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Study on strata behavior law of deep inclined coal seam

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Abstract. In order to understand and grasp the law of roof pressure on the working face of deep inclined coal seams, the law of support resistance distribution, the law of leading support stress distribution and the law of surrounding rock deformation of the two roadways, the 94101 working face of Zhangshuanglou Coal Mine was taken as the engineering background.Through a combination of field measurement, numerical simulation, theoretical analysis, etc, this paper analyzes the laws of roof migration and rock pressure manifestation in deep inclined coal seams.

1 Introduction

In the era of rapid economic growth, the status of energy has become more important. Coal resources play an important role in the development of our country. However, continuous integration and development are also needed to ensure the stable development of our society [1]. The law of the appearance of pressure in deep inclined coal seams is different from that of conventional working faces, and the frequent occurrence of accidents of the appearance of pressure in the mine brings serious harm to the sustainable production of the mine and worker safety [2,3].Therefore, it is necessary to conduct in-depth research on the breaking law of the overlying rock mass and the behavior of rock pressure in the deep inclined coal seam. It is possible to monitor and analyze the working resistance of the hydraulic support on the working face, and monitor the advance supporting stress and the deformation of the surrounding rock of the Liuzi road and the material road, so as to find the asymmetry and the imbalance of the rock pressure in the inclined direction and the strike direction of the working face. Support work resistance monitoring can infer the movement state of the roof covering on the working surface. By screening the end-of-cycle resistance of each coal cutting cycle, the law of the end-of-cycle resistance can be analyzed to determine the law of movement of the roof [4]. The borehole stress can monitor and analyze the change law of the stress field in front of the coal wall of the working face, obtain the high stress area and its corresponding change characteristics, and realize the real-time monitoring of the rock pressure [5-9].

2 Engineering background

The buried depth of 94101 working face is about 1000m, the average thickness of coal seam is 3.1m, the development of coal seam is stable, the hardness of coal quality is 2~3, and the coal seam and roof and floor have impact tendency; The working face has a strike length of 1,120 m, a tendency average length of 188.3m, and a coal seam dip angle of 28 on average. The longwall retreating mining technology is adopted, and the double roadway layout is adopted, which is adjacent to the goaf of 9121 working face in the south. The model of shearer in 94101 working face is MG450/1020-WD, the model of hydraulic support is ZY6800-20/42, the rated working resistance of support is 6800kN, and the model of scraper is SGZ1000/1050. See table 1 and table 2 for index value of strong impact tendency of No.9 coal.

Table 1. Physical properties of coal seam.

Seam number	9# coal seam
Serial number	Average value
Apparent density/kg・m^{-3}	1326
True density/kg・m^{-3}	1426
Moisture content/%	2.84
Natural water absorption/%	7.20

Table 2. Physical properties of surrounding rock

Seam number	9# coal seam	9# coal seam
Serial number	Average value	Average value
Apparent density/kg・m^{-3}	2685	2567
True density/kg・m^{-3}	2775	2651

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Moisture content/%	0.56	1.23
Natural water absorption/%	0.90	2.70

3 Field measurement research

Through monitoring and analyzing the characteristics of rock pressure in 94101 working face, it is found that the rock pressure behavior in 94101 working face is asymmetric and unbalanced, and the rock pressure behavior in the upper part of the working face and the material channel is stronger than that in the middle and lower part and the chute, which increases the possibility of impact behavior in the upper part of the working face and the material channel.

3.1. Monitoring purpose

In order to fully understand and master the roof weighting law, support resistance distribution law, advance support stress distribution law and surrounding rock deformation law of two roadways in fully mechanized coal mining face in deep inclined seam, the similarities and differences of mine pressure behavior in different areas of the working face inclination direction were found, and the intensity of mine pressure behavior in material roadway and valve roadway was found, which further provided basis for surrounding rock control.

3.2 Monitoring contents

1) Continuous monitoring of support resistance of hydraulic support in working face. Its characteristic data mainly include initial supporting force and cyclic working resistance.

2) Statistical observation of working face. It mainly includes the initial weighting step and the periodic weighting step of the basic roof in different areas of the inclined direction of the working face.

3) Advance mine pressure observation of roadway, mainly including advance bearing stress of material tunnel and valve tunnel and deformation of surrounding rock of roadway.

