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Research on Fracture Mechanism of Roof Plate and Filling Technology of Working Face Over-air Tunnel

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ABSTRACT

For a long time, the faults on both sides of the working face have been the technical problems faced by the coal mining face. Aiming at the situation that both sides of 7509 comprehensive workings in Wuyang coal mine are near to big faults, and through several long and short hollow alleys, the theoretical analysis, numerical simulation and other methods are used to study the fracture mechanism of the roof plate of comprehensive workings in both sides of the faults and the technology of safe and fast hollowing of the workings. Through theoretical calculation and numerical simulation, it is finally determined that the filling strength of 4 MPa is the most suitable. And through the field industrial test, it is proved that the working face can realize rapid, safe and stable mining after filling with ultra-high water material.

KEYWORDS

Overspill tunnel; filling; numerical simulation; ultra-high water material.

1. INTRODUCTORY

Coal is a non-renewable resource essential to human life, in the daily production process of coal mines, faults are a common geological structure of coal mines, and with the increasing depth of mining, the geological structure is also more and more complex, because of the complexity and dangers of faults and geological structure, there are often coal resources stopping and jumping to leave a coal pillar mining, resource loss and waste is serious, in order to deal with the problems caused by the different types of faults and faults structure to the safety of coal mines, it is particularly important to study the surrounding rock stress and surrounding rock deformation caused by different types of faults. In order to deal with different types of fault structure to coal mine safety production problems, the study of different types of fault structure caused by the surrounding rock stress and deformation of the surrounding rock is particularly important.

At present, a large number of studies have been carried out on the basic theories of the evolution of overburden structure, roof transport, and stress field distribution characteristics of the overburden quarry, among which the problem of overburden group in the face of comprehensive mining occurs from time to time, which affects the safe and efficient recovery of coal resources[1,2,3]. Numerous experts and scholars have analyzed and researched the engineering problems of the over-empty tunnel in the comprehensive mining face from the monitoring and analysis of mining pressure, the working face roof breakage and movement, the influence of mining characteristics, the stability of the coal pillar-roadway perimeter rock support, and gradually formed an effective technical method and process to solve the problem of the over-empty tunnel in the working face[4,5,6,7,8]. After the research of experts and scholars[9,10,11,12,13,14], domestic and foreign synthesis mining working face over the empty lane technology has tended to mature, but synthesis mining working face over a number of parallel to the working face of the empty lane group mining to pressure highlighting features to be further in-depth study[15,16,17].

2. ENGINEERING BACKGROUND

2.1. Basic overview of the working face

7509 return air lane (including 7509 return air lane coal lane, 7509 return air lane car park, 7509 return air lane return air passage, 7509 return air lane contact lane) is used for 7509 working face to mine back to the return air.7509 return air lane coal lane, 7509 return air lane and 7509 return air lane contact lane are located in the former east of the East Zhou village, the ground elevation of the ground for the +901 ~ +916 m. 7509 return air lane coal lane, 7509 return air lane (outside section), 7509 return air lane contact lane and 7509 return air lane (inside section) are located in the former east of the East Zhou village.

The 7509 Return Lane Outlet Lane, 7509 Return Lane (Outside Section), 7509 Return Lane Contact Lane and 7509 Return Lane (Inside Section) are located in the 75 mining area at the +600 level.

The designed length of 7509 return-air lane is 284.1 m, and the elevation of the roadway is from +599 to +620 m. The eastern and northern part of 7509 return-air lane is the preparation roadway for 75 mining area, the western part is 7503 and 7505 mining area, and the southern part is the exploration roadway for 7505 working face;

The design length of 7509 return air lane (outer section) is 522.9 m, and the elevation of the lane is from +581 to +599 m. The eastern and southern part of 7509 return air lane (outer section) is the general return air lane of 76-2# section, the western part is the 7515 mining area, and the northern part is the 7505 mining area;

The designed length of 7509 return-air lane is 128.9 m, and the elevation of the lane is from +581 to +583 m. The eastern and northern part of 7509 return-air lane is the exploratory lane of 7505 working face, the western part is the 7515 mining area, and the southern part is the general return-air lane of 76-2# section;

The design length of 7509 return-air lane (Li-section) is 329.5 m, and the elevation of the lane is +564～+581 m. The eastern part of 7509 return-air lane (Li-section) is the exploratory lane of 7505 working face, the western part is the 7515 air-mining area, the southern part is the general return-air lane of 76-2# section, and the northern part is the 7505 air-mining area.

