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Study on the structure and strata behavior regularity of repeated mining overburden of close-distance shallow buried coal seam group

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ABSTRACT:

This paper studies the collapse structure, plastic failure regularity, and overburden movement regularity in the mining process of the Shallowly Buried Coal Seam (SBCS) group in the Yulin area using physical similar material simulation, computer numerical simulation, and theoretical analysis. The objective of the present article is to explore the strata behavior regularity of the SBCS group, taking the engineering geological conditions of Hongliulin Coal Mine as the sample. According to the results, when the lower coal seam of the SBCS group is mined, the initial stress step increases, and the periodic stress step decreases compared to the upper first coal seam. During the mining of the lower coal seam, there is an extreme collapse span in the interlayer rock formation: the process induces the activation of the collapsed roof in the goaf of the upper coal seam, and the overall sinking phenomenon occurs. The dynamic stress is obvious. The roof stress is significant in passing through the upper coal seam's residual coal pillar (CP) into the lower coal seam. The CP is at a certain distance, and the residual CP is violently unstable and sinks the strata behavior regularity. The interlayer rock layer forms an inclined shear staggered fracture zone along the coal wall. The research results provide a theoretical method for controlling mine stress and green and safe mining in the SBCS group of coal production enterprises.

Keywords: SBCS group; similar material simulation; numerical simulation; residual coal pillar (CP); cover rock construction; strata behavior regularity

Estudio sobre la estructura y la regularidad del comportamiento de capas sobrecargadas en minería de un grupo de vetas de carbón enterradas a poca profundidad y a corta distancia

RESUMEN

Este artículo estudia la estructura de colapso, la regularidad de la falla plástica y la regularidad del movimiento de sobrecarga en el proceso de minería del grupo Veta de Carbón Somera (SBCS, literal del inglés Shallowly Buried Coal Seam) en el área de Yulin a través de simulación material, simulación numérica computarizada y análisis teórico. El objetivo del presente estudio es explorar el comportamiento regular del grupo SBCS con las condiciones ingenieriles y geológicas de la mina de carbón Hongliulin como ejemplo. De acuerdo con los resultados, cuando se extrae la capa más baja del grupo SBCS el punto de tensión inicial aumenta y los puntos periódicos de tensión disminuyen en comparación con la capa más alta de explotación. Durante la explotación de la capa más baja hay un punto de colapso extremo en la formación rocosa entre capas: el proceso induce la activación del techo colapsado en el socavón de la capa superior de explotación y el fenómeno hundimiento general ocurre. La dinámica de la tensión es evidente. La tensión del techo es determinante cuando pasa a través del pilar de carbón de la capa superior de explotación hacia la capa inferior. El pilar de carbón se encuentra a una distancia determinada y su residual es bastante inestable. La capa de roca forma una zona de fractura escalonada de corte inclinado a lo largo de la pared de carbón. Lo resultados de la investigación proveen un método teórico para el control de tensión al interior de una mina, y procedimientos de minería verde y segura para las empresas productoras en el grupo SBCS.

Palabras Clave: grupo Veta de Carbón Somera; simulación material; residual del pilar de carbón; estructura de la roca de cubrimiento; regularidad del comportamiento de capas.

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1. Introduction

Based on previous studies, many valuable conclusions have been obtained from the strata behavior regularity and rock formation control theory of the SBCS group. The compaction measurement of the N1200 working by Ningtiaota Coal Mine in the valley shows that the strata behavior regularity under the goaf is different from that of the conventional working interface, such as the stress intensity being large, the size of the cycle being alternate, and the stress being more sudden (Shuangcheng et al., 2013). Taking the 12101 working interface of Halagou Coal Mine as the engineering background, Liu Jiaxin concluded that the lower coal seam working interface passed through the upper concentrated CP, and the overall rotation movement of the CP and the critical block of the roof of the lower coal seam occurred in the CP stage. The CP was unstable, broken, and sinking, and strong mine stress appeared (Jiaxin, 2020). Huang Qingxiang studied the SBCS goaf in the very close distance of the Huoluowan Coal Mine. The initial and periodic stress step of the lower SBCS were significantly lower than that of the upper SBCS (Qingxiang et al., 2018A). Yu Bin found that the Jurassic coal seam group is relatively spacious, the interlayer rock layer is easily broken, and it is easy to connect with the upper coal's collapsed and broken roof structure to form a broken roof group structure (Bin, 2015). Huang Qingxiang proposed that the SBCS group should be divided into three types, which are no critical layer, single critical layer, and double key layer according to the inter-mining ratio (the thickness ratio of the interlayer to the mining height of the lower SBCS) (Qingxiang et al., 2018B). Qingxiang et al. (2019) found that when the lower coal seam was mined through the upper coal seam's goaf, the working interface's stress step distance became shorter. The strength increased, and the strata behavior regularity of the lower SBCS working interface had the most significant impact on the upper SBCS pillar. Huang et al. (2017) summarized the basic strata behavior regularity of a relatively single SBCS mining, with relatively small periodic stress step and high compressive strength in the mining process of the SBCS group. Qingxiang et al. (2018C) chose the downward mining of close-distance SBCS in the Yushen mining area of northern Shaanxi Province. They studied through physical simulation that during the mining of coal seams under the close-range coal seams, the roof of the interlayer rock layer generally has a single key layer, and the roof is broken for the first time. Huang et al. (2018) on-site investigation found that when the thickness of the interlayer rock layer of the SBCS group in the Shenfu mining area is mostly 15~ 45m, the interlayer rock layer is prone to a single key layer structure. The periodic stress step distance decreases, the strength increases, the coal wall is serious, and the dynamic load phenomenon, step sinking phenomenon, and large and small cycle stress phenomenon are obvious. Qingxiang et al. (2019) actual measurement of the 4^{-2} and 5^{-2} coal seams in the Shenfu mining area found that the SBCS shortened the compression step distance by 25% and increased the compressive strength by 15%~22% compared with the single coal seam mining cycle. In order to understand the changes in the cover rock construction of the SBCS group after mining, Jiang et al. (2022) studied the overburden regularity and bearing capacity of the abandoned coal mine of the SBCS group. Chen et al. (2022) used a combination of theoretical-numerical simulation to study the directional evolution of the maximum principal stress facing the influence of double coal seam mining.

