Time and Space Evolution Law of Surrounding Rock Deformation under the Influence of Mining

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Abstract. Under the influence of mining, the stress of the surrounding rock of the roadway is redistributed, and the surrounding rock of the roadway is deformed. In order to study the change rule of surrounding rock deformation with the advancing process of working face under the influence of mining, according to the field measurement results, the mechanical model of supporting pressure of advance working face and deformation of roadway top is established, and the change rule of time and space is analysed by numerical simulation. The results show that: in different stages of working face pressure, the advance bearing pressure presents different regularity. The peak value of bearing pressure and stress concentration coefficient are the largest when the pressure is applied for the first time, the minimum when the pressure is not applied, and the influence range of bearing pressure is not affected by the period of pressure.

1. Introduction
With the development of China's national economy, the demand for coal resources is also increasing, which requires the coal industry to develop in the direction of high-yield, efficient and safe production. However, under the influence of complex geological conditions and mine pressure, the underground support, including the support of driving roadway and fully mechanized working face, has been one of the key factors restricting the safe and efficient production of coal mines [1, 2].

With the advance of the working face, the original stable structure is destroyed, the stress of the surrounding rock of the roadway is redistributed, and the advance support stress is formed in front of the working face [3-5]. The transportation roadway and return air roadway in front of the working face are located in the superposition influence area of the advance supporting pressure and the lateral supporting pressure of the working face. The supporting pressure has a great influence on the integrity of the advance hydraulic support, the end support and the roof of the working face. In order to ensure the safety of the working face, it is necessary to adopt advance support for the two roadways, so as to reduce the damage degree of the support pressure and mining influence on the surrounding rock of the roadways [6-9]. Therefore, the research on the deformation law of surrounding rock under the influence of mining is an important part of mine pressure control.

2. Measured results of stress and deformation of roadway
Take 5302 working face of Linxi mine as an example. The buried depth of the working face is about 850m, the coal thickness is 4.3-9.5m, the average thickness is 5.5m, and the average dip angle of the
coal seam is 4°. Three observation stations of surrounding rock deformation and six borehole stress are arranged in the track roadway.

2.1. The monitoring results of roadway stress

The monitoring results of the advance supporting pressure of the roadway are shown in Figure 1. From the observation results of the above six measuring points, it can be seen that the influence area of the bearing pressure in front of the 5302 working face is 54.6-63.9m, with an average of 59.8m and a mean square deviation of 2.72m; the maximum stress concentration coefficient of the moving bearing pressure is 1.3777-2.5914, with an average of 1.9597 and a mean square deviation of 0.387; the maximum bearing pressure distance from the coal wall \( x_0 \) is 9.15-15.5m, with an average of 12.95m and a mean square deviation of 0.75m. Therefore, there is a moving bearing pressure in front of the solid coal work, the range of the influence area of the moving bearing pressure is 54.6-63.9m, and the maximum stress concentration coefficient is about 1.96.

2.2. The monitoring results of roadway deformation

Three drilling TVs are arranged in front of the working face, which are respectively 10m, 20m and 40m ahead of the working face, to watch the rock breaking and deformation. The observation results which is 20m ahead of the working face are shown in Figure 2.

It can be seen from the figure that the deformation and failure characteristics of overburden are as follows:

The roof of 0-3.50m section is coal seam, and the roof layer is behind 3.50m section. The coal seam between 0-0.5m is seriously broken; there is an obvious transverse fracture at 0.9m, 1.5m and 1.9m respectively, and the coal wall at the fracture is rough, so the coal seam may be broken; the coal wall of the borehole between 2.0m-2.6m is seriously broken, accompanied by a large vertical fracture development, and the fracture occurrence is a left inclined 45 degree angle; there are some small transverse fractures between 2.7m-3.2m, and the coal wall of the borehole is not smooth, there is a It is broken to a certain degree; there is a transverse fracture at 3.25m and 3.5m respectively, with a small opening; there is a transverse fracture and an oblique fracture at 3.85m or so, and finally the two fractures intersect into a significant separation fracture; there are several small transverse fractures between 4.0m-6.5m, with smooth rock wall and good rock integrity; there is a significant fracture at 6.8m. The transverse fracture may be a small separated layer; there is a transverse fracture at 7.4m, and a small oblique fracture is produced downward in the middle of the fracture; the rock stratum between 7.6m-
10.1m has good integrity, the hole wall is relatively smooth, only some small transverse fractures develop, and no obvious rock layer damage is found.

2.3. Analysis of measured results and distribution characteristics of bearing stress

It can be seen from the schematic diagram of stress change along strike in Figure 1 that the stress of coal body in front of stops during mining can be divided into four obvious areas along strike: ① stress stable area (area A), which is basically close to the original rock stress and in a stable state, which is roughly 60-80m away from the front of coal body; ② stress slowly rising area (area B), which is close to itself At the beginning of the original rock stress (area a), the increase rate is below 0.2Mpa/m, and the area is about 45-60m in front of the coal wall; ③ in the area with obvious increase of stress (area C), the increase range of stress is obvious, and it soon reaches the peak value, and the average increase rate is about 0.5Mpa/m, this area is roughly between 13-45m in front of the coal wall; ④ stress reduction area (area D), in this area, the stress in the coal body drops rapidly since the peak value of stress, this area is about 13m in front of the coal wall and to the coal wall.

Taking the bearing pressure greater than 5% of the original rock as the critical condition, the average value of the influence area of the bearing pressure is about 59.8m. At 60-80m in front of the coal wall, the stress tends to be stable, close to the original rock stress state.