2.2. Geological structure

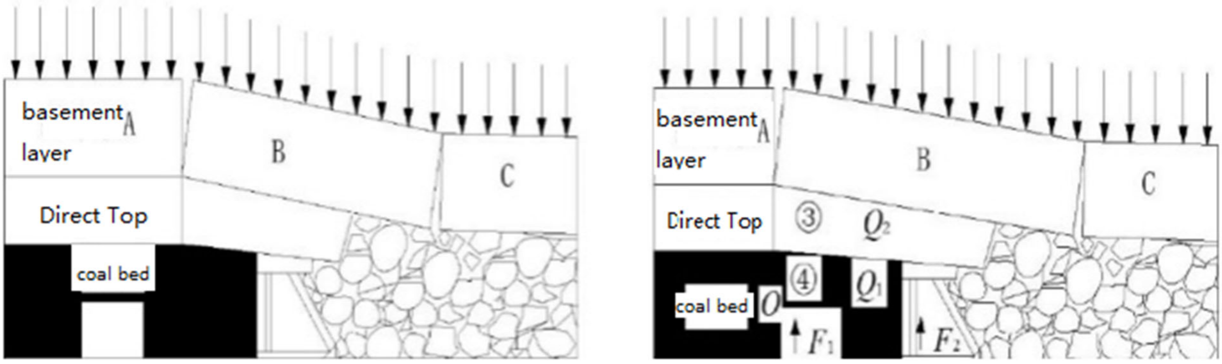
The inclination angle of coal seam along the 7509 return-airway exit lane is from -9 to -1 °, with an average of -5 °; the inclination angle of coal seam along the 7509 return-airway (outer section) is from -5 to -1 °, with an average of -3 °; the inclination angle of coal seam along the 7509 return-airway liaison lane is from -3 to -1 °, with an average of -2 °; and the inclination angle of coal seam along the 7509 return-airway (inner section) is from -5 to -1 °, with an average of -3 °.

According to the 3D seismic survey, the geological drilling results of the 76-2 # section general air return lane and the analysis of the adjacent roadway excavation data, the excavation of the 7509 air return lane will encounter the rising 7509-1 # positive fault with a drop of 1.2 meters in front of it at the 173 meters point from the opening of the coal roadway, and the excavation of the roadway will encounter the dropping 75-3 # positive fault with a drop of 6 to 8 meters in front of it at the 198 meters point from the opening of the roadway; When the roadway of 7509 return-airway liaison lane reaches 82 meters ahead of the opening, it will encounter the 7509-2 # positive fault with a 2.5-meter drop and a rise in front of it; when the roadway of 7509 return-airway (inner section) reaches 191 meters ahead of the opening, it will encounter the V-201 borehole reversal fault with a 5.5-meter drop and a drop in front of it, and then it will pass near the 76-10 # positive fault with an 8-meter drop and a dip of 70° when the roadway reaches 260 meters ahead of the opening and stops digging. The opening will pass near the 76-10 # normal fault with a drop of 8 meters and a dip of 70°, and the face may encounter small geological structures derived from this fault at this location.

3. STABILITY ANALYSIS OF THE BASIC ROOF IN THE CASE OF PASSING THROUGH THE EMPTY TUNNEL

3.1. Characteristics of basic roof breakage when the integrated mining face passes through the empty tunnel

As the comprehensive mining face gradually advances to the empty tunnel, the width of the coal pillar between the face and the empty tunnel gradually decreases, and its bearing capacity gradually decreases. When the coal pillar is broken and destabilized under the supporting pressure, the position and stability of the masonry beam structure will change to a certain extent, which mainly manifests itself in the location of the key block breakage and the length of the block, and then causes the change of the characteristics of the working face mine pressure. In the process of crossing the open road in the comprehensive mining face, when the breakage of the basic top occurs before the destruction and destabilization of the coal pillar and the distance from the open road is relatively close, the next key block will cross the working face, the coal pillar and the open road and the length of the block does not increase significantly, i.e., the cycle of the pressure step is normal, and the mine pressure is not obvious abnormality, as shown in Fig. 1(a). When the basic roof is about to generate cyclic pressure near the airway, the coal pillar destabilizes and causes the key block above to rotate in advance, and the key block does not break at the established position, and it crosses the coal pillar and the airway, and breaks near the airway, as shown in Fig. 1(b). At this time, the length of the key block is larger than the cycle pressure step of the working face, forming a "long key block across the lane", and the pressure strength of the working face increases, and the working face and the empty lane are in a dangerous state, which is not conducive to the control of the stent-surrounding rock in the quarry.



(a) Regular Key Blocks (b) Cross-lane long key block

Figure 1. Basic roof rupture model of the open-channel

Therefore, by analyzing the influencing factors of the overrun rupture of the basic roof when the comprehensive mining face passes through the hollow way, the location of the overrun rupture of the basic roof and the size of the "key block across the length of the way" are derived, and then the minimum support resistance required for the hollow way under the condition of guaranteeing the safety of the comprehensive mining face to pass through the hollow way is solved.

3.2. Stability analysis of the basic roof when crossing the empty tunnel

The working face of 7509 in Wuyang Mine has a cyclic pressure step =14.2 m, the width of the empty road =3.8 m, and the limit width of coal pillar instability =2.6 m. Therefore, the long key block across the roadway when crossing the empty roadway is about 20.6 m, and the length of it is 1.47 times that of the conventional key block, and the part of load caused by the increase of the length of the key block will be transferred to the stent through the direct top layer, and the stent's bearing capacity will be increased, which will result in the appearance of the mine pressure in the working face. Drastic. The structural stress state of the key block across the length of the lane is shown in Figure 2.

