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Research on the Change Law of Side Abutment Pressure Distribution in Stope with Coal Thickness Variation

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Abstract: To explore the pattern of side abutment pressure distribution under the condition of coal thickness variation in the same working face, the 7202 working face of Tianchen Coal Mine is taken as the background. The rock mechanics parameters obtained from rock mechanics experiments are used, and the method of numerical simulation is applied for the study. The results show that there is a nonlinear relationship between coal seam thickness and the peak value of side abutment pressure as well as its position. With the increase of the coal seam mining thickness, the peak value of side abutment pressure decreases, and its position moves further away from the coal wall, indicating that the peak position moves deeper into the coal wall with the increase of coal seam thickness. This indicates that as the coal seam thickness increases, the peak position of side abutment pressure shifts away from the coal wall direction, and this shift does not present a simple linear relationship.

1. Introduction

Coal thickness variation zones, as a special and very common geological structure, are mainly caused by geological factors such as folding structure, fault structure, magmatic intrusion, and sedimentary environment [1].

Changes in coal seam thickness are an important factor affecting coal mine mining, which not only affects the recoverable reserves of coal seams and the mining efficiency of mines, but also influences the redistribution of stress in the surrounding rock and the movement of overlying strata after the advancement of the working face. Therefore, it is necessary to study the pattern of support pressure distribution in different deep mine coal thickness variation mining fields to ensure the efficient and safe production of coal mines. In recent years, scholars have conducted a lot of research on the pattern of side abutment pressure distribution of overlying strata in the working face [2-5]. In the analysis and management of mining pressure phenomena such as rock bursts, Yu and Yang analyzed the characteristics of strong mining pressure in the goaf along the working face and proposed the hydraulic fracturing technology to transfer bidirectional stress on the top of the working face to reduce the concentrated stress in the headgate triangular area, ensuring the normal production of ultra-thick coal seam comprehensive mining faces [6,7]. Zhai and others used methods such as drilling, seismic CT to detect the distribution characteristics of side abutment pressure in the goaf, revealing the reasons for rock bursts occurring in the vicinity of deep mine comprehensive mining faces [8]. Guo and others took the collapsed mudstone roof of the self-supporting lane in the cut roof pressure relief of Haragou Coal Mine as the research object, established a mechanical model of the broken stone gangue, determined the calculation formula of the side pressure of the broken stone gangue and the relationship between the bulking coefficient, overburden pressure, mining height, and the side pressure of the broken stone gangue [9].

In existing research, studies involving deep mine coal thickness variation mining fields are not comprehensive. During deep mining, the frequency and intensity of rock burst disasters significantly increase, and it is difficult to effectively predict and prevent them, especially in coal thickness variation mining fields. Understanding the pattern of support pressure distribution in overlying strata of coal thickness variation mining fields is particularly important for the support of retreat mining roadways.

2. Field Overview and Experiment

2.1 Working Face Overview

The first mining face, 7202, of the mining area in Tianchen Coal Mine is located in the 3rd lower coal seam. The 7202 comprehensive mining face follows the direction of the coal seam and is positioned at a depth of approximately 750m, with the coal seam being nearly horizontal. The working face has a track roadway length of 850m, a transport roadway length of 900m, and an inclined length of 250m. The thickness of the coal seam varies significantly along its direction. In the early stages of mining, the coal seam thickness was 2m, which continuously increased during mining, eventually reaching 8m. Histogram of rock layers as shown in Figure 1.