The Jurassic coalfield is rich in coal resources in northern Shaanxi and has the regularity of many layers and close distance of the SBCS. At present, most of the large-scale mines in the Yushenfu mining area have been mined in the first layer of coal and have entered the lower SBCS mining stage successively (Haijun, 2019; Junhu, 2019; Limin et al., 2019; Shuangming et al., 2010.) The mining face of the lower SBCS will pass through the goaf of the upper one, the empty roadway, and all kinds of residual concentrations. Many years of production practice experience show that the repeated mining of the lower close SBCS group will have high mine stress intensity, violent stress, step subsidence, stress frame, and roofing. For example, when the 22103 fully mechanized mining face of Daliuta Well was 1.7m away from the boundary of the CP of the overlying 1^{-2} coal seam. The roof had intense stress, resulting in a frame accident in the middle of the working interface. During the period when the 31201 working interface of Shibitai Coal Mine passed the CP, it left over the overlying room-pillar goaf. The sheet gang roof and large-scale roof open-off cut and pressing frame accidents occurred. When the overlying CP was released, the 12102, 12103, and 12105 working interfaces had similar strong mine stress and pressing accidents. When the 43303^{-2} working interface of Yujialiang Coal Mine passed over the overlying concentrated CP, a large-scale strata failure open-off cut and pressing frame accident occurred. The working interfaces of coal seams 21304, 21305, and 21306 in the lower part of the third-panel area of the live Jitujing in Daliuta Coal Mine increased significantly after passing through the concentrated CP area (strip scouring zone) of the overlying coal seam and the coal wall sheet helped (Xiwen, 2020; Yongxi, 2015; Minggao, & Pingwu, 2020).

Based on the engineering geological conditions of the close SBCS group (3^{-1}, 4^{-2}, and 5^{-2} coals) in the Hongliulin Coal Mine in the Jurassic coalfield of northern Shaanxi, this paper analyzes the regularity of the mining stress of the lower coal seam, the fault structure regularity of the overlying strata and the interlayer rock layer of the upper coal seam through similar material simulation experiments. The working interface is deeply studied through the appearance regularity and generation mechanism of the overlying residual CP stress, which provides a new method for the control of the mining roof of the SBCS group.

Physical similar material simulation

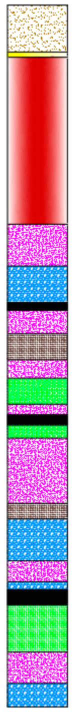
The coal-bearing strata of Hongliulin Coal Mine are the Middle Jurassic Yan'an Formation, and the designed main coal seams in the North Second Panel are 3^{-1} coal, 4^{-2} coal, and 5^{-2} coal. The average spacing between 3^{-1} coal and 4^{-2} coal is 43.51 m, and the average spacing between 5^{-2} coal and 4^{-2} coal is 61.54 m. The construction of the plane model experimental frame of similar materials is based on the engineering geological conditions of the North Second Panel in Hongliulin Coal Mine. The thickness of each rock layer is based on the histogram data of No. 6-HB6 borehole, see Figure 1. The physical and mechanical parameters of the main coal and rock are shown in Table 1 and the geometric similarity ratio is Cl = 200. The average density of the overlying strata layer is about 2400kg/m3, and the density of the model material is 1600kg/m3. The bulk density similarity ratio is CY = 1.5 ratio, stress similarity ratio is $C\sigma = 200 \times 1.5 = 300$. The size of the experimental model is $300 \times Ct = \sqrt{200} = 14.14$, 20×134.5cm, the length of the engineering geological prototype is 600m, and the height is 269m.

