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Research Article

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Application of the Top-cutting Pressure Relief without Coal Pillar Mining Technology in Jincheng Mining Area

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Abstract: There are numerous coal mines in Jincheng area. Reducing the excavation rate is of great significance [1,2]. The traditional long-arm mining method requires two tunnels to be excavated in one working face, and the coal pillars left for protecting the tunnels result in low coal recovery rate and serious problems of resource waste [3]. The top-pressure relief without coal pillars mining technology uses blasting pre-cracking to cut the roof, supports the old roof, and utilizes the roof collapse of the working face to form the mining tunnel for the next working face. It not only improves the coal recovery rate but also realizes the Y-type ventilation mode, effectively solving the problem of excessive gas in the upper corner [4–6]. It plays a positive role in the safe production of high-gas mines. Through experiments and applications in a certain mine in Jincheng, the engineering effect is good. It fundamentally prevents the frequent occurrence of disasters caused by the left coal pillars, resource waste, tight mining succession, and difficult maintenance of tunnels, and has great engineering practical value and high economic and social benefits [7].

Keywords: Top-cutting for pressure relief; Top-cutting for pressure relief; Open-pit mining without coal pillars

1. Introduction

Jincheng City is located in the southeast of Shanxi Province, in the southern part of Qinshui Coalfield. It is one of the five major anthracite production bases in China. In terms of coal quality, the anthracite in Jincheng has the characteristics of high fixed carbon content, high resistance to crushing strength, high thermal stability, high ash melting point, poor grindability and poor viscosity-temperature characteristics. It is particularly suitable for the gasification technology with fixed bed and solid slag discharge [8]. At the same time, it also has the characteristics of high fixed carbon content, high calorific value, low volatile matter, less flue gas, good environmental protection performance and low sulfur content. Compared with other coal types, it is a better fuel. Jincheng is one of the major anthracite production bases in China [9–12]. It is located in the southeast of Qinshui Coalfield. There are numerous coal mines there, and most of them adopt the traditional long-arm mining method. Coal pillars are left to protect the main drifts. During the mining process, one working face needs to excavate two drifts. The problem of large amount of tunnel engineering, high mining-to-extraction ratio, and resource waste has become increasingly serious [13]. Moreover, with the increase of mining depth, the coal pillars left may even cause geological natural disasters such as shock ground subsidence and coal and gas outburst due to stress concentration, which has become a major problem that hinders and affects the safe and efficient production of coal mines. Therefore, conducting the experiment of top caving and pillarless mining without coal pillars in the Jincheng mining area holds profound significance.

2. Engineering Background

Mine N is located in Gaoping City, Jincheng Prefecture, Shanxi Province. Currently, the 3rd coal seam is being mined. The 3207 working face is situated in the middle of the second mining area, with the southern part being the mined-out area of the 3208 working face, the northern part being solid coal, the western part being the boundary return airway of the second mining area, and the eastern part connecting with the tracks, transportation and return airways of the second mining area. The relative positions on the ground are mostly at mountain tops, ridges and gully sections, without farmland, villages or buildings. There are no water bodies on the surface. The ground elevation ranges from +992 to +1239 meters, while the underground elevation ranges from +720 to +825 meters. The average thickness of the coal seam is 5.31 meters, with local presence of intercalated seams, and the thickness of the intercalated seams is approximately 0.02 to 0.50 meters. The coal seam inclination angle ranges from 3° to 7°, with an average of 5°. The layout of the working face's roadways is in a Y-type ventilation pattern with two intake and one return, namely the belt road, the track road and the return airway of the second mining area. The 3207 working face has a strike length of 1868 meters and a dip length of 180 meters. The specific layout of the working face is shown in Figure 1.

