Numerical simulation study on the width of coal pillar in dynamic pressure roadway

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Abstract. The deep coal mine roadway is easy to deform and destroy under the high ground stress. At the same time, it is disturbed by the mining stress of the adjacent working face. At present, the scope and size of the influence of stope mining are mainly studied at home and abroad. However, there is not enough understanding of the propagation law of the working face support pressure and the surrounding rock control of the deep well dynamic pressure roadway, and there is no in-depth study of the influence of the pillar width on the stability of the roadway. Therefore, this paper comprehensively uses the methods of field investigation and FLAC³D numerical simulation to study the deformation and stress distribution of surrounding rock under different pillar width in the mining process of adjacent working faces. Studying conclude that when the pillar width is 80m, the roadway is less affected by mining.

1. Introduction

The mine pressure appearance of the mining roadway is much more complicated than that of the single roadway in the solid coal that is not affected by the mining[1]. Its maintenance depends on not only many factors that affect the support of the single roadway, but also the influence of mining operation, that is, the influence of the movement and redistribution of the rock strata around the stope caused by the mining process on the deformation, damage and maintenance of the mining roadway[2-3]. After the working face is mined, most of the overlying strata are in a suspended state, and the weight of the suspended strata is transferred to the coal body at the back and both sides of the working face, forming a much higher stress on the coal body at the back and both sides of the working face than the original rock, that is, the supporting pressure[4]. The supporting pressure caused by mining not only does great harm to the coal seam roadway, but also seriously affects the adjacent coal seam roadway arranged around the mining space. Especially in the mining of high-stress roadway, the roadway itself is easy to deform and destroy, and it overlaps with the support pressure in the coal and rock around the goaf, so the stress concentration degree increases obviously[5-6]. Under the influence of high stress and supporting pressure, the coal seam roadway often deforms rapidly and violently, especially when the surrounding rock of the roadway is soft and broken coal seam, the roadway may undergo strong deformation and instability in a short time after excavation, which seriously affects the normal use of the roadway[7].

The numerical simulation method is applied to analyze the deformation of the roadway and the distribution of stress in coal pillar under different width of coal pillar, and the deformation law of
roadway and the distribution law of stress in coal pillar are obtained \cite{8}. Li H established the concept of the equivalent instability coefficient of the roadway and analyzed the influence of coal pillar width. The peak position of the distribution of the supporting pressure and the instability coefficient of the roadway under different pillar width is not coincident, which shows that the position with the highest stress is not necessarily the position with the worst stability of the goaf roadway on one side. The deviation direction and size of the two are related to residual strength (confining pressure), top and bottom slate, coal seam thickness and other factors \cite{9}. H M carried out a similar material simulation test on the reasonable size of coal pillar of Lu'an Mining Bureau in the laboratory, and analyzed the influence of coal pillar size on mining \cite{10}.

Although many scholars have studied the width of coal pillars in the roadway, they have not studied the influence of different width of coal pillars in the dynamic pressure roadway. In this paper, the influence of the width of coal pillars in the dynamic pressure roadway is studied by numerical simulation method, which has great reference value for the selection of similar coal pillars in the future.

2. Engineering survey

In this coal mine, the vertical shaft is used for development, and the North Wing return air roadway is used for coal roadway, driving along the coal seam, and the support mode is combined support of anchor, mesh, and cable. The layout of working face in Cuimu coal mine is panel mining. The North Wing return air roadway is adjacent to the North Wing belt roadway on the left side and the 21306 working face on the right side. Although this kind of arrangement can form the working face quickly and speed up the production of the mine, in the later stage of the working face, the North Wing return air roadway will be affected by the strong dynamic pressure and the supporting pressure formed on the protective coal pillar of the roadway. At present, the North Wing return air roadway is excavated for about 1000m. According to the current situation of anchor mesh support in the North Wing return air roadway, a certain degree of pressure appears after the excavation of the roadway, especially at the shoulder of the roadway, the steel belt twists and turns seriously and the mesh pocket appears. The roadways fall into a vicious cycle of "before expansion and after a repair, repeated repair and repeated failure", which seriously affects the normal production of the mine.

![Roadway location map](image)

Figure 1. Roadway location map.

3. Stress analysis of roadway surrounding rock

3.1. Numerical analysis model
Based on the geological conditions of the mine, considering the lithology of the surrounding rock of the high-stress soft rock roadway, different constitutive models are established for different strata. Mohr-Coulomb yield criterion is adopted in the calculation:

\[
f_s = \sigma_1 - \sigma_3 \frac{1 + \sin \varphi}{1 - \sin \varphi} + 2C \sqrt{\frac{1 + \sin \varphi}{1 - \sin \varphi}}\]

In style: \(\sigma_1\) — Maximum principal stress;
\(\sigma_3\) — Minimum principal stress;
\(C\) — Adhesion of materials;
\(\varphi\) — Internal friction angle.