After the model is air-dried, the excavation scheme is designed, and the coal seam group adopts the descending mining sequence. Then, 60m protective CPs were set at both boundaries of each coal seam excavation: 1m was pushed forward at each step of the coal face (5mm of model excavation), and 20m CPs were set between the disk areas to reduce the influence of the boundary effect. Digital photography and sketching were used to observe and record the caving structure regularity and movement rules of overlying strata during the excavation of 3^{-1} coal, 4^{-2} coal, and 5^{-2} coal.

2 Overburden fracture structure and movement rules

2.1 3^{-1} coal roof breaking regularity and movement rules

3^{-1} coal is the first coal seam of the SBCS group. First, the open-off cut was arranged on the right side of the 3^{-1} coal. The working interface was gradually advanced from right to left, and when the working interface was upside to 50m, the overlying upper rock layer collapsed. The collapse height was 2m, and the roof produced a separation structure. With the continuous advancement of the working interface, the separation phenomenon gradually developed upward, and the number gradually increased. When the working interface advanced to 74m, the basic roof reached the initial limit collapse step and suddenly appeared a large range of falling bodies. The collapse height was 18m, as shown in Figure 2. With the continuous advancement of the working interface, the basic roof was periodically broken and collapsed. The working interface appeared to be cyclically pressed, and the periodic stress step distance was 8-16m (16, 8, 14, 16, 16, 12), advancing to 310m to stop mining. After that, the open-off cut was arranged on the left side of the 3^{-1} coal, and the working interface was pushed from left to right. It was observed that the basic roof initial stress step distance was 79m, and the periodic stress step distance was 10-16 m (16, 13, 11, 16, 16, 16, 10). Finally, the left side was excavated to 290m, leaving a 20m panel interval CP in the middle.



Number	histogram	Lithology	Thickness(m)	Burial depth (m)
1		Aeolian sand	18	18
2		Loess	2	20
3		Red soil	64	84
4		Siltstone	16	100
5		Medium siltstone	14	114
6		No3-1 coal mine	3	117
7		Siltstone	9	126
8		Fine siltstone	10	136
9		Siltstone	7	143
10		Sandy mudstone	10	153
11		Siltstone	4	157
12		No4-2 coal mine	4	161
13		Sandy mudstone	5	166
14		Siltstone	25	191
15		Fine siltstone	6	197
16		Medium siltstone	16	213
17		Siltstone	8	221
18		Medium siltstone	3	224
19		No5-2 coal mine	6	230
20		Fine siltstone	18	248
21		Siltstone	12	260
22		Medium siltstone	9	269

Figure 1. Coal seam histogram.

Table 1. Physical and mechanical parameters and ratio of SBCS

Rocky	Bulk density/g/cm^3	Tensile strength/ MPa	Internal cohesion/ MPa	Internal friction angle/°	Tomarimatsuhi	Ratio number
Aeolian sand	2.12	0.06	0.8	28	0.13	-
loess	1.86	0.08	0.92	29.4	0.15	-
laterite	2.02	1.22	1.28	27.4	0.18	-
Powdered siltstone	2.44	0.93	6.18	36.2	0.19	937
Medium siltstone	2.28	2.18	6.07	37.1	0.18	828
coal	1.34	1.24	4.72	35.2	0.26	-
Fine siltstone	2.29	2.29	5.6	37.3	0.2	837
Sandy mudstone	2.3	0.29	5.85	28.6	0.24	928

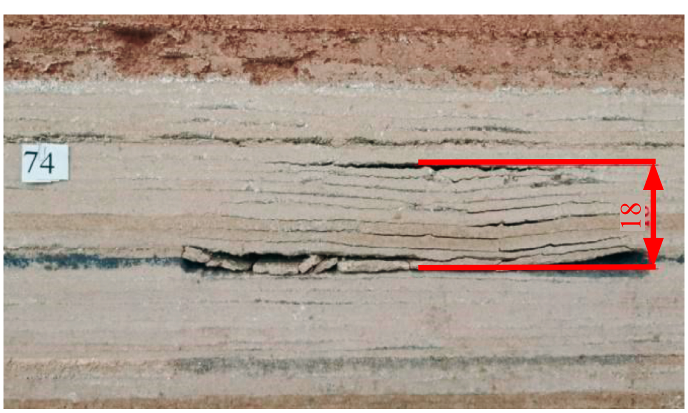


Figure 2. Structural regularity of the initial collapse of the 3^{-1} coal basic roof