Where θ_1, θ_2, is the angle of rotation of the key block B 、 C, $Q_{A'}$ 、 $Q_{B'}$ is the shear force, , T is the horizontal force, R_1 , is the support force of the direct roof on the key block, B , R_2 is the support force of the gangue on the key block, C , P_1 、 P_2 is the dead weight of the key block and the load, B ， C , a is the length of the extruded contact surface between the key blocks, h , is the thickness of the key block, L, is the length of the key block, and , is the length of the key block. For simplicity of calculation, take , $\sin\theta_2 \approx \sin\theta_1 / 4$, $\cos\theta_2 \approx 1$, $P_2 = R_2$.

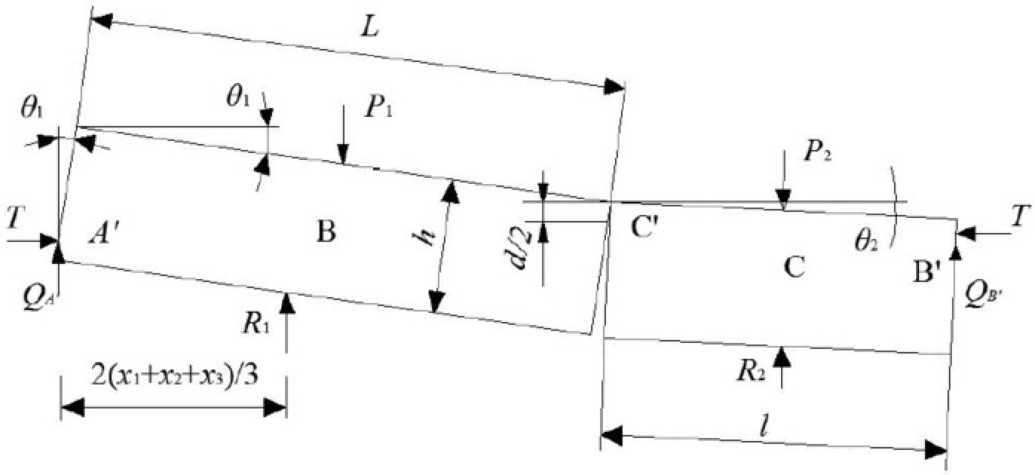


Figure 2. Force analysis of the "long key block across the lane".

Analyze the balanced equations based on the forces on the long key block shown in Figure 2:

$$2R_1(x_1 + x_2 + x_3)/3 + T(h - \Delta - \alpha) - (P_1 L\cos\theta_1)/2 = 0 \tag{1}$$

$$P_1 = R_1 + Q_A \tag{2}$$

Equations (1) and (2) give

$$T = \frac{P_1 L\cos\theta_1}{2(h - \Delta - a)} - \frac{2R_1(x_1 + x_2 + x_3)}{3(h - \Delta - a)} \tag{3}$$

According to mine pressure and control theory, conditions must be met to prevent slip instability of the critical block at the point:

$$Ttan\varphi \geq Q_{A'} \tag{4}$$

Substituting equation (3) into equation (4) yields

$$\begin{cases} R_1 \ge P_1\left[\dfrac{3L\cos\theta_1\tan\varphi - 6(h-\Delta-a)}{4\tan\varphi(x_1+x_2+x_3)-6(h-\Delta-a)}\right] \\ P_1 = bL(q+h\gamma_2) \\ \theta_1 = \arcsin\left[M-(K_p-1)\Sigma h\right] \\ a=(h-\Delta)/2 \end{cases} \tag{5}$$

Where, Δ is the rotary subsidence of the key block B, m; M is the thickness of the coal seam, m; $\sum h$ is the thickness of the direct roof, m; q is the unit load borne by the key block B, MPa; K_P is the coefficient of expansion; b is the width of the support, m; γ_2 is the capacity of the rock layer, kN/m3.

Figure 1 (b), ③, ④ combination of blocks for mechanical analysis, which acts on the place, acting on the place. The equilibrium equations of the combined block are listed: about the point bending moment O and $\sum M_O = 0$, the combined force in the vertical direction $\sum F_y = 0$, i.e.

$$\frac{F_1x_1}{2} + F_2\left(x_1+x_2+\frac{x_3}{3}\right) - \frac{2(Q+R_1)(x_1+x_2+x_3)}{3} = 0 \tag{6}$$

$$F_1 + F_2 = Q + R_1 \tag{7}$$

Equations (6) and (7) give

$$F_1 = \frac{2x_1+2x_2-2x_3}{3x_1+6x_2+2x_3}(Q+R_1) \tag{8}$$

Where, Q for the unit length of the direct top load, kN; γ_1 for the bulk weight of the coal body, kN/m^3, m for the direct top thickness, m; F_1 for the unit length of the critical support force of the roof plate of the airway, kN.

With the increase of the width of the airway, the critical support resistance of the airway also increases, and the rate of increase is gradually increasing, indicating that when the width of the airway is too wide, it is necessary to provide the airway with a considerable amount of support resistance, which is consistent with the previous subsection on the analysis of the impact of the airway span on the basic top of the overrun rupture, when the airway span is too large, it should be rearranged from the point of view of safety, economic considerations of the working face.

