

Research Article

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Strata behavior and control strategy of backfilling collaborate with caving fully-mechanized mining

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Abstract: This article analyzes the technical difficulties in full-section backfill mining and briefly introduces the technical principle and advantages of backfilling combined with caving fully mechanized mining (BCCFM). To reveal the strata behavior law of the BCCFM workface, this work establishes a three-dimensional numerical model and designs a simulation method by dynamically updating the modulus parameter of the filling body. By the analysis of numerical simulation, the following conclusions about strata behavior of the BCCFM workface were drawn. (1) The strata behavior of the BCCFM workface shows significant nonsymmetrical characteristics, and the pressure in the caving section is higher than that in the backfilling section. φ has the greatest influence on the backfilling section and the least influence on the caving section. C has a significant influence on the range of abutment pressure in the backfilling section. (2) There exists the transition area with strong mine pressure of the BCCFM workface. φ and C have significant effect on the degree of pressure concentration but little effect on the influence range of strong mine pressure in the transition area. (3) Under different conditions, the influence range of strong mine pressure is all less than 6 m. This article puts forward a control strategy of mine pressure in the transition area, which is appropriately improving the strength of the transition hydraulic support within the

influence range (6 m) in the transition area according to the pressure concentration coefficient. The field measurement value of J15-31010 workface was consistent with numerical simulation, which verifies the reliability of control strategy of the BCCFM workface.

Keywords: gangue backfill mining, caving fully-mechanized mining, strata behavior, transition area, strong mining pressure, control strategy, strata behavior

1 Introduction

As the main energy source, coal has made a great contribution to socioeconomic development in China. However, the traditional high strength and extensive mining methods have caused serious damage to the ecological environment, leading to a series of problems such as surface subsidence, destruction of groundwater resources, and pollution of mining area. Therefore, a green mining method of coal resources is needed [1].

Gangue backfill mining is one of the most commonly used green mining technologies, which has significant technical advantages in surface subsidence control [2,3], disposal of gangue waste [4,5], and ecological environment protection [6–8]. However, the large-scale popularization of conventional full-section backfill mining is limited due to following technical bottlenecks [9–11]. (1) The filling speed is slow, and filling processes and mining processes interfere with each other, which limits the filling efficiency, and the production capacity of backfilling workface is too low. (2) The discharge of gangue usually accounts for only 15% of coal production; nonetheless, the demand for full-section backfill mining is large, and the quantity of accumulated gangue is insufficient, which leads to the shortage of filling materials. (3) The cost of filling materials is high; furthermore, the reduction of filling efficiency further increases the cost of coal, so it is difficult to balance the filling cost and the coal mining benefit. Therefore,

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improving the filling efficiency while reducing the filling cost is the key requirement of large-scale backfill mining under the new intensive situation of coal mining [12].

Aiming at the engineering problems in Pingdingshan No.12 coal mine such as large discharge quantity of protective layer gangue, no accumulation space on ground, and insufficient production capacity, some scholars put forward a new partial backfilling mining method, namely, backfilling combined with caving fully mechanized mining (BCCFM) [13–17]. As a new partial backfilling method, the research on BCCFM mainly focuses on system layout and mining craft, while there are few studies on strata behavior and ground control of BCCFM. The researches have shown that there are distinct differences in overburden movement and strata behavior between traditional caving mining and gangue backfill mining [18–20]. The BCCFM workface integrates backfilling section and caving section within the same workface, and the strata behavior of the BCCFM workface will inevitably show its unique law. In particular, in the transition area where the backfilling section and the caving section influence with each other, the strata behavior will be more complex, which was the key of mine pressure control in the BCCFM workface. In this article, the technical principle and the characteristics of BCCFM are introduced, and the strata behavior of the BCCFM workface is simulated using FLAC^{3D} software. Moreover, the influence characteristics of mine pressure in the transition area are analyzed systematically, and the corresponding control strategies are put forward. Finally, the rationality of the proposed control strategy of strata behavior in the transition area is verified through engineering cases of Ji₁₅-31010 workface. The aim of this article is to provide reference for engineering design and mine pressure control of BCCFM.

2 Technical principle and characteristics of BCCFM

2.1 Technical principle and layout of BCCFM workface

BCCFM does not refer to mechanical superposition of traditional caving method and backfilling mining. In the same workface, the BCCFM workface integrates gangue backfilling section and caving section in the same workface, combining the backfilling method and the

caving method to joint manage the strata roof. Through strict equipment matching, the backfilling section and the caving section share a set of equipment to complete coal mining. In the backfilling section, the surface accumulation gangue or downhole output gangue is directly used for local filling with the assist of a series of filling equipment, including filling hydraulic support, bottom-dump scraper conveyor, filling material loader, and waste scraper conveyor.

The BCCFM workface is equivalent to adding caving workface based on the conventional backfilling workface, and the caving section is mining synchronously when the backfilling section is filling. This method retains the filling capacity and improves the productivity and efficiency compared to the conventional backfill mining, so that the BCCFM method can meet the multiple technical requirements of high filling efficiency, excellent productivity, and being capable of disposing gangue waste. The layout of the BCCFM workface is shown in Figure 1.

2.2 Technical characteristics of BCCFM

- (1) The length of the conventional backfilling workface is usually no more than 120 m considering the limited length of the bottom-dump scraper conveyor and filling efficiency. However, the total designed length of the BCCFM workface can exceed 200 m, which can meet the single-face capacity requirement. Moreover, the BCCFM workface has reduced the number of workface layouts and the frequency of workface removing and decreased the tunnel drivage ratio compared with the conventional backfilling workface.
- (2) Continuous mechanized filling is realized in the backfilling section, and the designed length of the backfilling section is more than 100 m, which can meet the demand of consuming a large amount of waste gangue.
- (3) In the BCCFM workface, filling process and mining process are carried out simultaneously without interfering with each other, so that improved filling efficiency can be achieved while satisfying the demand to filling efficiency and production capacity at the meantime.

But compared to the traditional caving method and the conventional backfilling mining, the weaknesses and limitations of BCCFM was that the required quantity of hydraulic supports and operating personnel was big. The