2.2 4^{-2} coal regularity and movement regularity of coal roof

At the end of 3^{-1} coal mining, the overlying strata formation of 4^{-2} coal was the roof of 3^{-1} coal, and the interlayer rock formation between 3^{-1} coal and 4^{-2} coal. After the collapse of the overlying strata layer of 3^{-1}, the coal reaches a stable state, and the working interface of the panel is arranged in the 4^{-2} coal. First, the open-off cut was arranged on the left side of the 4^{-2} coal, and the working interface was gradually advanced from left to right. When the working interface was advanced to 66m, the direct roof collapsed, and the height was 4m. When the working interface was advanced to 98m, the basic roof was pressed for the first time, but the stress was not violent. With the continuous advancement of the working interface, the roof separation gradually developed upward, but no large-scale collapse phenomenon occurred, and the mine stress appeared gentle. Until the working interface advanced to 118m, the interlayer rock layer suddenly broke through completely, the 3^{-1} coal collapse roof rock layer was activated, and the interlayer rock and the roof of the 3^{-1} coal goaf were formed. A whole, synchronous sinking, a wide range of collapse movement, the mine stress appeared violent, at this time for the third cycle of stress. The overburden fracture structure is shown in Figure 3. 4^{-2} Coal working interface cycle stress step distance 8-13m (8, 12, 12, 11, 13, 12, 12), the working interface was advanced to 350m to stop mining. 4^{-2} coal right side working interface, the initial stress step distance was 108m, and the periodic stress step distance was 10-12m (12, 12, 12, 12, 12, 10). In general, the initial collapse step distance of 4^{-2} coal was longer than that of 3^{-1} coal, and the step distance of periodic stress became shorter, advancing to 370m, leaving a 20m panel CP.

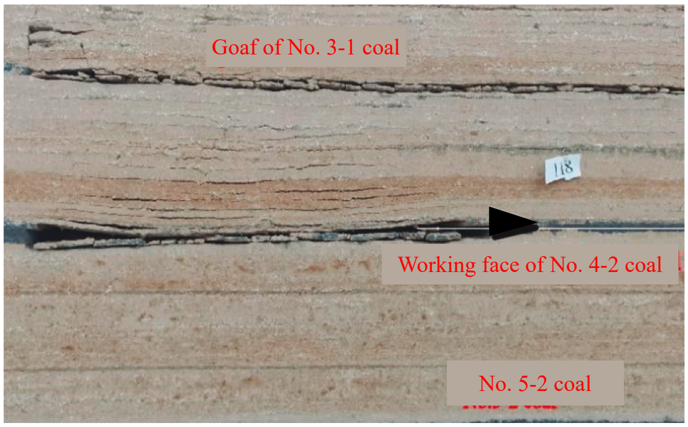


Figure 3. Structural regularity of 4-2 fractured rock in the third cycle of coal mining

2.3 5^{-2} fracture regularity and movement regularity of coal roof

At the end of 4^{-2} coal mining, the overlying strata formation of coal 5^{-2} is the goaf roof of 4^{-2} coal and the interlayer rock formation between 5^{-2} coal and 4^{-2} coal. After the collapse of the overlying strata layer of 4^{-2} coal reaches a stable state, the working interface of the panel is arranged in 5^{-2} coal. First of all, the open-off cut is arranged on the right side, and the working interface is pushed from right to left, and when the working interface is advanced to 100m, it collapses directly, and the height of the collapse is 4m. Similar to the excavation process of 4^{-2} coal, the working interface is advanced to 136m, and the old roof is pressed for the first time, but the mine stress is not violent. With the advancement of the working interface, the roof separation gradually develops upward, when the working interface is advanced to 152m, the interval between 5^{-2} coal and 4^{-2} coal and the sudden breakthrough break, 3^{-1} coal and 4^{-2} coal 3^{-1} coal goaf roof rock formation activation, synchronous sinking, large-scale collapse movement, the mine stress appears violent, and the working interface cycle stress step distance is 6-10m (10, 6, 8......), of which the fourth cycle is pressed as shown in Figure 4, which was advanced to 258m to stop mining. 5^{-2} Coal left side working interface, the initial stress step distance is 132m, and the periodic stress step distance is 8- 10m (8, 10, 8......). In general, the initial collapse step of 5^{-2} coal is longer than that of 3^{-1} coal and 4^{-2} coal, and the cycle stress step distance is shorter. Finally, the left working interface is advanced 238m, leaving a 20m panel interval CP.

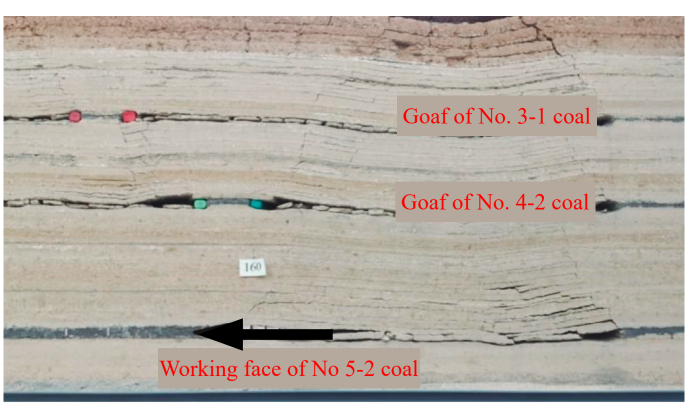


Figure 4. Structural regularity of the fourth cycle of coal mining to strata failure

3. The movement regularity of the overlying CP strata failure

3.1 Theoretical analysis of the influence of legacy CP

In the specific coal mine production practice, in order to ensure the safety of the mining work, it is necessary to leave a panel to protect the CP between the working interfaces of the two panels. In this simulation experiment, 3^{-1} coal and 4^{-2} coal seams are left with 20m panel CPs between adjacent working interfaces. In the process of 4^{-2} coal mining, there will be concentrated stress areas formed by CPs in the bottom plate of the coal mining interface through the 3^{-1} coal residual panels, and in the process of 5^{-2} coal mining, there will be concentrated stress areas formed by CPs in the bottom plate of the coal mining working interface through the 4^{-2} coal legacy panels.

