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Research Article

Determination of Reasonable Width of Filling Body for Gob-Side Entry Retaining in Mining Face with Large Cutting Height

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When gob-side entry retaining is adopted in the mining face with large cutting height, due to large stope space, strong dynamic pressure, and other reasons, the filling body is usually broken and unstable due to improper width of filling body, and the stability of surrounding rock of a roadway is poor. Taking the actual project of Shaqu mine as the background, we analyze the stability factors of gob-side entry retaining with large mining height, and considering the lateral pressure and overlying load on the filling body, the mechanical model of a gob-side retaining roadway is established, the calculation method of the reserved width of the filling body is simplified, and the reasonable width of the filling body is obtained quantitatively. Through the monitoring results of numerical simulation and field test, the rationality of the calculation results of the reserved width of filling body is verified. The results show that if the width of the filling body is too small, it will not be able to bear the load of the overlying strata, resulting in the fragmentation of the filling body. The larger the width of the filling body, the greater the cutting resistance provided, which can reduce timely the stress on the roadway and above the filling body, and the more stable the retaining roadway is, but when the width increases to a certain value, the displacement of the surrounding rock of the roadway has changed little. When the width of the filling body is 4 m, the stability of gob-side entry retaining can be guaranteed.

1. Introduction

In recent years, in order to reduce the waste of resource, coal pillar-free mining technology is more and more popular in China, which is not only good for improving production rate of mining area, relieving the tension of replacement, resolving the problem of gas accumulation and so on but has also active effect on the prevention of coal spontaneous combustion, impact pressure [1, 2]. Gob-side entry retaining is generally used to mine coal pillar-free mining method; its main idea is to maintain a section of the roadway for using in the next section; according to the different roadway protection ways, roadway retention can be divided into the filling body of gob-side entry retaining and gob-side entry retaining by cutting roof; the two ways under different geological types have own advantages, usually according to different engineering backgrounds to choose the suitable way [3, 4]. Due to the characteristics of large stope space and strong dynamic pressure, many difficult support problems often appear when filling body of gob-side entry retaining in mining face with large cutting height [5–7]. In the case of unreasonable parameter setting of filling body in the early stage, the roof of the roadway is often prone to large-scale, and the number of renovations is more, which seriously hinders the working of coal mining face [8, 9]. The determination of filling body strength, width, and other factors has always been an important condition to be determined at the beginning of the project. Reasonable filling body retention can not only achieve higher economic benefits but also bring more stable bearing effect to the load-bearing system of filling body along the roadway, and it is also more favorable to the control of surrounding rock of the roadway [2, 10].

Based on this, many scholars carry out relevant research on gob-side entry retaining in mining face with large cutting height. It is generally believed that reasonable length width ratio of filling body can greatly increase the yield area and reduce the damage degree of the roadway. Different widths of filling body bear different compressive stress, and the compressive stress will tend to be stable when the width reaches a certain value [11–13]. Pu et al. [14] also studied the width of filling body in gob-side entry retaining in mining face with large cutting height and obtained the setting method of filling body width. The field test also fully verified the correctness of theoretical analysis and numerical simulation. This article was previously published as a preprint. Appropriate strength of filling body can not only relieve roof pressure and strong impact load but also increase support resistance and prevent filling from being crushed [15–18]. Zhang et al. [19] through uniaxial compression test and AE test compared the postpeak performance of high water content material samples and concrete samples, and the results showed that the internal damage of high water content material samples was very slow in the postpeak stage, and the damage was much smaller than that of concrete samples.

The above provides a lot of reference for setting the parameters of filling body in the initial stage of gob-side entry retaining. In terms of initial entry retention, many scholars have focused on the width and strength of the filling body to ensure the stability of gob-side entry retaining. When the strength material selection of the filling body has been determined, the width setting of filling has become a research hotspot. But according to the current research and practice, most scholars only qualitatively analyzed the relationship between the width of the filling body and the support resistance, indicating that the larger the width of the filling body is, the higher the support resistance can be provided, and the stress distribution around the roadway and the mechanical behavior of rock materials are summarized [20–23]. However, there is little research on the stress change of the filling body and the deformation law of the surrounding rock of the roadway. And the preliminary calculation of the width of the filling body should be set, through the tedious calculation formula which can only deduce a large range. Therefore, according to the engineering background of Shaqu mine, we established the mechanical model of gob-side entry retaining, quantitatively determined the minimum width of filling body, and numerically simulated the evolution law of displacement and stress distribution of the filling body with different widths by FLAC^{3D}. Finally, the gob-side entry retaining project in Shaqu coal mine is verified in order to provide reference for similar projects.

2. Working Face Profile

Shaqu mine is located in Lvliang City, Shanxi Province, China. Its main type of coal is coking coal, which is mined by a close coal seam group, as shown in Figure 1. The gas content of coal seam in Shaqu mine is high, the gas emission is large during coal mining, and the gas overrun phenomenon of coal mining face is frequent, which seriously threatens the safety production of mine. In order to implement Y-type ventilation roadway retention technology along a gob, reduce gas accumulation phenomenon at working face, and realize greater utilization of resources, it is decided to adopt the technology along gob roadway retention technology at 24207 working face to create good conditions for safe and efficient mining at working face. The test roadway is 24207 working face belt roadway. The average dip angle of the working face is 5°. The combined mining of 3 + 4# coal seam is between 3.85 m and 4.36 m with an average thickness of 4.17 m. The length of the belt roadway is 1692 m, the length of the track roadway is 1688 m, the length of the working face is 220 m, and the mineable length is 1548 m, as shown in Figure 2. The floor elevation of the working face is between 360 m and 450 m, and the overlying surface of the working face is a loess covered area with the ground elevation between 866 m and 1001 m. The pseudoroof of the working face is not developed, and there is 0.2 m mudstone locally. The immediate roof of the 3 + 4# coal is gray medium fine sandstone with a thickness of about 5 m; the main roof is coarse sandstone with a thickness of about 5.5 m and the black mudstone with a thickness of about 9 m. The immediate bottom of the 3#+4# coal seam is gray medium sandstone with lumpy pyrite, the main bottom is about 2.5 m sandy mudstone, and then, the immediate roof of the 5# coal seam is 0.6 m carbonaceous mudstone.