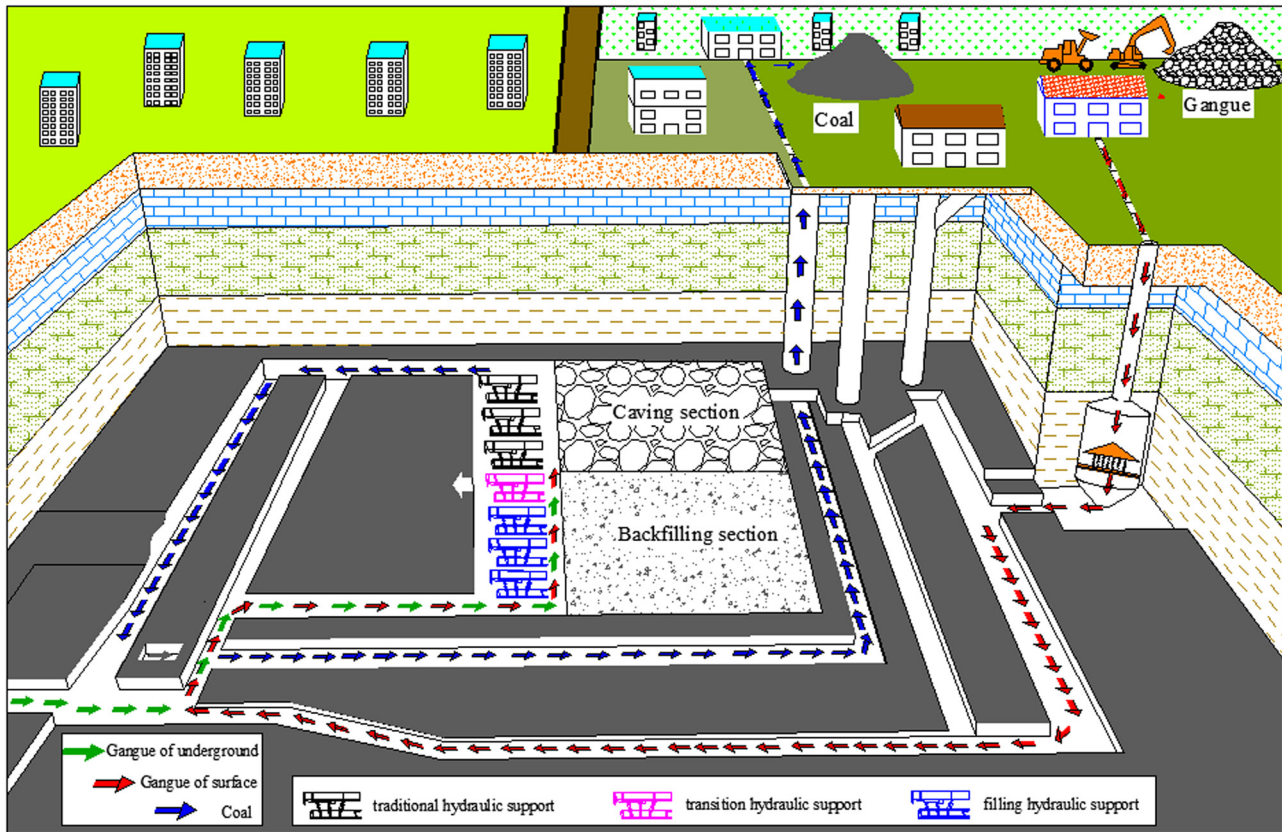


Figure 1: Layout of BCCFM workplace.

initial investment of the BCCFM workplace will be large if the coal mine has no idle hydraulic supports.

2.3 Mining and filling process

The BCCFM workplace mining process includes coal mining technology and filling technology. BCCFM workplace completed coal mining a under the joint assist of filling hydraulic support, transitional hydraulic support and traditional fully mechanized hydraulic support. Three different types of hydraulic supports share a set of shearer and bottom-dump scraper conveyor for mining and transporting coal. The coal mining process is the same as the traditional caving coal mining process [21].

The BCCFM workplace fills only the goaf in the filling section, and the coal mining and the filling process are conducted in parallel. Unlike the conventional gangue filling surface, which is filled after the coal cutting is finished and all the hydraulic supports are moved, the BCCFM workplace can be filled after the support is moved and straightened. The filling process is designed to be

starting from the tail to the head, and the specific process flow is as follows: the dumping holes are numbered and grouped along the filling direction, and four dumping holes are divided as a group. First, open the first group of four dumping holes in the tail direction. When the first dumping hole meets the filling requirements (the stacking height reaches the bottom of the bottom-dump conveyor when the natural blanking occurs, and the first dumping hole in the second group continues to be rammed repeatedly when the filling is dense), open the first dumping hole in the second group. Fill the dumping holes of each group in this order until the filling section is completely filled. The specific filling process is shown in Figure 2.

3 Mining pressure simulation of BCCFM workplace

A 3D numerical model of BCCFM workplace is established based on FLAC^{3D} software. It can be used to analyze the strata behavior and the influence characteristics of main

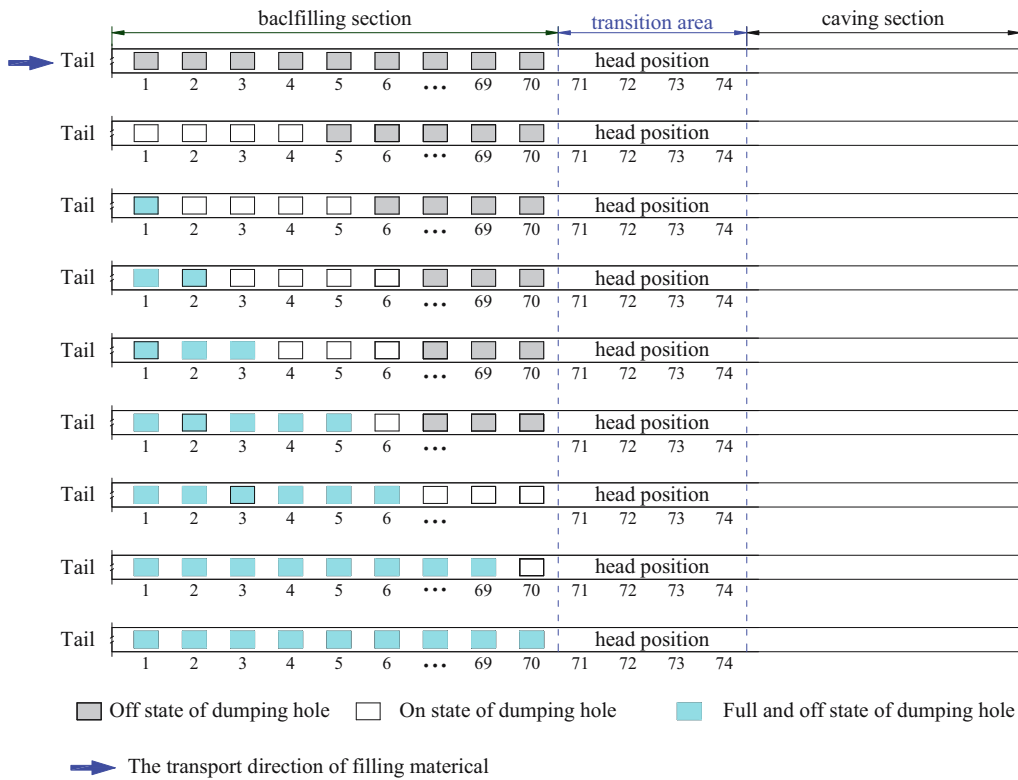


Figure 2: Filling process of BCCFM workface.

factors φ (filling ratio) and C (ratio of backfilling section length and caving section length) [22,23]. The definition of φ and C is shown in equation (1).

$$\begin{cases} \varphi = (M_0/M) \times 100\% \\ C = L_c/L_k \end{cases} \quad (1)$$

where M_0 is the height of the filling body after compression, in unit of m; M is the mining height of coal seam, in unit of m; L_c is length of backfilling section, in unit of m; and L_k is length of caving section, in unit of m.