4. NUMERICAL SIMULATION OF STRENGTH OF AIRWAY FILL

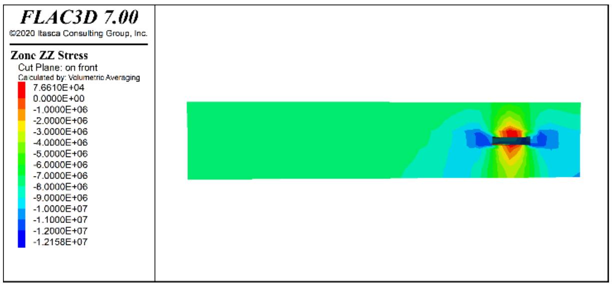
For the coal mining face to cross the empty road safely, it is decided to use super high water material filling grouting to fill the empty road. According to the above analysis, take =120 m (the length of the empty roadway is 120 m, not taking the actual working length of the working face); =13.5 °; =4.7 m; =6.5 m; =6 MPa; =11.92 m; =3.82 m; =8×4.7×0.025=0.94 MPa; =350 m; =4.4 m; =3.75 m; =0.025 MN/m3; =0.2; =5 MPa/m; =1000 MPa/m; =1.5; =1000 MPa/m. 0.2; =5 MPa/m; =1000 MPa/m; =1.5;

=80 MPa. Substituting the data into Eq. 7 and Eq. 8, we can find out that the final strength of the airway filling body is not less than 3.12 MPa.

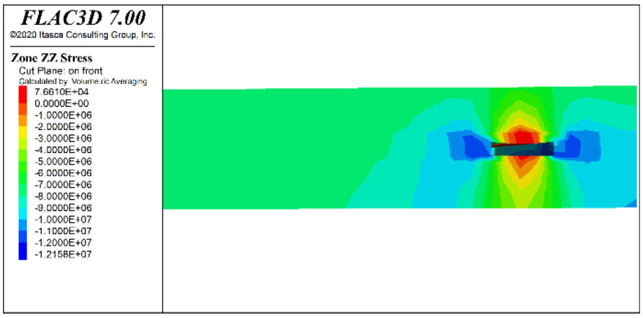
In the simulation, the strength of the filling body of 2 MPa, 3 MPa, 4 MPa and 5 MPa were analyzed. The main purpose is to analyze the stress distribution law and deformation law of the surrounding rock with different strengths of the filling body. According to the calculated results, the strength of the filling body is determined.

4.1. Study on vertical stress distribution in the surrounding rock of the open channel with filling body strengths

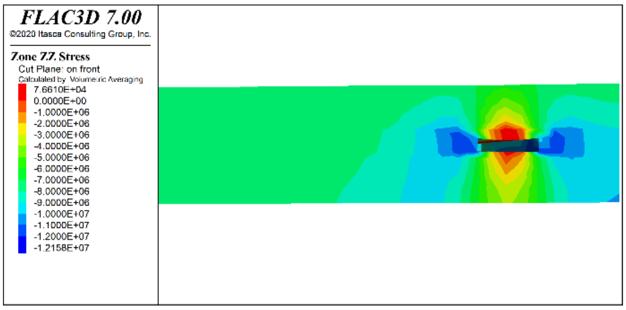
When the strength of the filling body is different, its ability to resist the compression of the upper rock layer is different. The greater the strength, the smaller the deformation of the filling body will be, and the greater the lateral support pressure on the coal pillar, the smaller the deformation of the coal pillar will be at this time. When the empty tunnel is filled with the filling body, the coal column will not be deformed significantly. The greatest deformation of the filling body is when the working face advances to the position of the empty tunnel and in the process of crossing the empty tunnel. The force of the filling body on the coal pillar and the upper rock layer is mainly manifested in the redistribution of vertical stress in the coal pillar and the coal and rock body around the airway. As Fig. 3-Fig. 6 show the vertical stress distribution when the width of coal pillar is 20 m, 10 m, 5 m and 0 m respectively with different strength of filling body.