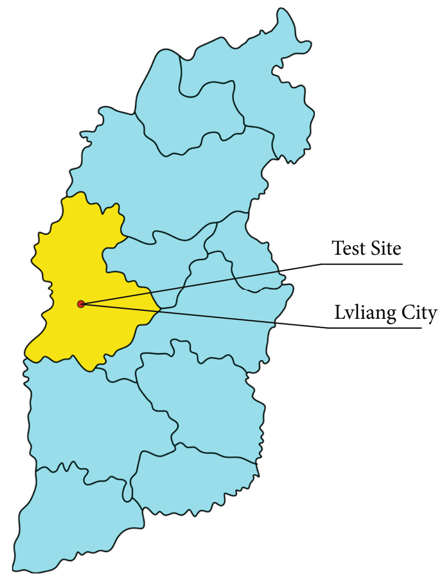


Figure 1: Geographical situation.

3. Analysis of Bearing Stability of Roadside Filling Body with Mining Face with Large Cutting Height

3.1. Analysis of Influence Factors of Stability. There are many factors affecting the stability of surrounding rock of the filling body of gob-side entry retaining. Gu et al. [24] and Wu et al. [25] conducted an experimental study on the roof of gob-side entry retaining and believed that the weak stability of surrounding rock supporting structure and the low lateral

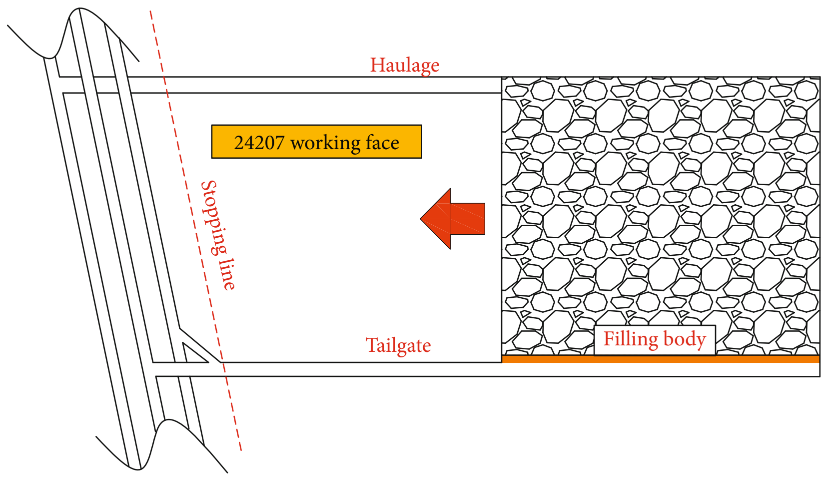


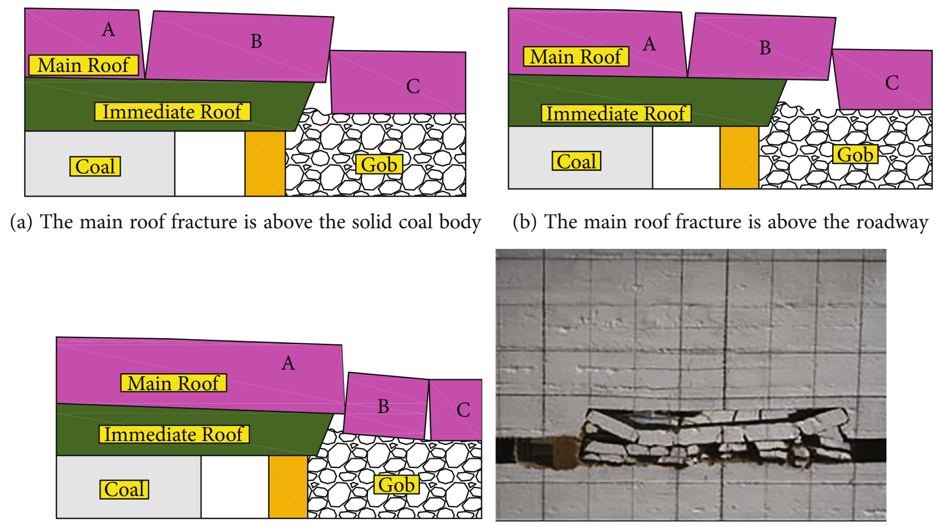
Figure 2: Working face layout.

cooperative bearing capacity of the roof were the subjective reasons for the deformation and failure of surrounding rock of gob-side entry retaining. In order to evaluate the adaptability of gob-side entry retaining, Yang et al. [26] analyzed the weight of each influencing factor under different conditions from geological factors such as coal seam dip angle, mining height, overburden thickness, immediate roof thickness, immediate roof lithology, and roof integrity and showed that mining height had a great influence on the stability of gob-side entry retaining. The overburden stratum at the mining height is a broken decision with activity space; the caving height and height are greater with the increase of mining height, which is a broken fissure zone and the support system on the force source of basic load from the fractured zone rock, so the requirements under the conditions of different mining heights are a broken lane beside the support system of the support resistance which is different also, with the increase of mining height which is broken, filling the pressure also increased significantly, when mining height is broken over after more than a certain value, the support resistance will increase significantly, and roof activity has more influence on the stability of surrounding rock. So for mining face with large cutting height, necessary for the carrying capacity of the filling body and roadway on the auxiliary support, higher requirements are put forward.