3.3 Monitoring methods

1) Monitoring of working resistance of hydraulic support in working face

A total of 24 roof pressure monitoring substations are arranged in the working face, and each monitoring substation is provided with two monitoring channels, which are respectively connected with the two columns of the support. According to the actual situation, the working face is divided into three measuring areas, which are the lower measuring area, the middle measuring area and the upper measuring area. The lower survey area contains 8 monitoring substations, which are installed on supports 10#, 11#, 12#, 13#, 14#, 15#, 16# and 17# respectively. There are 8 monitoring substations in the central survey area, which are installed on brackets 60#, 61#, 62#, 63#, 64#, 65#, 66# and 67# respectively. There are 8 monitoring substations in the upper measuring area, which are respectively installed on supports 100#, 101#, 102#, 103#, 104#, 105#, 106# and 107#, and the working resistance of 24 supports is monitored and recorded in real time and transmitted.

2) Monitoring of advanced bearing stress

The monitoring of advanced bearing stress is carried out by coal stress meter, which is connected with monitoring substation. There are 16 groups of measuring stations, with material channel numbers 3001 # ~ 3008 # and valve channel numbers 3009 # ~ 3016 #, with a spacing of 25m. The first group of measuring points is 25m away from the cut, and each group of measuring stations contains two drilling holes with a depth of 8m and 14m, with a hole spacing of 1.5m The stress meter needs to be laid in advance in the advanced coal seam. The monitoring substation moves forward with the mining of the working face, and the data of the stress meter can be monitored in real time by the upper computer.

The stress gauge sensor is mainly composed of drilling stress pillow and inclusion, with the maximum thickness of 38mm. By filling oil into the hydraulic oil pillow and increasing pressure, the inclusion expands, and the stress gauge can fully contact with the surrounding coal wall. The length of the pressure guiding oil pipe connected with the two drilling sensors of 8 m and 14m is 9m and 15m respectively, the stress measurement range is 0~60MPa, and the initial stress value is set at 3.0MPa.

3) Monitoring of surrounding rock deformation

The deformation of surrounding rock is measured by cross observation method, and a set of measuring points are respectively arranged at 150m of the advanced working face of the material road and the valve road, which are observed three times a week in the early stage and monitored once a day in the later stage. The observation frequency is determined according to whether it is affected by mining. Generally, it is within 50m from the working face and observed once a day, especially when it is within 10m from the working face, it should be observed many times a day. At other times, it can be observed 2 ~ 3 times a week according to the site conditions.

3.4 Result analysis

By analyzing and sorting out a number of data in three different areas of inclined working face, the following conclusions can be drawn:

1) Initial supporting force of hydraulic support

Statistics show that the initial supporting force of 24 supports monitored in three areas of the working face ranges from 1563~3957kN to 3957 kN, with an average value of 3300kN in the whole area, 3353kN in the upper area, 3222kN in the middle area and 3324kN in the lower area, accounting for 65.1%, 66.2%, 63.6% and 65.6% of the rated initial supporting force respectively.

The mean value of mean square deviation of initial bracing force is 360 in the whole region, 355 in the upper region, 377 in the middle region and 347 in the lower

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region, which account for 10.9%, 10.5%, 11.7% and 10.4% of the mean value of initial bracing force in each region, respectively.

According to the actual target requirement that the initial supporting force of the support working face needs to reach 80%(4051kN) of the rated initial supporting force, the utilization rate of the initial supporting force of the support working face is low, so it is necessary to give greater initial supporting force at the time of initial supporting.

2) End-of-cycle resistance of hydraulic support

The statistical end-of-cycle resistance of 24 supports monitored in three areas of the working face ranges from 3,357 kN to 6,970 kN, with an average value of 4886kN in the whole area, 5009kN in the upper area, 4832kN in the middle area and 4816kN in the lower area. The pressure value in the upper area is the largest, and the average value of end-of-cycle resistance of supports in the three areas does not exceed the rated working resistance, accounting for 71.8% of the rated working resistance respectively.

The mean value of mean square deviation of end-of-cycle resistance is 539.17 in the whole region, 598.46 in the upper region, 507.34 in the middle region, and 511.70 in the lower region, among which the mean square deviation of end-of-cycle resistance in the upper region is the largest and the mean square deviation of end-of-cycle resistance in the middle region is the smallest, accounting for 11.9% and 11.9% of the end-of-cycle resistance in each region respectively.

