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Study on the Optimization of the Sequence of Continuous Mining and Backfilling of 3 Coal in the Protected Coal Column

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Abstract: In the process of coal mining, unreasonable recovery sequence is likely to lead to rock subsidence and surface deformation. In order to ensure the safety of shaft works as well as surface buildings and structures during coal pillar recovery and extend the service life of the mine. In this paper, we adopt the continuous mining and charging mining method to recover the protected coal pillar with the engineering background of 3 coal recovery from the coal pillar under the dense building (structure) of Z coal mine industrial square. Based on the comprehensive consideration of the stability of coal pillar and resource recovery rate, the research methods such as theoretical analysis and numerical simulation are used to explore the overburden and surface subsidence reduction methods from the microscopic perspective of optimizing the sequence of supporting lane of coal mining with continuous mining and continuous charging for coal pillar 3 coal in coal mine industrial wide. It provides new ideas for reasonable recovery of coal pillar for mine protection.

1. Introduction

The advantage of continuous mining and charging mining method is that the mining and charging are independent of each other and the mining and charging work in parallel. It is an important part of "three down" coal mining and green mining because it can effectively reduce the settlement of the overlying rock layer, control the surface deformation and movement, and protect the surface construction, structures and ecological environment [1]. In the late stage of mining, in order to extend the mine life and improve the resource recovery rate, the recovery of the "three lower" coal pillars is the trend [2-4]. In different stages of coal filling, the support structure of the mine roof changes, and the roof bearing mechanism goes through three stages: coal pillar support, coal pillar and filler synergistic support, and filler support [5]. Wang Fangtian et al [6] further investigated the control effect of filling body and coal column synergistic effect on roof deformation, and revealed the filling body-support-coal body synergistic bearing mechanism in filling working face. The research on the retrieval sequence is more abundant, and most scholars use numerical simulation and the combination of numerical simulation and algorithm to study the retrieval sequence from the perspective of surrounding rock stability. Hu et al [7] used FLAC3D simulation technology to analyze five different retrieval schemes in pairs, and studied two feasible retrieval sequence simulation schemes under different stress timescales to optimize the retrieval sequence of deep shaft mining in Dongguashan.

The comprehensive analysis concludes that a reasonable retrieval sequence can effectively control the overburden movement damage and surface subsidence after mining, and protect the surface buildings and the ecological environment of the mine area during the mining process of "three lower" pressed coal. In this paper, we study the influence of mining sequence on surface movement in one mining cycle and the gradual bearing characteristics of the filling and isolation bodies in the process of continuous mining and filling, and use FLAC3D simulation software to establish the actual mining model. By coordinating the sequence of branch lane mining, adjusting the process of mining to control the degree, uniformity and influence of rock displacement, and selecting a reasonable sequence of back mining, we provide theoretical basis and scientific guidance for safe and efficient mine production.

2. Engineering Analysis

2.1. Project Overview

Z coal mine industrial square buildings, structures dense, in order to control surface subsidence, to protect the surface buildings, structures, proposed to use continuous mining and charging mining method to recover work wide coal column. The 3 coal seams within the industrial plaza coal pillar are thick coal seams with complex structure and stable thickness, the average burial depth of the lower coal seam is about 155m, the average thickness of the coal seam is 5.2m, the dip angle is 10 °, the coal seam recoverability index Km=1, and the coal thickness variation coefficient γ=10.3%.

2.2. Design method of continuous mining and charging mining

The layout of the mining support lane and the sequence of mining and charging in the coal column mining section are shown in Figure 1. The working face is divided into four mining sections, and each section contains 11 mining support lanes. The whole charging operation process is carried out in a cycle with 11 supporting lanes, the digging direction is from the lower chute to the upper chute (two 1# lanes are constructed at the same time), the filling direction is from the upper chute to the lower chute, and the charging is carried out in a cycle.

