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Numerical Simulation Study of Support Pressure around the Fully Mechanized Caving Face

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Abstract

During the fully mechanized caving face re-recovery process, due to the influence of mining and the redistribution of surrounding rock stress, a higher advanced support pressure and lateral support pressure will be formed around the working surface. The superimposed advanced and lateral support pressure will have a greater impact on the advanced support of the working surface roadway. In order to improve the stability of the surrounding rock, the three Hebi mines were used as the subject of the study. At the same time, Universal Distinct Element Code software was used to study the pressure distribution pattern of over-support at the working face. Finally, the results of the study are used as theoretical support and reference for the support scheme.

Keywords

Over-Supporting, Coal Mine Safety, Numerical Simulation, Support Analysis

1. Introduction

The ground surface of 3205 North working face of He Coal Mine No. 3 is located in the south of Houying Village; the ground elevation is 129.31 m - 134.05 m; the Tang River flows through the middle area of the working face; the working face roof elevation is −497.7 m - −545.9 m; the burial depth is 627.01 m - 679.95 m [1].

This workface is located in the second mining area of the third level in the north of the well field, with the reworked 3203 North workface to the west, the unrecovered 3207 North workface to the east, the 24F3 fault (H = 10 m ∠60˚) to the north, and the unrecovered 3205 Middle workface to the south.

The design length of the lower chute of 3205 working face is 516.5 m (medium-medium and flat distance), and the roadway enters from the three cross-channels of the 3205 rock road, and is constructed along the top plate of the coal seam according to the design orientation. In order to provide a theoretical basis for the lower chute support scheme, a theoretical analysis and numerical simulation study of the support pressure distribution law around the 3205 working face was conducted first.

This paper analyzes the situation of pressure distribution around the working face to provide a reference for similar working faces.

2. Theoretical analysis of the Support Pressure Distribution Law at Header Working Faces

The limit equilibrium theory of elastic-plastic mechanics is selected to divide the area in front of the working face when the coal wall produces plastic damage into the limit equilibrium zone and the elastic zone, and to carry out theoretical analysis and calculation of the overhead support pressure of the working face of 1,105,033,205 in the eight mine [2]. In the two-dimensional state, combined with **Figure 1** coal body in the plastic state under the mechanical model, take the width of the unit of dx, the unit body is in the ultimate equilibrium state, in this state to establish the plastic zone of the support pressure expression [3].

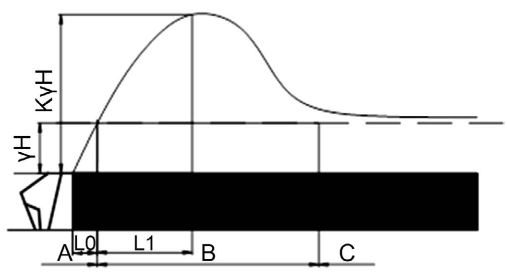
To analyze the depth of the coal wall slice gang, a micro-element of thickness 1 was removed from the area L0 and a static analysis was carried out on it, as shown in **Figure 2**.

Establish the static equilibrium equation based on the relationship shown in **Figure 2**

$$\begin{gathered}\sum X=0\\ m\left(\sigma_x+d\sigma_x\right)-m\sigma_x-2\sigma_y fdx=0\end{gathered} \tag{1}$$

$$\begin{gathered}\sum Y=0\\ \sigma_y dx-\sigma_y dx=0\end{gathered} \tag{2}$$

where, f —the friction coefficient between the coal seam and the rock level; m —the mining height; σ_x, σ_y are the stresses in the x and y directions, respectively.



H—Depth of burial; γ—Bulk capacity; A—Decompression zone; L0—Sheet gang zone; L1—Plastic zone; B—Augmentation zone; C—Primary rock stress zone.

Figure 1. Support pressure acting on large mining high coal bodies.

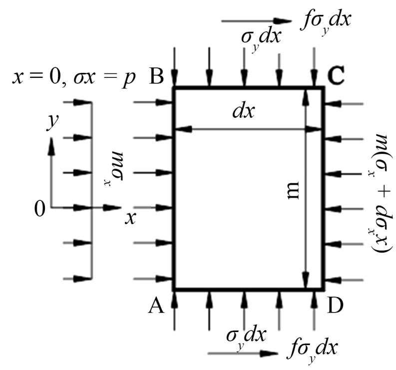


Figure 2. The force state of the microstructure in the limit equilibrium zone of the stope.