3.1 Construction of numerical model

A numerical model was built based on Ji₁₅-31010 BCCFM workface of Pingdingshan No. 12 coal mine. The size of the model is 400 m × 300 m × 130 m (length × width × height), and the total length of the BCCFM workface is 220 m ($L_c = 120$ m; $L_k = 120$ m). To eliminate the influence of boundary on model excavation, the coal pillars with a length of 40 m are left at the four sides of the model. The horizontal displacement of the four sides of the model is constrained, while the bottom of the model is constrained on the horizontal and vertical displacements.

The gravity acceleration of 9.8 m/s² is applied to the entire model, and a uniform load of 22.5 MPa is applied on the top boundary to replace the 900 m thick overburden weight. The model has a total of 4,72,500 units and 5,09,627 nodes. Numerical model is shown in Figure 3.

The Mohr–Coulomb model was adopted to simulate strata rock. Physical and mechanical parameters of coal seam were obtained according to the laboratory tests. The specific physical and mechanical parameters of the model are presented in Table 1.

3.2 Simulation method design of gangue filling material

To accurately simulate the compression characteristics of gangue filling material in the compaction process, YAS-5000 press machine was used in the laboratory to conduct compaction tests on gangue filling materials. The loading rate is 0.1 kN; the inner diameter of the steel tube is 250 mm, the height is 300 mm, and the wall thickness is 11.5 mm. The stress–strain curves are shown in Figure 4. Furthermore, Origin software toolbox of curve fitting was used to deal with the test data of gangue filling material. The fitting equation was

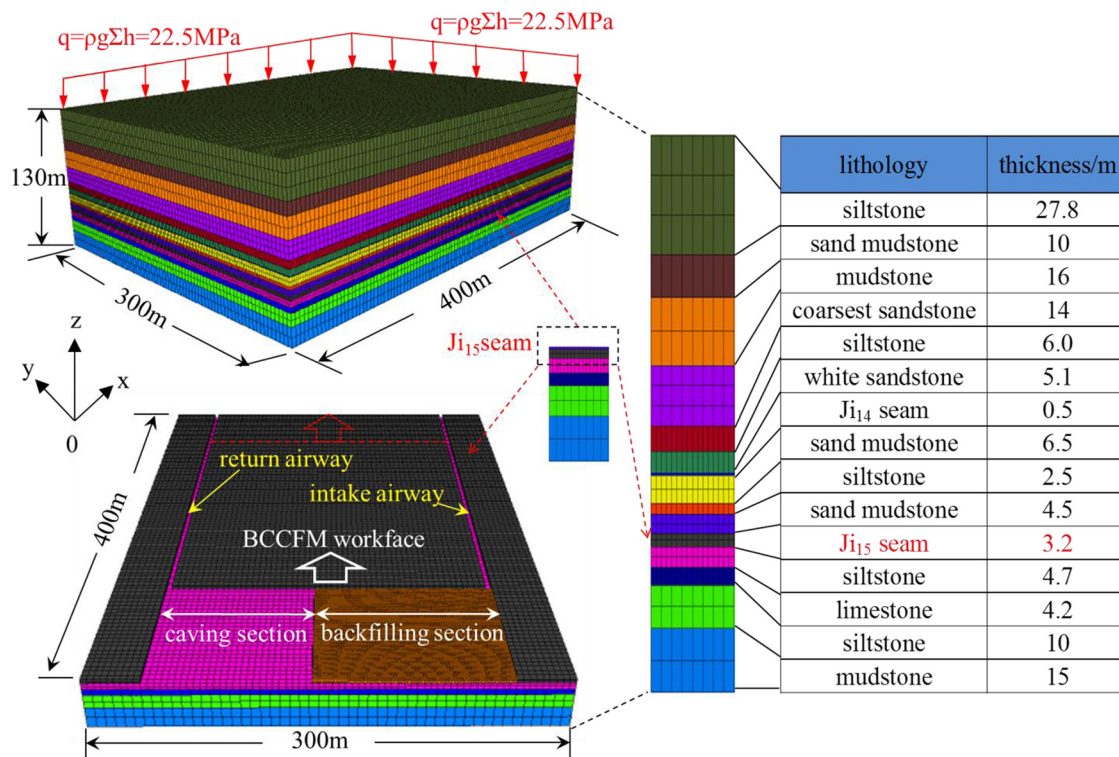


Figure 3: Numerical model of BCCFM workplace.

Table 1: Physical and mechanical parameters of coal and rock layers

Number	Lithology	Thickness/m	Bulk density/kg m ⁻³	Bulk modulus/GPa	Shear modulus/GPa	Cohesion/MPa	Internal friction angle/(°)
1	Siltstone	27.8	2550	13.8	7.1	7.5	32
2	Sand mudstone	10	2510	10.6	5.5	5.0	36
3	Mudstone	16	2460	9.8	3.8	5.0	30
4	Coarsest sandstone	14	2630	15.3	8.7	6.5	33
5	Siltstone	6.0	2550	13.8	7.1	7.5	32
6	White sandstone	5.1	2510	10.6	5.5	5.0	36
7	Ji ₁₄ seam	0.5	1450	5.8	2.7	2.5	28
8	Sand mudstone	6.5	2510	10.6	5.5	5.0	36
9	Siltstone	2.5	2550	13.8	7.1	7.5	32
10	Sand mudstone	4.5	2510	10.6	5.5	5.0	36
11	Ji ₁₅ seam	3.2	1450	5.8	2.7	2.5	28
12	Siltstone	4.7	2550	13.8	7.1	7.5	32
13	Limestone	4.2	2550	13.8	7.1	7.5	32
14	Siltstone	10	2550	13.8	7.1	7.5	32
15	Mudstone	15	2460	9.8	3.8	4.0	30

obtained, as shown in equation (2). The correlation coefficient F is as high as 0.9966.

$$\varepsilon = 0.117 \ln(2.45\sigma + 1.12), \quad (2)$$

where ε is strain of gangue filling material and σ is axial stress, in unit of MPa. According to equation (2), the constitutive relationship of gangue filling materials is

nonlinear under loading process, which indicates that gangues are not ideal elastic material. Therefore, it is impossible to choose fixed parameters to represent the stress-strain constitutive relationship in the compression process. When the gangue filling materials are compressed, the logarithmic nonlinear relationship between stress and strain is characterized by equation (3).

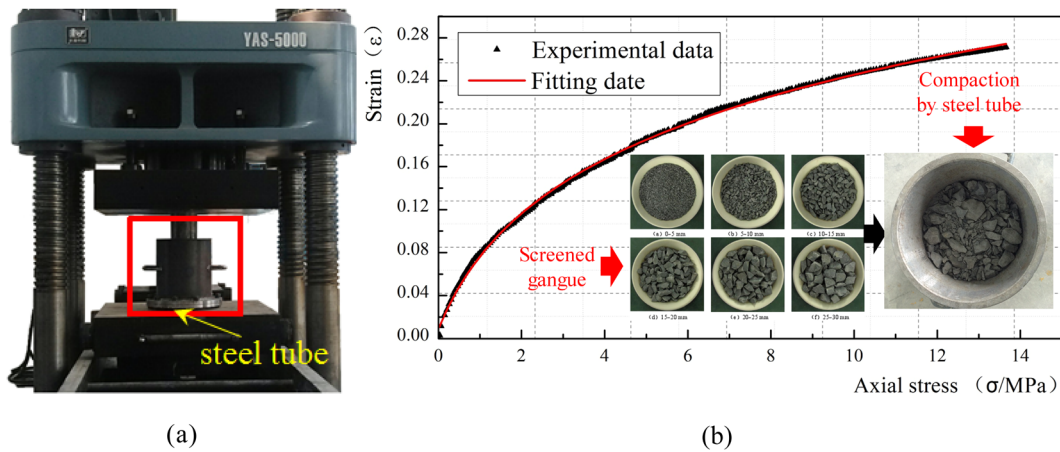


Figure 4: Compaction result of gangue filling material: (a) compaction equipment and (b) strain and stress curve.

$$\varepsilon = A \times \ln(B \times \sigma + C) \quad (3)$$

where A , B , and C are fitting parameters, $A = 0.117$, $B = 2.45$, and $C = 1.12$.