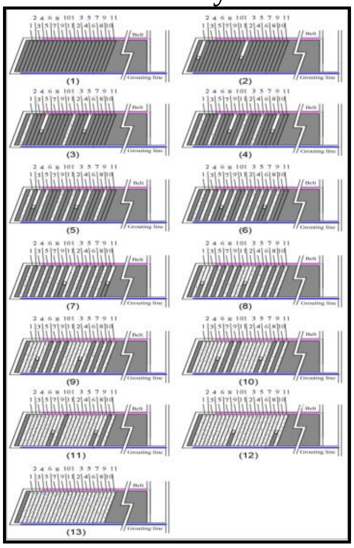


Figure 1: Flow chart of CECB and connection in trial mining face

2.3. Analysis of isolation body gradual bearing characteristics

In this paper, the area where the branch lanes are separated from each other in the same cycle of continuous mining and charging is defined as the isolation body. In the process of mining and charging, it is found that the overburden stress will be concentrated on the coal body on both sides when the parameters of the initial strength and deformation modulus of the branch lane filling body do not reach the ideal bearing state, and the restriction on the horizontal movement of the coal column on both sides subject to stress shear damage is small, and the overburden rock appears to sink to a certain extent at this time. With the solidification of the filler and its mechanical parameters gradually improve, the sinking rate of the overburden gradually decreases until the mechanical equilibrium between the overburden, coal column and the filler is reached again. Therefore, this paper proposes that the interaction between the coal column, the filling body and the overburden is a gradual bearing process, which can be divided into three bearing stages, as shown in Figure 2: the isolated body alone bearing stage, the filling body acting stage and the quarry stress balance stage. In Fig. 2, is the average overburden capacity; is the average depth of coal seam; (i=1, 2, ..., 10) is the stress concentration coefficient.

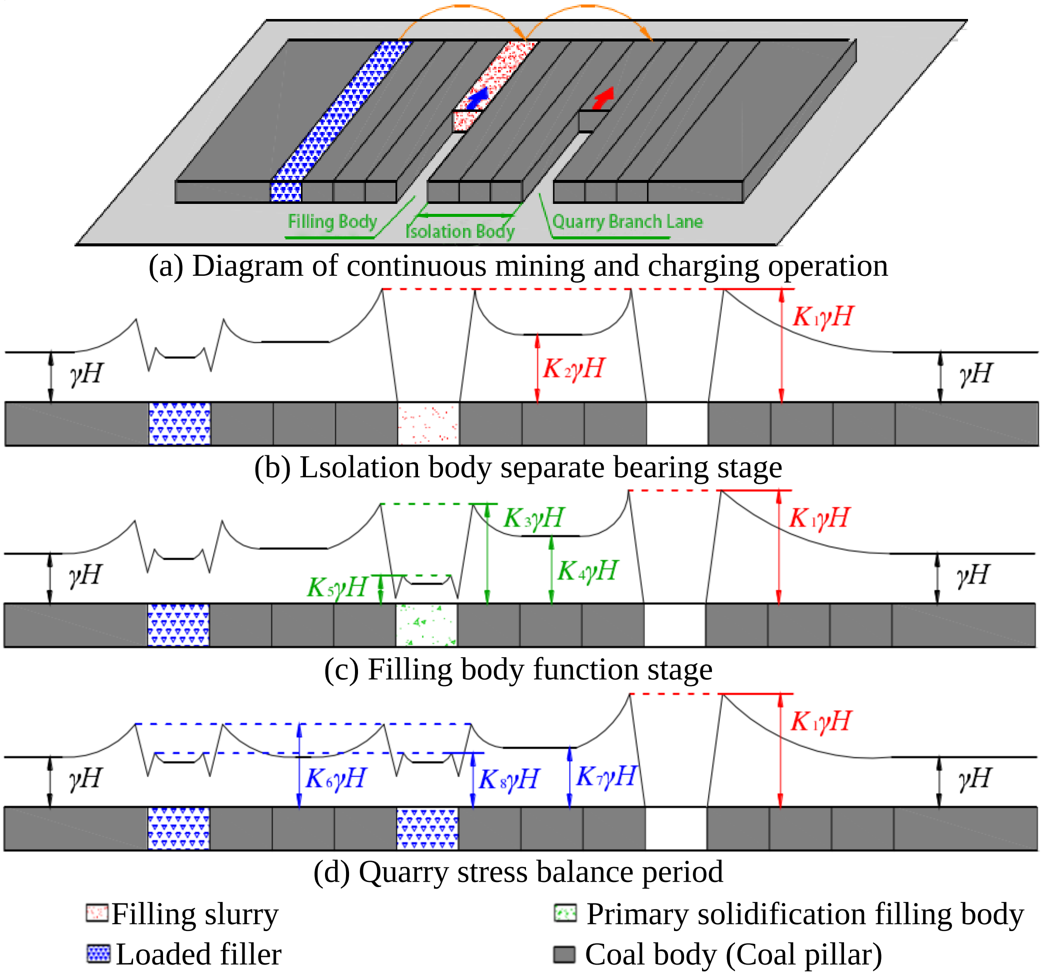


Figure 2: Progressive loading process of Continuous Excavation and Continuous Backfilling

