Hindawi
Geofluids
Volume 2022, Article ID 3429063, 16 pages
https://doi.org/10.1155/2022/3429063

Research Article

Study on the Deformation Mechanism of the Bottom Plate along the Empty Lane of Deep Mining and the Control Technology of the Bottom Drum

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Received 4 April 2022; Accepted 1 June 2022; Published 13 September 2022

Academic Editor: Hao Wu

Aiming at the problem of the deformation of the roadway floor plate during the laneway during the retention period, the mechanical model of the roadway floor is established, and the deformation characteristics of the roadway floor and the change law of the bottom drum are studied and analyzed through theoretical calculation and calculus simulation, revealing the instability mechanism of the surrounding rock of the roadway under the stress disturbance environment, and when not affected by the adoption, the roadway forms a certain stress concentration area within the effective range of support. During mining, under the comprehensive action of the original peripheral stress field and the mining stress field, the cliffhanger is unstable under the comprehensive action of the original peripheral stress field and the mining stress field, and the extrusion and stretching effect of the unflapped part of the rock layer above the goaf section of the coal seam is set up along the air, resulting in violent deformation such as the bottom drum, and the rotational sinking of this part of the unflinted rock layer further aggravates the transfer of the overburden load to the surrounding rock of the lane, so that the surrounding rock along the empty lane is subjected to a large additional stress, and the mining stress field plays a leading role, and the mining stress "far field" is the compound stress field, of which the tensile stress is the leading destructive factor. The deformation of the surrounding rock is mainly based on the bottom, and the horizontal stress on the bottom plate along the empty lane is mainly generated by the horizontal strain that occurs after the lower rock layer of the filling body and the coal gang is subjected to the supporting pressure transmitted by the top plate. With the mining of the working surface, the roof of the goaf area is broken and collapsed to form the characteristics of "vertical three belts," which is affected by the "large support" of the coal body of the working surface and the "small support" of the surrounding rock along the empty roadway, and the pressure relief of the cut roof can make the roof plate along the empty lane change from the "long arm beam" structure when the roof is not cut into the "short arm beam" structure, blocking the lateral stress of the goaf area to the roof plate of the alley and significantly reducing the degree of stress superposition of the roof plate of the alley. The technical means of blasting cutting roof active pressure relief and protective lane are used to block the transmission of lateral support pressure, the roof slate layer is precracked in advance, the sinking of the rock layer is accelerated, the disturbance time is reduced, the vertical stress of the rock layer and the rock layer above it along the empty roadway is reduced, the vertical stress concentration of the roadway is

reduced, the stress concentration coefficient is reduced, the degree of damage of the surrounding rock after the top is weakened, the damage range is reduced, and the technical problem of large deformation prevention and control along the bottom drum of the empty alley can be solved. Constructing the mechanical structure model of the top plate of the cut top pressure relief and the uncut top pressure relief along the empty lane, the stress change characteristics of the active protective rock surrounding rock along the hollow top of the cut top pressure relief were calculated, and after the technical scheme of the blasting cut top active pressure relief and protection lane was adopted, the deformation along the empty roadway was significantly weakened, the stability of the surrounding rock of the roadway after the blasting of the cut roof was significantly improved, the maintenance state along the section of the empty roadway was good, and the cross-sectional convergence rate was reduced by 37.3% compared with the original section. Cutting the roof active pressure relief and protective lane can effectively improve the stability of the surrounding rock.

1. Introduction

With the increasing depth of coal mining, the problem of roadway deformation is more and more serious, which seriously restricts the safe and efficient production of coal mines. Under the influence of "three highs and one disturbance" environment and secondary mining, the surrounding rock of deep roadway, especially the gob retaining roadway, shows strong floor heave deformation, which creates a huge obstacle to the safe production of coal mine [1, 2]. In view of the problems of large deformation, long deformation duration, and difficult support of deep mine high stress soft rock roadway, taking the goaf roadway of Panji Coal Mine 12 as the engineering background, it is revealed that high ground pressure and strong disturbance are the main power sources of large deformation and failure of the roadway. The fracture of surrounding rock with low load resistance intensifies the structural weathering and strength deterioration of surrounding rock of the roadway and intensifies the capacity expansion deformation of the roadway, which is the main internal cause of large deformation of the roadway [3, 4]. There are many factors causing the deformation of the roadway bottom drum, and the key influencing factors are rock layer stress, rock creep characteristics, large-section soft rock expansion, bottom slate lithology, structural state, bottom plate support strength, and secondary mining influence of adjacent mining area [5–7]. The bottom heave of the gob-side entry mainly occurs during the period from the first mining to the second mining. The reason is that the roadway floor is broken after the first mining. The fractured rock mass then undergoes postpeak creep under the action of mining stress during primary and secondary mining [8, 9]. The deformation force and deformation speed of the square bottom plate in front of the primary recovery work are small, and the deformation of the bottom plate behind the working surface is violent, and the bottom drum volume is larger [10, 11]; the deformation of the square bottom plate in front of the secondary recovery work is violent, and the bottom drum volume is larger [12, 13]. At this time, the roadway surrounding rock must be regarded as a whole, and the control of the bottom plate must be placed in the same important position as the top gang control, and the reinforcement of the bottom plate must be carried out while supporting the top gang, so that the entire roadway forms an overall bearing structure [14, 15].

In the stage of preemptive influence of a single operation, the advanced support pressure of the working surface sinks the support point of the top plate on the side of the working surface, and the stress concentration area is located along the empty roadway, the stress concentration coefficient increases, the degree of failure of the bottom plate is the largest, the depth of the surrounding rock failure and the development of the fracture are increased, the stress distribution is asymmetrical, the deformation of the two gangs is obviously asymmetrical, and the deformation of the side of the near goaf area is serious [16]. In the lane retention stage, the empty top distance and the wall filling deformation make the top plate further rotate and sink, the high-strength filler is embedded in the bottom plate, the bottom drum is serious, and the bias stress distribution pattern is obvious [17, 18]. The deformation of the surrounding rock in the secondary mining advanced influence stage is more asymmetrical on the basis of the deformation of the lane retention stage, and the "easy stable arch structure" starting from the excavation stage along the overburdened rock of the empty lane gradually evolves to the "conditionally stable arch structure" of the lane retention stage, and finally the evolution mechanism of the "difficult stable arch structure" in the stage of the secondary mine is ahead of the secondary mine. It reveals the reasons why the surrounding rock along the deep well is difficult to control along the empty lane [19, 20].

In this paper, the stress environment and mechanical characteristics and the deformation mechanism of the bottom drum mining along the empty roadway are explored and studied, and the mining is unstable under the comprehensive action of the original peripheral stress field and the mining stress field, and the mining stress field plays a leading role, the "far field" of the mining stress is the composite stress field, of which the horizontal tensile stress is the leading destructive factor, the surrounding rock deformation is dominated by the bottom scoop, and the multilayer thick and hard "rock beam" is the target rock layer with the cut top within the height range of the mining influence, which is the key rock layer affecting the appearance of the mine pressure of the roadway. The technical means of active pressure relief and protection of the tunnel are used to block the transmission of lateral support pressure, analyze its mechanical action characteristics, optimize the stress environment, precrack the top slate layer in advance, accelerate the sinking of the rock layer, reduce the disturbance time, reduce the vertical stress of the rock layer and the rock layer above it

along the empty roadway, reduce the vertical stress concentration of the roadway, reduce the stress concentration coefficient, weaken the degree of destruction of the surrounding rock after cutting the top, reduce the scope of destruction, and supplement the support and reinforcement means to solve the technical problems of large deformation prevention and control along the bottom drum of the empty alley. The main idea is shown in Figure 1:

2. Working Surface along the Empty Alley Bottom Drum Influencing Factors

2.1. Overview of the Working Surface Project. In Panji Mining Area, the principal mining is 11-2 coal, which thickness is around 1.7 ~ 2.87 m, and the average thickness is 2.26 m. The recovery height of the mining face is 2.6 m. The working surface is oriented in the east-west direction, the orientation is 278.5°, the direction is 1728 m, the width is 264 m, the ground elevation is +21.5~+22.1 m, the underground elevation is -738 m~-823 m, and the average burial depth is more than 750 m. When the working surface is mined, the roadway deformation is drastic, affecting the normal use; the amount of road repair engineering is difficult, the occupation time cost is high, especially the deformation of the bottom drum is large, the coal seam roof has thick hard rock beams, the soft rock distribution of the bottom plate is as much as 10 m range, and the bottom drum support treatment is difficult. Its geological histogram is shown in Figure 2:

2.2. The Main Influencing Factors of the Drum along the Empty Alley Bottom Drum. The initial width and height of the trough section of the 11-2 coal working surface track are 5 m, and the height is 3.5 m, and the width of the alley is 4.2 m, and the height is 3.4 m, and the main stage of the formation of the working surface along the bottom drum of the empty lane can be divided into the tunnel boring stage and the stage along the empty lane. The main influencing factors are engineering geological factors, mining technology factors, and support conditions.

