weighting (FW): When the basic roof (key stratum) of goaf is broken for the first time and caved in a large area, strong MGPA will be caused in the working face, which is called FW.

First weighting step distance (FWSD): The distance between the open-off cut and the breaking line of the basic roof is called the FWSD.

Periodic weighting (PW): After the FW, when the working face continues to advance and the span of the basic roof overhanging surface reaches a certain length, it breaks and collapses under the action of its weight and overburden. This phenomenon of periodic basic roof breaking and caving is called PW.

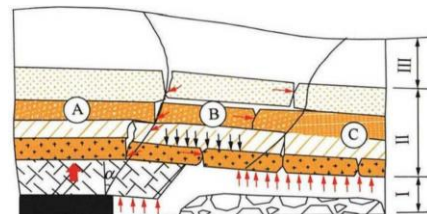


Figure 2. Conceptual model of overburden strata movement (I, II, III represent the caving zone, fractured zone, bending subsidence zone. A, B and C represent the area affected by mining abutment pressure, the rock strata vigorous movement area and the re-compaction area, respectively)

Periodic weighting step distance (PWSD): The distance between the two PW is called PWSD.

Dynamic load coefficient (DLC): The ratio of hydraulic support load during weighting to no weighting.

Column shrinkage of hydraulic support (CSHS): Cylinder shrinkage value of hydraulic support when weighting comes.

2. 2. Monitoring of MGPA (1) MGPA of panel 12106 in the Shangwan coal mine

The average thickness and buried depth of panel 12106 were 7.3 m and 90.2 m, respectively. The strike and dip length of panels were 2984 m and 298 m, respectively. There were two key strata in the overlying strata. The primary key stratum was medium sandstone with a thickness of 11.5 m, 41.9 m away from the coal seam. The inferior key stratum was siltstone with a thickness of 12.4 m, 3.2 m away from the coal seam.

The FW occurred when the working face was advanced to 43 m, and the FWSD was about 53 m. The PWSD was 9.5-11.4 m with an average of 10.3 m, and the persistence length (PL) was 2.5-4.5 m. During PW, the DLC was 1.16, the CSHS was about 6-8 mm. There was not coal wall caving or roof falling occurred in the working face.

(2) MGPA of panel 12401 in the Shangwan coal mine

The average thickness and buried depth of panel 12401 were 8.9 m and 160.6 m, respectively. The strike and dip length of panels are 5400 m and 260 m, respectively. There were two key strata in the overlying strata. The primary key stratum was medium sandstone with a thickness of 8.1 m, 87.2 m away from the coal seam. The inferior key stratum was siltstone with a thickness of 13.7 m, 9.3 m away from the coal seam.

The FW occurred when the working face was advanced to 49 m, and the FWSD was about 51 m. PWSD was 20.4-22 m with an average of 21 m, and the PL was 2.5-4.8 m. During PW, the average DLC was 1.08, and the CSHS was about 6-10 mm. There was not coal wall caving or roof falling occurred in the working face.

(3) MGPA of panel 52303 in the Daliuta coal mine

The average thickness and buried depth of panel 52303 were 7.0 m and 220.4 m, respectively. The strike and dip length of panels were 4443 m and 301.5 m, respectively. There were three key strata in the overlying strata. The primary key stratum was coarse sandstone with a thickness of 13.4 m, 101.7 m away from the coal seam. The inferior key stratum 1 was fine sandstone with a thickness of 6.9 m, 21 m away from the coal seam. The inferior key stratum 2 was siltstone with a thickness of 9.1 m, 83.5 m away from the coal seam.

The FW occurred when the working face was advanced to 62 m, and the FWSD was about 71 m.

During the FW, there were some problems in the middle of the working face, such as coal wall caving and roof falling. The depth of coal wall caving was 200-400 mm. PWSD was 13.3-26.1 m with an average of 16 m, and the PL was 2.5-4.7 m. During PW, the average DLC was 1.55, and the CSHS was about 300-500 mm. The MGPA was severe, and the maximum depth of coal wall caving and roof falling can reach 1000 mm and 800 mm, respectively.