The coal body within the limit equilibrium zone satisfies the Cullen-Moore criterion with

$$\sigma_y = R_c + \alpha\sigma_x \tag{3}$$

in which $\alpha = \frac{1+\sin\varphi}{1-\sin\varphi}$, $R_c = \frac{2c\cos\varphi}{1-\sin\varphi}$.

From (3) we get

$$\frac{d\sigma_y}{d\sigma_x} = \alpha \tag{4}$$

Combining (4) and (1), we get

$$\ln\sigma_y = \frac{2fx}{m}\alpha + C \tag{5}$$

In the limit stress equilibrium range, the lead stress gradually increases the value of the maximum, and then at the elastic-plastic junction, the stress gradually decreases, until at infinity close to the original rock stress. Generally, it is advisable to take 5% above the original rock stress as the dividing line of the overrunning support pressure, and then to the internal development that is in the original rock stress area. Therefore, the lead stress can be expressed as a function of segmentation as follows.

$$\sigma_y = \begin{Bmatrix} \sigma_c e^{\frac{2f\alpha}{m}(x-L_0)} & 0 \le x \le L_1 \\ \sigma_c e^{\frac{2f\alpha}{m}\frac{L_1^2}{x^2}(x-L_0)} & x > L_1 \end{Bmatrix} \tag{6}$$

3. Determination of the UDEC Numerical Model Ontology and Parameters

3.1. Introduction to the Numerical Simulation Program UDEC

UDEC (Universal Distinct Element Code) is a simulation software based on the theory of discrete unit method, which is widely used in the field of geotechnical engineering and underground engineering. The process of roof collapse at the header face is a discontinuous solid media damage process, and UDEC has more obvious advantages in dealing with discontinuous media links, especially suitable for the study of the damage process of solid media under the action of load. Therefore, in this paper, UDEC is chosen to simulate and analyze the pressure distribution law of the overrunning support at the 3205 working face of He Coal Mine 8 [4].

3.2. Model Ontology Selection

UDEC provides seven material ontological models and five jointing ontological models suitable for geotechnical soils, which can better adapt to the needs of rock movement under different lithology and different excavation state conditions, and can analyze the movement of the overburden rock and the subsidence of the ground surface after strip mining more accurately. This paper uses the Mohr-Coulonmb model to simulate coal rock masses. The Mohr-Coulonmb model is mainly targeted at loose cemented granular materials and can therefore be used to simulate coal rock seams, etc., so it is widely used in the mining field to analyze the stability of mining spaces. the Mohr-Coulonmb model is based on the Coulomb's Moore's law in geotechnics, the Moore The Coulomb strength theory formulation includes an equation for the hydrostatic pressure to yield criterion, which has been widely used in geotechnical and mining engineering because the effect of hydrostatic pressure on the yield criterion in the criterion reflects the characteristics of soil plasticity [5] [6] [7].

3.3. Determination of the Mechanical Parameters of the Physical Model

According to the geological conditions of He coal Mine 8, a physical model of the overrunning support pressure at the heaving workface was established by making a profile along the direction of advancement of the workface in order to consider the influence of the model boundary on the numerical simulation, with a 30m boundary left at the top and bottom of the workface and a 50 m boundary left at the left and right of the workface. The specific mechanical parameters are shown in **Table 1**.

Table 1. Table of rock formation mechanical parameters.

Rockiness	Density Kg/m³	Bulk modulus GPa	Shear modulus GPa	Internal Cohesion MPa	Angle of internal friction °
Medium-grained sandstone	2580	3.3	2.5	4	37
Coal	1410	2.5	1.1	1	25
Sandy mudstone	2400	5.6	3.8	2	36
Mudstone	2400	5.6	3.8	1.2	36

4. Numerical Simulation of Overrun Support Pressure Distribution at Header Workings

4.1. Numerical Modelling

The numerical model for the UDEC of the overrunning support pressure at the header face is shown in Figure 3 below. The model examines the distribution of the overrunning support pressure at the header face under mining stress. The model is 400 m long (width), 96 m high, with a mining cycle step of 30 m and a total advance of 210 m, and is analyzed for changes in the overrun support pressure [8].