2.2.1. Engineering Geological Factors. 11-2 coal working surface track trough depth is -818 m, buried depth is deeper, the roadway floor is deformed under the action of higher horizontal stress and vertical stress, and the working surface track is directly bottomed by mudstone and sandy mudstone. The surrounding rock is 6.6 ~ 10.5 m thick, with low rock strength, poor self stability, and developed joint fissures. This reduces the bearing strength of the surrounding rock. The straight roof of the mining roadway is a thick hard rock beam. The buried depth of the working face exceeds 800 m, and the self-weight stress of the overlying strata exceeds 16 MPa. The roof and floor of the roadway are both mudstone; therefore, under the action of high stress, the top plate is affected by the action of the annulment and sinks, and the filling wall is subjected to high pressure, and the transmission acts on the bottom plate, and the bottom plate constantly undergoes rheology, resulting in the deformation of the bottom drum.

2.2.2. Mining Technical Factors. The shape of the 11-2 coal working surface track along the groove section is rectangular, the initial width of the cross-sectional size is 4.5 m, the height is 3.5 m, and the deformation of the bottom drum of the roadway must go through the excavation stage, the post-excavation stabilization stage, the primary mining impact stage, the first lane impact stage, the first lane stabilization stage, and the secondary mining influence stage. In the stage of a mining impact, the key blocks of the roadway roof will rotate and sink, and the filler and the solid coal gang that maintain the stable support point of the roof plate will bear huge support pressure, and the two bottom plates will produce an overall sinking of the relative roadway bottom plate under the action of the support pressure [21]. In the stable stage of the laneway, the roadway is covered with a basic roof to form a stable masonry beam structure, the stress adjustment of the surrounding rock of the roadway is stabilized, and the slip of the block along the fracture surface after creep deformation and creep failure is the main reason for the development of the bottom drum at this stage. The influence of the secondary mining influence stage on the roadway bottom drum is similar to the primary mining impact stage, which aggravates the generation of the roadway bottom drum phenomenon, and the secondary mining, the mineral pressure caused by the action on the research roadway, mainly in the way of horizontal stress transmission to the research roadway, resulting in the increase of the horizontal stress of the two surrounding rocks of the roadway, and through the bottom of the roadway to transmit the bottom plate middle rock layer, increase the pressure of the bottom plate surrounding rock, and improve the possibility of the bottom drum.

2.2.3. Support Condition Factors. Through a large number of studies and practices, it is shown that the support form and support parameters of the roadway have a greater impact on the bottom drum along the empty lane. Factors such as the basic support of the roadway, the strengthening of the support in the alley, the width and stiffness of the filling body next to the alley, and the pressure of the back and lateral support in front of the work are closely related to the bottom drum along the empty alley [22, 23]. 11-2 coal working surface track trough is a typical large section along the empty lane, the initial support roof plate using anchor rod, anchor cable with channel steel for support, and two pairs of anchor rod with steel belt support, and the roadway bottom plate is not initially supported, and the roadway bottom drum is obvious.

3. Mechanism Analysis of Floor Heave of Gob Side Entry in Working Face

3.1. Force Constitutive Relationship Model of Drum at the Bottom of the Empty Alley. In the process of tunneling, the roof of the roadway sinks, and the supporting pressure is transmitted to the bottom plate through two gangs, and the rock layer in a certain depth of the roadway floor rises with vertical tension, and the following pull strain compression zone appears. The bottom drum of the deep large

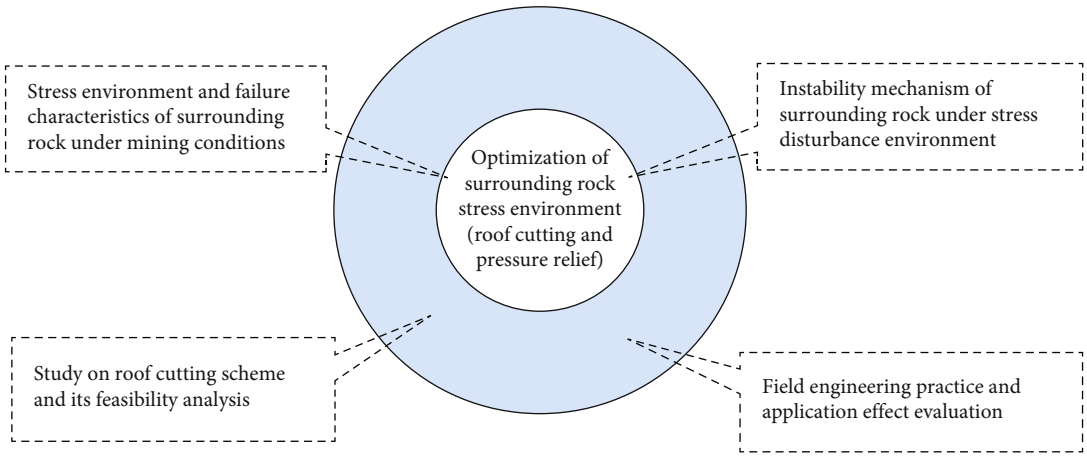


Figure 1: Research technology ideas for deformation control of surrounding rock along empty roadways.

Serial number	Thickness /m	Histogram	Lithology
1	6.8		Middle-fine sandstone
2	7.0		Mudstone
3	7.5		Siltstone
4	6.5		Packsand
5	6.7		Middle-fine sandstone
6	7.2		Sandy mudstone
7	7.7		Silty sand rock
8	2.6		Coal seam
9	7.4		Mudstone
10	7.5		Siltstone
11	6.8		Floor strata

Figure 2: Columnar model of overburden rock formations in coal seam.

section along the empty lane is not only related to the composition of the rock formation, the depth of mining, the size of the roadway section, and other factors, but also related to the factors such as roadway excavation and pressure relief, bottom cleaning disturbance, and so on. The bottom slate layer will be subjected to repeated disturbance actions of the advanced pillars on the bottom plate along the empty alley, resulting in an increase in the internal cracks in the rock mass and the overall destruction.

In order to simplify the force of the surrounding rock of the roadway, the expansion and deformation of the rock layer under the action of hydrology is not considered, and the force of the surrounding rock of the roadway is regarded as a plane problem to be solved. According to the experience of the site, under the influence of the support pressure, the roadway will sink as a whole. The supporting pressure first acts on the top plate and makes it sink; the sinking roof will transmit the supporting pressure to the filler and the coal gang and is compressed to produce a sinking, so that the bottom plate surrounding rock deformation, if the roadway bottom plate is a weak rock layer, the filling body, and the coal gang may crush the bottom slate layer and fracture, which will cause the bottom plate to form a secondary horizontal stress [24, 25].

In this paper, a study is conducted on the first mining stage along the empty retention lane, assuming that the horizontal stress on the bottom plate along the empty retention lane is mainly generated by the horizontal strain that occurs after the lower rock layer of the filling body and the coal gang is subjected to the supporting pressure transmitted by the top plate. The support pressure along the empty lane is mainly transmitted from the top plate to the filler and the coal gang and then to the bottom plate. The movement of the roof along the empty lane is divided into the early stage, the transition period, and the late stage, of which the transition period is the stage of rotational sinking of the key block, the stage where the bottom plate begins to bear the support pressure, and the most difficult period for surrounding rock control during the lane. With the mining of the working surface, the roof of the goaf area is broken and collapsed to form the characteristics of "vertical three belts," due to the influence of the "large support" of the coal body of the connecting working surface + the "small support" of the surrounding rock along the empty roadway, and the "long cantilever beam" structure is formed along the roof plate of the empty alley as shown in Figure 3. The structure and its overburden loads act intensively on the wall and along the empty roadway, resulting in violent deformation of the surrounding rock.