(4) MGPA of panel 12511 in the Bulianta coal mine

The average thickness and buried depth of panel 12511 were 7.8 m and 252.1 m, respectively. The strike and dip length of panels are 3193.3 m and 319 m, respectively. There were four key strata in the overlying strata. The primary key stratum was medium sandstone with a thickness of 28.9 m, 186.7 m away from the coal seam. The inferior key stratum 1 was medium sandstone with a thickness of 11.2 m, 5.1 m away from the coal seam. The inferior key stratum 2 was medium sandstone with a thickness of 19.1 m, 28.1 m away from the coal seam. The inferior key stratum 3 was siltstone with a thickness of 24.6 m, 106.1 m away from the coal seam.

The FW occurred when the working face was advanced to 40 m, and the FWSD was about 52 m. The CSHS is about 100 mm at most. PWSD was 7.2-16.8 m with an average of 10.6 m, and the PL was 2.5-4.2 m. During PW, the average DLC 1.48. The mine ground pressure was strong, but the support column did not appear the phenomenon of large shrinkage.

2. 3. Comparative Analysis of MGPA The MGPA characteristics of the above four working faces is shown in Table 1.

It can be seen from Table 1 that the four working faces were all super-large mining height working faces, but there were great differences in the intensity degree of MGPA. In general, the MGPA of the deep-buried working face was more obvious than that of shallow buried working face [8, 12, 19]. After entering PW, the working faces were greatly different from each other. At the same time, we can also see that the panel 52303 of the Daliuta coal mine showed stronger MGPA in all mines. According to the basic geological data, with the increase of burial depth, the number of the key strata of overburden increases correspondingly, and the relative position of primary key stratum changes obviously [3, 5]. The buried depth of panel 52303 and the number of the key strata above panel 52303 are less than panel 12511, but the MGPA of panel 52303 is stronger. Therefore, we believe that the number of key strata and the distance between the primary key stratum and the coal seam will have important influences on MGPA.

3. PHYSICAL SIMILARITY MATERIAL TEST

The physical similarity material simulation test is to

make a prototype similar model according to the similarity principle in the laboratory [20]. The mechanical parameters and their distribution in the model were observed utilizing measuring instruments. The results of the model are used to deduce the possible mechanical phenomena and the law of rock mass pressure distribution in the prototype, so as to solve the practical problems in rock mass engineering [21]. In this test, with the help of the independently developed physical similar material test system, we studied the impact of the key strata fractures above the coal seam roof on MGPA.

3. 1. Establishment of Physical Similarity Material Model

The test conditions and rock parameters refer to the engineering practice of panel

52303 of the Daliuta coal mine [22, 23]. The length, width and height of the model were 2.5 m, 0.3 m and 2 m, respectively. The model geometry similarity ratio, density similarity ratio, stress similarity ratio and time similarity ratio were 1:100, 1:1.6, 1:1.6 and 1:10, respectively. To facilitate qualitative analysis, the thickness and position of each key stratum in the model were adjusted. Similar material arrangements for each stratum in the model are shown in Table 2.

The established physical model of similar materials is shown in Figure 3. In the process of coal mining, a self-made small hydraulic support model with a pressure sensor was used to support the working face, and the support resistance data of the support was monitored and collected.