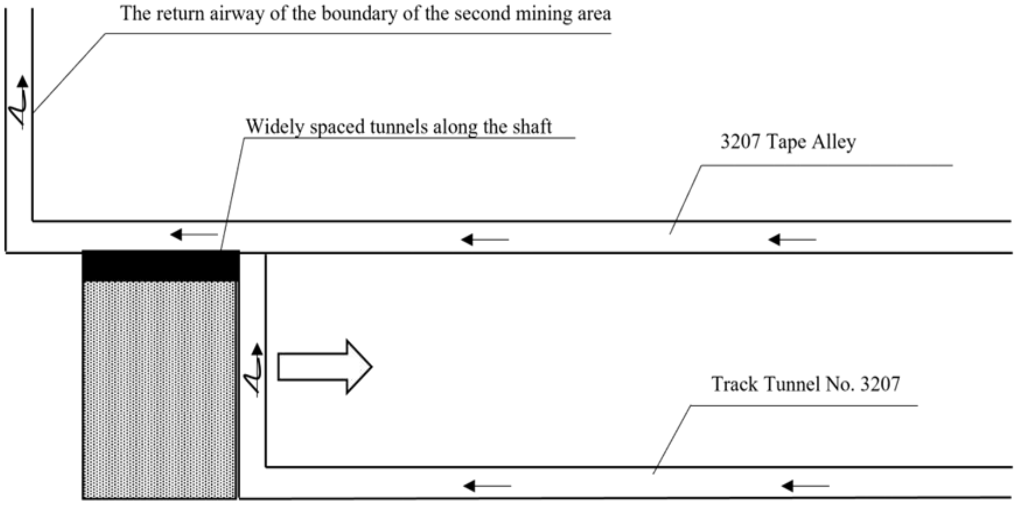
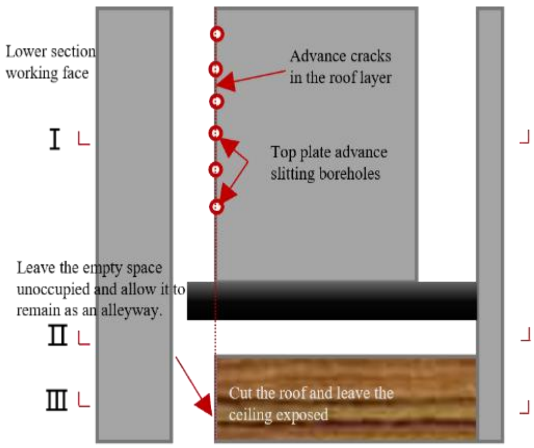


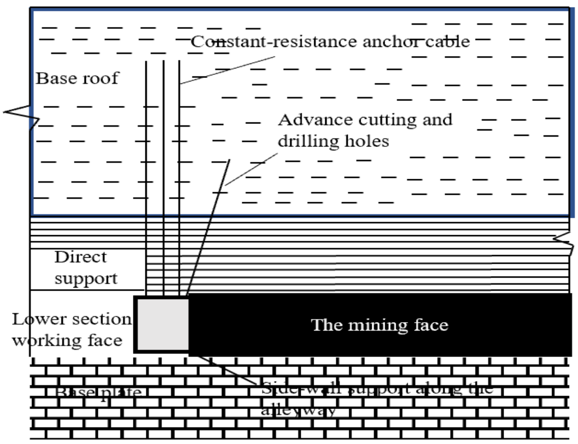
Figure 1: Layout of the working face

3. Top-Cutting Pressure Relief and Along-Striking Roadblock Technology

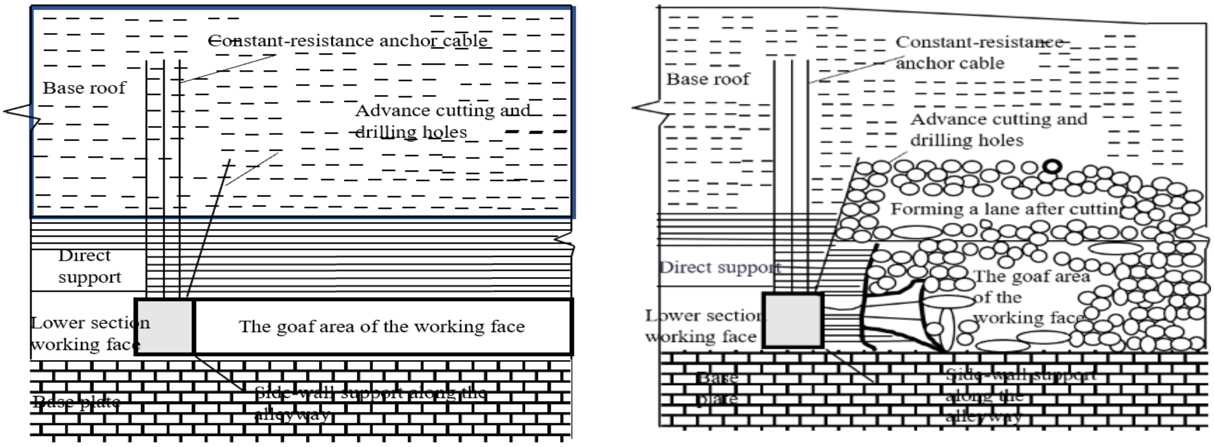
Based on the technical principle of top caving without coal pillar along with the backfilling of the mined-out area and the theory of short-arm beam, the process flow chart is shown in Figure 2.