The model boundary conditions, as shown in the figure: the left and right boundaries restrict the displacement in the horizontal direction, *i.e.* the horizontal displacement of the boundary is zero (u = 0); the bottom boundary is fully constrained, *i.e.* the horizontal displacement and vertical displacement of the bottom boundary node are zero (u = 0, v = 0); the upper boundary is the stress boundary, and 17Mpa stress is applied to simulate the overburden load.

4.2. Analysis of Simulation Results

According to the aforementioned simulation scheme, the maximum principal stress at 40 m in front of the working face at different advance lengths was extracted within the coal seam using the working face chute height of 3.4 m as a benchmark, and the data was processed using origin software to derive the overrun support pressure variation curve with distance, as shown in Figure 4.

According to the analysis of Figure 4, when the working face was advanced to 30m, the direct top fell and the old top formed a masonry beam structure, as the main bearing structure, the stress in the coal body was at a high level and the peak stress was located at about 10 m; with the advance of the working face, the peak stress gradually increased, among which when the working face was advanced to 60 m, the peak support pressure reached 52 Mpa and the support

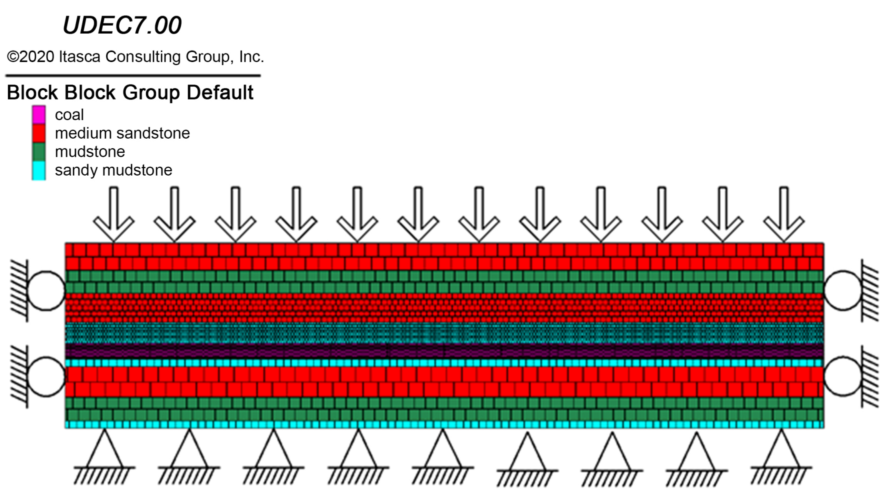


Figure 3. Comprehensive release of the working surface advanced support pressure UDEC numerical model.

pressure concentration coefficient reached 2.6. As the face continued to advance, the bearing pressure and concentration coefficient remained within a relatively stable range, with the peak bearing pressure position at 9 - 12 m in front of the face, affecting an area of about 30 m. Compared with the theoretical calculation, the situation is basically consistent, except for some differences in the peak position.

The plastic zone is analyzed in **Figure 5**, and the size of the plastic zone is measured by the distance measuring tool in UDEC, and it is found that the plastic zone on both sides of the coal gang is shear damage and inverted triangle distribution when advancing 30 m, and the plastic zone reaches the limit at the junction of the coal body and the direct top, and the plastic zone no longer expands outward in the direct top, and shear damage occurs in part of the old top; after 30 m, the plastic zone in front of the old top collapse work is stable at about 10 m. The plastic zone in front of the old roof collapse work after 30 m is stable at about 10 m, which is basically the same as the location of the peak stress, and

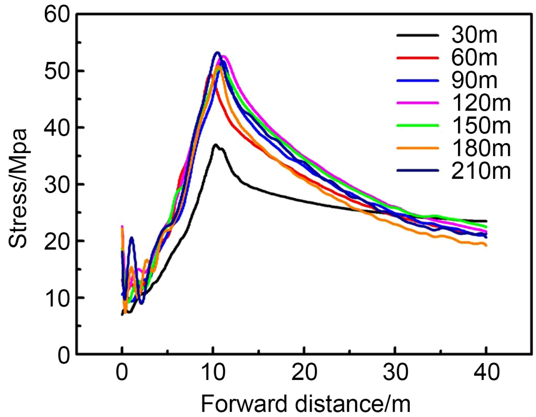


Figure 4. The pressure distribution of the advanced support of the working surface of the comprehensive discharge at different mining distances.