Generally, compression modulus is used to represent the antideformation characteristics of granular materials [24]. By taking derivative of equation (3), the expression of compression modulus E_c of gangue filling materials can be obtained, as shown in equation (4):

$$E_c = \frac{d\sigma}{d\varepsilon} = \frac{1}{A \times B} e^{\varepsilon/A} = \frac{1}{A} \sigma + \frac{C}{A \times B} \quad (4)$$

The Mohr–Coulomb model was also used for simulation of the gangue filling material. The main parameters involved in the model include bulk modulus K , shear modulus G , internal friction angle θ , etc. The bulk modulus K , shear modulus G , and compression modulus E_c of gangue filling materials satisfy equations (5) and (6).

$$K = E_c / 3(1 - 2\mu) \quad (5)$$

$$G = E_c / 2(1 + \mu) \quad (6)$$

where μ is the Poisson's ratio.

The nonlinear compression characteristic of gangue filling materials is programmed by FISH language embedded in FLAC^{3D} software. According to the stress–strain relationship, the bulk modulus K and the shear modulus G are dynamically updated every 50 steps until the mining is finished.

3.3 Surround rock stress distribution of BCCFM workface

Taking the condition of $\varphi = 85\%$ and $C = 120:100$ as an example, this article analyzes the strata behavior of the BCCFM workface. When the BCCFM workface is

advanced by 150 m, different profiles are made at advancing and tendency direction of workface, as shown in Figure 5. The stress (the stress is vertical stress, the same as below) distribution of the surrounding rock is analyzed. The distribution curve of the strata behavior is obtained after data processing, as shown in Figure 6.

- (1) The pressure distribution of the surrounding rock shows significant nonsymmetrical characteristics, with higher pressure in the caving section and lower pressure in the backfilling section, and there exists a high pressure transition area between the two sections.
- (2) Along the advancing direction of workface, the abutment pressure of backfilling section (A–A), caving section (B–B), and transition area (C–C) exhibits the pressure concentration, but the concentration degree and influence range are different. The peak value of the three sections is 0.49, 37.86, and 48.92 MPa, respectively, and the influence range is 17, 47 and 57 m, respectively. The degree of the abutment pressure can be ranked as follows: transition area > caving section > backfilling section. This indicates that the gangue filling body effectively bore the overburden loading and significantly reduced the influence range and peak value of abutment pressure in backfilling section.
- (3) Along the tendency direction of workface, there exists an obvious pressure concentration and rapid transition characteristics in the workface position (E–E) and goaf position (D–D). The peak values are 38.76 and 55.34 MPa, respectively. The influence range of high pressure in the transition area is about 5.53 m. However, there is no obvious pressure concentration phenomenon, but a slow transition characteristic in the front of workface position (F–F).

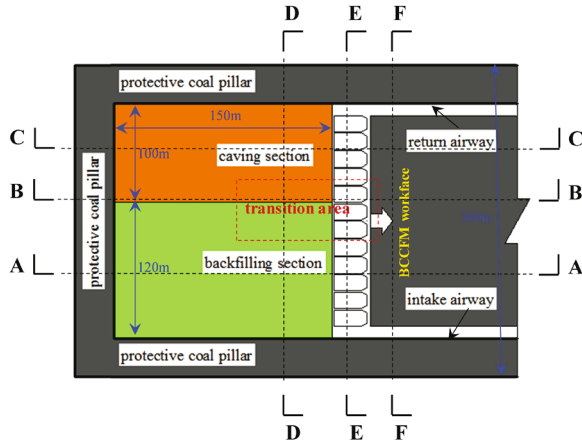


Figure 5: Profile of BCCFM workplace.

Along advancing direction of workplace

A-A section: the central of backfilling section

B-B section: the boundary of backfilling and caving section

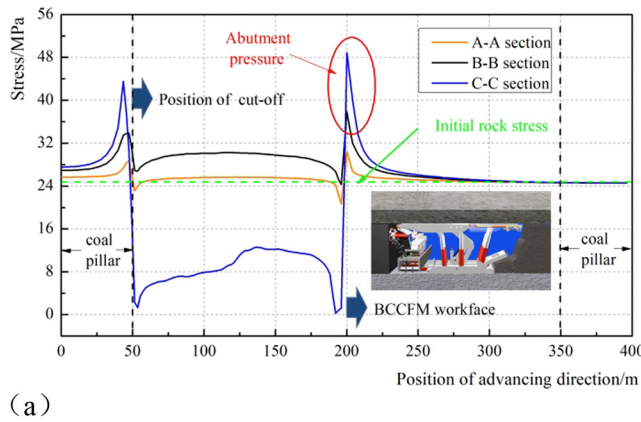
C-C section: the central of caving section

Along tendency direction of workplace

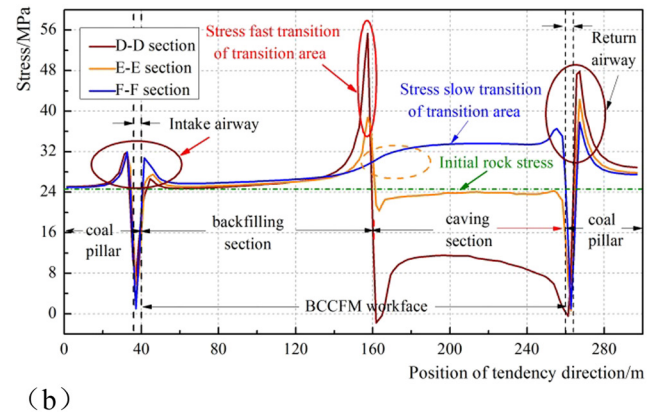
D-D section: position lagging 10 meters of workplace

E-E section: the face alone workplace

F-F section: position advancing 10 meters of workplace



(a)



(b)

Figure 6: The stress distribution of surround rock: (a) advancing direction and (b) tendency direction.

(4) The peak value of lateral support pressure is 47.85 MPa in return airway, while that of intake airway is just 31.92 MPa. The peak value of caving side's airway is 1.5 times of that of the backfilling side's airway. The peak values all appear on the side of the protection coal pillar. The pressure of the surrounding rock in backfilling side is significantly lower than that of the caving side, and the difference should be emphasized in support design.

3.4 Main influencing factors

The influencing factors (φ and C) were analyzed through numerical simulation. Three-dimensional pressure distribution of surrounding rock under different mining conditions is shown in Figure 7.