(a) Technical process flow chart



（b）I-I Section



（c） II-II Section （d） III-III Section

Figure 2: Process Flow Chart of the Methodology for Cutting Top and Implementing Pressure Relief while Leaving Intervening Roadways along the Mining Face

After the complete formation of the coal mining working face, constant-resistance large-deformation anchor cables are used to support the inner side of the roadway and the area on the side of the mined-out area. After the support work is completed, pre-split blasting holes are drilled ahead of the designated position of the working face in advance (see Figure 1b). A neat pre-split crack line forms inside the roadway roof (see Figure 1c). After the working face is mined out, dense hydraulic single column supports are arranged along the crack surface for support. Under the action of self-weight and mine pressure of the mined-out area, the roof of the mined-out area automatically forms the roadway side walls along the crack surface (see Figure 1d). After the roof is fully collapsed and compacted, the single-column supports are gradually withdrawn and sprayed on the side walls to isolate the mined-out area. The roadway is used as the return airway of the next coal mining working face and continues to be used, thereby achieving the purpose of no pillar mining while reducing the excavation of a roadway [14–16].

4. Analysis of the Observation Results of Mine Pressure in the Retained Alleyway Along the Ore Vein

Observation Contents and Methods of Mine Pressure along the Opened-Out Area

The monitoring of mine pressure along the goaf is mainly conducted on the goaf section and the section with advanced support. The design of the mine pressure observation contents for the 3207 working face is as follows:

Table 1: Content of Mine Pressure Observation

Serial Number	Observation content	instrument	Model number
1	The displacement of surrounding	steel ruler	
2	Anchor cable tension	Anchor cable tension monitoring instrument	MCS-200
3	Filling body support pressure	Pressure pillow	GPD60
4	Temporary support pressure in the retaining alley	Monolithic pressure monitor	YHY60
5	Strength of the concrete wall beside the alley	Rebound tester	HD-225B
6	Lateral support pressure	Drilling stress meter	KSE-II-1
7	Top plate displacement	Top plate displacement	LBY-3
8	Advance support pressure	Monolithic pressure monitor	YHY60

Starting from the working face tunneling, the first measurement station is set up in the tunneling area when the working face has been mined for 20m. Then, at intervals of 25m along the tunneling area, the second measurement station is set up, and so on. This process is repeated to set up a total of 8 measurement stations. The main purpose is to monitor the manifestation patterns of mine pressure in the 200m area of the tunneling section. The measurement stations in the tunneling section mainly include monitoring of the displacement of surrounding rock, anchor cable tension, support pressure of filling body, temporary support pressure of the tunneling section, concrete pressure beside the tunnel, and roof spalling.The measurement stations are managed by designated personnel for the collection and organization of data. Daily mine pressure reports are formed for analysis and summary.

(1) Deformation amount of surrounding rock of roadway

The observation of surface displacement is carried out by the "cross-measurement method", and the station layout is shown in the figure. The vertical and horizontal displacements of the roadway are measured by steel tape. The base points of each measurement surface must be firmly fixed. The observation method is as follows: pull the measuring tape tightly between C and D and measure the values of AO and AB; pull the steel tape tightly between A and B, and measure the values of CO and CD; the measurement accuracy should reach 1mm, and be estimated to 0.5mm.