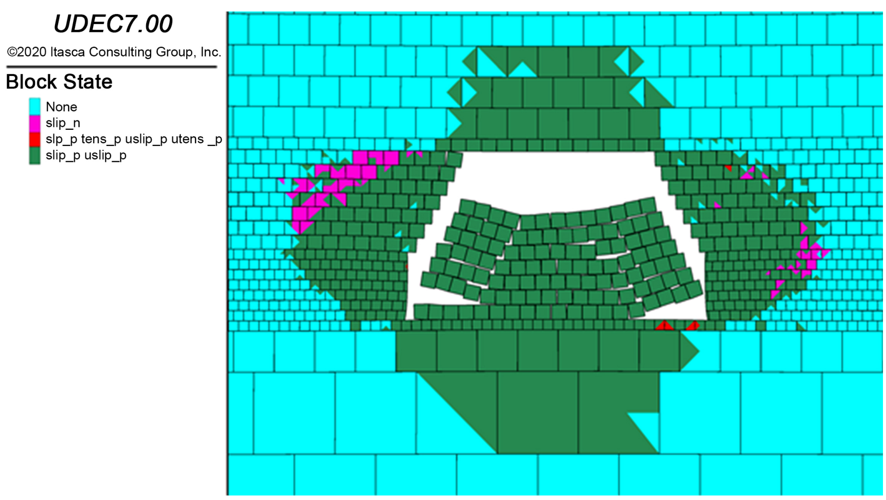


Figure 5. Comprehensive release of the working surface to promote the process of plastic area cloud map.

at the same time, a plastic zone in the form of an inverted triangle distribution appears on both sides of the coal gang similar to that at 30 m, the difference is that the plastic zone is a combination of shear and tensile damage, and the other parts of the plastic zone are shear damage. Along the working face advance direction, the initial collapse step of the old roof is about 30 m, the peak stress is located at about 10 m, and the influence range is 10 - 30 m; therefore, the influence range of the support pressure is the starting point of the grouting anchor line, and the specific value should be determined according to the subsequent research.

5. Numerical Simulation of Lateral Support Pressure Distribution on Header Face

5.1. Numerical Modelling

According to the geological conditions of He coal Mine 8, a physical model of the lateral support pressure of the header workings was established along the workings to consider the influence of the model boundary on the numerical simulation. 60 m of coal seam overburden was used, 50 m of coal pillars were left to the left and right of the workings, and the length of the workings was set to 150 m. The rock mechanics calculation parameters were the same as in the previous section, and the numerical model nodal surface normal stiffness was taken in the same way as in the previous section [9].

The model mainly examines the lateral situation of the header working face under the influence of mining stress [10]. The size of the model is 250 m (width) * 187 m (height), with 150 m long working face completed in one excavation, and the change of lateral support pressure on its right side is analyzed, as shown in **Figure 6**.

As shown in **Figure 6**, the boundary conditions are the left and right boundaries to limit the horizontal displacement, *i.e.* the horizontal displacement of the boundary is zero (u = 0); the lower boundary is the full constraint condition, *i.e.*

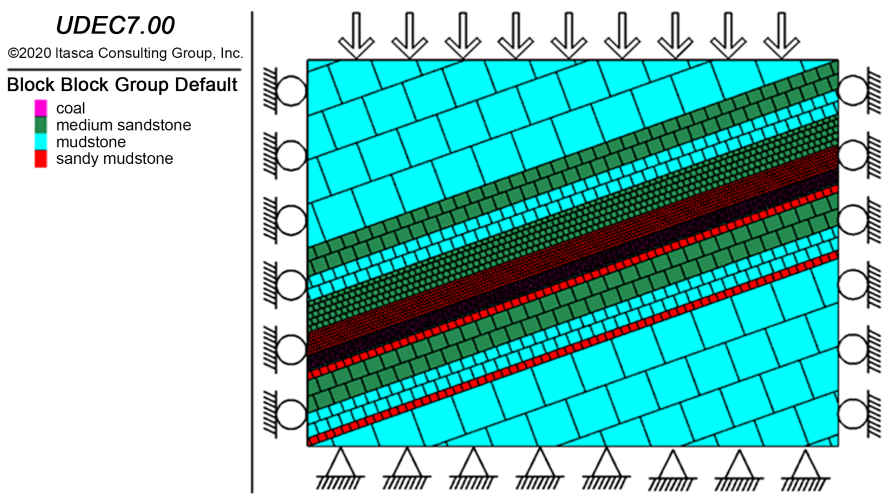


Figure 6. Comprehensive discharge work surface lateral support pressure UDEC model.

the horizontal displacement and vertical displacement of the bottom boundary node are zero (u = 0, v = 0); the upper boundary of the model is based on the burial depth of the rock formation, and a stress of 21.25 Mpa is applied according to the capacity of 2.5 as the stress boundary condition of the model.