3) Pressure value of roof weighting process

The pressure value of roof weighting process of 24 supports monitored in three areas of the working face ranges from 4900 ~ 6970kN to 6970 kN, and the average value of the whole area is 5782kN, the average value of the upper area is 5994kN, the average value of the middle area is 5624kN, and the average value of the lower area is 5727kN, accounting for 85.0%, 88.1%, 82.7% and 84 of the rated working resistance respectively.

The mean square deviation of support working resistance in the whole region is 311.17, 335.45 in the upper region, 309.18 in the middle region and 288.90 in the lower region.

4) Pressure value of roof in relatively stable stage

The pressure values of the roof of 24 supports monitored in three areas of the working face during the relatively stable stage range from 3,357 kN to 6,274 kN, with an average value of 4662kN in the whole area, 4743kN in the upper area, 4623kN in the middle area and 4620kN in the lower area, accounting for 68.5%, 69.7%, 67.9% and 660 kN of the rated working resistance respectively Among them, the pressure value of the roof in the upper region is the largest during the relatively stable period, which is about 100kN higher than that in the middle and lower regions, and the utilization rate of supporting resistance is relatively low at this stage.

The mean square deviation of support working resistance in the whole region is 295.63, that in the upper region is 295.03, that in the middle region is 292.70 and that in the lower region is 299.16.

5) Basic roof initial pressure interval

According to statistics, the basic top initial weighting steps of 24 supports monitored in three areas of the working face range from 33.6 m to 46.4 m, with an average of 39.03m in the whole area, 36.8m in the upper area, 38.1m in the middle area and 42.1m in the lower area, among which the first weighting step in the lower area is the largest.

The basic roof initial weighting duration ranges from 1.7 to 4.8 m, with an average of 3.14m in the whole region, 2.82m in the upper region, 3.27m in the middle region and 3.32m in the lower region, among which the first weighting duration in the lower region is the largest, followed by the middle region and the smallest in the upper region.

6) Basic top cycle weighting step

The statistical range of the basic top periodic weighting steps of 24 supports monitored in three areas of the working face is 11.2 ~ 21.6 m, which is equivalent to 14 ~ 27 coal cutting knives. The average value of the periodic weighting steps in the whole area is 15.7m, equivalent to 20 coal cutting knives, the average value of the periodic weighting steps in the upper area is 14.5m, equivalent to 19 coal cutting knives, and the average value of the periodic weighting steps in the middle area is 15.5. The average periodic weighting interval in the lower area is 17.6m, which is equivalent to 22 coal cutters, among which, the periodic weighting interval in the lower area is the largest, with an average of 2m larger than that in the middle area and 3.1m larger than that in the upper area.

The mean square deviation of the basic top cycle weighting step ranges from 0.4 to 3.6, with the mean square deviation of 1.9 in the whole region, 2.0m in the upper region, 1.5 in the middle region and 2.3 in the lower region, among which the mean square deviation of the lower region is the largest, and the discrete type is relatively large, followed by the upper region and the middle region is the smallest.

7) Significant movement step of basic roof

The range of significant movement steps of 24 supports monitored in three areas is 1.6~5.6m, which is equivalent to 2 ~ 7 coal cutting knives. The average of significant movement steps in the whole area is 3.8m, equivalent to 5 coal cutting knives, the average of significant movement steps in the upper area is 4.0m, equivalent to 5 coal cutting knives, and the average of significant movement steps in the middle area is 3.8m, equivalent to 5 coal cutting knives.

Among them, the significant movement step of the basic top of the 13# support has the largest change, which is 2.4 ~ 5.6 m, the difference between the maximum and the minimum is 3.2m, the mean square error is 2.0m, and the dispersion is the largest.

8) Monitoring and analysis of material channel and valve channel

Through the monitoring and analysis of the leading bearing stress of the material tunnel and the valve tunnel, it can be seen that the leading bearing stress of the material tunnel has an influence range of 120 ~ 150 m, and the maximum stress peak value is 32.7MPa. At a distance of 14m from the coal wall, the degree of change is relatively large within 30m, and within 30 ~ 70 m; The influence range of the leading bearing stress of the valve track is 130

~ 160 m, with the maximum stress peak value of 29.6MPa. It changes greatly within 35m from the coal wall, and it changes stably within 35 ~ 80 m, and the stress peak value of the material track is larger, so stress monitoring and support of the material track should be strengthened.