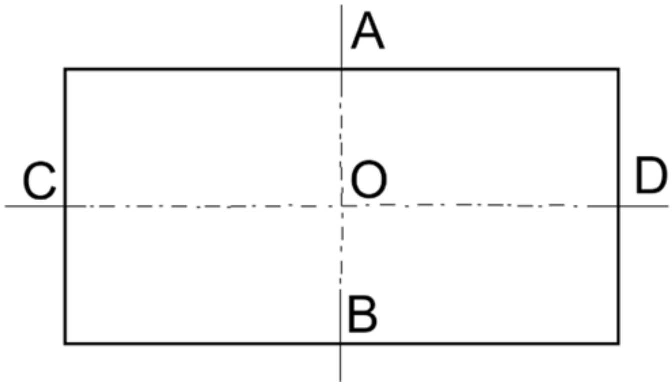


Figure 3: Layout of Measuring Points for Monitoring the Displacement of Surrounding Rock in the Retaining Shaft

(2) Anchor cable tension gauge

The working resistance of anchor cables is monitored by using anchor cable tension monitoring instruments. Before the face mining commences, anchor cable tension gauges are installed at the measurement stations in advance to test the changes in the tension of anchor cables as the face mining progresses and during the process of leaving goaf.

(3) Monitoring of the force exerted by the filling material

The monitoring of the stress of the filling body is carried out by using pressure pillows. Two sets of pressure pillows are pre-installed at the bottom of the concrete wall of the measurement station to observe the stress condition of the wall. If any abnormal situation occurs, corresponding reinforcement measures will be taken.

(4) Temporary support pressure monitoring in the retaining tunnel section

The pressure monitoring of the temporary support in the working face adopts the single pressure monitoring instrument for observation. Two sets of single pressure monitoring instruments are installed on the single support units of the temporary support in the working face. The single pressure monitoring instruments are installed on the liquid injection holes of the single support pillars. The reasonable distance of the temporary support in the working face is determined based on the stability of the single pressure changes.

(5) Strength Monitoring of Concrete Walls Adjacent to the Alley

The compressive strength of the concrete beside the alley was tested by using the rebound tester on the flexible mold concrete wall. The strength was monitored at 1d, 2d, 3d, 5d, 7d, 14d and 28d respectively. Due to the certain error of the rebound tester, concrete specimens were made for compressive strength test to determine whether the concrete strength met the standard.

The concrete specimens were fabricated using a 100mm×100mm mold. Concrete was taken from the discharge outlet of the underground mixer and poured into the molds. A total of 27 specimens were made and placed underground for curing. They were taken out at intervals of 1 day, 2 days, 3 days, 5 days, 7 days, 14 days, and

28 days respectively, and 3 specimens were taken each time. The compressive strength was tested at the testing center.

(6) Monitoring of lateral support pressure

The lateral support pressure is monitored by using borehole stress meters. Boreholes are drilled at the middle part of the coal face 30m away from the advanced working face. The borehole diameter is 50mm, the borehole spacing is 0.8m, and 5 boreholes are arranged in each set of measurement stations. The borehole depths are successively 5m, 8m, 10m, 12m and 15m. Then, the borehole stress meters are installed successively to monitor the lateral support pressure of the working face during the mining and the retention of the roadway.

(7) Monitoring of roof spalling

The observation of roof spalling is carried out by using the roof spalling instrument. The amount of spalling outside and inside the anchoring area is observed respectively. Each borehole includes two initial measurement points. The condition of roof spalling is judged by observing and recording the distance changes between the two measurement points and the roof of the roadway on a daily basis.

(8) Advanced support pressure monitoring

The monitoring of advance support pressure is carried out by using single pressure monitoring instruments. Two sets of single pressure monitoring instruments are installed on the advance single pillars 30 meters in front of the working face to observe the pressure changes.

Analysis of the results of mine pressure observation

The technicians of N Mine have collected and sorted out the data of the 3207 working face with goaf retention mining several times. The analysis results are as follows:

(1) Analysis of Surrounding Rock Deformation

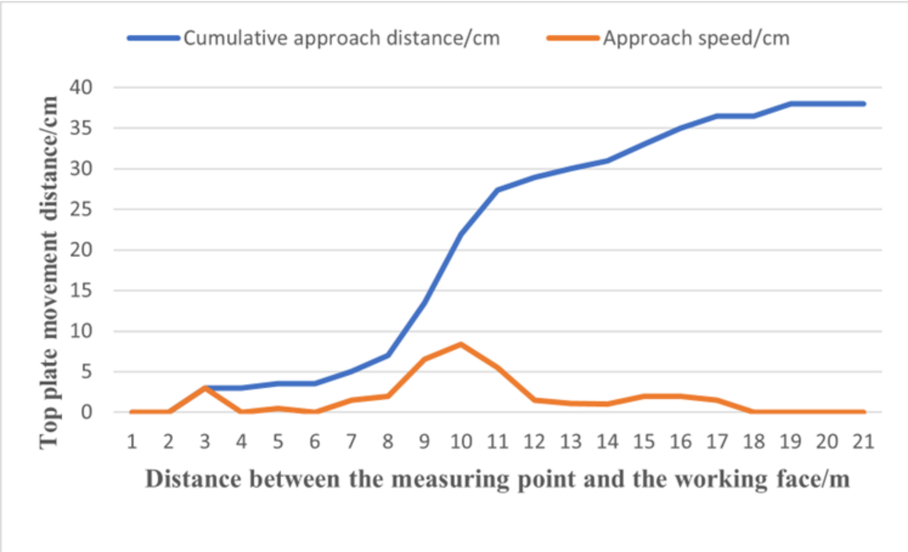


Figure 4: Diagram of the trend of roof displacement variation

It can be seen from Figure 4 that: Starting from 12 meters in front of the working face, the speed of the top and bottom plates approaching the coal seam begins to increase. At a distance of 20 meters behind the working face, the speed of the top and bottom plates approaching the coal seam reaches its maximum value of 8.4 cm/d.

Subsequently, as the working face advances, the speed of the top and bottom plates approaching the coal seam gradually decreases. At a distance of 68 meters behind the working face, the speed of the top and bottom plates approaching the coal seam tends to stabilize. At a distance of 214 meters behind the working face, the speed of the top and bottom plates approaching the coal seam approaches 0, and the stability of the roadway is maintained. The maximum amount of the top and bottom plates approaching the coal seam after the roadway is stable reaches 38 cm.

Combining the data of the top and bottom plate approaching amounts measured at other measurement points, the maximum amount of the top and bottom plates approaching the coal seam is 54.2 cm. The average maximum

amount of the top and bottom plates approaching the coal seam measured at each measurement point is 45 cm, accounting for approximately 8.3% of the coal seam height.
From the analysis of the top and bottom plate approaching amounts of the roadway, the effect of leaving a roadway along the coal seam is good, and it can be judged that the roadway is stable.

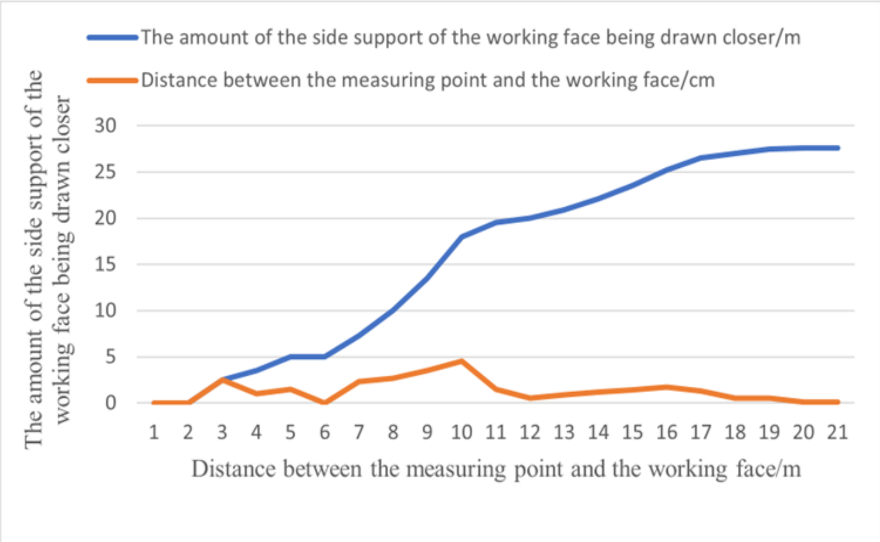


Figure 5: Trend Chart of the Distance of the Side Wall of the Working Face Moving Closer

As can be seen from Figure 5: Starting from 3 meters in front of the working face, the side support approach speed of the working face begins to increase. When it reaches 20 meters behind the working face, the side support approach speed of the working face reaches the maximum value of 4.5 cm. Subsequently, as the working face advances, the approach speed gradually decreases. When it reaches 68 meters behind the working face, the side support (the wall of the side support for the roadway) approach speed tends to stabilize. When it reaches 261 meters behind the working face, the approach speed is close to 0, and the side support wall remains stable. The maximum approach amount of the side support of the working face reaches 27.6 cm.
Combined with the measured data of the side support approach amount of the working face (the side support wall) at other measurement points, the average maximum side support approach amount of the working face (the side support wall) is measured to be 20.1 cm.