As shown in Figure 4, the stress environment and mechanical characteristics of the tunnel excavation and the process of mining along the empty roadway are analyzed, and the "near-far field" of the original peripheral stress field

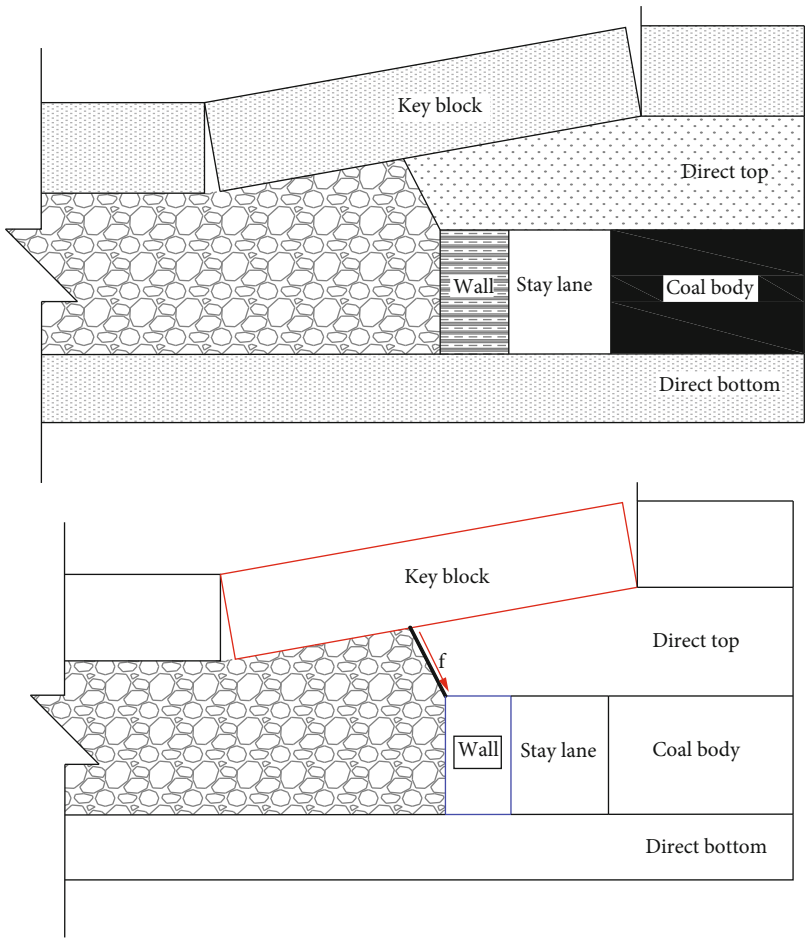
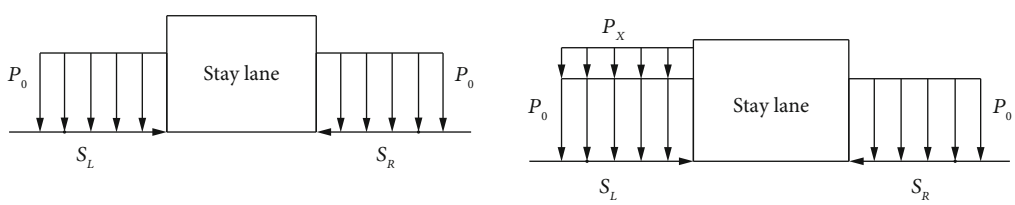


Figure 3: Schematic diagram of the movement status of the roof plate along the empty lane.



(a) Schematic diagram of the force under the tunneling state (b) Schematic diagram of the force after the mining

Figure 4: Simplified mechanical state model of the movement of the roof plate along the empty lane.

P_0 and the employment stress field P_X are unstable during the mining, and the mining stress field plays a leading role, and the "far field" of the adoptive stress is the composite stress field. The force transmission acting on the wall and coal side evolved into vertical pressure and horizontal extrusion force S_L and S_R on the bottom plate along the empty roadway, of which horizontal extrusion stress was the dominant destructive factor.

The mechanical model shown in Figure 4 can be decomposed into the basic mechanical model shown in Figure 5, where α represents the range of stress, p_0 represents the initial pressure, and θ is a function of (x, y, α). Figure 5 shows the stress of a semi-infinite body with a stress distribution of p_0 acting in an interval with an x-coordinate range of [-a, a].

$$\begin{cases} \sigma_x^0(x, y, a, p_0) = \dfrac{1}{\pi} \cdot \left[-\dfrac{1}{2} \sin 2\theta_1 + \dfrac{1}{2} \sin 2\theta_2 + \theta_1 - \theta_2\right], \\ \sigma_y^0(x, y, a, p_0) = \dfrac{1}{\pi} \cdot \left[\dfrac{1}{2} \sin 2\theta_1 - \dfrac{1}{2} \sin 2\theta_2 + \theta_1 - \theta_2\right], \\ \tau_{xy}^0(x, y, a, p_0) = \dfrac{1}{\pi} \cdot [-\cos 2\theta_1 + \cos 2\theta_2], \end{cases} \tag{1}$$

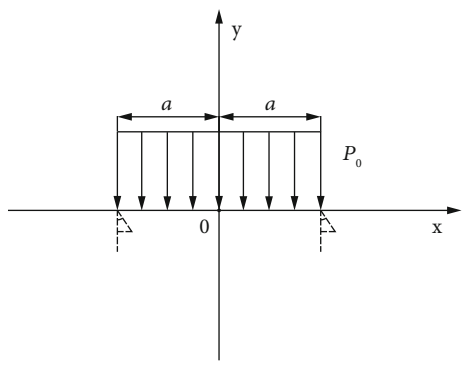


Figure 5: Basic mechanical constitutive model along the empty lane.

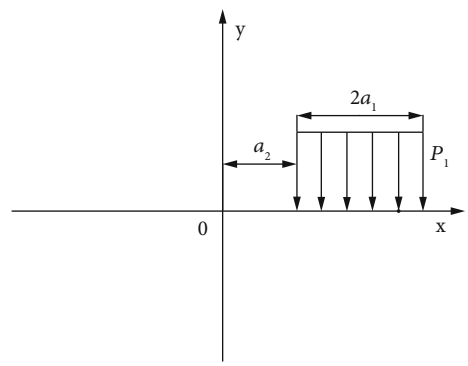


Figure 6: Basic mechanical constitutive model of wall side.

where α represents the range of stress, p_0 represents the initial vertical pressure, θ is a function of (x, y, a), σ_x represents the horizontal stress, σ_y represents the vertical stress, and τ_{xy} represents the horizontal extrusion stress, $\theta_1(x, y, a) = \arctan(x-a)/y$ and $\theta_2(x, y, a) = \arctan(x+a)/y$. The column (wall) side pressure model is shown in Figure 6:

The influence of the coal column on the bottom plate in Figure 4 is shown in Figure 6, where α_1 represents the half width of the coal column, α_2 represents the half width of the roadway, and p_1 represents the pressure on the side of the coal column. Its stress distribution can be applied (1), through the change of coordinates to obtain

$$\begin{cases} \sigma_x^1(x,y) = \sigma_x^0(x-a_1-a_2, y, a_1, p_1), \\ \sigma_y^1(x,y) = \sigma_y^0(x-a_1-a_2, y, a_1, p_1), \\ \tau_{xy}^1(x,y) = \tau_{xy}^0(x-a_1-a_2, y, a_1, p_1). \end{cases} \tag{2}$$

Bring equation (1) into the above equation, simplifying it to

$$\begin{cases} \sigma_x^1(x,y) = \dfrac{p_1}{2\pi} \cdot \left[2\arctan\dfrac{a_2-x}{y} - 2\arctan\dfrac{2a_1+a_2-x}{y} + \sin\left(2\arctan\dfrac{2a_1+a_2-x}{y}\right) + \sin\left(2\arctan\dfrac{-a_2+x}{y}\right)\right], \\ \sigma_y^1(x,y) = \dfrac{p_1}{2\pi} \cdot \left[2\arctan\dfrac{a_2-x}{y} - 2\arctan\dfrac{2a_1+a_2-x}{y} + \sin\left(2\arctan\dfrac{-2a_1-a_2+x}{y}\right) + \sin\left(2\arctan\dfrac{a_2-x}{y}\right)\right], \\ \tau_{xy}^1(x,y) = \dfrac{p_1}{2\pi} \cdot \left[\cos\left(2\arctan\dfrac{a_2-x}{y}\right) - \cos\left(2\arctan\dfrac{2a_1+a_2-x}{y}\right)\right]. \end{cases} \tag{3}$$