The residual CPs form a stress concentration phenomenon on its floor in the upper coal seam, and the influence range is determined by the influence angle of stress transmission in some literatures, the internal friction angle and stress influence angle of the foundation in soil mechanics, and the angle of inclusion in the stress reduction zone and the concentrated stress transmission angle in some literatures. The working interface of the lower coal seam is affected by the concentrated stress theory of the residual CP in the upper coal seam, as shown in Figure 5. The influence range L of the concentrated stress is calculated as Equation 1.

$$L = a + 2b \qquad 1$$

where: a is the width of the residual CP, b is the influence distance of the concentrated stress of the residual CP in the upper coal seam.

The influence distance b of the concentrated stress of the CP can be calculated by Equation 2.

$$b = h \times \tan\varphi \qquad 2$$

where: h is the thickness of the rock layer between the upper and lower coal seams, m, and is φ the angle of influence of stress transmission, °.

The CP in the residual panel area of this experiment is 20m φ, and the spacing between 3^{-1} coal and 4^{-2} coal is 40m according to the histogram data of borehole 6-HB6, and the distance between 4^{-2} coal and 5^{-2} coal is 63m, which is calculated by equation (1). The influence range of 3^{-1} coal residual CP on the concentrated stress of 4^{-2} coal working interface is 49.2m (b = 14.6m), and the influence range of 4^{-2} coal residual CP on the concentrated stress of 5^{-2} coal working interface is 65.8m (b = 22.9m).

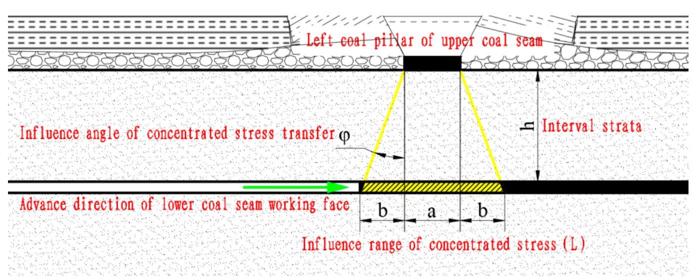


Figure 5. The mining of the lower coal seam affected by the concentrated stress of the residual CPs in the upper coal seam

3.2 The movement regularity of CP overburden in the 3^{-1} coal panel area of the 4^{-2} coal working interface

Affected by the CPs left over from the mining of the upper coal seam, the compression phenomenon of the bracket was greatly reduced in the process of mining the overlying CPs in the lower coal seam working interface in many mines in the Shendong mining area, which seriously affected the efficient production of the safety pipe of the coal mine. The statistical results show that this kind of frame generally appears within the boundary of the overlying CP mined in the working interface (related to the coal seam spacing), and there is generally no stress frame phenomenon in the mining process of entering the CP. It is necessary to explore the macroscopic structural regularity and internal mechanical mechanism of this kind of ore stress phenomenon.

At the beginning of the 4^{-2} coal working interface advancing 195m (15m away from the coal inlet pillar), the support stress increased significantly, and the coal seam force could be obviously felt during the excavation process. When the CP of the 3^{-1} coal residual panel is 22m out of the 4^{-2} coal working interface, the interlayer rock layer collapses, and the CP in the residual panel appears to be sharply unstable and sinking, and the strata failure failure regularity of the 4^{-2} coal working interface are sketched as shown in Figure 6.

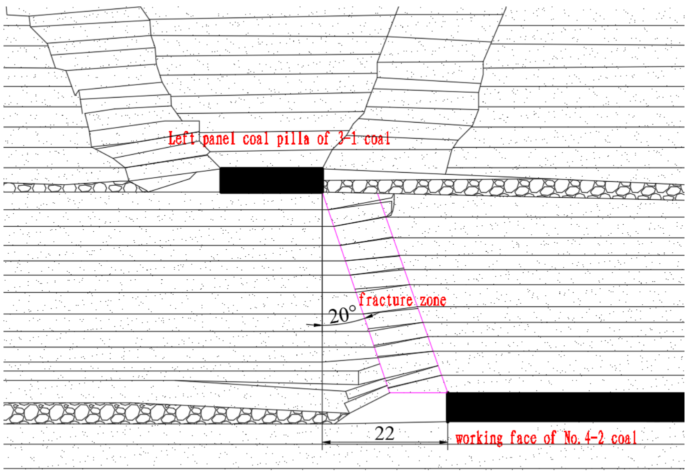


Figure 6. Sketch of the fractured structure of the overlying strata with the instability of the intervaled rock strata and the 3^{-1} CP