TABLE 1. Periodic weighting characteristics of working face

Name of panel	Mining height/m	Buried depth/m	Distance from the primary key stratum	No. of the key strata	PWSD/ m	PL/ m	Support force/ kN	DLC	Depth of wall caving /mm	CSHS/ mm	Depth of roof falling/ mm
12106	7.0	90.2	41.9	2	10.3	2.5-4.5	11775-13737	1.16	--	6-8	--
12401	8.8	160.6	87.3	2	21.0	2.5-4.8	25865-28243	1.08	--	6-10	--
52303	7.0	220.4	101.7	3	16.0	2.5-4.7	17670-18089	1.55	1000	300-500	500
12511	8.0	252.1	186.9	4	10.6	2.4-4.2	20874-21562	1.48	200	10-100	150

TABLE 2. Ratio table of rock similar material

No.	Stratum	Thickness/cm	Ratio number	Sand/kg	Carbonate/kg	Gesso/kg	Water/L
1	Incompetent bed	60	673	617.14	72	30.86	80.00
2	Primary key stratum	9	373	81.00	18.9	8.10	12.00
3	Incompetent bed	50	673	370.29	43.2	18.51	48.00
4	Inferior key stratum 2	8	337	67.20	11.76	5.04	9.33
5	Incompetent bed	34	673	349.71	40.8	17.49	45.33
6	Inferior key stratum 1	5	437	48.00	3.6	8.40	6.67
7	Incompetent bed	12	673	123.43	14.4	6.17	16.00
8	Coal seam	7	773	73.50	7.35	3.15	9.33

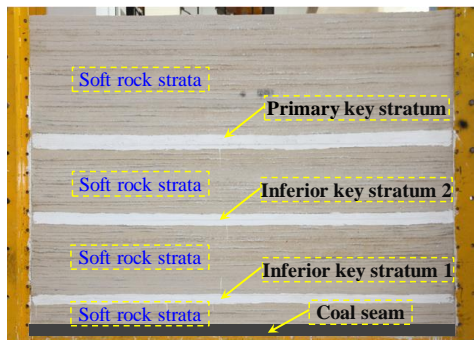
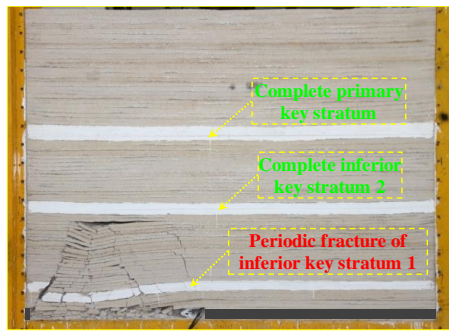


Figure 3. Model of physical similarity material test

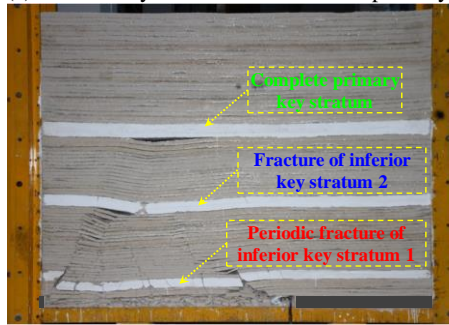
3. 2. Analysis of Dynamic Overburden Migration

The fracture patterns of key strata at different locations during model excavation are shown in Figure 4. A total of nine fractures occurred in the inferior key stratum 1 during the excavation process of the whole physical model, and drastic changes in support resistance were observed for 8 times. The detailed data are shown in Table 3. The working resistance data collected by self-made small support models were sorted out, as shown in Figure 5.

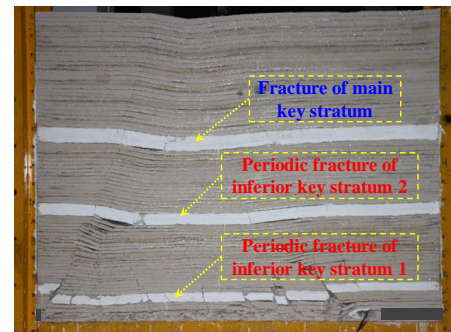
Before the key strata were broken synchronously, the resistance of support and DLC were not large, as



(a) Inferior key stratum 1 is broken separately



(b) Inferior key stratum 1 & 2 are broken synchronously



(c) Three key strata are broken synchronously

Figure 4. Test results of different key strata breaking forms

shown in Table 3. During the synchronous breaking of key strata, the resistance of support increased sharply and DLC also increased dramatically to 2.12-2.40, and the support was failed twice under weighting.