2.4. Optimization of mining support lane sequence

According to the analysis of the isolated body gradual bearing characteristics, in the process of continuous mining and even filling mining, should try to avoid continuous mining and filling adjacent or interval ($K_1\gamma H$ adjacent or spaced consecutively), to avoid the isolated body alone bearing stage and filling body to play a role as well as bearing concentrated stress. 2# left and right two are filling body, and the left side of the interval 1 branch lane of 11# in the filling stage, mining 2# will appear stress concentration phenomenon ($K_1\gamma H$ adjacent or at intervals in succession). The same problem will occur if 8# and 10# are mined. At this point only 4# and 6# are left to choose, after a total of 48 alternative options, after a preliminary analysis, some of the options are listed. As can be seen from Table 1, there are four options meet the requirements, where the difference between option (I) and option (II) is the sequence of 6# and 10# mining order, option (I) working face moving farther away, option (II) mining 10# first, 6# in this mining cycle, play a better support role, and mining 10# branch lane first, the impact on the next cycle is smaller. Option (III) and option (IV) mining moving distance is farther, considering the actual mining situation, option (II) is selected as the optimized order of branch lane.

Table 1: Optimization scheme of support roadway sequence in CECB

<table>
<tr><td rowspan="15">11#</td><td rowspan="7">4#</td><td>2#</td><td colspan="4">At the time of 2# mining, 4# was in the filling stage. The middle 3# filling body carries double side load.</td></tr>
<tr><td>6#</td><td colspan="4">At the time of 6# mining, 4# was in the filling stage. The middle 5# filling body carries double side load.</td></tr>
<tr><td rowspan="4">8#</td><td rowspan="2">2#</td><td>6#</td><td>10#</td><td>Optional program (I)</td></tr>
<tr><td>10#</td><td>6#</td><td>Optional program (II)</td></tr>
<tr><td>6#</td><td colspan="3">At the time of 6# mining, 8# was in the filling stage. The middle 7# filling body carries double side load.</td></tr>
<tr><td>10#</td><td colspan="3">At the time of 10# mining, 8# was in the filling stage. The middle 9# filling body carries double side load.</td></tr>
<tr><td>10#</td><td colspan="4">At the time of 10# mining, 11# was in the initial condensation stage of the filling body, and the mining support lane was adjacent to each other, and the empty roof distance was >5.5m.</td></tr>
<tr><td rowspan="8">6#</td><td rowspan="5">2#</td><td>4#</td><td colspan="3">At the time of 4# mining, 2# was in the filling stage. The middle 3# filling body carries double side load.</td></tr>
<tr><td rowspan="2">8#</td><td>4#</td><td>10#</td><td>Optional program (III)</td></tr>
<tr><td>10#</td><td colspan="2">At the time of 10# mining, 8# was in the filling stage. The middle 9# filling body carries double side load.</td></tr>
<tr><td rowspan="2">10#</td><td>4#</td><td>8#</td><td>Optional program (IV)</td></tr>
<tr><td>8#</td><td colspan="2">At the time of 8# mining, 10# was in the filling stage. The middle 9# filling body carries double side load.</td></tr>
<tr><td>4#</td><td colspan="4">At the time of 4# mining, 6# was in the filling stage. The middle 5# filling body carries double side load.</td></tr>
<tr><td>8#</td><td colspan="4">At the time of 8# mining, 6# was in the filling stage. The middle 7# filling body carries double side load.</td></tr>
<tr><td>10#</td><td colspan="4">At the time of 10# mining, 11# was in the initial condensation stage of the filling body, and the mining support lane was adjacent to each other, and the empty roof distance was >5.5m.</td></tr>
</table>

3. Model Building

3.1. Odel Design

The model range was selected to study the mining pressure emergence law and surface deformation law under the conditions of the two mining schemes, with the mining filling sequence of the test mining face as scheme (I) and scheme (II). The model size is 540m (length) × 110m (width) × 185m (height), and the Mohr-Coulomb model is used for the overburden and coal seam floor. Considering the factors of calculation accuracy and calculation time, the grid refinement is carried out for the rock layers near the coal seam. Due to the complex topography, certain simplifications were made, and the built model is shown in Figure 3. The model is divided into 731,790 cells and 843,760 nodes.