The main influencing factors of gob-side entry retaining are the geometric characteristics or geological conditions of the working face, which cannot be changed by humans. In terms of retention and performance of the filling body, reasonable support resistance can adapt to the severe deformation of gob-side entry retaining, and it also requires fast resistance increase speed and low filling cost. However, when the strength of the filling body material is low and the stiffness is small, the bearing capacity of the filling body is limited, and the load of the overburden is mainly borne by coal; then, the filling body has little influence on the lateral fracture law of the basic roof. When the filling materials on the strength and stiffness are bigger and have a certain width, overburden load is shared by the mass media and the roadway beside filling body and roof coal and the pack on the structure of the two supporting functions; key block B in the coal side fracture location will change with the change of the support resistance; when the immediate roof can be large enough to be transferred to the main roof, the support resistance on the key block B may even occur at the gob-side secondary fracture [27, 28]. In the case of different support resistances, the fracture positions of the main roof are mainly divided into the following three categories [29], as shown in Figure 3. Among them, according to different parameters of the filling body, the formation of the bearing structure within the support resistance is different; when the filling body of support resistance and the real bearing capacity of coal are reasonable, the solid coal with filling physical carrying overburden load and lateral cut overburden on the filling body, at this time of roadway stability, is best, as shown in Figure 3(c). The fracture position of the basic roof is not only related to lithology, coal seam dip angle, and other geological factors; on the other hand, a major factor determining the fracture position of the basic roof is the parameter setting of the filling body. Therefore, the setting of filling body width and strength plays a crucial role in the stability of gob-side entry retaining [30, 31].

3.2. The Determine of Reasonable Width of Filling Body. After screening the filling materials of the roadway, it was decided to adopt CHCT paste concrete filling material for retaining the roadway and then add 30 mm gravel. This method can increase the compressive strength of the filling material by about 30% and reduce the cost by about 15%. Therefore, after determining the filling material, the final parameter that determines the performance of the filling body is the width of the filling body. As shown in Figure 4, the mechanical model of load-bearing structure of gob-side entry retaining is established. The filling body beside the gob is mainly subjected to overburden load; friction force between the surrounding rock and lateral pressure is provided by gangue caving in the gob [32].

3.2.1. Lateral Stress Analysis of Filling Body. Assume the gob caving coal gangue on the pack on force F and caving waste rock and filling body above the force for uniform load Q; is the bending angle of roof; the friction angle between the



(a) The main roof fracture is above the solid coal body (b) The main roof fracture is above the roadway

(c) The main roof fracture is located outside the filling body

Figure 3: Main top lateral fracture structure.

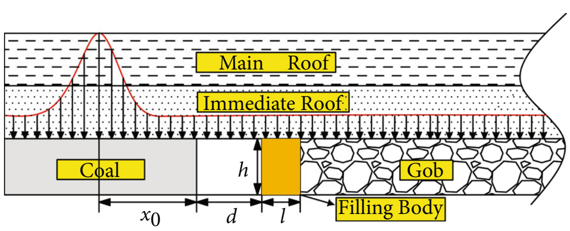


Figure 4: Mechanical model of bearing structure of gob-side entry retaining.

filling body and top coal gangue isδ. Under the condition of mining face with large cutting height, the mining space is large, the dynamic pressure is obvious, the immediate roof is easy to break, and the caving gangue at the bottom of the gob is easy to be compacted. Therefore, the gangue filling body can be approximately regarded as coarse-grain soil for calculation, and F can be regarded as the pressure on the surface of the filling body under the uniform distribution load of gangue. According to the geomechanical conditions, the force F exerted on the filling body at this time is equivalent to the active earth pressure. The Coulomb earth pressure theory is used to calculate [33], and then,

$$F = \frac{1}{2}\gamma {h_1}^2 K_a + h_1 K_a Q \sec \beta, \tag{1}$$

where γ is the average bulk density of filling gangue, h_1 is the height of filling body after compaction, K_a is the Coulomb active earth pressure coefficient, and its value is

$$K_a = \frac{\cos^2\varphi}{\cos \delta \left\{ 1 + \left[(\sin (\varphi + \delta) \sin \varphi)/\cos \delta \right]^{1/2} \right\}^2}, \tag{2}$$

$$h_1 = h - \Delta h, \tag{3}$$

$$\Delta h = (x_0 + d + l) \tan \beta, \tag{4}$$

where h is the filling height of the filling body and φ is the internal friction angle of the caved gangue. $\Delta h$is for compression deformation of gob side after filling compression;$d$and$l$are roadway width and filling body width, respectively; x_0 is the distance between the bending base point of roof rock beam and the side of gob roadway; and its value is [34]

$$x_0 = \frac{\lambda h}{2 \tan \varphi_0} \ln \left[\frac{k\gamma H + (c_0/\tan \varphi_0)}{(c_0/\tan \varphi_0) + (p_0/\lambda)} \right], \tag{5}$$

where λ is the lateral pressure coefficient and 0.36 is taken according to Poisson's ratio; φ_0 and c_0 are the internal friction angle and cohesion of the interface between coal seam and roof and floor, respectively, taking 28° and 2 MPa; k is the stress concentration factor, which is 1.6; H is the buried depth of roadway, taking 529 m; p_0 is the coal support strength, and 2 MPa is taken.

For the filling body, if it is to be stable, its friction force f should meet the following requirements:

$$f \geq F h_1 \cos \delta. \tag{6}$$

The filling body is subjected to friction along the normal direction of the wall. In the case that the buried depth of the working face is large and the stress is large, the gravity action of the filling body can be ignored. Therefore, the friction force of the filling body can be approximated as

$$f = \mu (2Ql + F h_1 \sin \delta), \tag{7}$$

where μ is the friction coefficient between the filling body and the roof and floor.