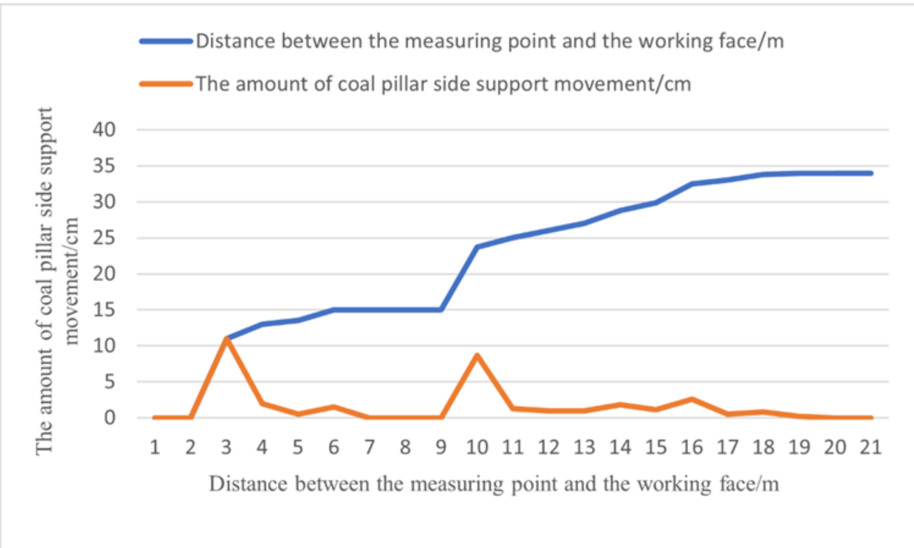


Figure 6: Trend Chart of the Variation of the Distance of the Roof Support Movement in the Coal Pillar Area

It can be seen from Figure 7 that: starting from 21m in front of the working face, the speed of the coal pillar's side support approaching begins to increase; when it is 3m in front of the working face, the speed of the coal pillar's side support approaching is 0; when it is 20m behind the working face, the speed of the coal pillar's side support approaching suddenly increases and reaches the maximum value of 8.7cm; when it is 50m behind the working face, the speed of the coal pillar's side support approaching stabilizes and when it is 237m behind the working face, the speed of the coal pillar's side support approaching is close to 0, and the roadway basically remains stable; the maximum speed of the coal pillar's side support approaching is 34cm.
Combined with the measured data of the coal pillar's side support approaching at other measurement points, the average maximum speed of the coal pillar's side support approaching is 28.1cm.