5.2. Analysis of Simulation Results

The lateral support pressure and collapse and plastic zone of the heaving face obtained by numerical simulation are shown in Figures 7-9.

Using the working face chute height of 3.4 m as a benchmark to extract the maximum principal stress at 35 m on the left side of the working face within the coal seam and using professional data processing and plotting software origin to process the data and derive the lateral support pressure variation curve with distance, as shown in Figure 10.

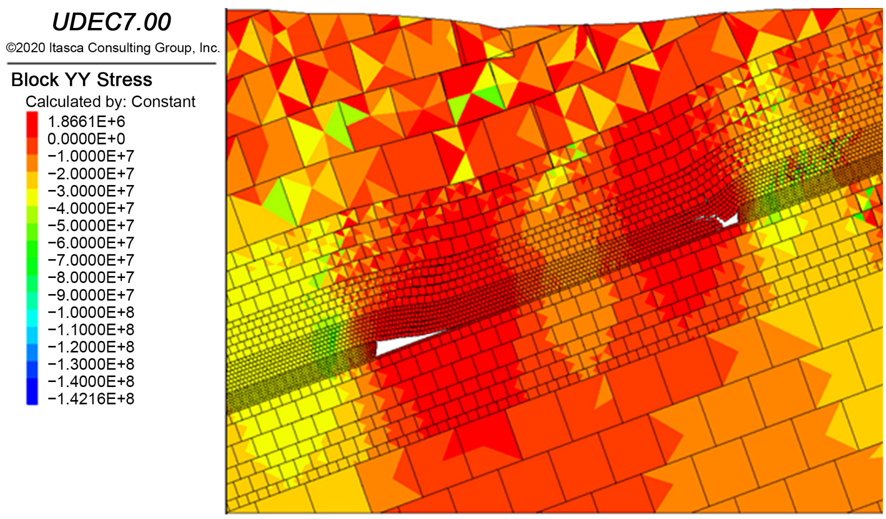


Figure 7. Lateral support pressure UDEC model Lateral support pressure cloud at the heaving face.

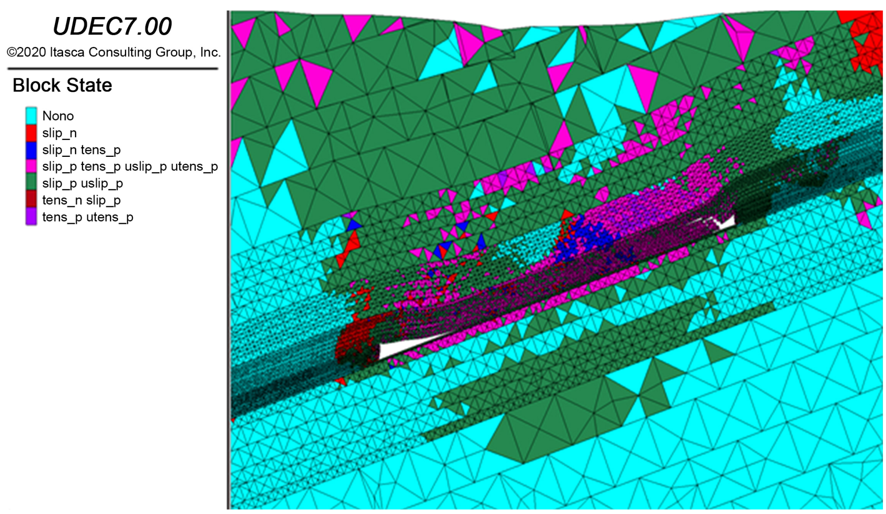


Figure 8. Cloud view of lateral plastic zone at header face.