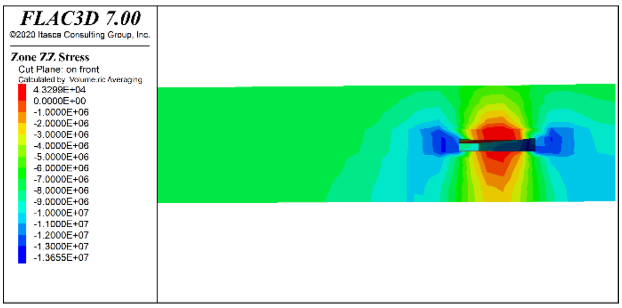
(a)2MPa



(b)3MPa

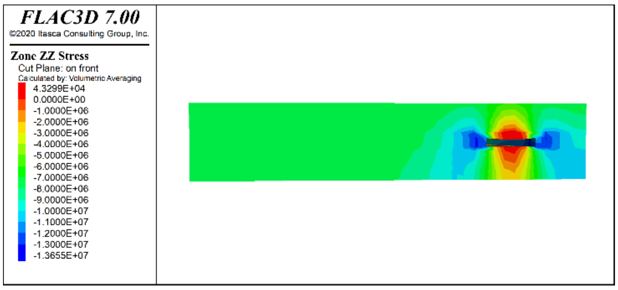


(c)4MPa

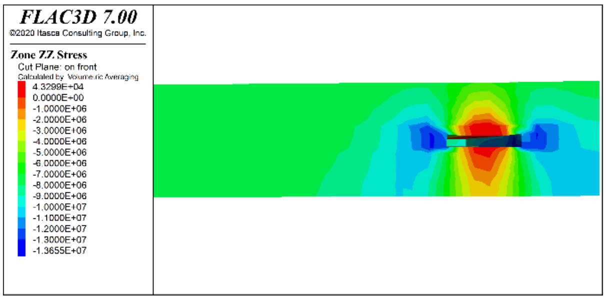


(d)5MPa

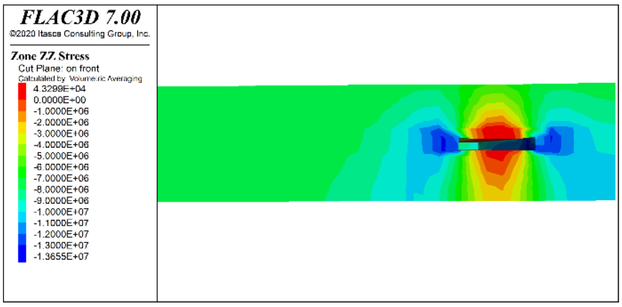
Figure 3. Stress distribution of 20 m coal pillar with different strength of filling body



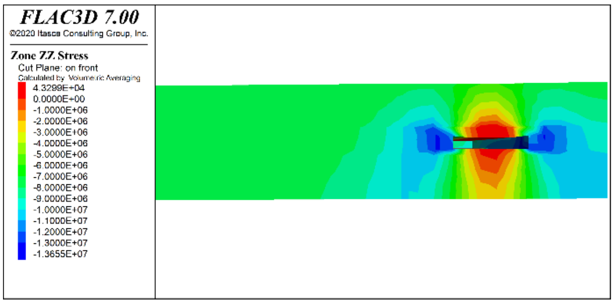
(a)2MPa



(b)3MPa

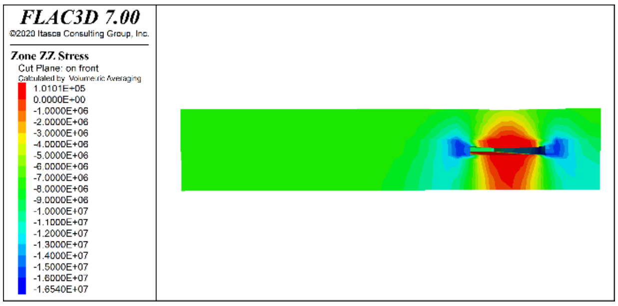


(c)4MPa

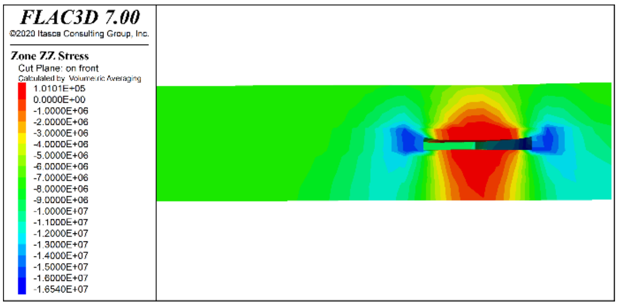


(d)5MPa

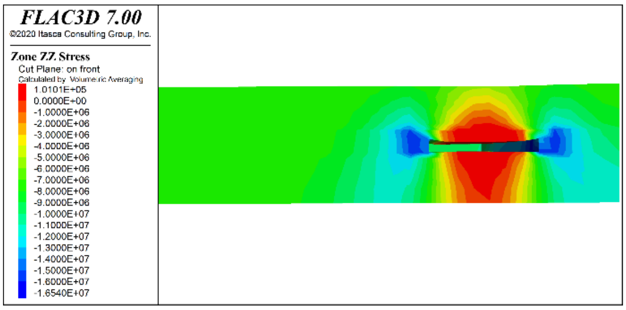
Figure 4. Stress distribution of 10 m coal pillar with different strength of filling body