To compare the effects of different influencing factors on strata behavior in the BCCFM workplace, the

pressure distributions shown in Figure 7 are further analyzed and the results are presented in Table 2.

3.4.1 The effect law of factor φ

Along the advancing direction of workplace, with φ gradually decreasing from 85% to 55%, the peak value of abutment pressure and the influence range of high pressure in each section gradually increased, and the average value of the goaf pressure gradually decreased, with the increasing amplitude of the peak value and the influence range reaching 71.5% and 194%, respectively. While in the caving section, the growing rate of the peak value and the influence range were only 5.67% and 11.3%, respectively. The factor φ had the greatest influence in the backfilling section but the least influence in the caving section.

Along the tendency direction of workplace, with the gradual decrease of φ , the peak value of the transition

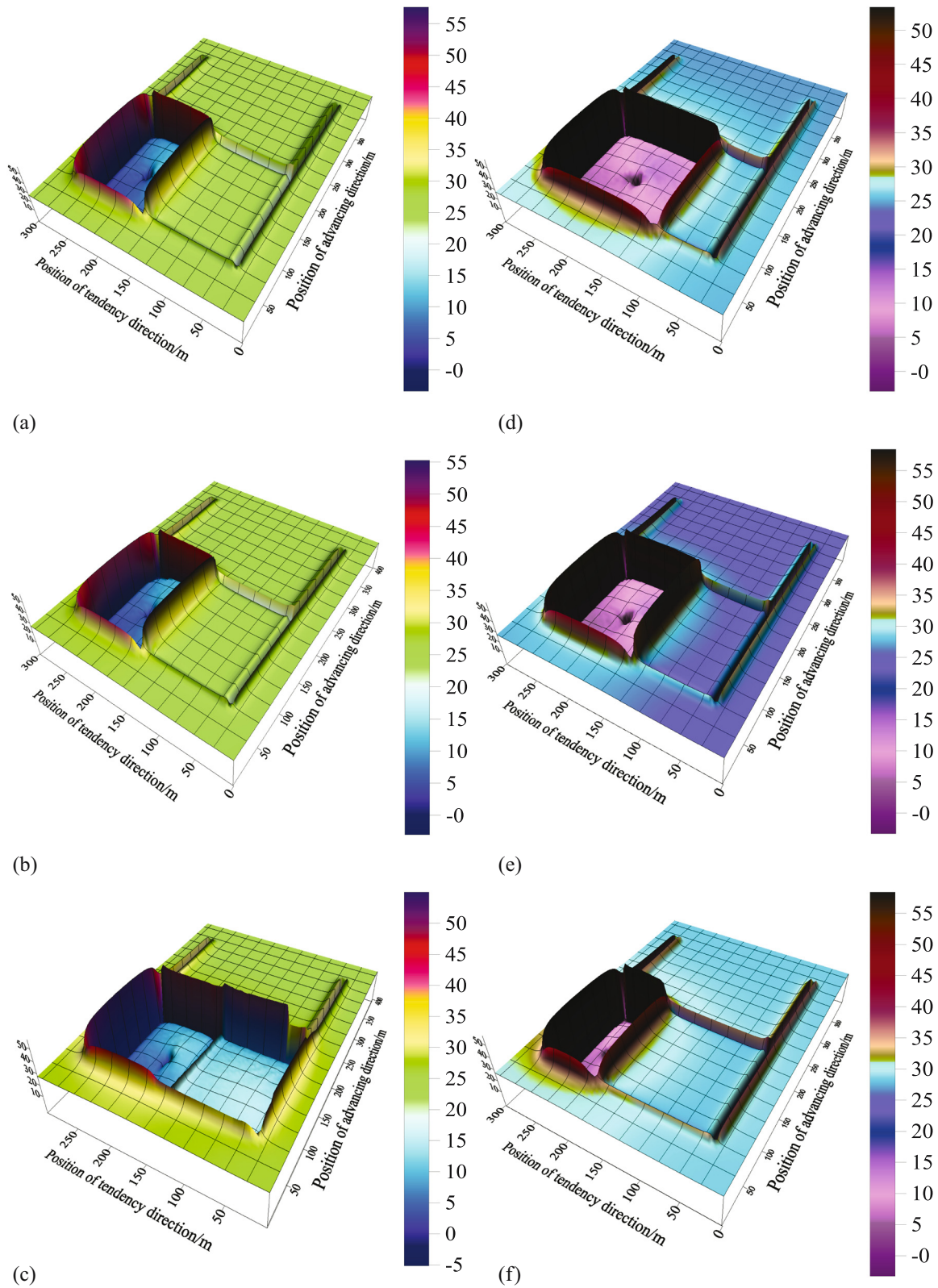


Figure 7: Pressure distribution under different mining conditions: (a) $\varphi = 85\%$ ($C = 120:100$), (b) $\varphi = 70\%$ ($C = 120:100$), (c) $\varphi = 55\%$ ($C = 120:100$), (d) $C = 50:170$ ($\varphi = 85\%$), (e) $C = 100:120$ ($\varphi = 85\%$), and (f) $C = 150:70$ ($\varphi = 85\%$).

Table 2: The effect law of influencing factors (φ and C)

Section	Monitoring target	φ			C			
		85%	70%	55%	70:150	100:120	120:100	150:120
A–A	Peak value	29.32	30.49	50.29	30.78	30.38	30.49	30.09
	Influence range of high pressure	17	23	50	32	24	17	8
	The average value of goaf pressure	25.25	25.03	12.66	26.11	25.54	25.25	24.89
B–B	Peak value	36.61	37.86	50.32	34.42	36.16	37.86	35.09
	Influence range of high pressure	47	49	58	49	48	47	44
	The average value of goaf pressure	29	28.60	8.85	26.49	27.14	29.33	27.64
C–C	Peak value	46.34	48.29	48.92	45.36	47.83	48.92	44.85
	Influence range of high pressure	53	57	59	68	58	57	54
	The average value of goaf pressure	8.86	9.36	6.55	8.867	9.124	8.86	7.10
D–D	Peak value of transition area	55.34	51.72	13.73	40.45	51.74	55.34	41.42
	The average value of backfilling section	25.47	25.27	10.4	26.17	25.54	25.47	25.23
	The average value of caving section	8.97	9.16	7.86	9.48	8.34	8.97	7.10
E–E	Peak value of transition area	38.76	36.52	30.27	32.73	39.69	38.76	33.52
	The average value of backfilling section	25.64	25.59	26.26	25.98	26.03	25.64	25.53
	The average value of caving section	23.45	22.43	23.21	21.43	23.24	23.45	22.97
	The average value of backfilling section	26.37	26.28	32.70	27.57	26.93	26.85	26.76
	The average value of caving section	33.19	35.33	36.25	38.03	36.01	33.19	32.54

area in the position of workface and goaf showed a downward trend, with the decreasing amplitude of 75.2% and 21.9%, respectively. The average pressure of the backfilling section in the rear of the workface gradually decreased, while the pressure in the front of the workface gradually increased. The average pressure had no obvious change at the workface position, and the average pressure of caving section varied little in each region.

The above changes are mainly due to decreased φ and weakened control effect of filling body on overlying strata. As a result, the degree of strata behavior was aggravated, and the supporting stress tended to shift to the area ahead of workface.