The influence of the coal wall on the bottom plate in Figure 4 is shown in Figure 7, where α_2 represents the half width of the roadway and p_2 represents the pressure on the side of the coal wall. Its stress distribution can be applied (1), through coordinate changes and taking limits to obtain

$$\begin{cases} \sigma_x^2(x,y) = \lim\limits_{a \longrightarrow +\infty} \sigma_x^0(x+a+a_2, y, a, p_2), \\ \sigma_y^2(x,y) = \lim\limits_{a \longrightarrow +\infty} \sigma_y^0(x+a+a_2, y, a, p_2), \\ \tau_{xy}^2(x,y) = \lim\limits_{a \longrightarrow +\infty} \tau_{xy}^0(x+a+a_2, y, a, p_2). \end{cases} \tag{4}$$

Bring equation (1) into the above equation, simplifying it to

$$\begin{cases} \sigma_x^2(x,y) = -\dfrac{p_2}{2\pi} \cdot \left[\pi - 2\arctan\dfrac{x+a_2}{y} + \sin\left(2\arctan\dfrac{x+a_2}{y}\right)\right], \\ \sigma_y^2(x,y) = \dfrac{p_2}{2\pi} \cdot \left[-\pi + 2\arctan\dfrac{x+a_2}{y} + \sin\left(2\arctan\dfrac{x+a_2}{y}\right)\right], \\ \tau_{xy}^2(x,y) = -\dfrac{2 \cdot p_2 \cdot y^2}{\pi \cdot \left[(x+a_2)^2 + y^2\right]}, \end{cases} \tag{5}$$

where α indicates the range of stress, α_2 represents the half-width, p_2 of the roadway represents the coal wall side pressure, σ_x indicates the stress in the horizontal direction, σ_y indicates the stress in the vertical direction, and τ_{xy} represents the horizontal extrusion stress. By superimposing equations (3) and (5), the elastic solution of the mechanical model shown in Figure 4 is

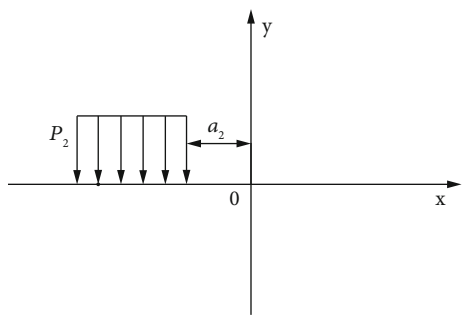


Figure 7: Basic mechanical constitutive model of coal wall side.

$$\begin{cases} \sigma_x(x,y) = \sigma_x^1(x,y) + \sigma_x^2(x,y), \\ \sigma_y(x,y) = \sigma_y^1(x,y) + \sigma_y^2(x,y), \\ \tau_{xy}(x,y) = \tau_{xy}^1(x,y) + \tau_{xy}^2(x,y). \end{cases} \quad (6)$$

3.2. Analysis of Bottom Drum Damage along the Empty Alley. The bottom drum of the roadway is mainly manifested as the compression deformation of the bottom slate layer under the action of horizontal stress and vertical stress, and when the deformation reaches a certain level, it will show obvious bottom plate uplift. Manifested in (1) high stress. The field measurement shows that the maximum horizontal main stress is 18 MPa, and the ground stress level is high stress, which is easy to cause the top gang and the bottom plate of the roadway to undergo large expansion deformation. (2) Low baseplate strength. The direct base plate is a weak rock layer in the range of 10 m, the compressive strength is only 10 MPa, the strength is relatively low, and it is easy to deform and break. (3) The bottom plate is not supported. The original support plan along the empty roadway only considers the support of the top plate and the two gangs, and the bottom plate of the roadway is not supported, resulting in the bottom plate being crushed under the action of high stress, and the free deformation is serious.

From the analysis of the constitutive relationship of 2.1, it can be obtained that the destructive form of the bottom drum roadway is mainly extruded flow type. The main features are as follows: (1) rock rheology under high ground stress. The 11-2 coal mine in Panji mining area is buried more than 800 m deep, and the self-gravity stress of the overlying rock layer reaches 9 MPa along the empty roadway. Under the long-term action of high stress, rheology mainly occurs in the plastic region and the elastic region and gradually transitions from the plastic region to the elastic region, and the rheological radius of soft rock continues to increase with the increase of time and eventually tends to stabilize, but the time to achieve stability is often very long. The soft rocks along the bottom plate of the empty roadway are constantly rheological under the action of high ground stress, and when this rheological deformation reaches a certain level, the bottom drum problem will occur. (2) Soft rock expansion. For the deep buried large-section soft rock roadway, the horizontal stress is much greater than the vertical stress, the shallow rock layer of the bottom plate is compressed horizontally, and the expansion deformation is easy to occur under the action of vertical surrounding rock pressure, and when the vertical expansion of the bottom slate layer reaches a certain degree, it will show obvious bottom drum. (3) The bottom plate of the large cross-sectional roadway is not supported. The extrusion force of the two gangs is transmitted to the bottom plate, so that the bottom slate layer is stretched upwards, the tensile strength of the soft rock of the bottom plate is extremely low, and there is no support structure to constrain it, and gradually cracks are gradually generated in the bottom slate layer, which eventually causes the bottom plate of the roadway to rise. (4) Roadway excavation and mining in adjacent mining areas. Adjacent mining is the main factor in the generation of the bottom drum; the ore pressure formed in the adjacent mining area will be transmitted to the roadway within its influence range; this transmission method is mainly based on horizontal stress transmission, under the influence of this influence, the stress of the two groups of surrounding rocks in the roadway increases, and through the bottom angle to the middle rock layer of the bottom plate, thereby increasing the pressure of the bottom plate surrounding rock, resulting in the deformation of the bottom drum.

4. Cut the Roof along the Empty Lane to Actively Unload the Pressure and Protect the Bottom Drum Treatment Technology of the Lane

4.1. Theoretical Analysis of Cutting the Top and Unloading Pressure along the Empty Lane. With the large-scale mining of coal, shallow resources are gradually depleted, and the mine gradually enters the deep mining state, with the increase of mining depth, due to the concentration of stress above the re-recovery work surface caused by the large deformation of the surrounding rock of the upper roadway, impact pressure, coal (rock) explosion, and coal and gas protrusion, and other geological disasters are also very serious, in the process of working surface recovery, along the empty roadway roof by the unbroken part of the rock layer above the coal seam goaf section squeezing and stretching, resulting in a bottom drum and other violent deformation; the rotational sinking deformation of this part of the undeveloped rock layer further aggravates the transfer of the overburden load to the surrounding rock of the left lane, so that the surrounding rock along the empty roadway is subjected to greater additional stress, in order to achieve the intact retention protection along the empty roadway during the process of working surface recovery, through the advanced blasting precracking roof pressure unloading method, interrupt the key role rock layer at the upper end of the protected alley, weaken the stress transmission of the top plate of the goaf to the roof plate of the left lane, avoid the rapid pressure increase caused by the impact of the roof plate breaking, slow down the movement of the overburden rock layer, and avoid the collapse of the overburden rock layer after the

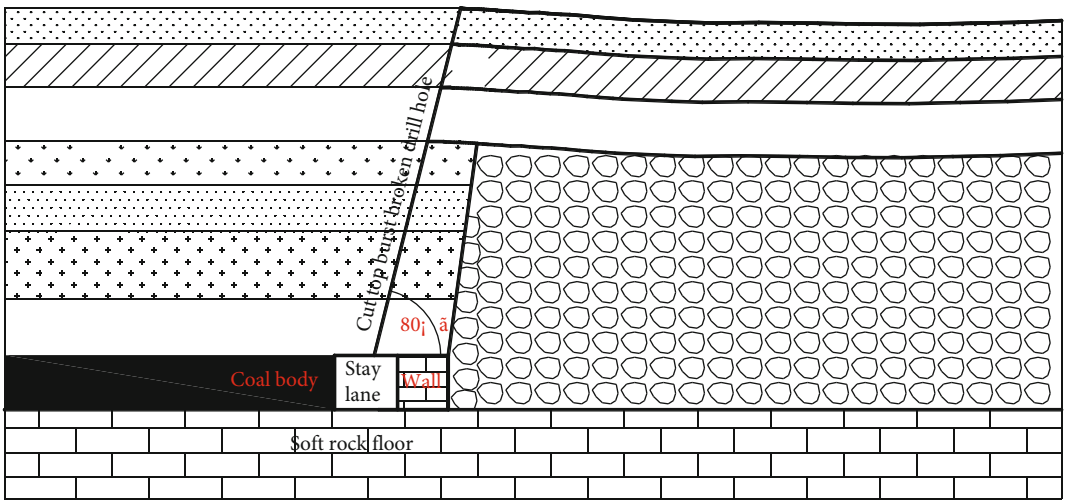


Figure 8: Schematic diagram of the status of the blasting cutting roof active pressure relief and protection alley.