It can be seen in Figure 6 that the overlying strata of the roof on both sides of the 3^{-1} coal mining has fully collapsed, and the CPs in the residual panel have formed a certain stress concentration on the floor. The coal and rock types of the intervals between 3^{-1} coal and 4^{-2} coal include siltstone, fine-grained siltstone and sandy mudstone, and their lithology is relatively similar and does not form obvious key layer structure. The collapse position of the interlayer rock formation and the residual CP does not occur along the influence angle of stress transmission, that is, the 4^{-2} coal working interface is located at the 14.6m of the CP, but occurs near the 22m position of the CP, due to the close spacing of the coal seams, the overall breaking movement regularity of the interlayer rock formation occurs, and the CP of the 4^{-2} coal working interface is between 14.6~22mAn oblique shear staggered fracture zone is formed to the lower right.

3.3 The movement regularity of CP overburden in the 5^{-2} coal working interface through the 4^{-2} coal panel

The 5^{-2} coal working interface advances from right to left, and when it reaches the influence range of concentrated compressive stress of the CP in the 4^{-2} coal panel, the stress of the working interface support begins to increase. In the process of excavation, there is also no obvious ore stress regularity. When the CP of the 4^{-2} coal residual panel is 32m out of the 5^{-2} coal working interface, the interlayer rock layer collapses, and the CP in the residual 4^{-2} coal panel also appears sharply unstable and sinks, and the overburden failure regularity of the 5^{-2} coal working interface are sketched as shown in Figure 7.

Also from Fig. 7, it can be seen that the CP in the panel left over from the 4^{-2} coal forms a concentrated compressive stress on the bottom plate, which is transmitted to the 5^{-2} coal working interface through the spacer rock layer. The types of coal rocks in the intervals between 4^{-2} coal and 5^{-2} coal are siltstone, medium-grained siltstone, fine-grained siltstone and sandy mudstone, and no critical layer structure is formed. The stress transmission influence angle does not occur at the collapse position of the interlayer rock formation and the residual CP, that is, the 5^{-2} coal working interface is located at the CP b=22.9m, but occurs near the 32m position of the CP, and the interlayer rock formation forms an inclined shear staggered fracture zone to the lower left between the CP 22.9~32m of the CP of the 5^{-2} coal working interface. Subsequently, when the excavation of the 5^{-2} coal working interface is located below the CP in the 3^{-1} coal residual panel, the stress increase of the working interface support is not obvious, and there is no strong ore stress appearance, indicating that due to the

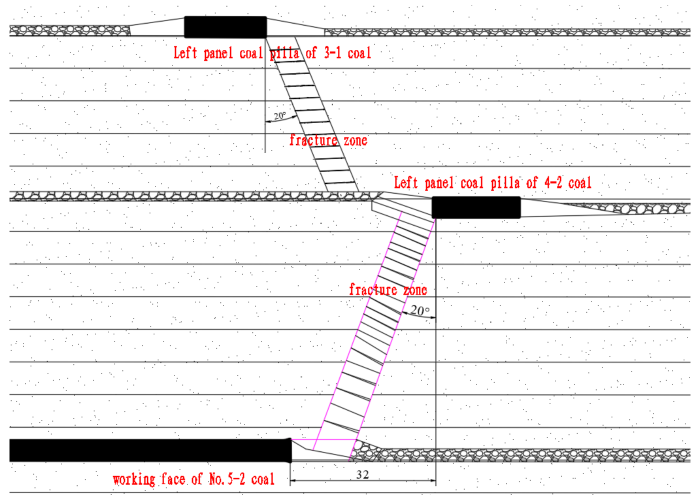


Figure 7. Sketch of the fractured structure of the strata failure with the instability of the intervaled rock strata and the CP left over from the 4^{-2} coal

4 FLAC^{3D} simulation

4.1 Establishment of the model

The similar material simulation experiments in the laboratory analyzed the geometric structure regularity of the overburden roof formation and the macroscopic fracture phenomenon of the movement regularity during the repeated mining process of close SBCS groups from the appearance and morphology. However, it does not reflect the size and location of the plastic failure range of the roof and overburden during the coal seam excavation process. It is necessary to use FLAC3D computer numerical simulation software to analyze the internal mechanism of fracture motion (plastic distribution, stress and displacement regularity) of overburden during the mining process. The calculation model is also constructed according to the histogram data of borehole 6-HB6 and Table 1, with a strike *length of 600 m (x-direction), a trend length (y-direction)* of 8 m, and a height (*z-direction*) of 269m, the model has a total of 147225 grids and 191936 nodes. According to the same excavation sequence and process as similar material simulation experiments, the excavation of the calculation model was carried out (60m boundary protective CPs were left on each side), and each excavation was 10m, and the calculation of 100 hours was carried out after the mining of each working interface. Due to the large number of coal seams and the cumbersome excavation process, this simulation does not analyze the stress regularity of the coal seam group mining process, but focuses on the failure regularity and movement regularity of the CP overburden in the upper coal seam working interface through the upper coal seam left panel.