After monitoring and analyzing the deformation of surrounding rock of material roadway and valve roadway, it can be seen that the deformation of surrounding rock is faster when it is 50m away from the working face, and the support and monitoring should be strengthened at this time, and the deformation of surrounding rock will basically remain stable after mining to 150m; The deformation amount and deformation rate of surrounding rock of material tunnel are larger than that of the chute. The maximum displacement of roof and floor and two sides of the chute are 1508mm and 1206mm respectively, and the maximum displacement of roof and floor and two sides of the chute are 1093mm and 897mm respectively.

4 Theoretical analysis and research

In 94101 working face of Zhangshuanglou Coal Mine, the upper section of the working face is the goaf of 9121 working face, with solid coal on the road side, small coal pillar to protect the roadway on the material roadway side, and the width of coal pillar is 5m. Because of the special conditions of deep inclined small coal pillar to protect the roadway, the overlying rock mass is in a different motion state from the ordinary stope. On the material roadway side, after the upper section coal seam was mined, all the direct roofs above the roadway did not directly collapse into the upper section goaf. Instead, a special filling structure is formed, and the overlying strata break and collapse. The goaf state formed by the upper section working face will affect the mining characteristics of this section. The fracture structure of the overlying rock mass during the mining of 94101 working face is shown in Figure 1.

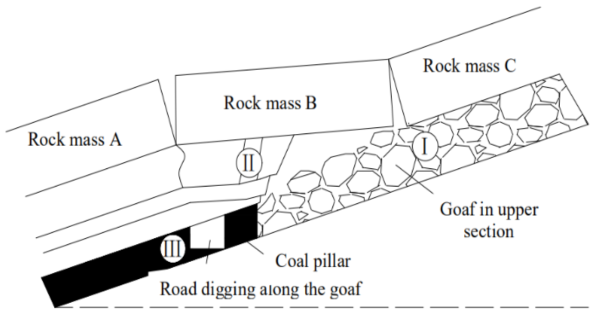


Fig. 1. Fracture structure of overlying rock mass during mining in 94101 working face.

When mining 94101 working face, because the support keeps moving forward with the coal mining, the top of the support will collapse after moving, but because 94101 working face is an inclined coal seam with small coal pillars to protect the roadway, the direct roof will collapse irregularly below the rock block B and above the rock block A. After that, the fracture of the basic roof will be affected to a certain extent, and the movement of the overlying strata will be different from that of the horizontal coal seam. However, rock block ABC will form an articulated structure, and the key block of this structure is rock block B, which plays a very important role in the stability of the whole structure, so it is necessary to discuss rock block B in detail.

4.1 Mechanical model of key block structure of surrounding rock

The 94101 working face is adjacent to the goaf of the 9121 working face in the south and the solid coal side in the north. In the process of back mining, the upper section will form a rock block hinged structure as shown in Figure 1, forming an arc triangle block B.

1) research on b parameters of arc triangle block

The special structure formed by the working face of deep inclined coal seam is closely related to the physical and mechanical properties of overlying strata. Further, the physical and mechanical properties of direct roof, basic roof and coal seam determine the parameters of this structure. This paper mainly considers the influence of the length L1 of rock block B in strike direction and the length L_2 in dip direction on mining in this section. The top view of arc triangle block B in this section is shown in Figure.

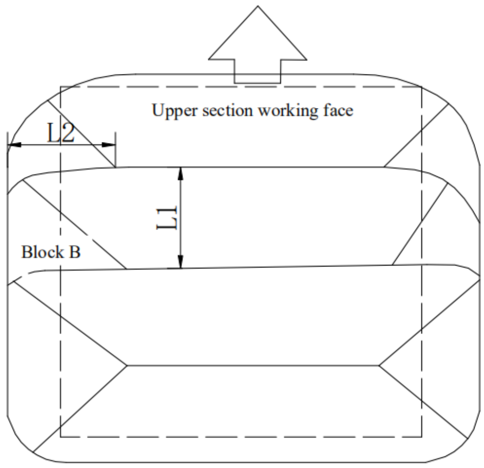


Fig. 2. Top view of arc triangle block B

It can be analyzed from fig. 2 that the length L_1 of the arc triangle block b in the strike direction is consistent with the pressing step distance of the basic top period, and the results of field observation and theoretical calculation can be referred. L_1 can be calculated by Formula 1:

$$L_1 = h\sqrt{\frac{R_t}{3q}} \quad (1)$$

In which: h—the basic roof thickness, m; R_t—the tensile strength of basic roof, MPa; q—the load per unit area of the basic roof, MPa.