Equations (1), (2), (6), (4), (5), and (7) are formulated together, and the function of filling body width under lateral

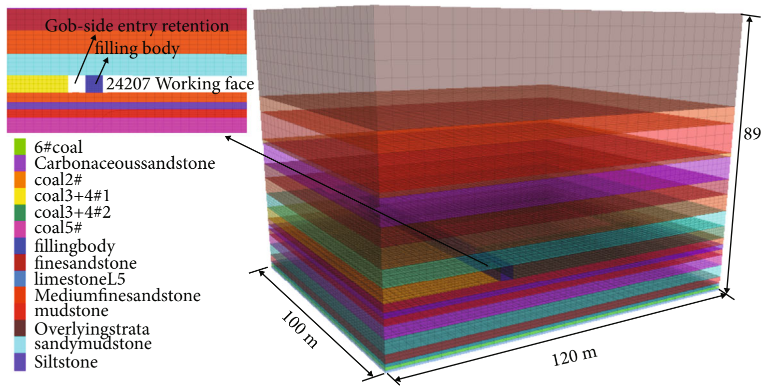


Figure 5: Numerical simulation model diagram.

Table 1: Mechanical parameters of rock mass.

Rock name	Density (kg·m^{-3})	Bulk modulus (Gpa)	Shear modulus (Gpa)	Cohesion (Mpa)	Tensile strength (Mpa)	Internal friction angle (°)
Mudstone	2 350	2.10	1.95	1.5	1.400	32
Fine-grained sandstone	2 600	1.89	1.20	8.3	1.252	35
Coal 2#	1 400	0.72	0.58	1.3	0.325	30
Sandy mudstone	2 600	1.34	1.00	8.2	1.025	36
Coal 3 + 4#	1 400	1.44	1.38	1.3	0.200	30
Siltstone	2 800	4.90	4.67	1.2	1.000	36
Coal 5#	1 400	1.44	1.38	1.3	0.200	30
Limestone L_5	2 730	1.21	1.20	6.3	1.119	40
Coal 6#	1 400	1.44	1.38	1.3	0.200	30
Medium sandstone	2 600	2.67	1.12	8.0	3.170	35
Carbonaceous sandstone	2 520	1.86	1.15	1.4	1.790	33
Filling body	2 950	2.60	1.70	3.0	1.650	34
Overlying strata	2 500	2.28	1.80	6.0	1.550	33

pressure should meet the following requirements:

$$l \geq \frac{Fh_1(\cos\delta - \mu\sin\delta)}{2\mu Q}. \tag{8}$$

The angle of β is related to the filling rate of the filling area. According to the field experience, the angle of β is set as 8°. According to the field investigation of Shaqu mine, relevant parameters can be obtained as follows: $h = 4.2$ m, $\delta = 30°$, $\varphi = 45°$, $Q = 3$ MPa, $\mu = 0.5$, and $d = 4$ m. The minimum width of filling can be obtained as 2.2 m when applied into equation (8).

3.2.2. Analysis of Overburden Load on Filling Body. When the overlying strata are bent and deformed, the load on the filling body is regarded as the weight of the roof strata of the filling body, the roadway, and the weak and broken part of the coal wall, which can be equivalent to the weight of $n = 4\sim8$ times of the mining height [35]. Therefore, for the filling body with strength q, there is a certain value

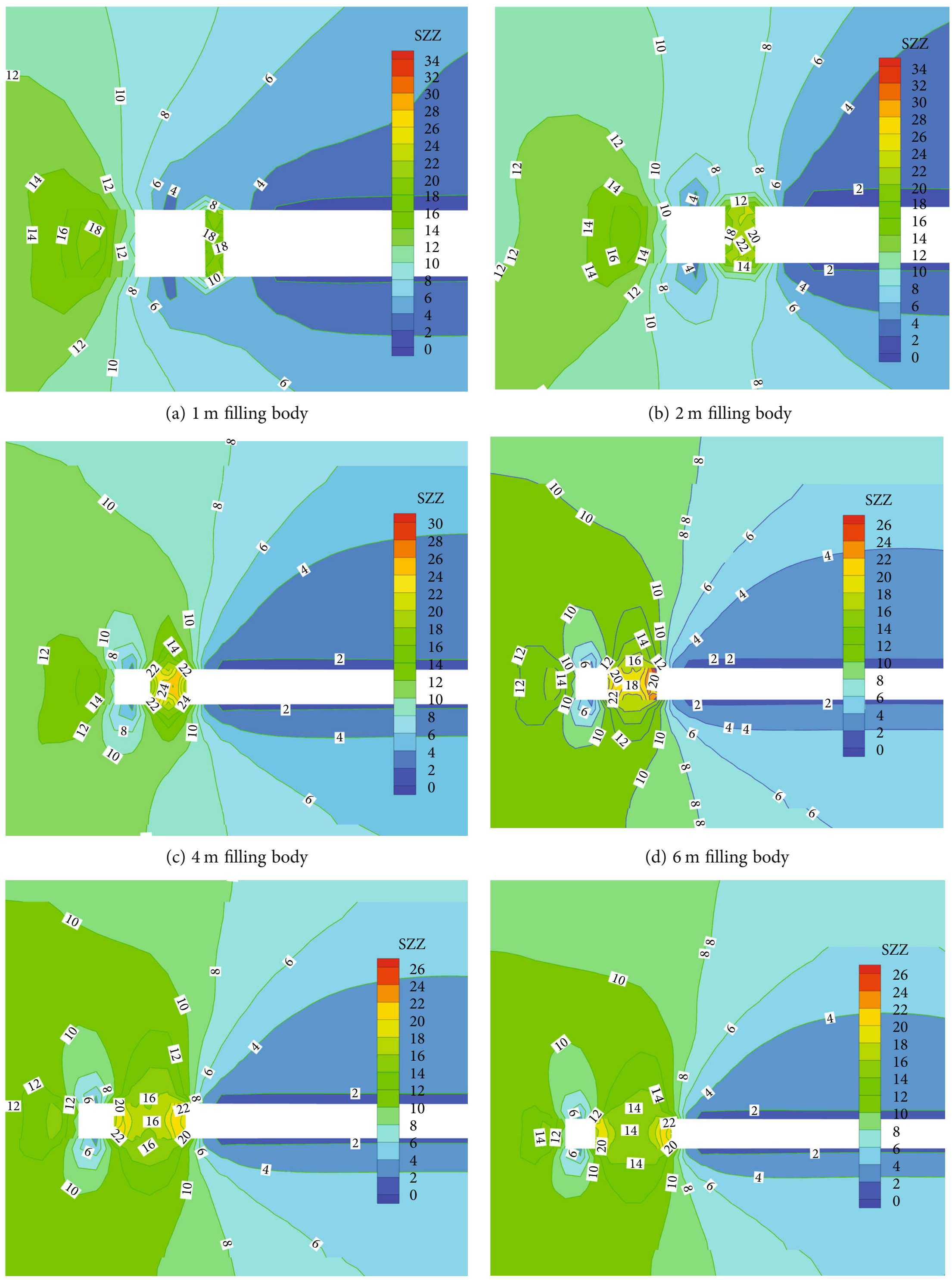
$$q \geq \frac{N(l + d + x_0)\gamma_0 h}{l}. \tag{9}$$