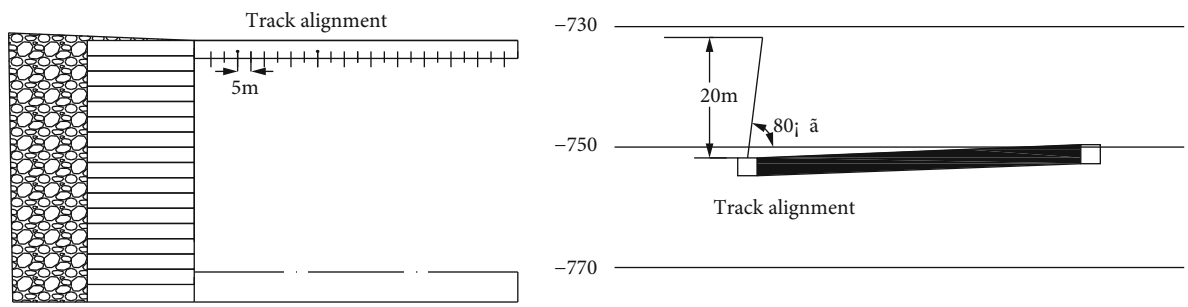
coal seam is mined. Rotational stretching occurs on the critically critical rock formations that protect the roof of the roadway far above [26, 27].

The top plate of the goaf area is forcibly cut off by manual blasting of the top, and the roof plate is thrown into the goaf area along the side of the empty lane, which significantly reduces the length of the cantilever beam. Due to the limited depth of the cutting roof, the field test caused the basic top part of the rock layer to be cut off, while the other part of the rock layer is still in a continuous state; the rock layer is located on the side of the goaf area under the action of self-weight and overburden load on the connection point bending moment, because there is no tensile stress between the cutting rock layers, so the bending moment at the connection point will produce a tensile stress greater than the rock tensile strength to pull the basic top off and then form the structure shown in Figure 8.

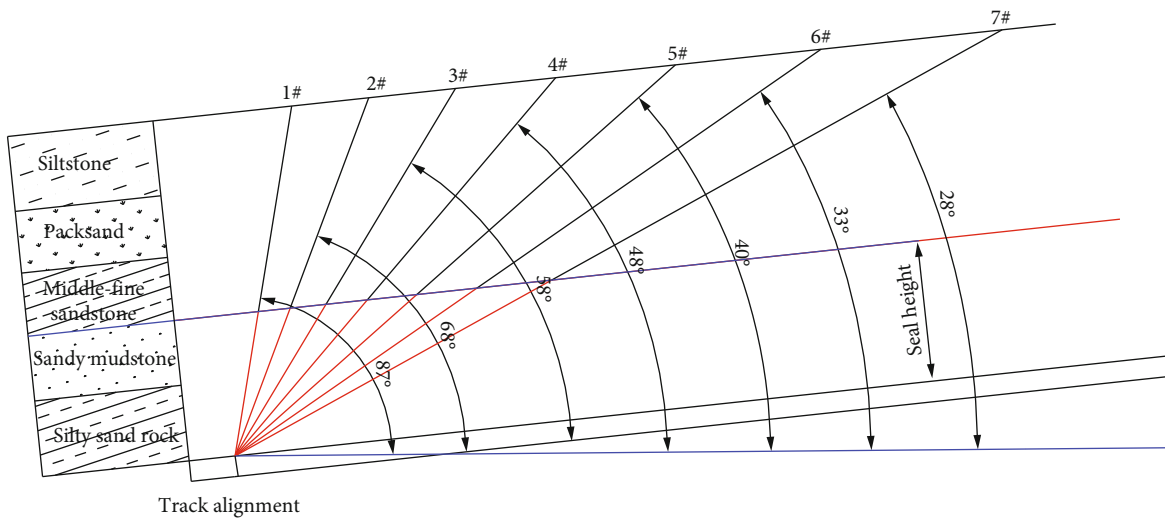
According to the best parameters of the cut top pressure relief and protection lane determined by the above research institute, the 11-2 coal working surface of the Panji mining area was implemented on the spot, and before the recovery work began, the cut top blasting drilling hole adopted the deep and shallow hole cut top pressure relief blasting scheme, and the holes were evenly distributed along the centerline of the roadway in the middle of the top of the lane, and the deep holes were first constructed and blasted, and the shallow holes were built later, and the deep holes were detonated at once, and the length of the shallow holes was not more than 6 m, and finally the drilling hole was cut off, and the overburden layer of the goaf was cut off.

4.2. Design of Cut Top Pressure Relief Scheme along the Empty Lane. According to the site situation, the construction is carried out along the axial direction of the roadway, and the construction is carried out from the position of the mining line to the coal wall of the working surface. The minimum height of the cut roof is 16.2 m; considering the workload of drilling construction and the influence of the inclination angle of the working surface, the height control line of the cut roof is designed to be 20 m, and the vertical angle of the cutting top angle is 11-2 coal working surface direction 10°, that is, the elevation angle of the drilling hole is designed to be 80°, the length of the gun hole is 21 m, and the spacing between the cut top is 5 m, perpendicular to the construction along the empty roadway, the cutting top height: (1) the impact height of more than the supporting pressure is 16 m; (2) cut off all thick hard rock layers within the affecting height range. Cut top angle (1) is conducive to the rapid collapse of the roof along the pre-cracked top line; (2) the collapsed rock mass is gradually compacted and forms a stable bearing structure, preventing the breaking, rotation, and bending of the high top slate layer from sinking; (3) the length of the lateral overhang structure is small. The cut tops of thick hard rock layers at high and low levels are arranged alternately with deep and shallow holes. The specific layout is shown in Figure 9.

In this way, with the recovery of the coal seam on the working surface, the coal seam is goafed, the overlying rock layer on the top of the coal seam falls, the rock layer far above the coal seam will lose the support of the overlying rock layer on the top of the lower coal seam, the bottom plate line will bend downwards, and the overlying rock layer above the coal seam will bend and sink, and at this time, the overlying rock layer of the coal seam and the overlying rock layer along the empty roadway have been cut off, and after the overburden layer of the coal seam is bent, regardless of whether it will break or not, the bending and sinking of the overlying rock layer 6 far above the coal seam will not bring stretching and slewing sinking to the overlying rock layer 7 of the roadway far above, so that the surrounding rock of the far upper roadway 4 is subjected to less additional stress, thereby protecting the far upper roadway 4. The cut top model is shown in Figure 10.



(a) Schematic diagram of the arrangement of blast holes



(b) Cross-sectional view of the arrangement of blast holes on the yunshun side

Figure 9: Design of deep hole cutting top discharge blasting scheme for return mining roadway.

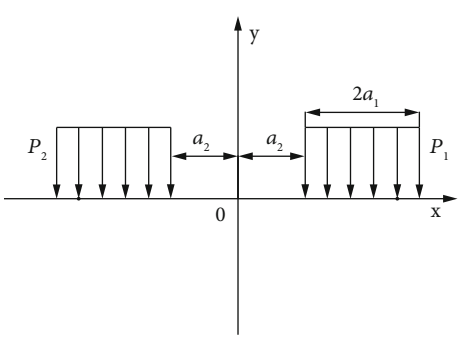


Figure 10: Basic mechanical constitutive model of an empty roadway after cutting the roof.