3.4.2 The effect law of factor C

Along the advancing direction of workface, with the increase of C , the peak value of abutment pressure and average value of goaf pressure in each sections exhibited small reductions. The influence range of abutment pressure in each area decreased, but the decreasing amplitude of three sections was significantly different. The decreasing amplitude of the caving section and transition area was 24% and 14%, respectively, while that of the backfilling sections was as high as 75%. It indicates that factor C has a significant influence on the influence range of abutment pressure in the backfilling section.

Along the tendency direction of workface, with the increase of C , the peak value of the transition area in the position at workface and goaf first increased and then decreased. The average pressure of the backfilling section in back of the workface decreased gradually, while that in front of the workface decreased first and then increased, in which the amplitude of variation did not change significantly.

4 Impact and control strategy of strong mining pressure

4.1 Main influencing factors

There is a significant difference between the backfilling section and the caving section of BCCFM workface, and there exists a strong mine pressure area between the two sections. The mine pressure control of transition area is the core of the BCCFM workface. It is necessary to master the strong mine pressure law and its influencing characteristics. In this article, the analysis focuses on the effects of influence range of high pressure and the peak value of strong mine pressure in the transition area. The influence range of high pressure refers to the area where the overburden pressure value exceeds the average pressure value of the filling section by 1.3 times.

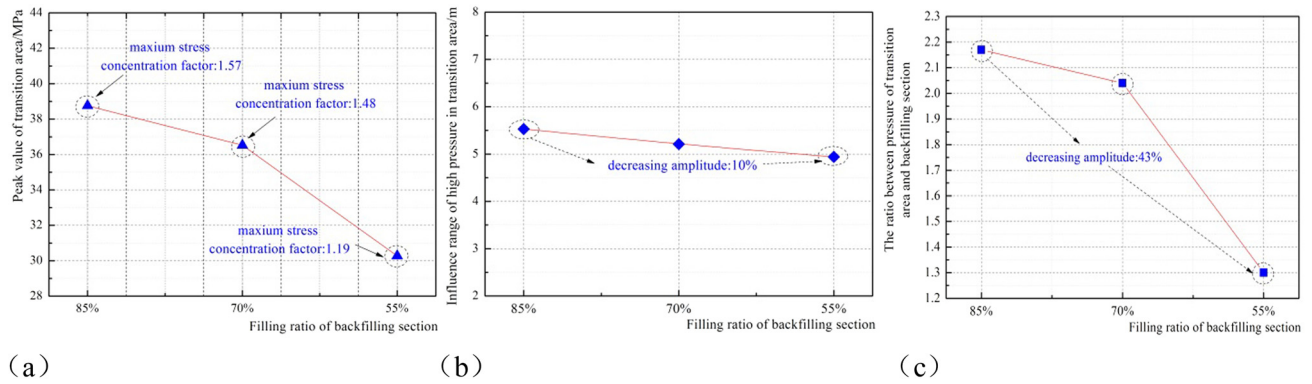


Figure 8: Impact characteristics of ϕ : (a) peak value, (b) influence range, and (c) ratio of pressure.

The strata behavior in the transition area affected by ϕ is shown in Figure 8.

Figure 7 shows that

- (1) When ϕ was 85%, 70%, and 55%, the maximum stress concentration factor in the transition area was 1.57, 1.48, and 1.19, respectively. It indicates that the pressure concentration degree decreased with the decrease of ϕ , and the decreasing amplitude became increasingly large.
- (2) When ϕ was 85%, 70%, and 55%, the influence range of high pressure was 5.53, 5.21, and 4.94 m, respectively. The influence range of high pressure in the transition area was all less than 6 m, without obvious change. This indicates that the factor ϕ had no significant effect on the influence range of high pressure in the transition area.
- (3) The strata behavior in the transition area was significantly higher than that in the backfilling section. With ϕ decreasing from 85% to 55%, amplitude decreases by as high as 43%.

The strata behavior in the transition area affected by C is shown in Figure 8. Figure 9 shows that

- (1) As the C gradually changed from 70:150 (<1) to 150:70 (>1), the maximum stress concentration factors in the transition area were 1.32, 1.61, 1.57, and 1.36, respectively. The maximum stress concentration factor first increased and then decreased. It indicates that the factor C had a significant effect on pressure concentration degree in the transition area.
- (2) As the C gradually changed from 70:150 to 150:70, the influence range of high pressure was 5.42, 5.53, 5.63, and 5.71 m, respectively. The influence range of high pressure in the transition area was less than 6 m and exhibited no significant change. It indicates that the factor C had no significant effect on the influence range of high pressure in the transition area.
- (3) With the C gradually changes from 70:150 to 150:70, the ratio of pressure between the transition area and the backfilling section increases at first and then decreases.

In conclusion, the pressure concentration in the transition area was significantly affected by factors ϕ and C . While factors ϕ and C had little influence on the influence range of high pressure, and the influence range

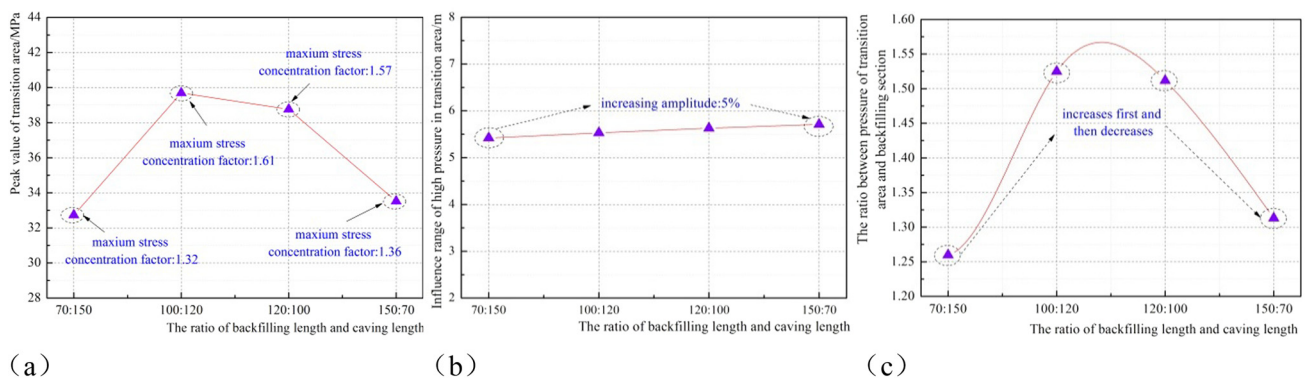


Figure 9: Control characteristics of C : (a) peak value, (b) influence range, and (c) ratio of pressure.

was less than 6 m. Through analysis, it was found that change of factors φ and C only transformed the distribution of the pressure but did not change the fracture characteristics of overburden in the transition area. No matter how the mining conditions changes, the overburden damage in the transition area inevitably will occur.

4.2 Support structures in BCCFM workface

There are three types of hydraulic supports in the BCCFM workface, namely, filling hydraulic support, transition hydraulic support, and traditional hydraulic support. The basic frame of the filling hydraulic support and transition hydraulic support is the same. The support structures and working states are shown in Figure 10.