(a)2MPa



(b)3MPa



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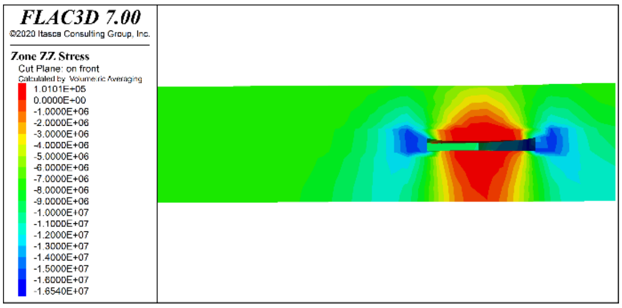
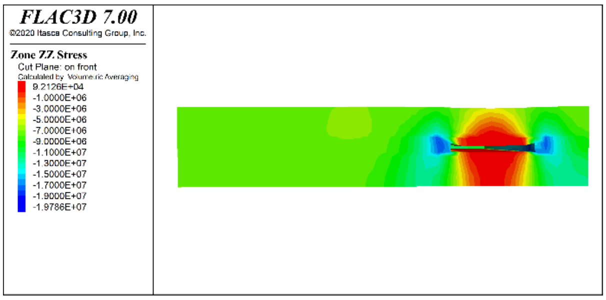
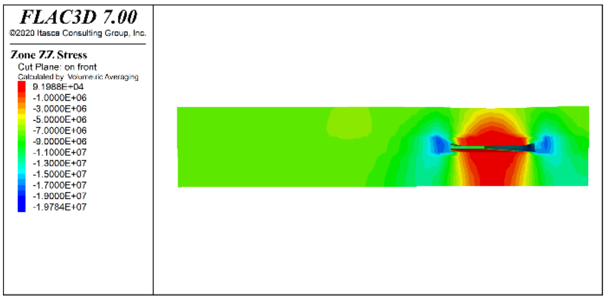


(d)5MPa

Figure 5. Stress distribution of 5 m coal pillar with different strength of filling body



(a)2MPa



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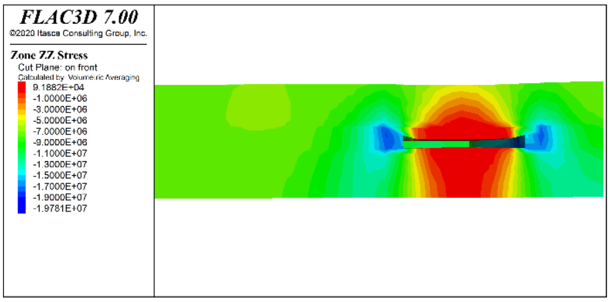
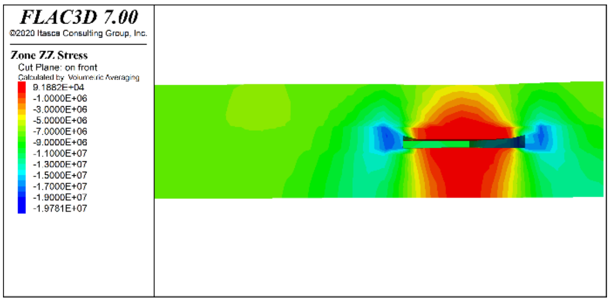


(c)4MPa



(d)5MPa

Figure 6. Stress distribution of 0 m coal pillar with different strength of filling body

It can be seen from Figure 3-Figure 6:

(1) When the strength of the filling body gradually increases, the vertical stress on the filling body also increases gradually. However, the vertical stress of the coal pillar shows a decreasing trend, which indicates that the stronger the filling body is, the smaller the load of the upper rock layer on the roof plate is, but the trend is not very big;

(2) When the width of coal pillar gradually decreases, the vertical stress of coal pillar gradually decreases. However, the maximum vertical stress is always located in the upper rock layer in front of the working face, and the empty tunnel and the unmined solid coal in front of the working face do not bear the maximum vertical stress;

(3) When the strength of the filling body is 4 MPa, the vertical stress around the filling body is almost the same as the stress distribution law when it is greater than 4 MPa. Therefore, from the point of view of the stress distribution law, the filling body strength of 4 MPa has reached the required requirements.

4.2. Deformation analysis of coal pillar body

The deformation of coal pillar body is asymmetric, near the working face end, the deformation of coal pillar is larger, near the end of the empty lane, the coal pillar is affected by the excavation of the empty lane without lateral support, the deformation is also larger, and the deformation in the middle of the coal pillar is the smallest. Then record the deformation of the coal column near the working face (hereinafter referred to as the left end), near the end of the empty lane (hereinafter referred to as the right end) and the middle of the coal column, and then take the average value to make the deformation curve of the coal column, as shown in Fig. 8.