The results are as follows:

$$l \geq \frac{N(d + x_0)\gamma_0 h}{N\gamma_0 h - q}, \tag{10}$$

where γ_0 is the volumetric force of the immediate roof and q is the initial strength of the gob-side entry retaining filling body. According to the site conditions, q takes 2 MPa, N takes 4, and substituting formula (10) to get the minimum width of the filling body is 3.9 m.

To sum up, in addition to geological factors, the setting of filling body width and strength plays an important role in the stability of gob-side entry retaining. Whether the filling body can remain stable mainly depends on the friction force of filling body in the horizontal direction and the gravity load of overlying strata. Through comprehensive consideration of calculation, the minimum width of the filling body should be 3.9 m.



(a) 1 m filling body

(b) 2 m filling body

(c) 4 m filling body

(d) 6 m filling body

(e) 8 m filling body

(f) 10 m filling body

Figure 6: Vertical stress distribution of different filling body widths.

4. Parameter Determination of Roadway Side Filling Body

According to the mechanical model of the bearing structure of gob-side entry retaining, it can be considered that the filling body has the same strength per unit length, and the pouring material of the filling body has been determined. Therefore, the final parameter determining the performance of the filling body is the width of the filling body. According to the actual situation of the 24207 working face, FLAC^{3D} is used to simulate the vertical stress, horizontal displacement, and plastic zone distribution when the filling body width is

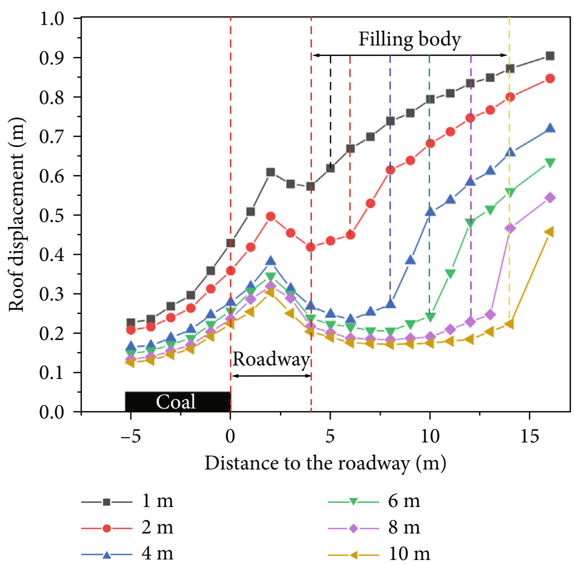


Figure 7: Vertical displacement distribution of the filling body with different widths behind the working face.

1 m, 2 m, 4 m, 6 m, 8 m, and 10 m, respectively. The calculation model as shown in Figure 5 is established, filling body is set in the model in advance, and roadway is excavated first, followed by the working face. The length, width, and height of the model are 120 m, 100 m, and 89 m, respectively. A total of 18 coal beds have been established. The coal seam is near horizontal, and the thickness of the coal seam is 4 m. The bottom boundary of the model is fixed; that is, the displacement of the bottom boundary in X, Y, and Z directions is zero. The top of the model is a free boundary, and the equivalent load is applied to the upper strata. The self-weight load is set in the z-axis direction, and its value is 8.2 MPa. The Molar-Coulomb criterion is used for calculation. By sampling the coal and rock mass of the roof and floor of the 24207 working face on site and testing the mechanical parameters of coal and rock mass in the laboratory, the mechanical parameters of coal and rock mass are obtained, as shown in Table 1.