Figure 9 shows that the filling hydraulic support is used in the backfilling section. The bottom-dump conveyor is hung at the bottom of the rear top beam to transfer the filling gangue material. The punning apparatus is installed on the base of the support to pre-compress the gangue material and improve the density of the filling body. Traditional hydraulic support is arranged in the caving section. The basic frame of the transition hydraulic support is the same as that of the filling hydraulic support, and the only difference is that the punning apparatus is replaced by the baffle plat, which prevents goaf gangues and caved rocks from flooding into the support operation space and thus avoids occurrence of equipment damage and casualties.

4.3 Control strategy of strong mining pressure in transition area

The backfilling section and the transition area have the same type of hydraulic support, while the strength of strata behavior in the transition area is higher than that of the backfilling section. When designing the support resistance, one must consider the situation that one support may have obvious different load bearings. Under these circumstances, this article proposes to properly improve the support strength of the transition hydraulic support within the influence range of transition area. Therefore, the high pressure concentration degree and the influence range of strong mining pressure should be calculated according to parameters φ and C . Moreover, according to the pressure concentration coefficient, the support strength of the transition hydraulic support

should be properly increased so as to control the strong mining pressure in the transition area.

5 Engineering practice

5.1 Control strategy of strong mining pressure

The total length of the Ji₁₅-31010 BCCFM workface is 218 m, in which the length of backfilling section is 120 m and the length of the caving section is 98 m. The average thickness of Ji₁₅ coal seam is 3.2 m. The aim of backfilling is to consume the waste gangue, so the filling of waste gangue is realized under the force of gravity. It has been calculated that the filling ratio is about 55%. The type of the traditional hydraulic support of the caving section is ZY6800/20/40, and the support strength is 1.0 MPa.

In the backfilling section, the type of the filling hydraulic support is ZC5200/20/40. According to the equivalent mining height theory [12], the support strength of the filling hydraulic support is 0.225–0.45 MPa. Finally, for the sake of security, the support strength is set to 0.84 MPa. The type of the hydraulic support in the transition area is as same as that of the filling hydraulic support. It can be obtained by numerical simulation that the pressure in the transition area is 1.3 times of that in the backfilling section. Through calculation, it can be known that theoretical strength of the transition hydraulic support should be 0.508–0.585 MPa. Considering the low filling ratio and the weak pressure concentration degree of the transition area, which is consistent with that of the filling hydraulic support, the support strength of the transition hydraulic support is also set to 0.84 MPa.

According to the simulation calculation, the influence range of strong mine pressure of the transition area is 5.53 m, so four transitional hydraulic supports (the width of support is 1.5 m) are arranged in Ji₁₅-31010 BCCFM workface. However, it needs to be emphasized that the support strength of the transition hydraulic support must be properly increased to ensure the safety when the filling ratio is high and the pressure concentration degree in the transition area is strong.

5.2 Measurement and analysis of mine pressure

In consideration of different types of supports in the BCCFM workface, 17 support resistance monitors are

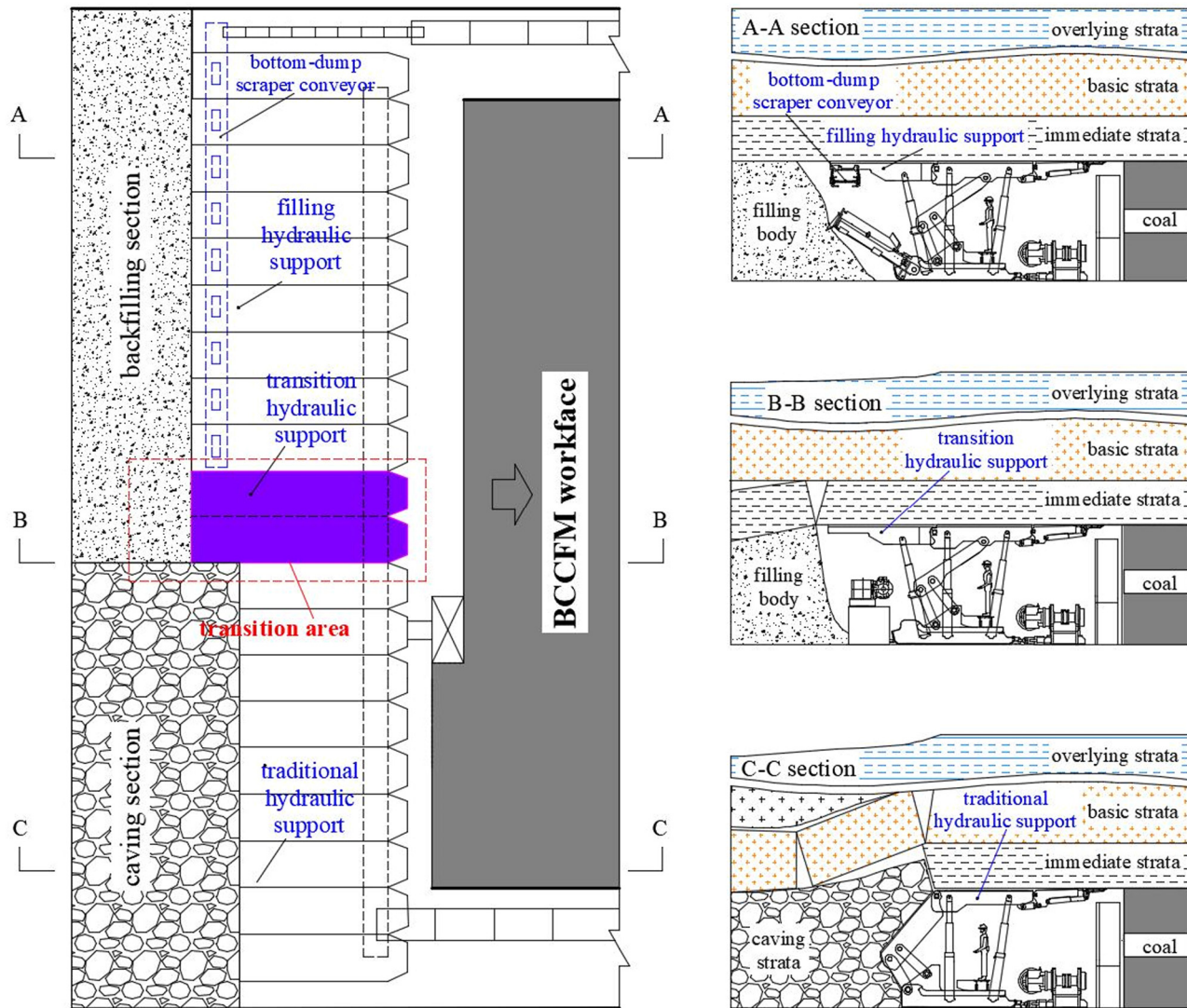


Figure 10: Support structures and working states.

arranged along the Ji₁₅-31010 workface. Among them, one-channel resistance monitors (1#–7#) are arranged in traditional hydraulic support, two-channel resistance monitors (8#–17#) are installed in transition hydraulic support and filling hydraulic support. The specific monitoring scheme is shown in Figure 11.

The measured results of working resistance are shown in Figure 12.