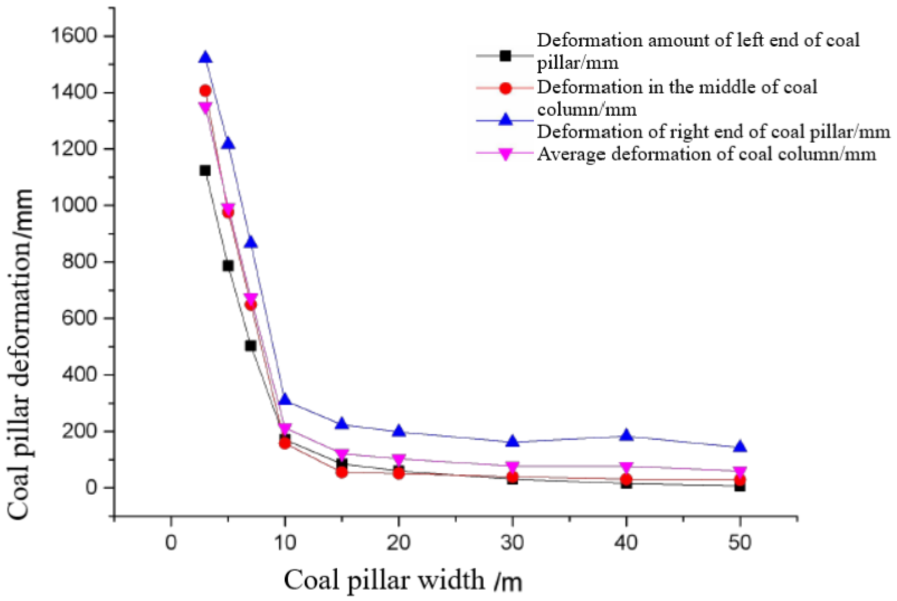


Figure 7. Deformation curve of coal pillar body

From Fig. 7, it can be seen that the deformation amount of the left end, center and right end of the coal pillar body is different in size, but the change trend is the same. The deformation amount of the right end of the coal pillar is the largest, followed by the deformation amount of the middle part of the coal pillar, and the smallest deformation amount is the left end of the coal pillar. Therefore, it can be determined that the change of the influence of the airway excavation on the coal pillar is not very big, and the deformation of the coal pillar is mainly caused by the forward transfer of the overrunning support pressure as the working face keeps advancing. The average deformation curve of the coal pillar is similar to the deformation curve of the surrounding rock of the empty tunnel. When the width of coal pillar is more than 15 m, the deformation of coal pillar is very small, almost tends to be flat, when the width of coal pillar is 10 m-15 m, the deformation of coal pillar body starts to increase dramatically, when the width of coal pillar is less than 10 m, the coal pillar body starts to appear sharp deformation, and finally the deformation of coal pillar is too large, exceeding its maximum deformation, and destabilization occurs.

In summary, the risk range of coal pillar width can be divided into 3 parts:

(1) Unaffected width: the width of coal pillar is more than 15 m, the deformation of the surrounding rock and the coal pillar body tends to be almost smooth, at this time, the deformation is small, and it will not affect the normal mining of the working face;

(2) Larger impact width: the width of the coal pillar is 10-15 m, at this time the deformation of the top and bottom plates and the two gangs of the empty tunnel starts to increase significantly, and the coal pillar starts to show obvious compression deformation, which will have a certain impact on the normal mining of the working face;

(3) Drastic impact width: the width of the coal pillar is less than 10 m, the deformation of the top and bottom plates of the empty tunnel and the two gangs begins to increase dramatically, the coal pillar begins to appear sharp compression and deformation, and the top plate of the working face appears to be drastically sinking, and at this time there will be accidents such as the pressure frame, and at this time, the face can not be carried out back to the mining work.

Therefore, through the above analysis, it can be seen that the airway filling body to reach the minimum resistance required by the airway should be in the coal pillar width is greater than 10 m, or the working face from the straight line distance of the airway is greater than 10 m, at this time to control the intense deformation of the surrounding rock of the airway, so that the working face safely through the airway.

5. ANALYSIS OF MINING PRESSURE OBSERVATION RESULTS

5.1. Working face hydraulic support force analysis

The working face is a comprehensive mechanized large mining height once mining high, the hydraulic support model is ZY12000-30/68D, in order to monitor the 7509 working face stent pressure and changes in the situation, set up the working face hydraulic support measuring station, using YHY-604 hydraulic support force measuring instrument. The line is arranged along the direction of the tendency length of the working face.

When the working face exposes the empty tunnel and continues to advance into the empty tunnel, the force on the stent inside the partially filled empty tunnel is different, and the force on the stent in the unfilled section must be greater than that on the stent in the filled section. Therefore, the monitored data of the hydraulic stent in the unfilled section of the central position of the 7509 working face, i.e., the 65th frame, 66th frame, 67th frame, and 68th frame, are averaged, and the curve is plotted to observe the average pressure change of hydraulic stent in the process of mining back. The average pressure change of the hydraulic support is shown in Figure 9.

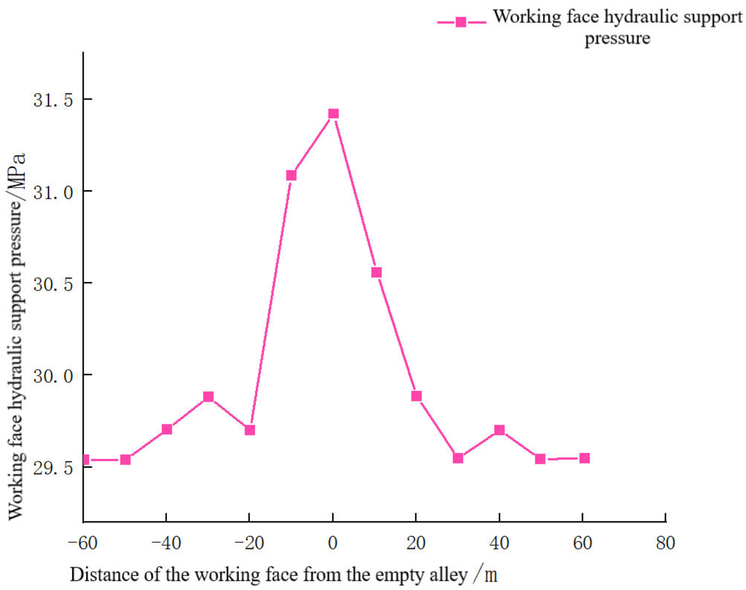


Figure 8. Hydraulic support pressure at different distances from the working face to the empty tunnel