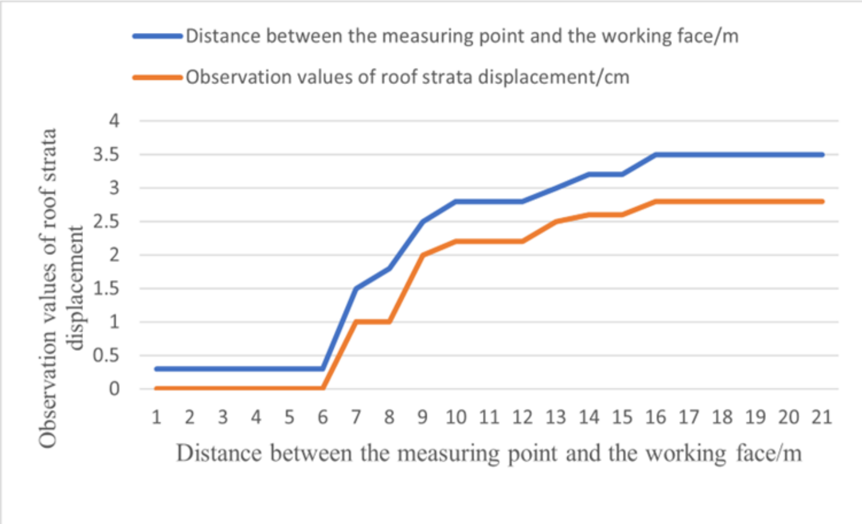


Figure 7: Trend Chart of Roof Dislocation Observation Changes

The 3m base point begins to show dislocation from 3m in front of the working face and gradually increases. The dislocation speed is the highest at 1-8m behind the working face. After 8m, the dislocation speed gradually decreases. When the dislocation measurement value of the 3m deep base point roof reaches the top of the working face at 159m behind the working face, it no longer increases and remains stable. The maximum dislocation measurement value of the 3m deep base point roof is 2.8cm, which means a dislocation of 2.8cm within the range of 3m.
The main reason is that within the range of 8m behind the working face, it is the stage of setting up the side support wall for the roadway. During this period, the roadway on the side close to the goaf is suspended. After setting up the side support wall, the dislocation of the roof does not further intensify.
The 9m base point shows a certain dislocation in front of the working face. The dislocation intensifies from 3m in front of the working face and gradually increases. When it reaches 159m behind the working face, the dislocation measurement value of the 9m deep base point roof no longer increases, and the maximum dislocation measurement value is 3.5cm.
From the comparison of the displacement curves of the 3m base point and the 9m base point, the change trends of the 3m deep base point and the 9m deep base point are consistent. The roof dislocation mainly occurs within the range of 0-3m of the roof. It is expected to occur between the top coal and the immediate roof. There is almost no dislocation in the rock layer within the range of 3m-9m of the roof height, which can also indirectly prove that the large structure of the goaf leaving roadway remains intact and has not been damaged.

(2) Rock mass stress analysis

The monitoring of surrounding rock stress mainly includes the working resistance of anchor cables, the supporting pressure of single pillars and the lateral supporting pressure.
The lateral supporting pressure is monitored by using borehole stress gauges. The observed variation values of the lateral supporting pressure are shown in Figure 8.

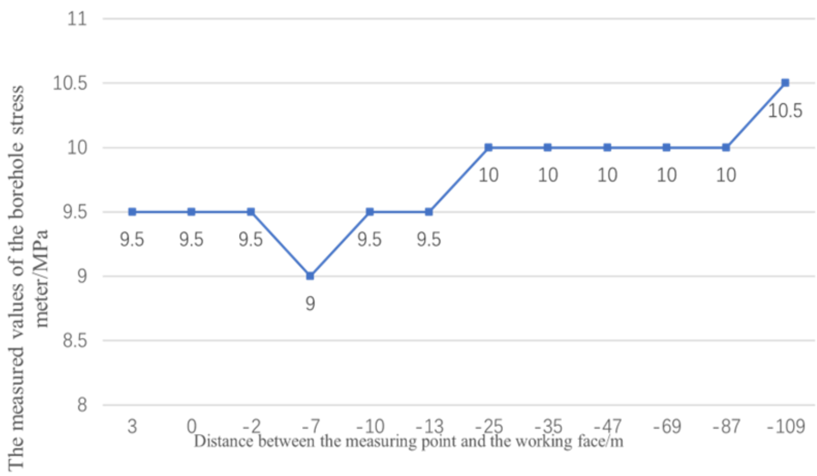


Figure 8: Trend Chart of Sideways Support Pressure Changes

It can be seen from Figure 2-8 that: The lateral support pressure at this measurement point increases slightly from the front to the rear of the working face, and no obvious stress concentration phenomenon is observed; The maximum support pressure is shown to be 10.5 MPa, which is less than the compressive strength of the coal pillar, and the test area of the surface stress meter is an elastic region.

4. Conclusion

1. In the 3207 working face, the roadways have undergone considerable deformation. In some sections, the side supports of the roadways have cracked and there are cases where the side supports have penetrated the roof. However, the overall structure remains stable. The roadways can be reused after restoration, but the amount of roadway repair and maintenance is considerable. Further measures such as brushing the sides, lowering the floor, and strengthening the supports are required before they can be put into use.
2. The main reason for the good effect of the "empty space left behind" method is that the parameters for roof caving and pressure relief have been optimized, the pre-split blasting range has been expanded, the height of roof caving has increased, the "given deformation" of the masonry beam structure has decreased, the roof subsidence has been reduced, and the rotation angle of the roof has decreased.
3. The experiments have proved that after adopting the technology of cutting the roof and releasing pressure while leaving the roadway along the mining face, the mine pressure gradually stabilizes during the working face's mining process, and the damage degree of the roadway is within the acceptable range. It is feasible to promote this technology in the Jincheng mining area in combination with other technical measures. This provides reference experience for other mines to achieve coal pillarless mining and increase the mining rate.

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