Figure 12 shows that:

- After Ji₁₅-31010 workface advanced to 87 m, the working state of supports was stable and the safety valves of hydraulic support remained unopened. But the working resistance of supports in different sections is different.
- Through monitoring data analysis of No. 44, 69, and 107 hydraulic supports (respectively represent cavering section, transition area, and backfilling section), it can be known that the support resistance varied greatly in the cavering section and the transition area and obvious periodic pressure phenomenon was observed, which indicates that the periodic break of overburden occurred. In contrast, the support resistance of filling hydraulic supports was relatively stable and the backfilling section exhibited no obvious periodic pressure phenomenon, indicating that the gangue filling material effectively reduced the intensity of pressure of the backfill section.
- Along the tendency of workface, the average support resistance of supports in the backfilling section, transition area, and cavering section was 25.9, 32.7, and 27.6 MPa, respectively. The average support resistance of the transition hydraulic support was

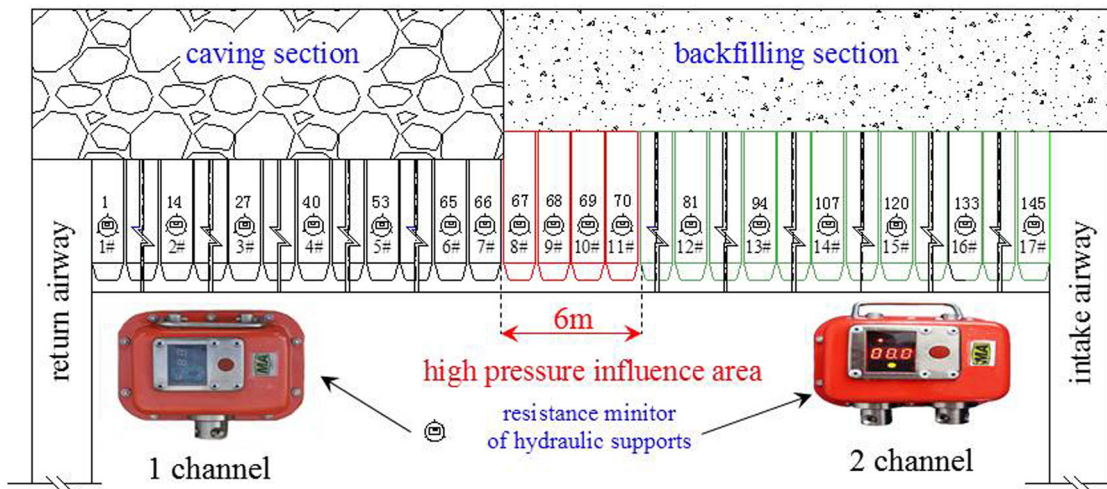
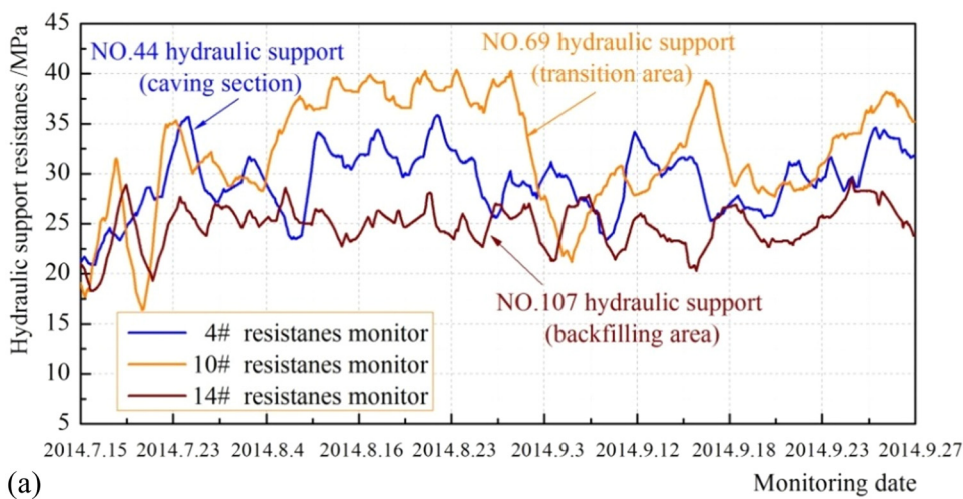
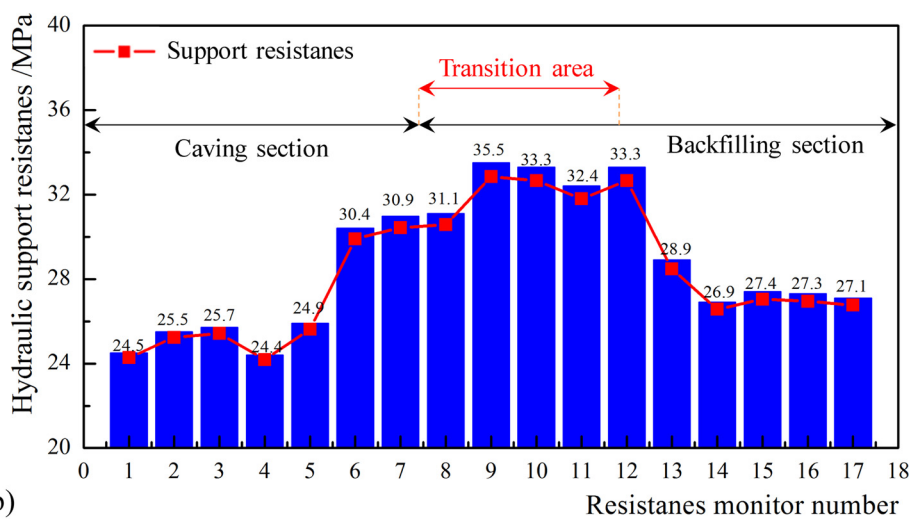


Figure 11: Monitoring scheme.



(a)



(b)

Figure 12: Pressure distribution of support: (a) advance direction of workplace and (b) tendency direction workplace.

1.26 times of that of the filling hydraulic support. The field measurement result was consistent with numerical simulation, which verifies the reliability of control strategy of strong mining pressure in the transition area.

6 Conclusion

- (1) Aiming at the actual technical difficulties in full-section backfill mining, this article briefly introduces the technical principles and technical advantages of BCCFM.
- (2) A three-dimensional numerical model is established, and a simulation method is designed by dynamically updating the modulus parameter of the filling body. This study investigates the nonsymmetrical strata behavior law and the main influence factors of the BCCFM workface. The results show that the φ has the greatest influence on the backfilling section but the least influence on the caving section. In contrast, C has a great influence on the influence range of abutment pressure in the backfilling section.
- (3) There exists a transition area with strong mine pressure between the backfilling section and the caving section of the BCCFM workface. The researches show that φ and C have a great effect on degree of pressure concentration but little effect on the influence range of strong mine pressure in the transition area. Under all conditions, the influence range of strong mine pressure was always less than 6 m.
- (4) This article puts forward a control strategy of strong mine pressure in the transition area, that is, properly improving the support strength of the transition hydraulic support within the influence range (6 m) in the transition area according to the pressure concentration coefficient. The field measurement results of J₁₅-31010 workface were consistent with the numerical simulation results, which verify the reliability of control strategy of BCCFM.

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