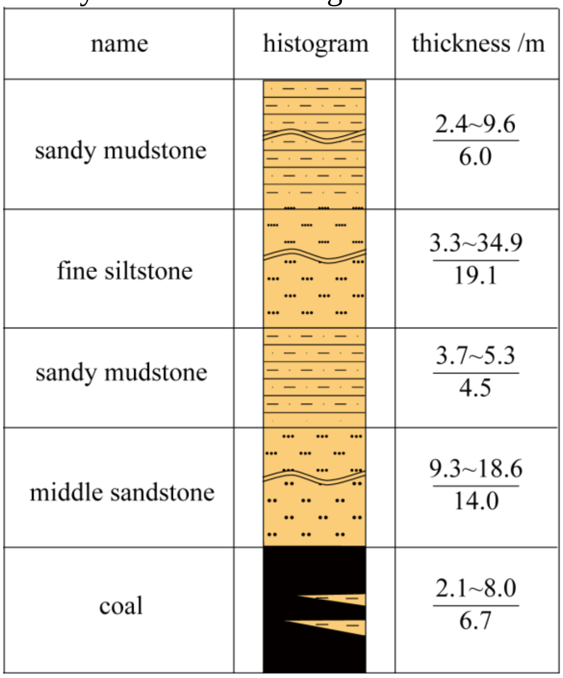


Figure 1: Histogram of rock layers

2.2 Determination of physical and mechanical parameters of coal rock body

The testing equipment used for the mechanical parameters testing of the coal seam and overlying rock strata on the 7202 working face includes the SAW-2000 electro-hydraulic servo rock triaxial testing machine and the Rock600-50 rock triaxial multi-field coupled mechanical testing system. These machines were used for uniaxial tensile testing, uniaxial compression testing, and triaxial compression testing to obtain the fundamental mechanical parameters of the coal seam and overlying rock strata.

2.2.1 Uniaxial tensile test

In the current uniaxial tensile testing, the SAW-2000 electro-hydraulic servo rock triaxial testing machine was employed, and the Brazilian Splitting Test method was utilized to measure the tensile strength of the rock. This method involves applying orthogonal tensile forces at the two ends of the specimen, causing it to split, thereby determining the rock's tensile strength, as illustrated in Figure 2.

Figure 2: Brazilian split test

The tensile strength of the rock was calculated by Equation 1 based on the data measured from the tests.

$$\sigma_t = \frac{2F_{\max}}{\pi DL} \tag{1}$$

In the formula, σ_t represents the tensile strength of the rock, in megapascals (MPa); $F_{\max}$ denotes the maximum pressure the specimen can withstand, in kilonewtons (kN); D is the diameter of the specimen, in millimeters (mm); L refers to the thickness of the specimen, also in millimeters (mm).

Upon conducting uniaxial tensile tests on four different rock types, their tensile strengths were determined based on the average values obtained from three repeated experiments for each type. Specifically, the tensile strengths for fine sandstone, sandy mudstone, medium-fine sandstone, and coal were found to be 7.01 MPa, 4.15 MPa, 7.39 MPa, and 2.96 MPa, respectively.

2.2.2 Uniaxial compression test

Uniaxial compression tests were performed on coal and rock samples using the Rock600-50, a specialized rock sample triaxial multi-field coupling mechanical testing system. During these tests, variations in load and displacement were monitored and are detailed in Figure 3.

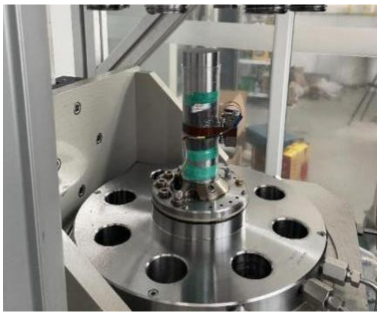


Figure 3: Uniaxial compression test

In practical applications, the stress and strain values when the compressive strength reaches 50%

are typically used to calculate key mechanical properties such as the elastic modulus and Poisson's ratio.

$$\sigma_c = F_{\max}/A \tag{2}$$

In the formula, F_{max} represents the maximum load borne by the sample, in kilonewtons (kN); A denotes the cross-sectional area of the sample, in square millimeters (mm^2).

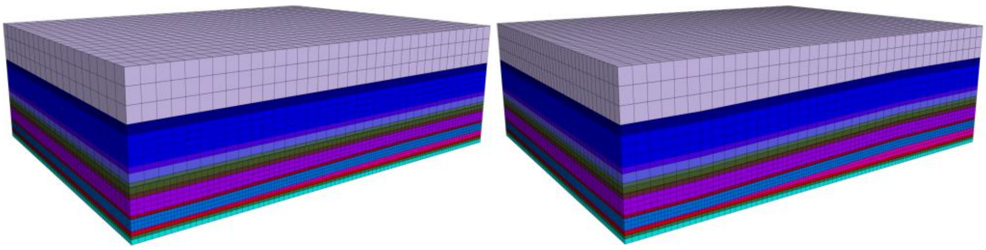
$$\begin{aligned} E &= \sigma_{50}/\varepsilon_{a50} \\ \mu &= \varepsilon_{e50}/\varepsilon_{a50} \end{aligned} \tag{3}$$

In the formula, σ_{50} represents the stress at 50% of the compressive strength, in megapascals (MPa); ε_{a50} denotes the axial strain at 50% of the compressive strength, in percent (%); ε_{e50} refers to the radial strain at 50% of the compressive strength, also in percent (%).