4.2 Distribution regularity of plastic failure areas of overburden mining in coal seam groups

The plastic failure regularity of the overlying strata after the mining of the left working interface of 4^{-2} coal seam (x=290~310) in the coal panel area of the upper coal seam 3^{-1} are shown in Figure 8. After the mining of the right side of the 5^{-2} coal working interface through the CP (x=350~370) of the upper coal seam 4^{-2} coal panel, it reaches x=258, and the plastic failure regularity of the overlying strata after the excavation of the left working interface (the CP of the 5^{-2} coal panel area is x=238~258) are shown in Figure 9.

As can be seen from Figure 8, the stress concentration of the CP in the 3^{-1} coal legacy panel formation on its bottom plate causes the stress of the roof of the underlying 4^{-2} coal working interface to increase through the influence range of the area, and the plastic failure of the interlayer rock layer is mainly shear failure, supplemented by tensile failure. The plastic failure phenomenon shows that the vertical stress formed by the CP in the residual panel will cause the shear dislocation of the overall fracture structure in the interlayer rock formation between the CP in the 3^{-1} coal legacy panel and the 4^{-2} coal propulsion working interface, resulting in the phenomenon of slippage and instability, resulting in the pressing accident of the working interface. It can also be seen from Figure 9 that the CP in the 4^{-2} coal legacy panel also forms a stress concentration on its floor, and the interlayer rock layer between 4^{-2} coal and 5^{-2} coal is dominated by shear failure, supplemented by tensile failure.

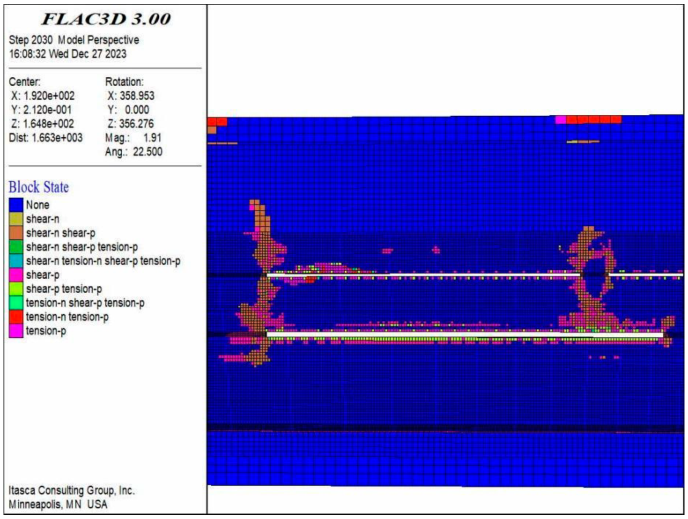


Figure 8. Regularity of plastic failure of strata failure after mining on the left side of the 4^{-2} coal working interface

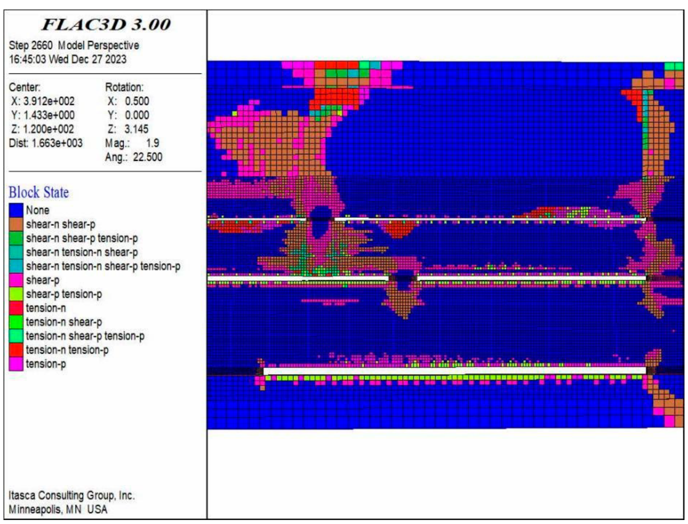


Figure 9. Plastic failure regularity of strata failure after mining on the right side of the 5^{-2} coal working interface

4.3 Deformation regularity of strata failure mining

In the process of advancing the working interface of the lower coal seam through the CP in the residual panel of the upper one, the sinking deformation of the CP is in a dynamic change process. The history function of FLAC^{3D} was used to record the dynamic changes of the vertical displacement of the CP. The occurrence of the severe instability of the CP was analyzed. In the mining process of the left working interface of 4^{-2} coal, the displacement monitoring point is set in the middle position of the CP at the bottom of the CP in the 3^{-1} coal panel (x=300, y=4, z=152), which is recorded as history id=2, and the vertical displacement curve of the residual CP in the 3^{-1} coal panel is shown in Figure 10. The displacement contour diagram of the left working interface of 4^{-2} coal after the end of mining is shown in Figure 11.