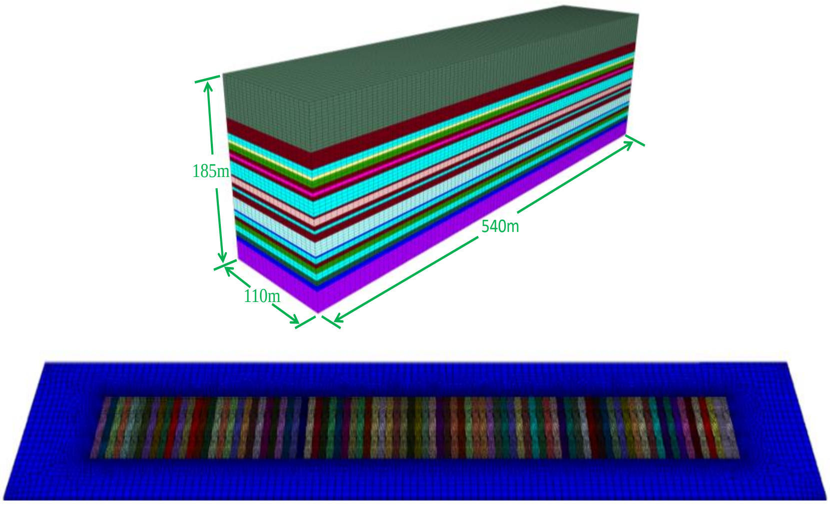


Figure 3: Numerical simulation model

3.2. Selection of material parameters

Table 2: Table of mechanical parameters for numerical models

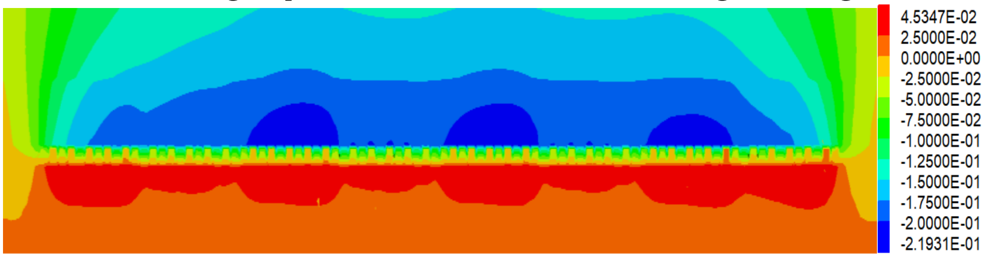
Rockiness	Bulk modulus/GPa	Shear modulus/GPa	Internal cohesion/MPa	Internal friction angle/ °	Tensile strength/MPa	Density/ (kg/m3)
Loose layer	0.03	0.02	0.03	23	0.16	1650
Limestone	5.20	3.50	2.00	40	4.00	2400
Batu lanau	2.50	1.60	4.00	41	3.00	2600
Batu pasir halus	3.40	1.90	1.60	30	1.40	2700
Lapisan tanah liat berpasir	2.60	1.70	1.50	26	1.60	2100
Batu pasir sedang	3.20	1.80	1.60	35	2.20	2700
Batu pasir kasar	4.90	4.10	2.30	33	1.70	2850
Batulempung berkapur antarbatu	3.10	1.20	2.10	30	3.00	1450
Batubara 1 (2)	0.57	0.23	0.60	48	2.00	1300
Clayey siltstone	2.60	0.90	2.00	32	0.80	2100
Coal Line	0.57	0.23	0.60	48	2.00	1460
Batubara 3	0.57	0.23	0.60	48	2.00	1460
Filling body	0.50	0.40	1.10	34	0.60	1800

The rock otology model of this simulation study refers to the actual observation data of surface deformation during the recovery process of Gongguang protection coal pillar 302 test mining face, and takes into account the influence of homogeneity, joints, fissures and other factors of the rock body, the mechanical parameters of the filling body and each rock layer are shown in Table 2.