When inferior key stratum was broken alone, the pressure zones were marked as 1, 2, 3 and 4, respectively. When inferior key strata were broken synchronously, the pressure zone was marked as 5.

TABLE 3. Statistics of key stratum breakage

Excavation length /cm	Breaking type			Support resistance /kPa	DLC	Comment
	Inferior key stratum 1	Inferior key stratum 2	Primary key stratum			
75	FW	/	/	320	1.28	
85	PW	/	/	352	1.40	
100	PW	/	/	450	1.80	
130	PW	/	/	484	1.92	
145	PW	FW	/	530	2.12	Synchronous breaking
174	PW	PW	FW	600	2.40	Synchronous breaking& support crushed
190	PW	PW	/	548	2.20	Rotation of Primary key stratum
205	PW	PW	PW	600	2.40	Synchronous breaking & support crushed

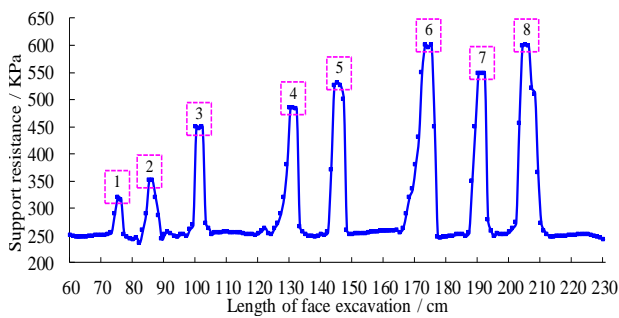


Figure 5. Support resistance curve of support

When the three key strata were broken synchronously, the pressure zones were marked as 6, 7 and 8, respectively. The breaking photos of each stage are shown in Figure 4. By comparing the relevant data of each pressure zone, it can be obtained that the intensity degree of MGPA in the working face caused by the simultaneous breaking of multiple key strata was greater than that of a single key stratum. The greater the number of key strata in which synchronous breaking occurs, the greater the intensity degree of MGPA in the working face.

4. NUMERICAL SIMULATION

4. 1. Establishment of Numerical Model UDEC 6.0 numerical simulation software was used to study the effect of primary key stratum on MGPA [24, 25]. We kept the position of inferior key stratum immovable and changed the distance between primary key stratum and coal seam. The coal seam was buried 200 m underground, the mining height of the coal seam was 7 m, and the top of the model was unconsolidated formation. There were two key strata in the overlying strata. The thickness of the inferior key stratum was 5, 12 m from the coal seam, and the thickness of the primary key stratum was 9 m, as shown in Figure 6. In the numerical simulation, the coal seam was excavated 20 times in total and each time excavated 10 m. The coal seam was excavated from left to right. The model parameters are shown in Table 4.

The length and height of the model were 300 m and 230 m, respectively. To eliminate the boundary effect, a 50 m boundary coal pillar was set on both sides. The model was calculated using the Mohr-Coulomb criterion. The hydraulic support was stimulated by the "Beam" built-in UDEC and the data was recorded automatically in UDEC. A total of 7 simulation schemes were established. The distance between the primary key stratum and coal seam of each plan was 55, 75, 95, 115, 135, 155 and 175 m, respectively.

4. 2. Analysis of Numerical Simulation Results

Three representative calculation results were selected from the 7 simulation schemes, as shown in Figure 7. The blue part of coal seam in the figure represented a hydraulic support model, and the red part represented mining-induced fracture. Compared with Figures 7(a) and 7(b), the farther the primary key stratum is from the coal seam, the wider the goaf roof failure range. However, when Figure 7(b) is compared with Figure 7(c), the law is reversed.