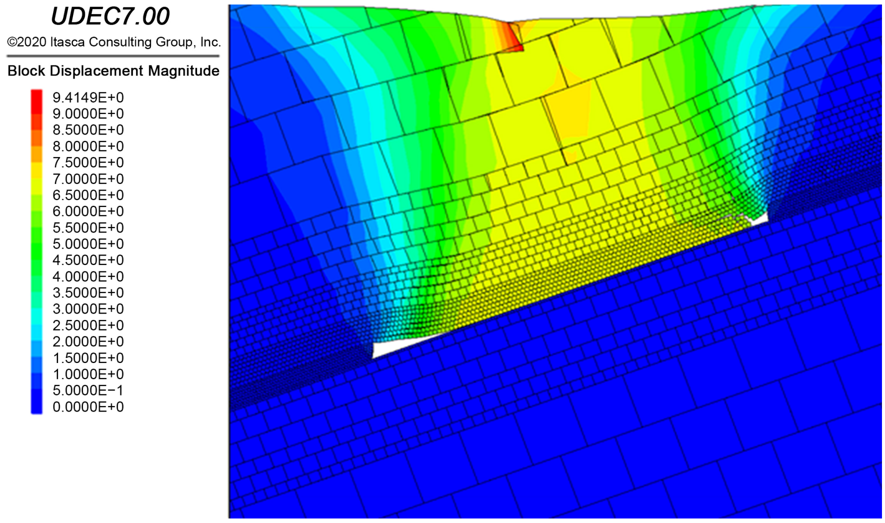


Figure 9. Cloud view of lateral plastic zone at header face.

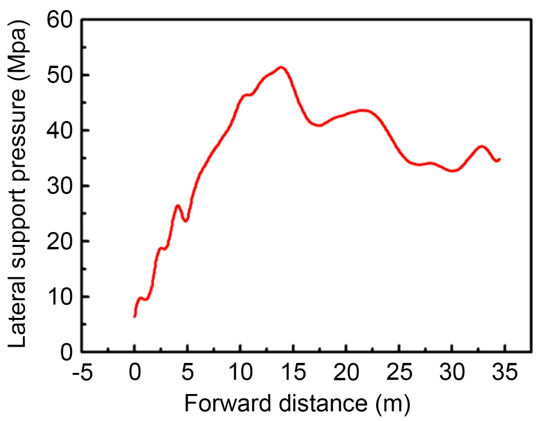


Figure 10. Lateral support pressure to lateral distance variation graph.

As can be seen from **Figure 7** and **Figure 10**, the lateral support pressure rises continuously from 0 - 13 m on the side of the working face and reaches a peak at 13 m, with a peak stress of 51 MPa and a stress concentration factor of 2.5, while the size of the lateral plastic zone is also consistent with the peak stress point; afterwards, the support pressure slowly decreases to a steady level from 13 - 25 m, and the lateral stress remains stable at 25 - 35 m without further change. It can be seen that the influence area of the lateral bearing pressure is around 30 m, which is basically the same as the influence range of the overrunning bearing pressure.

In summary, the superimposed support pressures, especially in the track chute, will be subject to superimposed overrun and lateral support pressures and the overrun grouted anchor cable support parameters need to be optimized to meet the functional requirements of the roadway.

6. Conclusions

The article uses theoretical analysis and numerical simulation methods to study the overrunning and lateral support pressure of the comprehensive release working face of Yushu Ling coal mine eight, and obtains the stress environment law in which the retraction roadway is located, as follows:

1) The theoretical analysis shows that the coal wall has a greater chance of flaking during the workings retrieval process, the width of the crushing zone is 3.72 m, the width of the plastic zone is 10.83 m, the bearing pressure affects a farther range and decreases slowly, the over-front bearing pressure affects a farther range and has a greater impact on the over-front support.

2) Numerical simulation analysis shows that along the direction of workface advance, the initial collapse step of the old roof is about 30 m, the peak stress is located at about 9 - 12 m, and the influence range is 30 m; on the side of workface hollow area, the peak location of lateral bearing pressure is 13 m, the concentration coefficient of bearing pressure is about 2.5, and the influence range reaches about 25 m; the superimposed over-front and lateral bearing pressure will have a greater influence on the workface down-slot. The superimposed overrun and lateral support pressure will have a large impact on the overrun support of the working face.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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