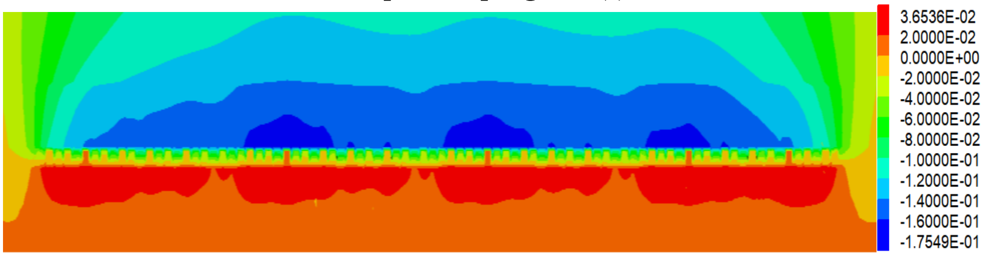
4. Analysis of results

4.1. Ovement deformation analysis

Numerical simulation of scenario (I) and scenario (II) were carried out separately, and the displacement comparison analysis was calculated. The overburden and surface movement deformation under two mining sequence conditions are shown in Figure 4, Figure 5 and Figure 6.

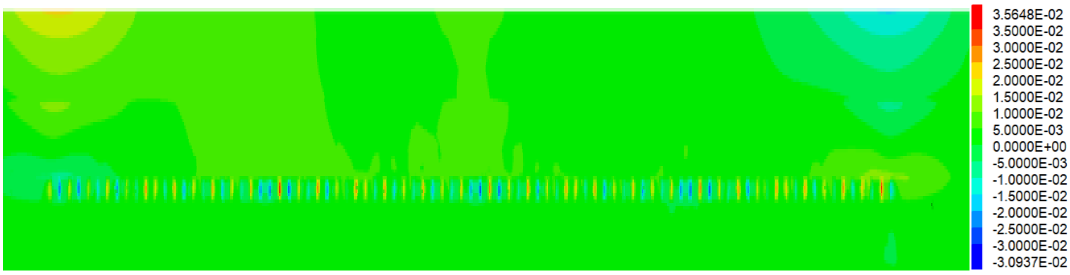


Optional program (I)



Optional program (II)

Figure 4: Vertical displacement diagram of different mining schemes



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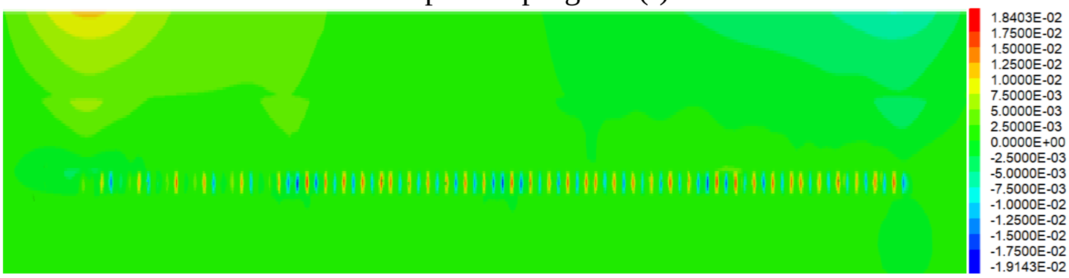


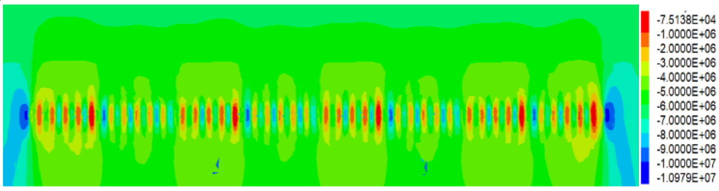
Optional program (II)

Figure 5: Horizontal displacement diagram of different mining schemes

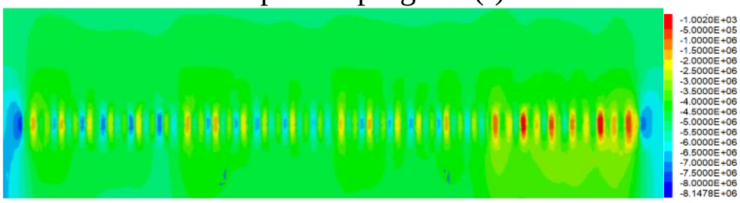
From Fig. 4 and 5, it can be seen that after the complete mining and filling of the continuous mining and filling face, the overburden movement and surface settlement of the two mining solutions are obviously different, the peak of vertical displacement is 219mm and the peak of horizontal displacement is 30.9mm. from the displacement analysis, it can be seen that after the excavation of the quarry, the roof of the quarry is affected the most and the surface is affected the least, and the roof of the quarry should be supported during the excavation of the quarry to protect the roof stability. Comparing the displacements of the two mining solutions, it can be found that the mining solution (II) optimized according to the gradual bearing characteristics of the isolated body and the filling body and the overlying rock can reduce the impact on the overlying rock layer and reduce the damage to the surface.