It can be seen from Figure 10 that the mining process of 4^{-2} coal working interface caused the subsidence deformation of the CP in the 3^{-1} coal legacy panel, the initial stage of the subsidence trend is relatively gentle, from 1860~2030 steps of vertical displacement sinking sharply, after the model excavation is completed, 100 hours of step calculation, 1860 hours after the start of 4^{-2} Coal working interface out of the CP 3^{-1} coal left panel mining process, it can be concluded that in the engineering production practice, the CP in the upper coal seam residual panel will be violently submerged in the process of CP out of the lower coal seam working interface. It can be seen from Fig. 11 that the displacement of the CP and the lower interlayer rock formation in the 3^{-1} coal legacy panel changes greatly along the CP and the working interface, which is similar to the simulation experiment of similar materials, and the two corroborate each other. In the mining process of the 5^{-2} coal working interface, the vertical motion regularity and displacement change regularity of the CPs left in the 4^{-2} coal panel are similar to those of the CPs in the 3^{-1} coal panel, which will not be repeated here.

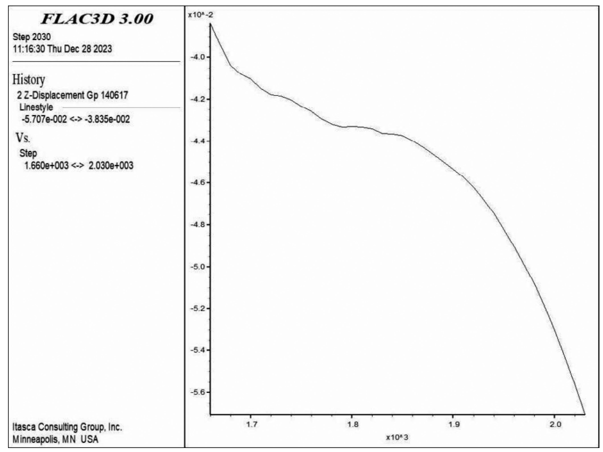


Figure 10. The vertical displacement of the CP in the left working interface of the 4^{-2} coal mining 3^{-1} coal legacy panel changes step by step

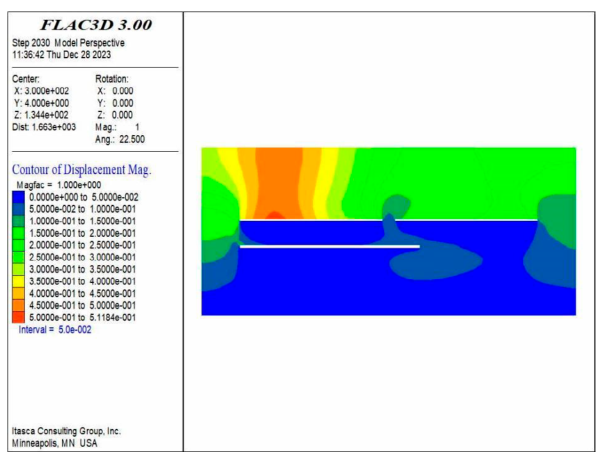


Figure 11. 4^{-2} Displacement contour after the end of mining at the left working interface of the coal

5 Conclusion

1. In the initial stage of coal seam mining under the SBCS group, due to the formation of a "large structure" of the strata failure of the upper first coal seam, the stress of the roof overburden in the goaf is not fully transmitted to the interlayer rock layer, and the interlayer rock layer has a specific thickness and strength, and the initial stress limit collapse step L is larger, and the initial mining stress step is larger than that of the upper one, and the mine stress is not violent.
2. In the process of lower coal seam mining, under the action of the stress of the collapsed roof in the goaf of the upper coal seam, the overall instability, fracture and collapse of the interlayer rock formation in a certain position of the working interface (affected by the intermediate-mining

ratio) appears, and the collapsed roof of the overlying goaf of the upper coal seam is activated, and the mine stress is violent, which needs to be paid attention to in the specific mining practice of mine stress control. After the mining of the coal seam in Yulin area, the overlying strata layer mainly forms a falling zone and a fracture zone, after the mining of the upper coal seam of the coal seam group, the overlying strata is in a loose state, especially the mining of the lower coal seam is advanced for a certain distance, and the activation of the collapsed roof of the overlying coal seam is easy to transfer the stress to the interlayer rock layer, resulting in the reduction of the periodic stress step of the lower coal seam roof (interlayer rock layer).

3. In the process of the lower coal seam mining face passing through the stress concentration range of the residual CP in the upper coal seam, the support stress increases, and the CP is at a certain distance (outside the influence angle of stress transmission), and the overall collapse and instability of the residual CP and the interlayer rock layer occurs, forming an inclined shear dislocation fracture zone. In production practice, it is inevitable that the shear failure of the close SBCS group in Yulin area will be violently unstable, and the load transmitted by it is also difficult for the support to bear. In the process of mining in the lower coal seam, it is necessary to optimize the mining design, pre-cracking and blasting of the CP, accelerate the advancing speed of the working interface, adjust the inclined working interface, and increase the working resistance of the hydraulic support to avoid the impact on the safety of the working interface.

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