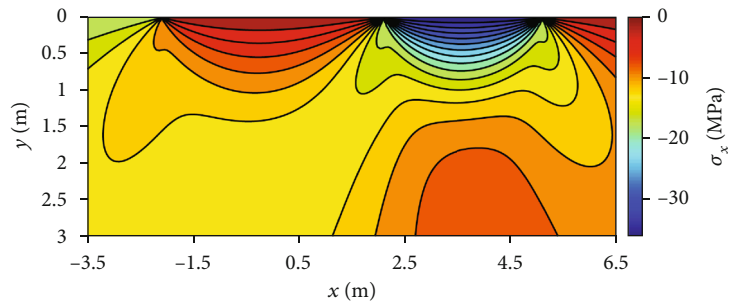
Its mechanical characteristic analysis is shown in equation (7).

$$\begin{cases} \sigma_x(x,y) = \sigma_x^1(x,y) + \sigma_x^2(x,y), \\ \sigma_y(x,y) = \sigma_y^1(x,y) + \sigma_y^2(x,y), \\ \tau_{xy}(x,y) = \tau_{xy}^1(x,y) + \tau_{xy}^2(x,y), \end{cases} \tag{7}$$

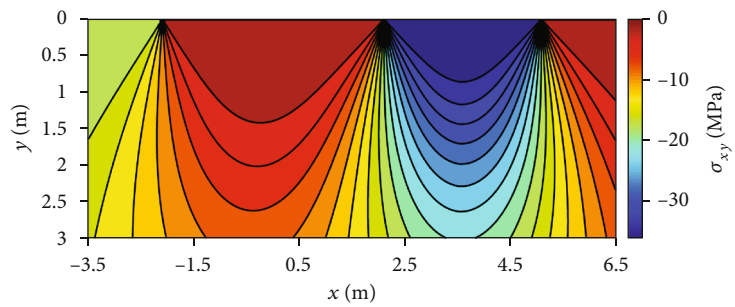
where α indicates the range of stress, α_1 represents the half width of the coal column, α_2 represents the half width of the roadway, p_1 represents the side pressure of the coal column, p_2 represents the side pressure of the coal wall, θ is a function of (x, y, a), σ_x represents the stress in the horizontal direction, σ_y represents the stress in the vertical direction, and τ_{xy} represents the horizontal extrusion stress.

4.3. Stress Calculation Characteristics of Surrounding Rock in the Roadway of Cutting the Roof and Unloading Pressure along the Empty Retention Lane

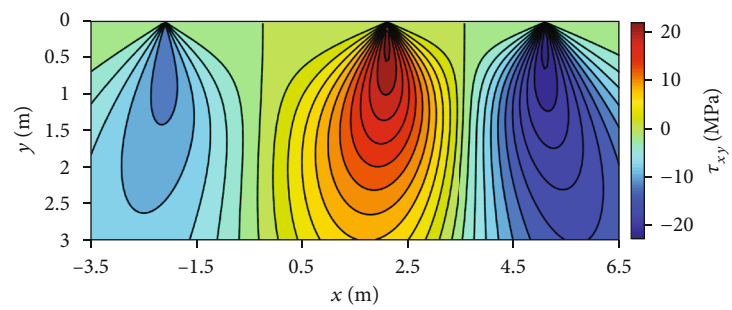
4.3.1. Stress Characteristics along the Empty Lane Before Cutting the Top. According to the field test, the coal wall side pressure p_2 is obtained to take 18 MPa, and the coal column side pressure p_1 is taken from 36 MPa, and the surrounding rock change characteristics of the coal column side roadway are calculated by the 2.1 section mechanical model as shown in Figure 11. As can be seen from Figure 11, there is a large positive stress concentration phenomenon on the underside of the coal column, as shown in the dark blue areas in Figures 11(a), 11(b), 11(d), and 11(e). There is a large shear stress concentration at the bottom angle of the coal column and the bottom corner of the coal wall, as shown in the red and blue areas in Figures 11(c) and 11(f). At the same time, at the roadway, the bottom plate stress is small. Therefore, the bottom plate at the roadway is squeezed by the coal column side and the coal wall side bottom plate, and the



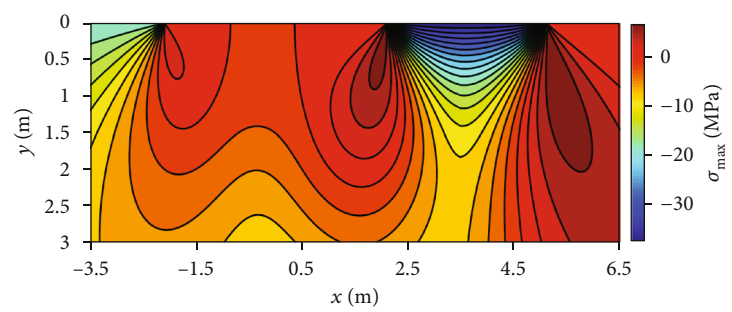
(a) Contour plot of the horizontal stress distribution



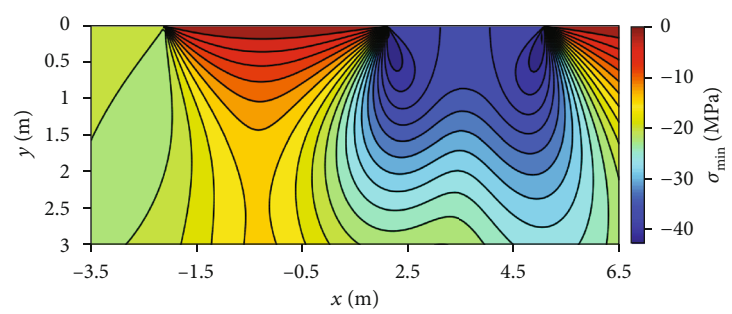
(b) Contour plot of vertical stress distribution



(c) Contour plot of shear stress distribution

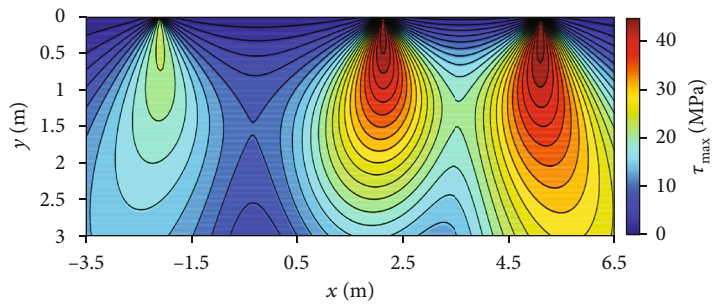


(d) Contour plot of the maximum principal stress distribution



(e) Contour plot of the minimum principal stress distribution

Figure 11: Continued.



(f) Contour plot of the maximum shear stress distribution

Figure 11: Stress evolution characteristics of surrounding rocks along the empty roadway before cutting the roof.

bottom angle on both sides of the roadway is very easy to be damaged, and the bottom drum phenomenon occurs at the same time.

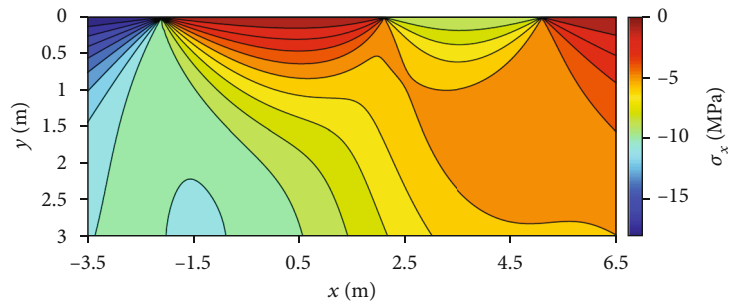
4.3.2. Stress Characteristics along the Empty Lane after Cutting the Roof. According to the field test, the coal wall side pressure p_2 is obtained to take 18 MPa, and the coal column side pressure is taken from p_1 to take 9 MPa, and the surrounding rock change characteristics of the coal column side roadway are calculated by the 2.1 section mechanical model as shown in Figure 12. As can be seen from Figure 12, after cutting the top, the stress on the bottom plate on the lower side of the coal column is greatly reduced, as shown in the green areas in Figures 12(a), 12(b), 12(d), and 12(e). Shear stress concentration at the bottom corner of the coal column and the bottom corner of the coal wall has also been appropriately mitigated, as shown in the green areas in Figures 12(c) and 12(f). Therefore, the bottom plate at the roadway is less squeezed by the coal column side and the coal wall side bottom plate, which alleviates the degree of the roadway bottom drum.

As shown in Figures 11 and 12, during the mining of the working surface along the empty lane, the stress concentrates on the surrounding rock on both sides of the roadway, of which the stress on the coal column side is more intense, and the horizontal shear stress acts on the bottom of the roadway, where the stress concentration at the center of the roadway bottom is obvious, and there is a bias towards the coal wall side, and the top of the cut and unloading pressure along the top plate of the empty lane cantilever beam structure becomes shorter due to the existence of the cut joint. It blocks the transmission of the top plate stress in the goaf area to the alley and effectively alleviates the sinking of the roof plate in the alley. However, the cut roof pressure relief along the empty lane leads to the discontinuity of the roof of the roadway and the increase in the crushing degree of the two gangs, and the advanced support pressure of the working surface will further enhance the disturbance of the surrounding rock of the lane, restricting the overall maintenance effect and service life of the roadway, and the anchor cable strengthening support technology can enhance the stability of the roadway roof and the two gangs and weaken the influence of the lateral support pressure and the advanced support pressure on the roadway maintenance effect.