3. Numerical Simulation Analysis

3.1 Modeling

In this chapter, the FLAC3D numerical simulation software is employed for analysis. The study constructs models representing longwall mining with caving methods in coal seams varying in thickness from 2m to 8m, and 2m to 12m. The dimensions of these models are 650m in length, 500m in width, and 200m in height, as depicted in Figure 4. Boundary conditions are imposed such that the lower boundary is restricted in both horizontal and vertical directions, and the lateral boundaries are horizontally constrained. A vertical load of 17MPa is applied to the upper boundary, simulating the overlying strata's load not represented in the model. Stress monitoring points a, b, c are strategically placed at the front, middle, and rear of the variable thickness zones in the coal seam to track the variations in side abutment stresses at different coal seam thicknesses.



(a) Coal thickness variation 2-8m working face (b) Coal thickness variation 2-12m working face

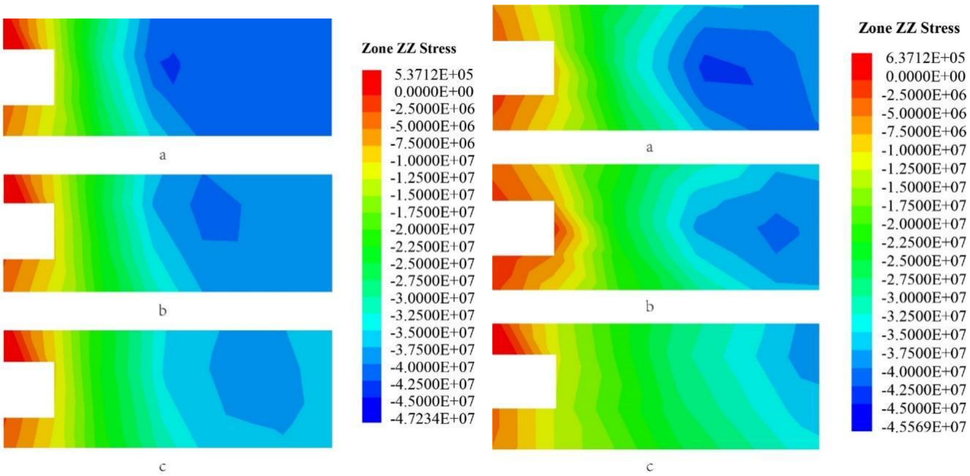
Figure 4: Numerical simulation model of FLAC3D

3.2 Analysis of results

3.2.1 Side abutment Pressure Distribution Contour

As depicted in Figure 5 (a), within the 2-8m range of coal seam thickness variation, the following observations are noted: at measurement point a, where the coal seam is approximately 4m thick, the peak side abutment pressure is around 47.2MPa. At point b, with a 4.4m thick seam, this peak pressure drops to about 44.3MPa, and further declines to approximately 42.2MPa at point c, where the seam thickness reaches 8m. This data indicates a trend of decreasing peak side abutment pressure in the later stages of mining, with a total reduction of 5MPa, as the coal seam thickness increases. Between points a and c, where the seam thickness expands by 4m, there is an average decrease of 1.25MPa in peak side abutment pressure for each additional meter of coal thickness.

Interpreted from Figure 5 (b) for the coal seam with a thickness variation range of 2-12m, the following data is noted: at measurement point a, with a coal thickness of approximately 5.2m, the peak side abutment pressure is around 45.5MPa. At point b, where the thickness is about 8.4m, the peak pressure is approximately 41.5MPa. Further along at point c, with a 12m thick seam, the pressure peaks at around 39.2MPa. This indicates a significant decrease of 6.3MPa in peak side abutment pressure in the later stages of mining relative to the initial stages, as the coal thickness increases. Spanning from point a to c, where the coal seam thickness augments by 6.8m, there is an observed average decline of 0.92MPa in peak side abutment pressure for each meter increase in coal seam thickness.