The support strength of simulated results in each scheme is arranged as shown in Table 5, and the

obtained data is shown in Figure 8. The following conclusions can be drawn from Figure 8. when the distance between primary key stratum and coal seam was 115 m, the support resistance of hydraulic support reached to the maximum, with an average of 1.88 MPa. Meanwhile, when the distance between primary key stratum and coal seam was 55 m, the support resistance of hydraulic support was only 1.09 MPa. The difference between the two values was 1.72 times. After the distance between primary key stratum and coal seam was more than 115 m, the support resistance of

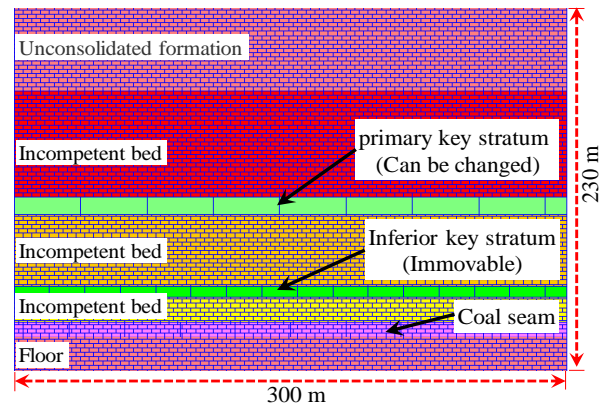


Figure 6. Numerical simulation model

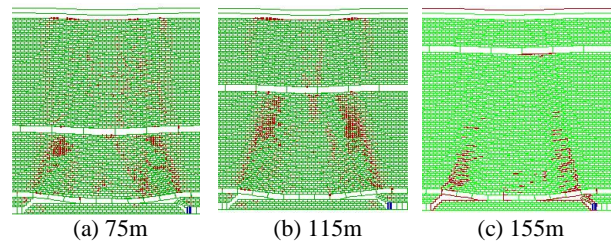


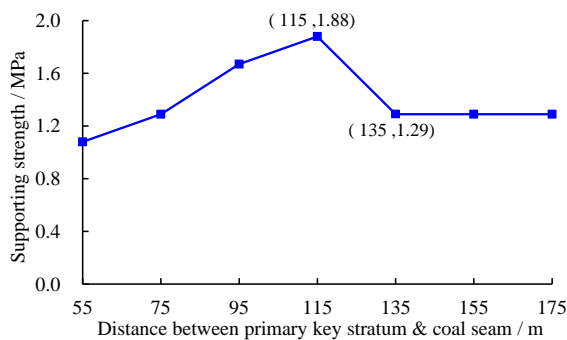
Figure 7. Mining-induced fracture in primary key stratum at different positions

TABLE 4. Mechanical and physical parameters of the numerical models

Stratum	bulk modulus/ GPa	Shear modulus/ GPa	Density/(kg·m ⁻³)	internal friction angle/(°)	Tensile strength/ MPa
Unconsolidated formation	10	36	1500	10	1.1
Incompetent bed	15	8	2100	20	3.2
Primary key stratum	45	26	2500	35	6.7
Incompetent bed	15	8	2100	20	3.2
Inferior key stratum	40	25	2500	30	5.6
Incompetent bed	15	8	2100	23	3.2
Coal seam	12	5	1500	17	1.7
Floor	50	28	2500	35	5.8

TABLE 5. Supporting strength of working face at different primary key stratum locations

Distance between primary key stratum & coal seam /m	Support resistance of each hydraulic support/ MPa					Average/ MPa
	1	2	3	4	5	
55	1.18	1.17	1.06	1.02	0.97	1.09
75	1.40	1.27	1.38	1.25	1.15	1.29
95	1.75	1.78	1.66	1.61	1.55	1.67
115	1.92	2.03	1.85	1.85	1.77	1.88
135	1.26	1.39	1.41	1.21	1.18	1.29
155	1.40	1.40	1.27	1.22	1.16	1.29
175	1.40	1.40	1.27	1.22	1.16	1.29

**Figure 8.** The average support strength of the primary key stratum at different positions

hydraulic support decreased gradually, and the support strength tended to be stable when the distance was 135-175 m.