L_2 represents the parallel component along the inclined coal seam working face. According to the plate yield line analysis method, it can be determined that L_2 is closely related to the length s of the inclined coal seam working face and the basic roof periodic weighting step L_2. Therefore, the length of L_2 can be calculated by Formula 2:

$$L_2 = \frac{2L_1}{17}\left[\sqrt{\left(10\frac{L_1}{S}\right)+102} - \frac{L_1}{S}\right] \quad (2)$$

The lateral fracture span of the basic roof in longwall retreating mining face is approximately equal to the periodic weighting step of the basic roof, and the suspension span L_2 of the 94101 arc triangle block B is 12 ~ 19m.

Roadway driving along goaf in deep inclined coal seam, the rock above the roadway is constantly changing with the mining of working face, and its arc triangle block B is located above the material tunnel of 94101 working face, which can be approximately considered as the function of a bridge. In different mining stages, it is particularly important to the mining of this section, and its stress range is relatively large, which further affects the motion state of other rock masses and forms a dynamic change process.

5 Numerical simulation research

In the process of mining in the working face, the original rock stress of the stope changes due to the influence of mining. With the continuous advancement of the working face, the surrounding rock stress is constantly in the process of alternating balance and failure, and the surrounding rock in front of and above the working face is constantly damaged by tension and compression, and the range is continuously increased until the stress release occurs. For the mining of deep inclined coal seam, the phenomenon of stress release also exists, which is different from that of horizontal coal seam and easy to cause dynamic disaster. Therefore, this section takes the 94101 working face in Zhangshuanglou Coal Mine as the research background, and carries out numerical simulation research and analysis on the stope in the process of pushing mining.

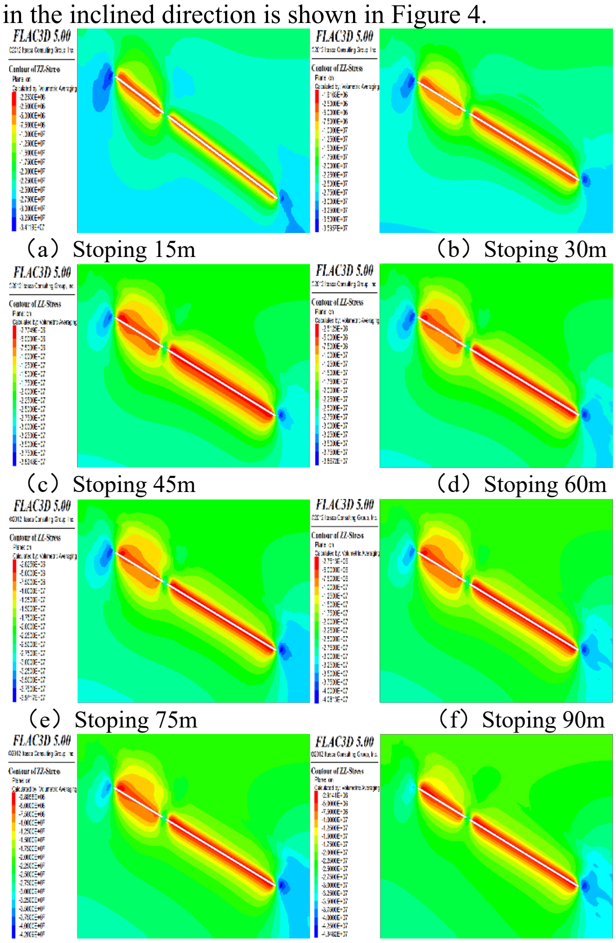
According to the existing mechanical characteristics of rock mass, in the mining process of deep inclined coal seam working face, rock mass and coal seam will be damaged and destroyed to some extent, and then elastic-plastic deformation will occur. Rock mass and coal seam have certain physical properties and can still bear a certain range of forces after receiving damage and destruction. Based on this, the elastic-plastic constitutive model is the first choice model for this numerical simulation, i.e. Mohr-Coulomb yield criterion, as shown in Formula 3.

$$f_s = \sigma_1 - \sigma_3 \frac{1+\sin\varphi}{1-\sin\varphi} - 2C\sqrt{\frac{1+\sin\varphi}{1-\sin\varphi}} \tag{3}$$

Where: σ_1— maximum principal stress, MPa; σ_2— minimum principal stress, MPa; C-cohesion, MPa; φ— internal friction angle,°.