(a) Coal thickness variation 2-8m working face (b) Coal thickness variation 2-12m working face

Figure 5: Side abutment Pressure Distribution Contour for Coal Thickness Variation Working Face

In conclusion, the analysis of side abutment pressure distribution across various coal seam mining thicknesses on the same mining face reveals a pronounced correlation between the thickness of the coal seam being mined and the side abutment pressure. Notably, an increase in mining thickness leads to a discernible reduction in peak side abutment pressure.

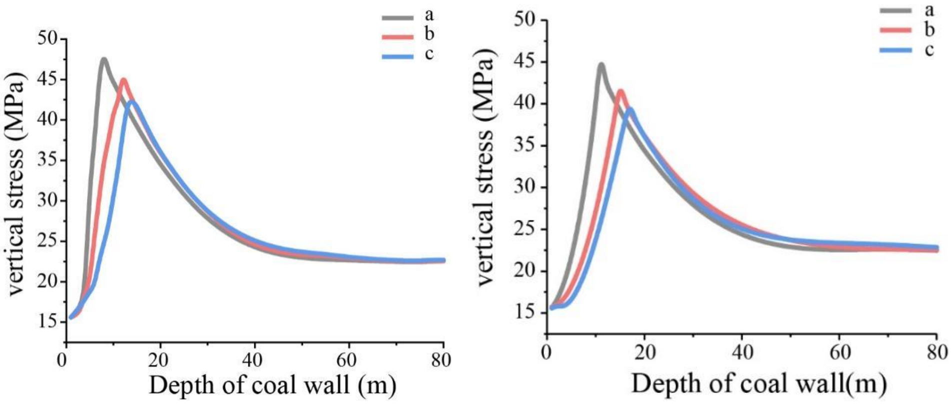
This pattern suggests a nonlinear relationship between increasing coal seam thickness and diminishing peak side abutment pressure. As the mining progresses from thinner to thicker coal seams, the decrement rate of peak side abutment pressure gradually decreases, indicating a nonlinear dynamic. This finding is crucial for both theoretical understanding and practical applications in stress distribution analysis during coal mining and mine safety management.

3.2.2 Side abutment Pressure Distribution Curve

Figure 6 presents the side abutment pressure distribution graph, elucidating the pressure distribution and variations at different observation points across each mining face.

The stress distribution relative to varying distances from the coal wall in each coal thickness scenario demonstrates distinct gradient changes. Closest to the coal wall, in the stress reduction zone, the coal wall loses its structural integrity to support the overlying strata due to plastic deformation, leading to a notable reduction in support pressure. Progressing outward, there's a marked increase in stress, forming a stress elevation zone where the stress not only returns to the original rock level but also peaks, followed by a gradual decline with increasing distance. Ultimately, the stress stabilizes to an equilibrium, aligning with the original strata stress.

In the 2-8m coal thickness scenario, these peaks shift to 8m, 12m, and 14m from the coal wall, correlating with a 6m increase in coal thickness and a 4m deeper movement of peak pressure. Similarly, in the 2-12m variation, the peak pressures at points a, b, and c move further to 11m, 15m, and 17m from the coal wall, with a 6.8m increase in coal thickness resulting in a 6m deeper movement of peak pressure.



(a) Coal thickness variation 2-8m working face (b) Coal thickness variation 2-12m working face

Figure 6: Side Abutment Pressure Curve for Coal Thickness variation Working Face

4. Conclusion

With the increment in coal seam mining thickness, there is a gradual reduction in the peak side abutment pressure observed at the mining face. This reduction follows a nonlinear pattern, where the rate of decrease in peak pressure diminishes as the seam thickness increases. Concurrently, the peak pressure point progressively shifts deeper into the lateral side of the coal wall, illustrating a nonlinear trajectory. This indicates that the impact of increased coal seam thickness on the magnitude and position of the peak pressure deviates from a simple linear relationship. The identification of this nonlinear dynamic is critically significant, both theoretically and practically, for comprehending stress distribution dynamics in coal mining operations and enhancing mine safety.

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