The MGPA of the working face was affected by the primary key stratum and there was a critical limit height. When the primary key stratum was located within the critical height limit, the fracture of primary key stratum would aggravate MGPA in the working face, while when the primary key stratum was located outside the critical height limit, the fracture of primary key stratum would not aggravate MGPA. When the primary key stratum in this model was 115 m away from the coal seam, the MGPA was the most severe, and when the distance was greater than 115m, the hydraulic support gradually returned to normal support strength. The numerical simulation results are in good agreement with the field practice. Therefore, under this condition, the critical height of MGPA in the working face affected by the primary key stratum was 115 m.

5. DISCUSSION

Physical similarity material test results show that the number of key strata is positively correlated with the MGPA of the working face. Because the key stratum is usually composed of rocks with hard and thick lithology.

Therefore, the immediate roof collapses immediately after coal mining, while the key strata form a suspended roof above the goaf. The key strata of the overhang hold huge amounts of energy until it can no longer withstand the load of itself and its overlying layers before suddenly breaking. Therefore, for field engineering, if the number of key strata is large, the roof management of coal mining working face should be strengthened, such as weakening the powerful MGPA employing supports selection and hydraulic fracturing.

The UDEC numerical simulation with simplified geological conditions shows that the influence of the primary key stratum on MGPA has a limit influence distance. Therefore, after deep mining, although the key strata overlying the coal seam also becomes complex, including the distance between the primary key stratum and the coal seam, the number of key strata and the rock strength, then the key strata will not affect MGPA indefinitely. This could be because the rock collapse beneath the higher key strata is filled with goaf, i.e., the broken and swelling rock blocks in the goaf form support for the goaf roof, so that the key layer is no longer broken or the rotation angle is small after being broken.

In this paper, the influence mechanism of key strata on MGPA in Shendong mining area has been preliminarily obtained. However, due to the limitations of the physical similarity material test system and the idealized simplification of the numerical model, there are still some deficiencies. Factors such as the number of key layers, rock strength and relative distance of each key layer are complex and changeable, so it is temporarily impossible to conduct quantitative analysis on various influencing factors, which is also the research direction of this paper in the future.

6. CONCLUSION

1) The field measurement of four super-large working faces in the Shendong mining area shows that the MGPA law of super-large working faces is complicated.

Relative to the buried depth and mining height of coal seam, the number of key stratum and the location of the primary key stratum have a more drastic influence on MGPA.

2) In the case of larger buried depth, the overburden load of synchronous fracture of multi-layer key strata in working face with large mining height is larger than that of the single fracture of key stratum, which results in more severe MGPA in working face.

3) The position change of primary key stratum will affect MGPA in working face, and there is a critical limit height. The critical height is 115 m according to the numerical simulation results in Shengdong mining area.

7. ACKNOWLEDGEMENT

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Persian Abstract

چکیده

منطقه معدنکاری شندونگ که در شمال غربی چین واقع شده دارای بالاترین سطح کار کاملاً مکانیزه در جهان است. هدف از این مقاله درک علل ظاهر غیر طبیعی فشار مین (MGPA) بر روی سطح معدن کاملاً مکانیزه کار با ارتفاع فوق العاده بزرگ در منطقه معدن شندونگ است. برای بررسی عوامل تأثیرگذار MGPA غیرطبیعی روی سطح کار بسیار بزرگ استخراج از مانتورینگ میدانی، آزمون ماده تشابه فیزیکی و شبیه سازی عددی UDEC استفاده شد. نتایج نشان می دهد که حرکت شکستن همزمان چندین لایه کلیدی بار بیشتری نسبت به یک لایه کلیدی را منتقل می کند، که باعث تشدید MGPA در چهره کار می شود. فاصله لایه اصلی کلید و درز ذغال سنگ MGPA را تعیین می کند، اما این فاصله به ۱۱۵ متر بالاتر از درز ذغال سنگ محدود می شود. نتایج این مطالعه برای کنترل MGPA در منطقه استخراج شندونگ از اهمیت بالایی برخوردار است.