4.1. Vertical Stress Analysis of Different Filling Body Widths. Figure 6 shows the vertical stress distribution diagram of the filling body with different widths. As can be seen from the figure, with the increase of the width of the filling body, the vertical stress of the filling body increases gradually, and the stress of the roof above and the floor below the filling body also increases gradually. When the filling body width is 6~10 m, the vertical stress of the filling body decreases with the increase of the filling body width, and the stress concentration area gradually changes from the symmetrical type when the filling body width is 1~4 m to the eccentric load type; that is, the stress concentration area changes from the middle part of the filling body when the filling body width is 1~4 m to the side of the filling body near the gob. This is because when the width of the filling body is too small, the resistance of the cutting top is too small to be a bearing body. The main roof breaks at the solid coal body side. Most of the force of the main roof when the main roof is rotated and sunk needs to be borne by the filling body. However, the overbroken filling body cannot play the bearing capacity, which leads to the sharp asymmetric subsidence of the roof and filling body of the roadway. When the filling body is 1 m, the filling body is the smallest, the overall maximum stress is only 18 Mpa, and the stress of roadway roof and floor is 4 MPa. At this time, it is very likely that the roadway roof has subsided violently and the filling body is seriously damaged. When the width of the filling body reaches a certain value, it can provide enough roof cutting resistance. At this time, the stress of the roof and floor of the roadway increases, and the filling body can cut off the roof of the gob side in time, so that the stress of the filling body decreases with the increase of the width, and the stress of the roof and floor of the roadway is normal.

4.2. Vertical Displacement Analysis of Different Filling Body Widths. Figure 7 shows the vertical displacement distribution diagram of the filling body with different widths behind the working face. As can be seen from the figure, roof subsidence decreases gradually with the increase of filling body width. When the width of filling body is 1 m, the maximum roof subsidence is 0.61 m, the serious roof subsidence has occurred, and the asymmetric distribution of roadway deformation is obvious. The side subsidence of the filling body is far greater than that of the solid coal body, and the side subsidence of the gob is also significantly greater than that of the roadway. Because the width of the filling body is too small to form an effective bearing body, the filling body is seriously damaged, and the roof and filling body sink sharply, which is consistent with the stress analysis, and the roof is basically broken on the side of the solid coal body. When the width of the filling body is 2 m, the roof subsidence of the roadway is still very large, the reason is the same as that when the width of the filling body is 1 m, and the roadway and the filling body also have asymmetric deformation. When the width of the filling body is 4 m, the roof subsidence decreases obviously compared with that of 1 m and 2 m. At this time, the subsidence of the roadway and the filling body appears to have obvious symmetrical distribution. The subsidence in the middle of the roadway is the largest, and the two sides are slightly smaller, and the maximum subsidence is 0.38 m. The subsidence in the middle of the filling body is the smallest, and the two sides are slightly larger, and the maximum subsidence of the filling body is 0.27 m. In the controllable range, it shows that the filling body provides the appropriate cutting resistance at this time, which can cut off the roof on the side of the filling body in time, which is conducive to the stability of the roadway and the filling body. When the width of the filling body is 6-10 m, the roof subsidence law is consistent with that of 4 m, but it is not obvious that the subsidence of the roadway and the roof above the filling body is reduced.

4.3. Distribution of Plastic Zone of Filling Body with Different Widths. As shown in Figure 8, the distribution of plastic zone of the filling body with different widths is shown. It can be seen from the figure that when the filling body width is 1 m or 2 m, the filling body has been completely damaged,

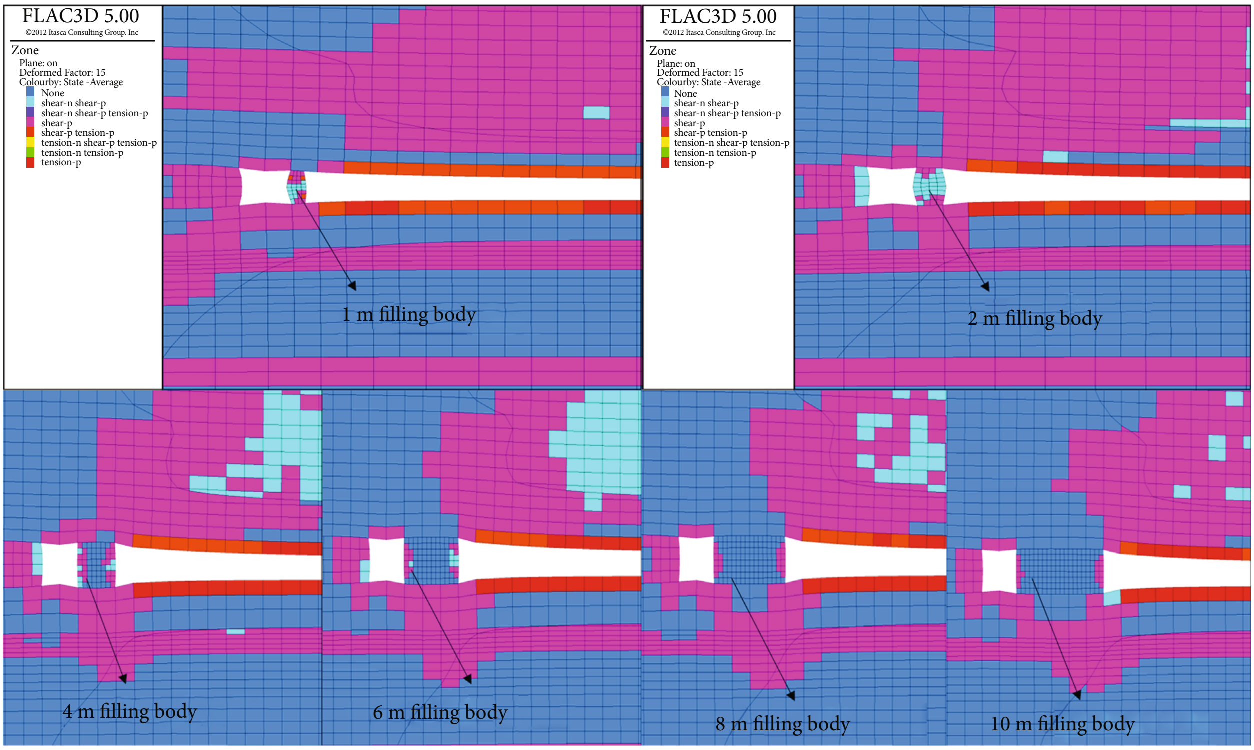


Figure 8: Distribution of plastic zone of different width filling bodies.