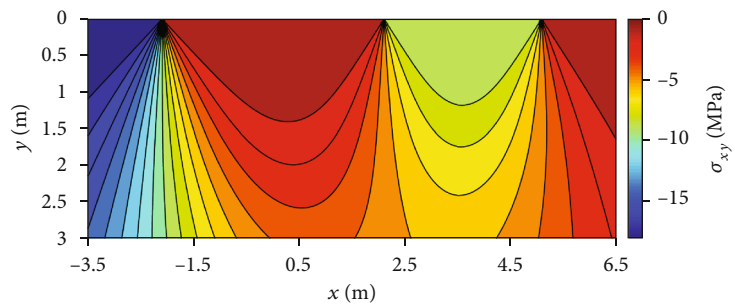
4.4. Support Reinforcement and Effect Analysis

4.4.1. Support Reinforcement Analysis. Through theoretical analysis, it is concluded that the reinforcement of the roof plate, the reduction of the given deformation amount applied to the filler by the top slate layer, and the reduction of the load imposed by the overlying rock layer on the filler can effectively weaken the disturbance of the filling body to the bottom slate layer of the roadway and control the drum volume of the bottom drum of the roadway [28, 29]. While reinforcing the roof, effective reinforcement measures for the physical coal gang can reduce the plastic area of the physical coal gang. Through the above theoretical calculations, it can be seen that reducing the plastic area range of the solid coal gang can reduce the length of the key blocks, which is conducive to controlling the sinking of the roof plate of the roadway to reduce the given deformation amount imposed by the key blocks of the top slate layer on the filling. Reinforcing the solid coal gang can also enhance the bearing capacity of the coal gang, increase the degree of support matching of the two gangs of the roadway, and maintain the integrity of the roadway, but when determining the support parameters, a reasonable support strength and support form should be selected, and the bearing capacity of the coal gang should be increased while controlling the disturbance of the bottom slate layer by the coal gang [30, 31]. Therefore, in the process of preventing and treating the bottom drum along the empty lane, attention should be paid to the systematic comprehensive treatment of the top plate, bottom plate, and coal gang of the roadway, and the integrity of the roadway can be increased, which can effectively control the amount of the roadway bottom drum.

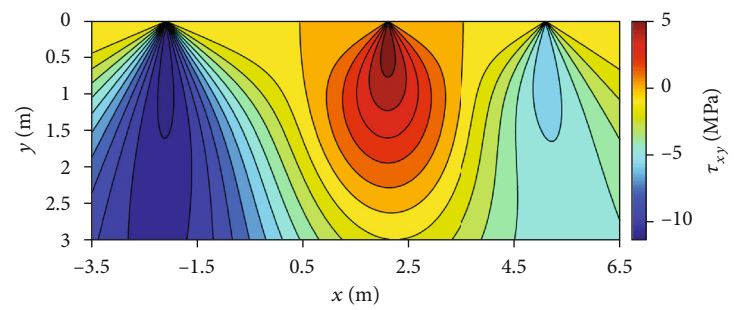
Combined with the above-mentioned analysis of the genesis of the bottom drum, the use of anchor spray net or concrete hardening alone cannot effectively control the soft rock roadway bottom drum, and a variety of joint support technologies are required. From the rock formation stress distribution and support strength control, put forward the anchor beam + anchor rod + net spray + poured concrete joint support technology, roadway arch, and two gangs of support in accordance with the original support form unchanged and the bottom plate to strengthen the support; the advantages of the joint support technology are as follows: (1) anchor + anchor beam flexible support as an active support improve the overall strength of the bottom slate layer



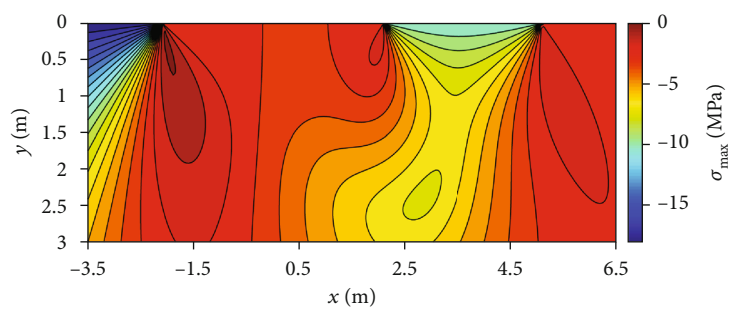
(a) Contour plot of the horizontal stress distribution



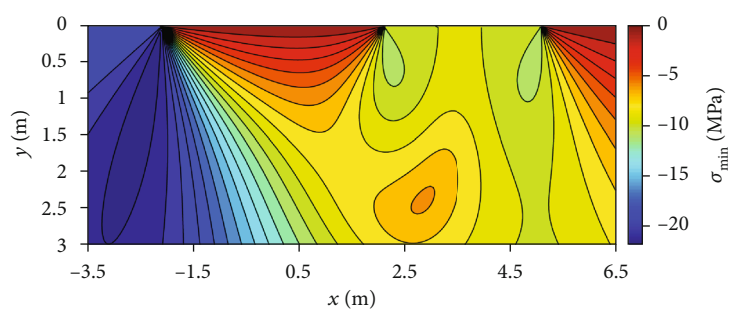
(b) Contour plot of vertical stress distribution



(c) Contour plot of shear stress distribution

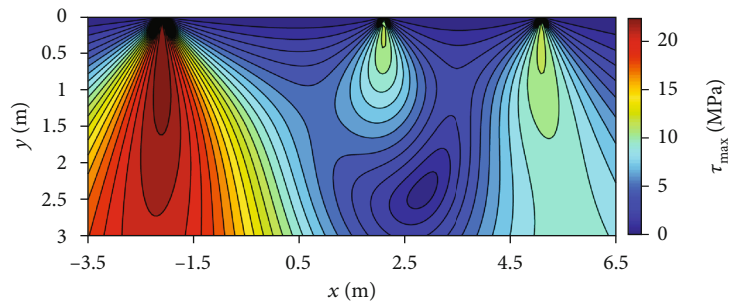


(d) Contour plot of the maximum principal stress distribution



(e) Contour plot of the minimum principal stress distribution

Figure 12: Continued.



(f) Contour plot of the maximum shear stress distribution

Figure 12: Characteristics of stress evolution along the surrounding rock of the empty roadway after cutting the roof.

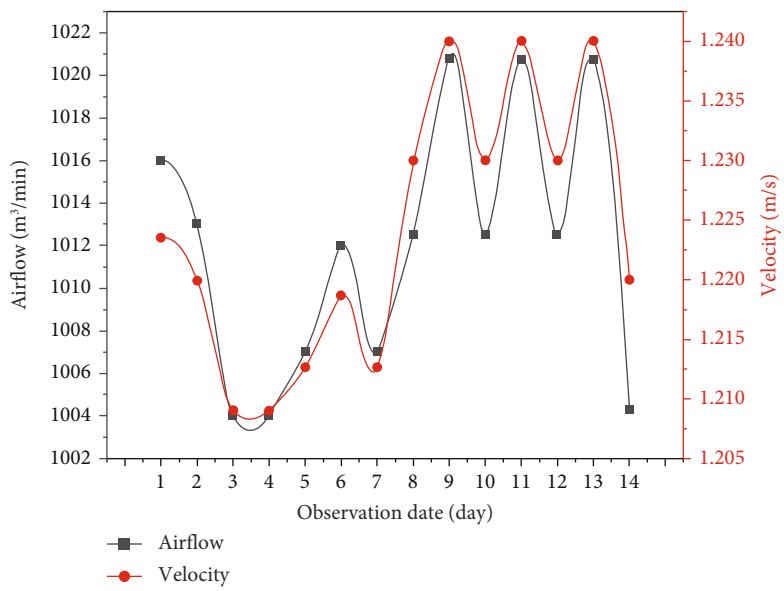


Figure 13: Wind speed and air volume monitoring results along the empty roadway.