3. Theoretical analysis of deformation of surrounding rock of roadway

According to the elastic-plastic theory, the corresponding areas A, B, and C in the above figure are elastic areas. The coal body in this area has not been damaged, which is in the state of three-dimensional stress. The ability of supporting overlying strata is obviously higher. The corresponding D area is the crushing area and the plastic area, in which the coal body breaks or plastic breaks, and the bearing capacity is very low. Calculation diagram of advance bearing stress is shown in Figure 3.

![Figure 3](image)

Figure 3. Calculation diagram of advance bearing stress

The basic equation used to solve the interface stress in the limit equilibrium region is shown in equation (1).

\[
\begin{align*}
\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} &= 0 \\
\frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} &= 0 \\
\tau_{xy} &= \sigma_y \cdot \tan \phi + C
\end{align*}
\]

(1)

At the junction of the stress limit equilibrium zone and the elastic zone (the elastoplastic junction), i.e. when \( x = s_1 \), the equilibrium equation is as follows \(^{(10)}\):

\[
[\sigma_y]_{x=s_1} = K_{max}yH \quad \sigma_x = \lambda[\sigma_y]_{x=s_1} = \lambda K_{max}yH
\]

(2)
According to the mechanical model shown in Figure 1, the coal body (A, B, C and D) in the whole stress limit equilibrium area is taken as the separation body, and the resultant force in X direction is zero. The equilibrium equation can be obtained as formula (3):

\[ m \cdot \sigma_x - 2 \int_0^{S_1} \tau_{xy} dx - p_x m = 0 \]  \hspace{2cm} (3)

The theoretical model of the support pressure of the coal body and the width of the limit equilibrium zone S1 can be obtained by solving the equations (1), (2) and (3).

\[ \sigma_y = \frac{c}{f} \left( e^{\frac{2fx}{m\lambda}} - 1 \right) \]  \hspace{2cm} (4)

\[ s_1 = \frac{m\lambda}{2f} \ln \left( \frac{K_{max} \gamma H f}{c} + 1 \right) \]  \hspace{2cm} (5)

Where, \( \sigma_y \) - normal stress on coal body (Mpa); \( \sigma_x \) - horizontal stress (Mpa); \( \lambda \) - lateral pressure coefficient of coal body; \( C \) - cohesion of coal seam and rock (Mpa); \( \phi \) - internal friction angle of rock stratum; \( f \) - friction coefficient of coal seam interface; \( K_{max} \) - stress concentration factor; \( \gamma \) - average unit weight of overburden (KN / m³); \( H \) - buried depth of coal body (m); \( S_1 \) - ultimate stress equilibrium zone (m), also known as plastic zone; \( S_2 \) - elastic zone (m); \( S_x \) - influence range of bearing pressure (m).

4. Numerical simulation of deformation of roadway surrounding rock

According to the geotechnical parameters of 5302 working face in Linxi mine, the numerical calculation model is established. Model dimensions are shown in Figure 4.

In the initial pressure, periodic pressure and normal mining (non-pressure) stages, the advance bearing pressure will show different changes, and the numerical simulation will be carried out around these three periods.

According to the simulation results of pressure step distance of working face, the cloud chart of vertical stress distribution along the direction of roadway is recorded when the working face is pushed 30 m, 40 m and 50 m respectively, and the survey line is arranged to record the change curve of advance supporting pressure above the roadway. The distribution characteristics of the advance support pressure above the roadway are analysed respectively when the working face is 200m long with the initial pressure, non-pressure and periodic pressure. For each propulsion length, the change of support pressure is shown in Fig. 5.

It can be seen from Fig. 5 that: When the first pressure comes from the working face, that is, when the working face is pushed 30m, the peak value of the advance supporting pressure above the roadway is 55.17 Mpa, 16.4m away from the working face, and the range of the increasing area of the supporting pressure is 3.9-60.3m in front of the working face; When the working face is not under pressure, that is,
when the working face is pushed 40m, the peak value of the advance supporting pressure above the roadway is 38.63Mpa, 15.1m away from the working face, and the range of the increasing area of the supporting pressure is 8.8-61.5m in front of the working face; When the working face is pressed periodically, that is, when the working face is pushed 50m, the peak value of the advance supporting pressure above the roadway is 46.78Mpa, 14.9m away from the working face, and the range of the increasing area of the supporting pressure is 11.4-61.3m in front of the working face. The distribution of advance bearing pressure in each period is shown in Table 1.

Table 1. The distribution of advance bearing pressure in each period

| Stopping period | Peak bearing pressure /Mpa | Stress concentration factor | Distance from working face /m | Influence range of bearing pressure /m |
|-----------------|---------------------------|----------------------------|------------------------------|----------------------------------------|
| First Pressure  | 55.17                     | 2.45                       | 16.4                         | 3.9-60.3                               |
| Periodical Pressure | 46.78                   | 2.08                       | 14.9                         | 11.4-61.3                              |
| Non-Pressure    | 38.63                     | 1.72                       | 15.1                         | 8.8-61.5                               |

5. Conclusion
(1) In front of the working face, the coal body can be divided into four areas: A, B, C and D. Among them, the coal body in area A, B and C has not been damaged and is in three-dimensional stress state. D area is a fracture area and a plastic area. The coal body in this area is fractured or plastic damaged, and the bearing capacity is very low.
(2) In different periods of working face pressure, the peak value of advance bearing pressure shows great difference, which is shown as: first pressure > periodic pressure > non-pressure.
(3) The influence range of the advance bearing pressure is 8.0-61.0m, which is basically not affected by the pressure period.

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