4.2. Stress analysis

The quarry excavation makes the original rock stress balance of the quarry broken, and the quarry stress is redistributed. From Fig. 6 and 7, it can be seen that the stresses are concentrated at the coal walls on both sides of the working face after the continuous mining and filling is completed, and the values are larger.

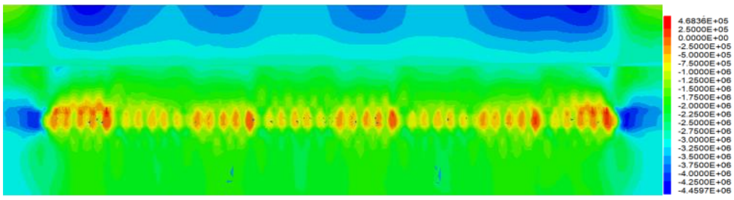


Optional program (I)

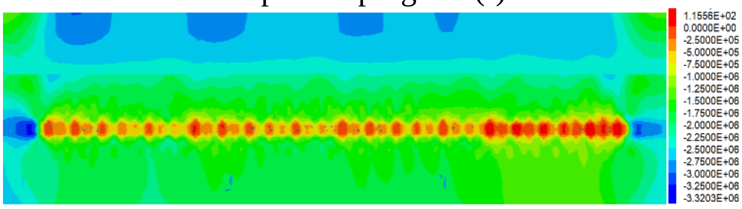


Optional program (II)

Figure 6: Vertical stress cloud map of different mining schemes



Optional program (I)



Optional program (II)

Figure 7: Horizontal stress cloud map of different mining schemes

Through Table 3 and 4, when comparing the two schemes, under the condition that the filling rate and the strength of the filling body are certain, the scheme (II) reduces the isolated body $K_1\gamma H$ load adjacent to each other or appearing continuously, which can reduce the stress concentration and make the overlying rock layer sink evenly after continuous mining and filling, so that the vertical stress of the filling body and the tensile stress of the top plate are relatively balanced.

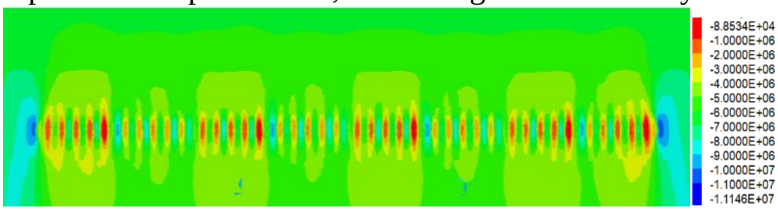
Table 3: Stress calculation results for each scheme

Group number	Vertical stress maximum/MPa	Horizontal stress maximum/MPa
Program (I)	10.9	4.45
Program (II)	8.14	3.32

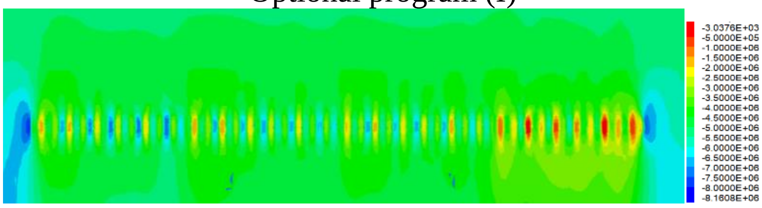
Table 4: Calculation results of stress in different zones of each scheme

Group number		Maximum force on filling body/MPa	Max. tensile stress in the roof support road/MPa
Program (I)	First mining section	4.09	1.78
	Second mining section	4.45	1.91
	Third mining section	4.21	1.8
	Fourth mining section	3.31	1.57
Program (II)	First mining section	3.26	1.48
	Second mining section	3.21	1.45
	Third mining section	3.14	1.39
	Fourth mining section	2.35	1.15