According to the geological conditions of 94101 working face in Zhangshuanglou Coal Mine, the original rock stress is unbalanced and redistributed after mining by using numerical simulation software, which leads to the change of mechanical parameters of surrounding rock, forming plastic zone and even instability. According to the comprehensive histogram and geological data of coal seam in 94101 working face, the length of working face is simplified to 180m and the thickness of coal seam is simplified to 3.0m. Establish a model with a dip angle of 30, and the mining height is 3.0m. According to the real geological data and practical experience, the model is established, and the length × width × height of the model is 330m×200m×280m. The simulation is divided into two mining steps, the first mining is the mining in the upper section, which is 80m along the dip direction, and the second mining is the mining in this section, with a mining step of 15m each time. The roof displacement, vertical stress and other parameters of the 94101 working face are recorded. The stress boundary conditions of the model are as follows: the average buried depth of the upper boundary of the model is 1000m, the displacement of the bottom surface and its surroundings is fixed, the uniformly distributed compressive stress of 25MPa is applied to the upper boundary of the model, and the lateral compressive coefficient is 0.30.

By studying the roof stress and displacement in the inclined direction of coal seam, we can see the distribution of stress and displacement in the inclined direction more intuitively, and mainly study the distribution of stress and displacement in the inclined direction of coal seam when the advancing distance is 15m, 30m, 45m, 60m, 75m, 90m, 105 and 120m. Through the numerical simulation of displacement in the inclined direction, the stress distribution nephogram in the inclined direction is shown in Figure 3, and the displacement distribution nephogram in the inclined direction is shown in Figure 4.



(g) Stoping 105m (h) Stoping 120m

Fig. 3. Distribution of stress nephogram at different advancing distances in inclined direction

1) Roof stress analysis

Through the concrete analysis of the vertical stress distribution of roof at 15m, 30m, 45m, 60m, 75m, 90m, 105 and 120m, it can be seen that the stress release range of overlying strata in goaf and the pressure relief range of floor in lower area also increase with the advancing distance, but the pressure relief area in lower area is smaller than that in upper area. When the working face is mined to 15m, 30m, 45m, 60m, 75m, 90m, 105 and 120m, the stress value and stress concentration coefficient in the upper, middle and lower areas of the working face are all increasing. When the working face is mined to 15m, the maximum vertical stress of the roof of the inclined coal seam working face reaches 34.11MPa, and the stress concentration coefficient is 1.36. When the working face is mined to 30m, the maximum vertical stress of roof in inclined coal seam working face reaches 35.96MPa, and the stress concentration coefficient is 1.43; when the working face is mined to 45m, the maximum vertical stress of roof in inclined coal seam working face reaches 38.24MPa, and the stress concentration coefficient is 1.52; when the working face is mined to 60m, the maximum vertical stress of roof in inclined coal seam working face reaches 38.67MPa, and the stress concentration coefficient is 1.54; when the working face is mined to 75m, the maximum vertical stress of roof in inclined coal seam working face reaches 39.71MPa, and the stress concentration coefficient is 1.58; when the mining face reaches 90m, the maximum vertical stress of roof in inclined coal seam face reaches 40.81MPa, and the stress concentration coefficient is 1.63; when the mining face reaches 105m, the maximum vertical stress of roof in inclined coal seam face reaches 42.00MPa, and the stress concentration coefficient is 1.68; when the mining face reaches 120m, the maximum vertical stress of roof in inclined coal seam face reaches 43.48MPa, and the stress concentration coefficient is 1.73.