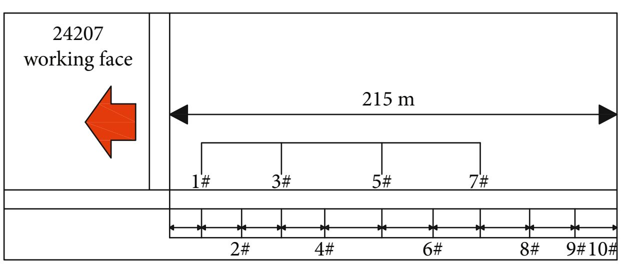


Figure 9: Layout of measuring station for 24207 gob-side entry retaining.

and the surrounding rock deformation of the roadway is serious. When the width of the filling body is 4 m, there is a small amount of plastic damage on both sides of the filling body, and most of the middle area is elastic area, which accounts for more than 80% of the whole filling body. When the width of the filling body is 4~6 m, it can be seen that with the increase of the width of the filling body, the plastic area of the filling body is less, which fully proves that the increase of the width of the filling body is conducive to the stability of the roadside bearing structure.

Therefore, through the analysis of the distribution of vertical stress, vertical displacement, and plastic zone in the working face, it can be concluded that if the width of the filling body is too small, the vertical stress of the filling body will be too small, and the vertical displacement of the roadway roof will be too large. This is because the filling body beside the roadway has been too broken to bear the load, which makes the roadway roof and filling body have serious asymmetric deformation. The larger the width of the filling body, the greater the cutting resistance, the more timely the roof of the gob side of the filling body can be cut off to reduce the stress on the roadway and above the filling body, and the more stable the retained roadway is. However, when the width of the filling body reaches a certain value, with the increase of the width of the filling body, the roof subsidence of the roadway has little change. Based on the above analysis and considering the economic cost, when the filling body width is 4 m, the roadway deformation is within the controllable range, and the plastic failure range of the filling body is less, which has little difference with the theoretical calculation, and the economic cost of this scheme is lower, so the filling body width is selected as 4 m.

5. Field Measurement

Monitoring the support effect of the filling body beside the roadway is an important means to check the success of roadway retaining. According to the above analysis, the survey station layout of the 24207 working face in Shaqu mine is carried out. The measuring station is arranged in the range of 0~260 m behind the working face. The observation work and mining are carried out simultaneously. When the filling length of the retained roadway reaches 220 m, it is installed uniformly and observed in time. As shown in Figure 9, from the working face to 215 m, the distance between 15 m and 30 m is not equal. A surface displacement measuring station is arranged, with 10 groups arranged, as shown in the figure; 1-10 # each surface displacement measuring station is arranged with a comprehensive station, as shown in Figures 1, 3, 5, and 7. The comprehensive measuring station

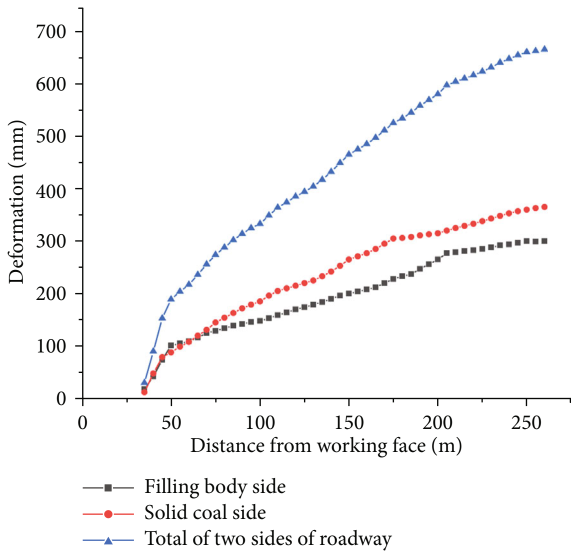


Figure 10: Deformation curve of two sides of 24207 gob-side entry retaining.

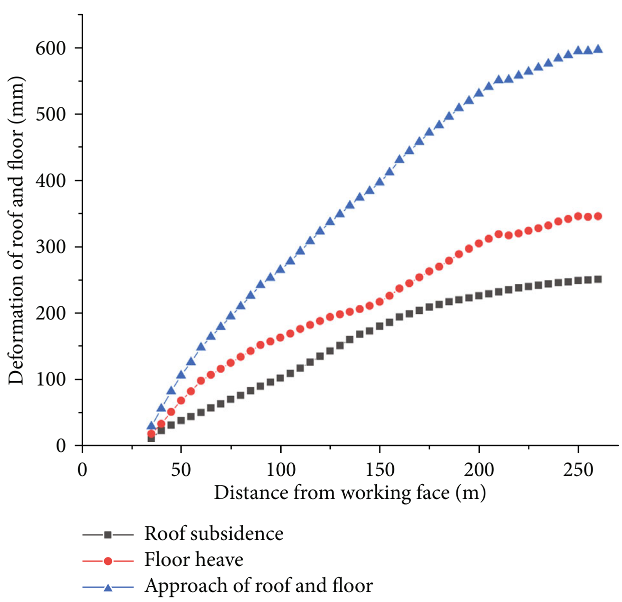


Figure 11: Curve of the roof and floor deformation of 24207 gob-side entry retaining.

includes one surface displacement measuring station, one roof off layer measuring station, and one filling body deformation station.

The displacement of the roof and two sides of the gob-side entry retaining of 4 m filling body at the 24207 working face were monitored, and the rationality of the filling body was verified by analyzing the monitoring data. The monitoring results are shown in Figures 10 and 11.