Here: \(\sigma_1, \sigma_3\) Represents the maximum and minimum principal stresses respectively, \(C\) and \(\varphi\) The adhesion and friction angle of materials. When \(f_s < 0\), shear failure of material.

According to the basic principle of numerical analysis, in order to reduce the error in the calculation process and eliminate the boundary effect that may appear in the calculation, the established model should have enough size. The size, length, width and height of the determined calculation model are 192 \(\times\) 112 \(\times\) 32m, totally 93194 units are divided. The left and right surfaces of the model are set as the horizontal displacement constraint boundary, and the lower boundary of the model is set as the vertical position. The upper boundary is free, but the equivalent vertical stress is applied. The equivalent overburden load is 12.6mpa, and the horizontal lateral pressure coefficient is 2.0. The cross-section of the rectangular roadway in the North Wing return air roadway is 5.6m \(\times\) 4.2m.

In the process of simulation calculation, the selection of various rock mechanical parameters plays a decisive role in the simulation effect. The numerical calculation model must conform to the actual situation on site. Combined with the tested rock block strength of Cuimu mine, surrounding rock conditions of surrounding roadways and the rock lithology exposed in the excavation, the rock mechanical parameters required for the numerical simulation are determined. See Table 1 for the mechanical parameters of coal and rock mass-selected in the numerical calculation model.

| number | Strata name | kg·m\(^{-3}\) | GPa   | GPa   | MPa   | \(\varphi^\circ\) |
|--------|-------------|---------------|-------|-------|-------|------------------|
| 1      | mudstone    | 2450          | 8.9   | 7.8   | 2.2   | 32               |
| 2      | sandstone   | 2450          | 10.3  | 8.2   | 2.2   | 35               |
| 3      | mudstone    | 2400          | 5.3   | 3.2   | 1.0   | 31               |
| 4      | 3#coal      | 1350          | 2.9   | 1.4   | 0.92  | 25               |
| 5      | mudstone    | 2400          | 4.1   | 2.5   | 1.0   | 31               |
| 6      | sandstone   | 2450          | 8.2   | 7.6   | 1.8   | 32               |

3.2. Determination of protective coal pillar width

In order to study the reasonable width of the protective coal pillar under the influence of the mining of the adjacent working face, the coal pillar width of 40m, 60m, 80m and 100m is simulated respectively, so as to analyze the distribution law of the surrounding rock stress and displacement under the different width of the coal pillar and determine the reasonable width of the coal pillar.

The width of the protective coal pillar will affect the stress distribution of the surrounding rock mass of the roadway, and then affect the stability of the surrounding rock of the roadway. Figure 2 (a) - (d) shows the vertical stress distribution of the surrounding rock mass of the roadway under different width of the coal pillar.
It can be seen from Figure 2 (a) that there is a visible stress concentration area outside the 21306 working face. The right side of the North Wing returns air roadway is about 14m away from the stress concentration area. The stress peak value of the stress concentration area is about 35.1mpa, and the stress concentration coefficient is 2.79. Besides, due to the influence of the stress concentration area of the coal pillar, the vertical stress distribution of the surrounding rock of the roadway shows that the stress near the coal pillar is larger than that on the side of the solid coal pillar, and the vertical stress on the right side is larger. At the same time, it can be seen that due to the influence of the stress concentration area, the vertical stress range of the roadway roof and floor is also obvious near the stress concentration area.

It can be seen from Figure 2 (b) that the range of stress concentration area is increased compared with that of coal pillar at 40m, but the distance from the right side of the roadway to the stress concentration area is about 38m, and the distance from the roadway is increased by about 2.7 times compared with that of coal pillar at 40m. The peak value of stress in the stress concentration area also decreased, about 31.3mpa, and the stress concentration coefficient was 2.48. The influence range of vertical stress on the right side of coal pillar is smaller than that of 40 m coal pillar.

From Figure 2 (c), it can be seen that the distance between the right side of the roadway and the stress concentration area is about 60m, and the distance between the roadway and the stress concentration area is significantly increased. The stress peak value of the stress concentration area is about 30.1mpa, and the stress concentration coefficient is 2.38. Compared with the coal pillar width of 40m and 60m, the distance between the stress concentration area and the roadway and the stress peak value are reduced, and the vertical stress distribution of the two sides of the roadway is balanced.