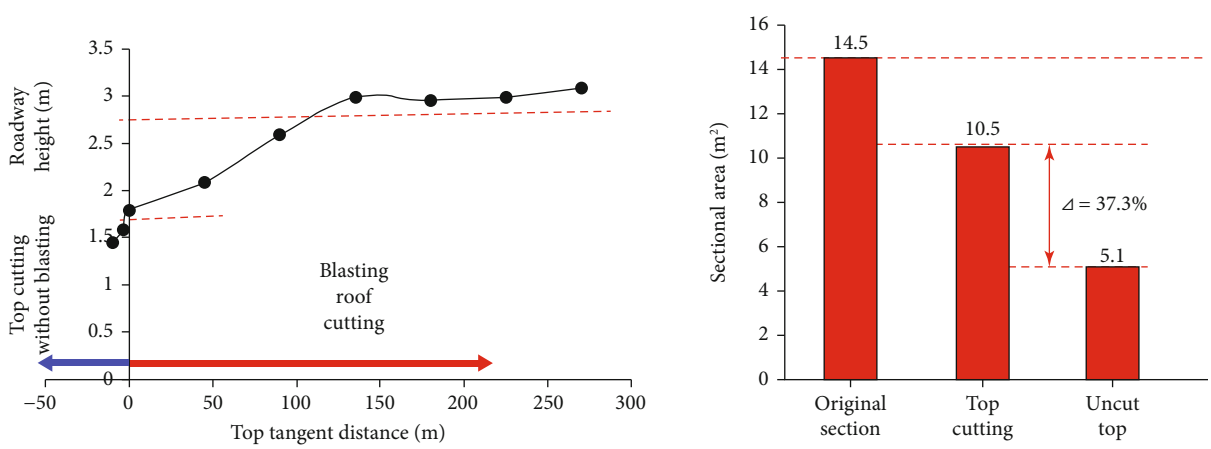
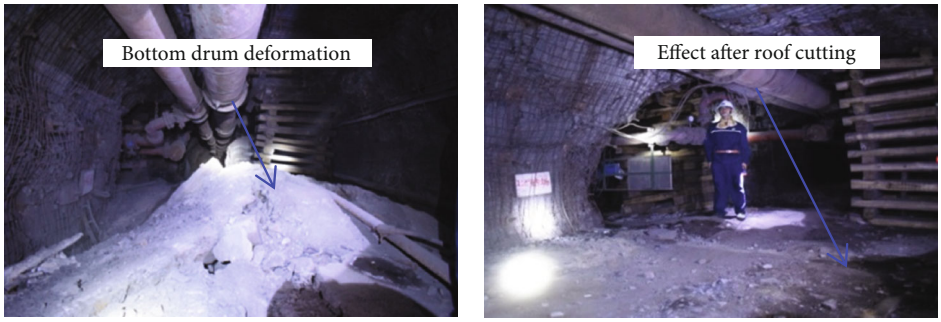


Figure 14: Display of deformation data of surrounding rock along the empty roadway before and after cutting the roof.

and give full play to the stability of its deep rock layer; (2) net spray + poured concrete as a passive support can improve the overall stiffness of the bottom plate, resist the bottom drum pressure, and inhibit the deformation of the baseplate; (3) the joint support gives full play to the advantages of active and passive support and forms a closed support system together with the top plate anchor net spray + anchor cable support and the two sets of anchor net spray support,



(a) Cut the top of the roadway bottom plat (b) Cut the top of the back roadway floor

Figure 15: Deformation site of the bottom drum along the empty roadway before and after the cutting of the top.

effectively controlling the deformation of the roadway and finally realizing the stability control of the bottom plate.

4.4.2. Engineering Effects. In order to monitor the deformation along the empty roadway and the effect of cutting the roof to protect the alley, the air volume and wind speed monitoring station are set up; Figure 13 is the on-site air volume and wind speed monitoring, tested every 10 days, a total of 14 times, with the change of wind speed to reflect the internal space change of the roadway, that is, the deformation of the bottom drum of the roadway.

It can be seen from Figure 13 that during the recovery of the 2121(1) working surface, the air volume and wind speed along the empty roadway change are small, the air volume is about 1000-1020 m^3/min, and the wind speed is about 1.2-1.4 m/s, which is generally stable; the contraction of the roadway section at the station is small, only 0.12m^2.

As shown in Figures 14 and 15, after the technical scheme of active pressure relief and protection of the lane was adopted, the deformation along the empty roadway was significantly weakened, and the stability of the surrounding rock of the roadway after the blasting and cutting of the roof was significantly improved. The section along the empty roadway is in good maintenance, and the section convergence rate is reduced by 37.3% compared with the original section. Comparing and analyzing the maximum sinking amount and cross-sectional area characteristics of of the top plate of the hollow lane and the unloading of the top of the cut roof along the empty lane, it can be seen that the maximum deformation of the top and bottom along the empty roadway is from 1.65 m before and 0.8 m after the active pressure relief and protection of the alley after the blasting of the top of the cut top is reduced by 51.52%.

5. Conclusion

In this paper, the stress environment and mechanical characteristics and the deformation mechanism of the bottom drum in the process of mining along the empty roadway are explored and studied, and the vertical stress of the original peripheral stress field and the mining stress field is unstable under the comprehensive action of the original peripheral stress field and the extraction stress field, and the technical means of the blast cutting roof active pressure relief and protection alley are used to block the transmission of lateral support pressure, the roof slate layer is precracked in advance, the sinking of the rock layer is accelerated, the disturbance time is reduced, the vertical stress of the rock layer and the rock layer above it is reduced along the empty roadway, the vertical stress concentration of the roadway is reduced, and the stress concentration coefficient is reduced. After cutting the top, the degree of destruction of the surrounding rock is weakened, the scope of destruction is reduced, and the technical problems of large deformation prevention and control along the bottom drum of the empty alley are solved by means of support and reinforcement, and the following main conclusions are obtained:

(1) The instability mechanism of the surrounding rock in the alley under stress disturbance environment is revealed. When not affected by mining, the roadway forms a certain stress concentration area within the effective range of support, and when mining, it is unstable under the comprehensive action of the original peripheral stress field and the mining stress field, and the extrusion and stretching of the unflapped part of the rock layer above the goaf section of the coal seam is set up along the empty roadway roof, resulting in violent deformation such as the bottom drum, and the rotational sinking deformation of this part of the unbroken rock layer further aggravates the transfer of the overburden load to the surrounding rock of the left lane, so that the surrounding rock along the empty roadway bears a large additional stress, and the mining stress field plays a leading role

(2) The horizontal stress on the floor along the empty lane is mainly caused by the horizontal strain that occurs after the lower rock layers of the filling body and the coal gang are subjected to the supporting pressure transmitted by the top plate. The support pressure along the empty lane is transmitted from the top plate to the filler and the coal gang and then extruded to the bottom plate. There is the influence of the "large support" of the coal body on the working surface and the "small support" along the surrounding rock of the empty roadway. Cutting the top pressure can change the roof plate along the

empty lane from the "long arm beam" structure when the roof is not cut into the "short arm beam" structure, blocking the lateral stress of the goaf area to the roof plate of the alley and significantly reducing the degree of stress superposition of the roof plate of the alley

(3) A mechanical structure model of the roof plate along the empty lane before and after the cut roof and pressure relief is constructed, the stress change characteristics of the surrounding rock of the active shelter lane are calculated along the top of the cut roof and the pressure relief of the active shelter lane, and after the technical scheme of the blast cutting roof active pressure relief and protection lane is adopted, the deformation along the empty roadway is significantly weakened, and the stability of the surrounding rock of the roadway after the blasting of the cut roof is significantly improved. The cross-sectional convergence rate was reduced by 37.3% compared with the original cross section, respectively. Comparing and analyzing the variation characteristics of the cross-sectional area of the cut top and the uncut top pressure relief along the empty lane, it can be seen that the cut top pressure relief can effectively improve the deformation problem of the drum along the bottom of the empty lane and improve the stability of the surrounding rock

Data Availability

The [DATA TYPE] data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (no. 52174103), the Natural Science Foundation of Anhui Provincial Natural Science Foundation (no. 2008085ME147), the Special Project of Science and Technology Innovation and Entrepreneurship Fund of Tiandi Science and Technology Co., Ltd. (2021-2-TD-ZD008), and the Key Issues of Open Fund for State Key Laboratory of Mining Response and Disaster Prevention and Control in Deep Coal Mines (SKLMRDPC20KF01).

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