As can be seen from Figure 8, when the distance between the working face and the empty lane is more than 40 m, the average working resistance of the working face bracket is around 29.3 MPa, when it is affected by the partial filling of the empty lane. When the distance between the working face and the empty lane is 20-40 m, the resistance of the working face increases, when the working face is less than 20 m from the horizontal distance of the empty lane, the maximum resistance of the hydraulic support of the working face reaches 30.3 MPa, the increase is not too big, only an increase of 3.5 %, and the maximum pressure is lower than the opening pressure of the support safety valve. After the working face passes through the empty tunnel, the pressure returns to the normal value, which indicates that the test empty tunnel with partial filling has a better effect and can pass through the empty tunnel quickly and safely.

5.2. Deformation characteristics

A roadway surface displacement measurement point is arranged at 5 m at both ends of the empty tunnel, and each station adopts the cross-point method to set up surface displacement monitoring section to analyze the filling effect of ultra-high water filling material, and the monitoring data and curve diagram are shown in Figure9.

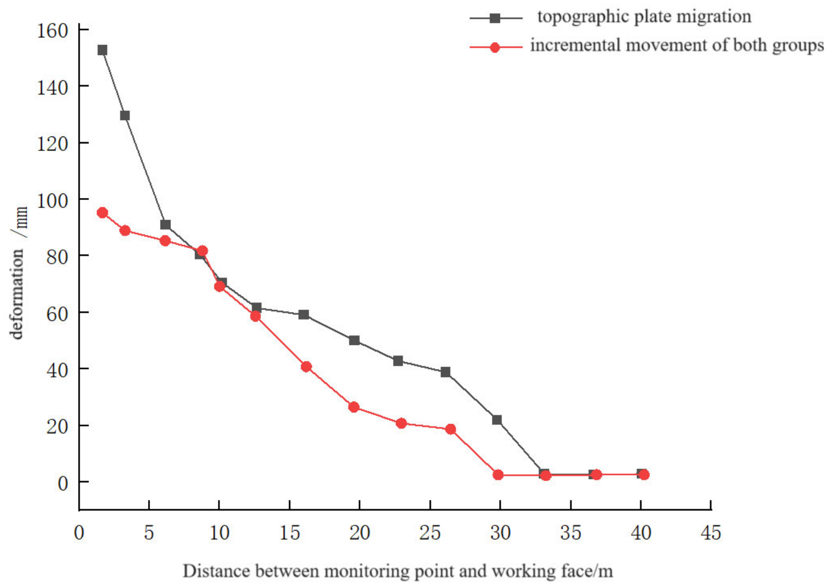


Figure 9. Canyon deformation monitoring results

From Fig. 9, it can be seen that the deformation monitoring of the roadway at the side of the filling area is reduced, which indicates that the filling effect of the empty roadway is better, and it can play a good role in supporting the roadway.

(3) Maintenance condition of empty tunnel

When the working face is fast advancing to the empty road, the filling body of high water material effectively reinforces the broken coal rock bodies of two gangs in the empty road; when advancing to the empty road, the strength of the filling body is not too strong, and the coal mining machine can cut the filling body smoothly, and there is no gang phenomenon of the filling body, and there is no roof phenomenon in front of the stent, and the plastic deformation characteristics of the filling body and the good performance of letting the pressure, which provides good technical way for the working face to pass the empty road quickly and safely. It provides a good technical way for the working face to pass through the empty tunnel quickly and safely.

6. CONCLUDE

(1) A three-dimensional mechanical model of basic roof breakage was established, and the formula for calculating the minimum support resistance of the airway required for the roof plate of the airway not to be destabilized was derived, and then according to the actual situation, the minimum support resistance of the airway in the 7509 working face was 3.62 MPa.

(2) Numerical simulation analysis of the transport and stress evolution law of different strength of filling body for the surrounding rock of the airway was carried out, and it was found that when the strength of the filling body was less than 4 MPa, the vertical stress suffered by the filling body of the airway was less than the stress of the surrounding rock, and at this time, the surrounding rock of the airway would produce a certain amount of deformation, and the filling body would produce a compressive deformation. When the face is mined back to the empty lane, the lateral deformation of the filling body is more serious. When the strength of the filling body is more than 4 MPa, the deformation of the filling body is relatively small, and the requirements have been met. Therefore, it is determined that the final strength of the filling body is 4 MPa.

(2) The industrial test comprehensively concluded that the ultra-high water material can play a more effective control of the deformation of the empty tunnel, enhance the strength of the surrounding rock of the empty tunnel, and effectively guarantee the safety and stability of the comprehensive release working face over the empty tunnel.

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