The vertical stress nephogram of roof in inclined coal seam working face is asymmetrically distributed. along the inclined direction of working face, the vertical stress in the lower area of working face is smaller than that in the upper area of working face. the maximum value of stress concentration area is located at the junction of middle area and upper area. the maximum value of vertical stress in the upper area reaches 49.26MPa, and the minimum vertical stress is 35.15MPa, with a difference of 14.11MPa. The maximum vertical stress in the middle region reaches 46.52MPa and the minimum vertical stress is 33.28MPa, with a difference of 13.24MPa. The maximum vertical stress in the lower region reaches 45.63MPa and the minimum vertical stress is 32.65MPa, with a difference of 12.98MPa.

2) Roof displacement analysis

Through the numerical simulation of roof displacement at different distances in the inclined direction of the working face, it can be seen more intuitively that the upper section of the working face has certain influence on the lower section of the working face during the mining process of the deep inclined coal seam with small coal pillars, which changes the displacement and influence range of the overlying roof surrounding rock in the mining of the lower section of the working face to a certain extent. By comparing and analyzing the analysis of roof displacement at different advancing distances, the following conclusions can be drawn.

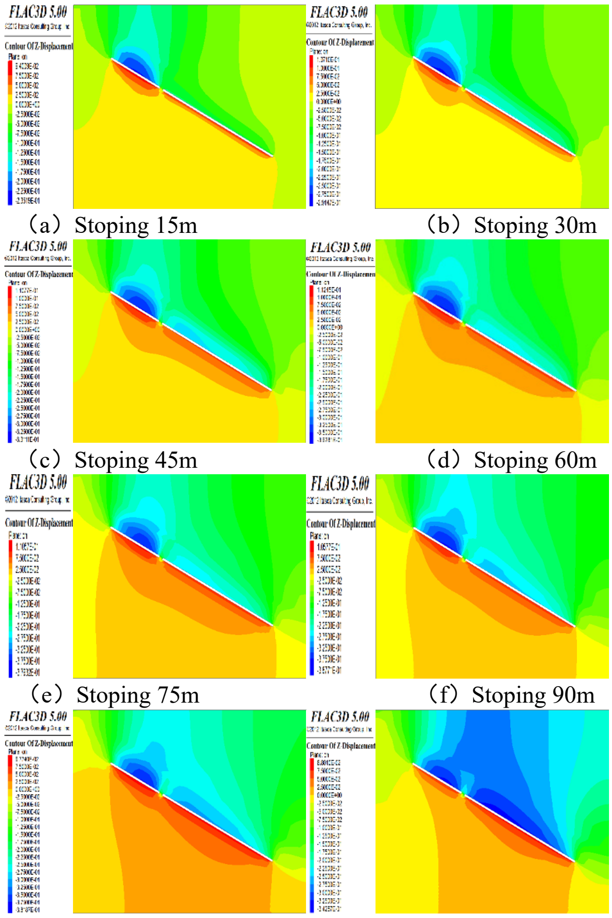

(a) Stoping 15m (b) Stoping 30m
(c) Stoping 45m (d) Stoping 60m
(e) Stoping 75m (f) Stoping 90m
(g) Stoping 105m (h) Stoping 120m

Fig. 4. Distribution of displacement nephogram with different advancing distance in inclined direction

Through the concrete analysis of displacement distribution figure 4 at 15m, 30m, 45m, 60m, 75m, 90m, 105 and 120m, it can be known that the vertical displacement of overlying strata in goaf also increases with the advancing distance in the continuous mining process of the working face. When the working face is mined to 15m, the maximum vertical displacement of the roof reaches 235.1mm; when the mining face reaches 30m, the maximum vertical displacement of the roof reaches 291.4mm; when the mining face reaches 45m, the maximum vertical displacement of the roof reaches 331.1mm; when the working face is mined to 60m, the maximum vertical displacement of the roof reaches 362.8mm; when the working face is mined to 75m, the maximum vertical displacement of roof reaches 379.3mm; when the mining face reaches 90m, the maximum vertical displacement of the roof reaches 387.7mm; when the mining face reaches 105m, the maximum vertical displacement of the roof reaches 381.8mm; when the mining face reaches 120m, the maximum vertical displacement of the roof reaches 342.5mm; through the analysis, it can be seen that the displacement and subsidence of roof in the vertical direction change greatly before the mining face reaches 75m. When the working face is mined to 30m, the maximum displacement of the roof is 56.3mm larger than that when it is mined to 15m, and the maximum displacement increases by about 0.23 times; when the mining face reaches 60m, the maximum displacement of roof is 71.4mm larger than that when the mining face reaches 30m, and the maximum displacement increases by about 0.24 times. When the working face is mined to 90m, the maximum displacement of the roof is 24.9mm larger than that when it is mined to 60m, and the maximum displacement increases by about 0.06 times; when the mining face reaches 120m, the maximum displacement of the roof is 42.5mm smaller than that when the mining face reaches 90m, and the maximum displacement decreases by about 0.11 times.