After the completion of mining in the quarry, the main stress concentration appears at the coal wall on both sides of the working face, and it is expressed as tensile stress when the maximum main stress is positive, and as compressive stress when the maximum main stress is negative. During the mining process, the rock displacement and each filling body is unevenly loaded, and compressive stress concentration appears at the coal wall on both sides of the working face, which makes the stress change range different and the overburden damage degree different. As shown in figure 8, The maximum principal stress value is 11.1 MPa in option (I) and 8.16 MPa in option (II), and the stress variation range in option (I) is gradually developed upward, and the overburden damage height is also larger. The top and bottom of the filling body are prone to tensile damage, and the plastic zone damage is mainly shear damage. If the area of the plastic zone is large in both walls of the working face, and a section of the filling body has a plastic zone penetration, the quarry has the possibility of destabilization damage. As shown in figure 9, Program (II) mining plastic area is smaller than program (I), the top and bottom plate only sporadic tensile damage, and the filling body does not appear plastic zone penetration, the mining site is relatively stable.

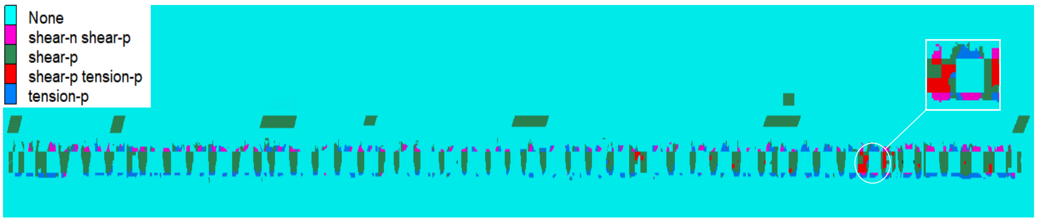


Optional program (I)

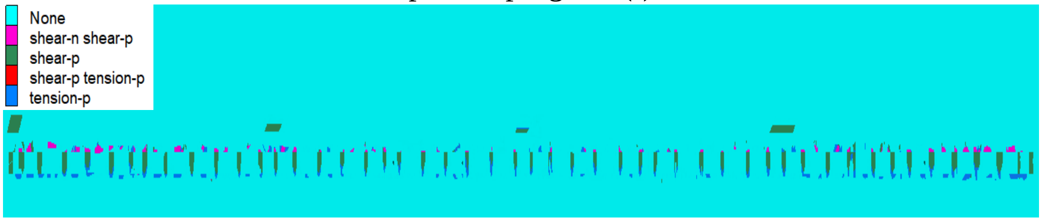


Optional program (II)

Figure 8: Cloud diagram of maximum principal stress in different mining schemes



Optional program (I)



Optional program (II)

Figure 9: Plastic zone diagram of different mining schemes

5. Conclusion

(1) Through the analysis of the observation data of surface movement and deformation at the trial mining face of 3 coal 302 in the protection column of Gongguang, the surface movement and deformation law in the mining process was explored and the asymptotic bearing characteristics model of the filling body and isolated body in the process of continuous mining and filling was proposed, and the sequence of branch lane retrieval was optimized according to the asymptotic bearing characteristics model, and the optimized mining sequence was finally determined as 1#, 5#, 9#, 3#, 7#, 11#, 4#, 8#, 2#, 10#, 6#.

(2) Based on the geological mining conditions of the mine, the FLAC^{3D} numerical model of continuous mining and filling mining of the working face was established, and the effects of the two mining scenarios on the overburden and surface movement deformation as well as the overburden and filling body stresses were simulated and analyzed. The maximum vertical displacement is 175mm, the maximum horizontal displacement is 19.1mm, the maximum surface subsidence is 104mm, and the horizontal surface displacement ranges from 14.3mm to -12.1mm. compared with option (1), the displacement of this option is moderate, and the overburden and surface displacement are smaller. By analyzing the overburden and filler stresses, it is found that the peak vertical stress of scheme (II) is 8.14 MPa, the maximum horizontal stress is 3.32 MPa, and the maximum principal stress is 8.16 MPa, all of which are smaller than that of scheme (I). Based on this, it can be concluded that scheme (II), which is optimized according to the progressive bearing characteristics model for the branch lane retrieval sequence, is significantly better than scheme (I), and the stability of the underground surrounding rock can be better maintained under this scheme.

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