As shown in Figure 10, 24207 gob-side entry retaining two side deformation curves from the figure can be seen; with the farther away from the working face, the greater the deformation of roadway side. As shown in Figures 10, 24207 gob-side entry retaining two side deformation curves

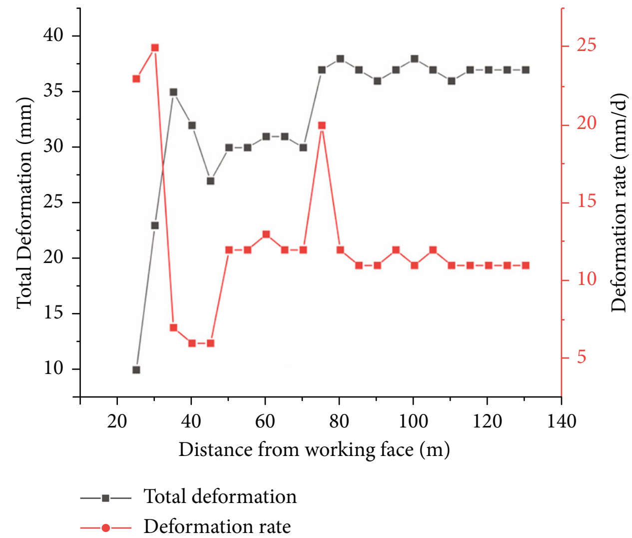


Figure 12: Relationship curve between deformation of filling body and distance from working face in 24207 gob-side entry retaining.

from the figure can be seen; with the farther away from the working face, the greater the deformation of roadway side. The deformation rate of the two sides is the fastest at about 30~60 m behind the working face and gradually decreases and tends to be stable after about 200 m behind the working face. The final deformation of the solid coal body side is 365 mm, the final deformation on the filling body side is 300 m, and the total deformation of the two sides is 665 mm. The deformation of the side of the solid coal body accounts for 55% of the total deformation of the two sides, which indicates that the filling body beside the roadway keeps good integrity, and the deformation is mainly affected by the revolving subsidence of the roof.

As shown in Figure 11, 24207 gob-side entry retains the roof and floor deformation curve. It can be seen from the figure that the deformation of the roof and floor is slightly lower than that of the two sides. With the increase of the distance from the working face, the deformation of the roof and floor is greater and then tends to be stable. The final subsidence of the roof is 251 mm, the final heave of the floor is 346 mm, and the final approach of the roof and floor is 597 mm. The deformation degree of the floor is greater than that of the roof, accounting for 58% of the total amount of the approach, which is in line with the deformation law of the surrounding rock of gob-side entry retaining. Moreover, the roof of the roadway has no severe subsidence and obvious cracking, and the floor has no excessive floor heave, indicating that the effect of roadway retaining is good.

As shown in Figure 12, the relationship between the deformation of the filling body and the distance from the working face in gob-side entry retaining is shown. In the figure, the left ordinate represents the cumulative deformation of the filling body (mm), and the right ordinate represents the deformation velocity of the filling body (mm/d). It can be seen from the figure that the filling body has a large deformation in a short time after filling solidification, and the cumulative deformation has reached 32 mm at 35 m behind the working face, and the cumulative deformation after that is only 7 mm. The deformation rate of the filling body has two large changes in the whole process. It shows that the filling body has two large deformations in a short time after filling and solidification. The filling body is greatly affected by the previous two periodic weighting of the working face, and then, the deformation of the wall is not obvious with the stability of the overlying strata.

In summary, it can be seen that the total deformation of the two sides of the roadway and the roof and floor of the roadway tended to be stable after 665 mm and 597 mm, respectively, and the deformation of the solid coal side accounted for 55% of the total deformation of the two sides, indicating that the filling body at the side of the roadway maintained a good integrity, and its deformation was mainly affected by the rotation and subsidence of the roof. The roof of the roadway did not appear to have sharp subsidence and obvious cracking, and the floor did not appear to have large floor heave. The effect of roadway retention was good.

6. Conclusion

(1) This paper analyzes the stability factors of gob-side entry retaining in mining face with large cutting height and obtains the setting of filling body width and strength, which plays an important role in the stability of gob-side entry retaining. Based on the lateral pressure and overlying load on the filling body, the mechanical model of the bearing structure of gob-side entry retaining is established. The minimum width of the filling body is 2.2 m in the lateral direction and 3.9 m in the vertical direction. Finally, the minimum width of the filling body is determined to be 3.9 m by theoretical calculation

(2) By using FLAC^{3D} numerical simulation software, the variation law of stress, displacement, and plastic zone of surrounding rock roadway with the width of filling body is obtained. When the width of the filling body is too small, the filling body has been over broken and cannot bear the bearing effect, resulting in serious asymmetric deformation of the roadway roof and the filling body, and the vertical displacement of the roadway roof is too large. The larger the width of the filling body is, the greater the cutting resistance is provided, the more timely the roof on the goaf side of the filling body can be cut off, the less the stress on the roadway and above the filling body, and the more stable the retained roadway is. Finally, when the filling body width is 4 m, it can ensure the stability of surrounding rock and reduce the economic cost, which has little difference with the theoretical calculation

(3) Through the observation of deformation of roof, two sides, and filling body of 24207 gob-side entry retaining, it is found that the total deformation of two sides and roof and floor tends to be stable after 665 mm and 597 mm, respectively, and the deformation of solid coal body side accounts for 55% of the total deformation of two sides, which indicates that the filling body beside the roadway maintains good integrity, the roadway roof does not appear to have severe subsidence and obvious cracking, and the floor does not appear to have excessive floor heave. The effect of retaining roadway is good, which shows that 4 m filling body can meet the needs of practical engineering and verifies the correctness of theoretical analysis and numerical simulation

Data Availability

All data, models, and codes generated or used during the study appear in the submitted article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Shijiang Pu and Guiyi Wu contributed equally to this work.

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