It can be seen from Figure 2 (d) that the distance between the right side of the roadway and the stress concentration area is about 85m, and the distance between the roadway and the stress concentration area is significantly increased. The stress peak value of the stress concentration area is about 30.1mpa, and the stress concentration coefficient is 2.38. Compared with the 80m width of the coal pillar, the stress concentration range and peak value have no change. The vertical stress of the roadway is mainly concentrated on two sides, and the stress concentration range of the two sides is about 5.4m.
Generally speaking, the stress of surrounding rock around the roadway is obviously different under different pillar width. With the increase of coal pillar width, the distance between the North Wing return air roadway and the stress concentration range is gradually increasing; the stress of the surrounding rock near the coal pillar of the North Wing return air roadway is gradually increasing within the range of the coal pillar width less than 80m, and the stress is basically unchanged when the coal pillar width is greater than 80m.

4. Deformation analysis of roadway surrounding rock

4.1. Numerical analysis model

In order to analyze the deformation and failure rule of surrounding rock in the roadway under different pillar width, four displacement monitoring lines are arranged in the roadway, and the layout mode is shown in Figure 3, among which the roof is 1#, the floor is 2#, the left side is 3#, and the right side is 4#. 13 monitoring points are arranged on each monitoring line. The distance between each monitoring point of roof, floor and two sides and the roadway surface is 0m, 0.8m, 1.6m, 2.4m, 3.2m, 4.0m, 4.8m, 5.6m, 6.4m, 7.2m, 8.0m, 8.8m, 9.6m.

4.2. Determination of surrounding rock deformation of roadway

The deformation of the surrounding rock of roadway roof under different pillar width is shown in Fig. 4 (a) - (d).

![Figure 3. Arrangement of numerical simulation model’s displacement monitor line.](image)

(a) roof  
(b) floor
According to figure 4 (a), when the width of coal pillar is 40m, the deformation of roadway roof is the largest, reaching 720mm. With the increase of coal pillar width, the deformation of roadway roof decreases gradually. When the width of coal pillar is 100m, the influence of mining on the North Wing return air roadway is the weakest, the deformation of roadway roof is the smallest, the deformation is 115mm. At the same time, when the width of coal pillar is 80m, the deformation of roadway roof is 132mm. The difference between the deformation of roadway roof and that of coal pillar when its width is 100m is very small, and the maximum difference is only 18mm.

According to figure 4 (b), when the width of coal pillar is 40m, the deformation of roadway floor is the largest, reaching 459mm. With the increase of coal pillar width, the deformation of roadway floor gradually decreases. When the width of coal pillar is 100m, the North Wing return air roadway is the weakest affected by mining, and the deformation of roadway floor is the smallest, only 53mm. When the width of coal pillar is 80m, the deformation of roadway floor is 64mm. The difference between the deformation of roadway floor and that of coal pillar with the width of 100m is very small, and the maximum difference is only 11mm.

According to figure 4 (c), when the coal pillar width is 40m, the deformation of the left side of the roadway is the largest, reaching 185mm. When the coal pillar width is 60m, 80m and 100m, the deformation of the left side of the roadway is 98mm, 96mm and 97mm respectively, and there is little difference in the deformation of the left side of the roadway. When it is 3.2m away from the roadway surface, the deformation of the left side shows a significant downward trend, and the minimum displacement is only 34mm.

According to figure 4 (d), when the coal pillar width is 40m, the deformation of the right side of the roadway is the largest, reaching 836mm. With the increase of the pillar width, the deformation of the right side of the roadway decreases gradually. When the width of coal pillar is 100m, the influence of dynamic pressure on the North Wing return air roadway is the weakest, and the deformation of the right side of the roadway is the smallest, only 112mm. At the same time, it can be seen that when the pillar width is 80m, the deformation of the right side of the roadway is 116mm. The difference between the deformation of the right side of the roadway and the deformation of the right side when the width of the coal pillar is 100m is very small, and the maximum difference is only 4mm.

5. Conclusion
Through the simulation of the vertical stress distribution of the protective coal pillars with different width under the influence of mining in the working face, it can be seen that the smaller the width of the coal pillars is, the larger the influence range of the working face on the coal pillars is, and the larger the corresponding peak value and corresponding position of the vertical stress are. The influence range of the lateral bearing pressure of the coal pillar near the working face is more than 60m, and the influence range increases with the decrease of the protective coal pillar. When the reserved width is more than 80m, the influence range of the protective coal pillar near the working face increases slowly; when the reserved width is less than 80m, the influence range of the working face becomes larger.

It can be seen from the simulation of the surrounding rock deformation under the protective coal pillars of different width under the influence of mining face that with the decrease of coal pillars, the
surrounding rock deformation of the roadway gradually increases, mainly with the strong internal displacement of the two sides of coal and the overall subsidence of the roof, and the overall deformation of the roadway is extremely uneven, of which the uneven deformation of the right side is the largest. With the increase of the width of coal pillar, the degree of non-uniform deformation of the two sides of the roadway decreases gradually. When the width of coal pillar is more than 80m, the deformation of the left and right sides of the roadway is basically the same.

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