Roof displacement nephogram of inclined coal seam working face is asymmetrically distributed, and the displacement in the lower part of working face is smaller than that in the upper part of working face. The maximum vertical displacement in the upper part reaches 503.2mm, the minimum displacement is 125.8mm, the difference is 377.4mm, and the maximum vertical displacement in the middle part reaches 461.2mm, The minimum displacement is 109.9mm, with a difference of 351.3mm. The maximum vertical displacement in the lower region reaches 401.2mm, and the minimum displacement is 94.6mm, with a difference of 306.6 mm. The influence heights of overlying strata in the dip direction are also different, with the maximum influence ranges of 52.2m in the upper region, 51.3 m in the middle region and 50.2m in the lower region.

6 Main conclusions

Through field measurement, it can be found that the ground pressure behavior of 94101 working face is asymmetric and sequential in the process of mining; the average values of roof weighting in three areas of the inclined direction of the working face are 5994kN, 5624kN and 5727kN respectively, the initial weighting steps are 36.80m, 38.1 m and 42.10m respectively, and the periodic weighting steps are 14.5 m, 15.6m and 17.6 m respectively. The leading bearing stress and deformation of surrounding rock of material tunnel and valve tunnel also show asymmetry, and the rock pressure of material tunnel and upper area of working face is obviously larger. Through theoretical analysis, it can be seen that the upper goaf has an impact on the lower working face in the mining process of the inclined coal seam with small coal pillar to protect the roadway, which is mainly manifested by the superposition of advanced supporting pressure and lateral supporting pressure of the upper goaf. Under the superposition of supporting pressure, the lower gangue, coal seam and direct roof are further compressed and sunk, and the stress release in the upper area of the working face in this section increases.

According to the numerical simulation study, the displacement and roof stress release in the upper part of the working face are larger than those in the middle and lower part of the working face, which is basically consistent with the measured data. It shows that the goaf in the upper part of the inclined coal seam working face has an impact on the mining of the working face in this section, and it is easy to cause the mine pressure disaster.

References

1. Zhang baiwang. study on the importance of coal resources integration in coal economic development [J]. modern economic information, 2019(09):362.
2. Meng Xiangjun. Coal side support technology for gob-side entry driving in fully mechanized top-coal caving face based on basic top fault position [J]. Coal Science and Technology, 2020,48(01):61-68.
3. Mi Wenbao, Wei Hui. Study on reasonable pillar size of gob-side entry driving in deep thick coal seam face [J]. China Coal, 2016,42(06):67-70.
4. Zhao Jiyu. Research on automatic analysis technology of mine pressure behavior law in working face based on support working resistance [D]. Shandong University of Science and Technology, 2017.
5. Duan Marshal, Fang Jin. Study on optimization of coal pillar width in adjacent working face of high mining depth and high stress coal seam [J]. Shandong Coal Science and Technology, 2019(05):71-73.
6. Wei li, Qi Wei, Wu Xinghui. Study on stress evolution and numerical simulation of surrounding rock in deep mining based on borehole stress monitoring [J]. Gold, 2019,40(05):27-32.
7. Lv youchang, He Zhiqiang, Wang Yingwei, et al. the law of mining stress appearance in deep mines over 1000 meters [J]. journal of coal science, 2019,44(05):1326-1336.
8. Zhang Wenquan. Study on borehole stress monitoring of fully mechanized top-coal caving mining roadway in extra-thick coal seam [J]. Shandong Coal Science and Technology, 2018(06):174-175+178.
9. Tan Wei, Huang Mingqing. Stress and displacement monitoring during the mining process of the ore body in the stress concentration area[J]. Non-ferrous metals (mining part), 2018, 70(02): 84-87.