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Analysis on mechanism and key factors of surrounding rock instability in deeply inclined roadway affected by argillation and water seepage

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ABSTRACT

Based on the characteristics of surrounding rocks for deeply inclined roadway affected by argillation and water seepage, a structure model of layer crack plate was established to analyze the shear sliding instability mechanism. Through solid mechanics analysis of anchored surrounding rock with defect from water seepage, combined with numerical analysis for instability mechanism under water seepage in deeply inclined roadway, key factors were proposed. Results show that with increasing height of layer crack plate, lateral buckling critical load value for high wall of the roadway decreases; there is a multi-stage distribution for tensile stress along the anchor bolt with defect under pulling state condition; groundwater seepage seriously affects the strength of surrounding rock of the roadway, to some extent the plastic zone of the high side rises up to 8 m. Finally some support strategies were proposed for the inclined roadway and successfully applied to Haoyuan coal mine in Tiela mining area, western China.

1. Introduction

Although coal resources in western China are widely distributed and rich in reserves, mining conditions are rather complicated there. The regional structure is relatively static. Coal seams are characterized by their numerous layers and thick depths. The effect of late tectonic transformation is weak, and a few surfaces have developed into thrust nappe structure [1,2]. The control of surrounding rocks in mining areas in western China is rather difficult, with coal seams shallow-buried, top soil weak and loose, strata fracture and pore been developed, water from surface, goaf area and fractured zone infiltrated into coal seam, and argillaceous rocks in the roof and floor. Meanwhile, dip angle of coal seams is large and the space between coal seams is small, thus, surface water, goaf water and fissure water seep into coal seams, leading to the formation of coal seam groups containing water. Huang et al. conducted studies on deeply inclined roadway or working face by establishing mechanics model, and acquired the steady state and space–time migration rule of deeply inclined coal seam [3–5]. Also, Zhang et al. did in-depth researches on surrounding rocks influenced by argillation and water seepage, which revealed the instability mechanism and the percolation rule of them [6–15]. However, few studies have been carried out on instability mechanism and control countermeasures for argillaceous surrounding rocks in deeply inclined coal seams containing water in western mining areas of China. Under the influence of water, significant changes have taken place in the deformation characteristics of soft and weak rock strata, displaying obvious argillation and attenuation and prominent rheological properties. In the meantime, fracture structures, joints, fractures of rock mass in western mining areas of China are well-developed, leading to dilatation, expansion and fracture of surrounding rocks. Besides, extraction gives rise to tremendous stress difference, making the stability-maintaining efforts of argillaceous surrounding rocks in deeply inclined coal seam containing water in those mining areas more difficult and complex. This paper aims to analyze the instability mechanism and influencing factors of roadways influenced by argillation and water seepage in deeply inclined coal seam under the condition of mining coal seam groups containing water in western mining areas of China.

2. Shear sliding analysis on the high siding-wall of roadway in deeply inclined coal seam affected by argillation and water seepage

Coal is excavated along the coal seam roof in roadway of deeply inclined coal seam affected by argillation and water seepage. Stress

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distribution and deformation law of surrounding rocks are different from other mining roadways. With the increase of span, height, and dip angle, and under the influence of groundwater seepage and argillation, the scope of losing circle in the high siding-wall formed after the excavation of roadway is relatively large. The original three-dimensional-stress-state in roadway surrounding rocks changes into the state of biaxial stress. Under the clamping function of the roof and floor, coal and rock mass near the high siding-wall can concentrate compressive resistances, producing a large number of secondary fractures which provide sufficient space for groundwater seepage. When the expansive force generated because of coal and rock mass absorbing water and experiencing argillation, which is greater than the tensile strength, coal and rock mass would rip to destroy, damaging the integrity, further accelerating the crack formation and conduction, as shown in Fig. 1. Under the influence of repeating water seepage, fractures penetrate and connect with each other, forming a structure of surrounding rock layer crack plate, which determines the stability of coal and rock mass.

When processing roadway in deeply inclined coal seam influenced by argillation and water seepage, the stability of the rock mass structure would be broken, resulting in the increase of roadway pressure, redistributing of stress and intense deformation. These consequences manifest themselves significantly when serious wall caving occurs in the high siding-wall and tremendous shear deformation appears in large-scale. On the overall consideration of coal and rock mass in the high siding-wall, the process of wall caving in the high siding-wall along the roadway would generate seepage damage, consequently, coal and rock mass would form layer crack plate structure. Therefore, to better analyze it, a model of layer crack plate structure in the high siding-wall was built up.

Under the clamping force between the roof and floor, the integrity of coal and rock mass at the apex and corner of the roadway was seriously damaged. When the layer crack plate experienced

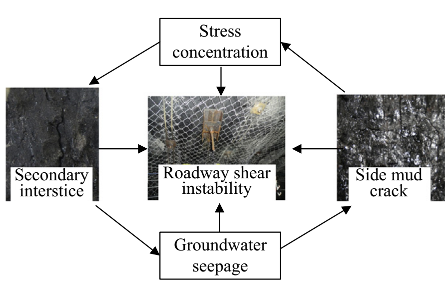


Fig. 1. Sketch of deeply inclined coal seam influenced by argillation and water seepage in process of loss of stability.

flexion deformity, its top and bottom ends did not suffer from lateral deformation with no deflection but the layer crack plate can rotate around its ends. So the ends of layer crack plate were both simplified as simply supported constraints. Supposing that the coal and rock mass did not suffer from the interlayer shear force and friction force and it was the ideal thin plate of isotropic medium, the plate structure model of coal and rock mass can be simplified as single model with simply supported on both ends, as shown in Fig. 2.

Buckling equilibrium equation of layer crack plate can be expressed as:

$$\frac{\partial^4\psi}{\partial x^4}+2\frac{\partial^4\psi}{\partial x^2\partial y^2}+\frac{\partial^4\psi}{\partial y^4}=-\frac{N_x}{D}\frac{\partial^2\psi}{\partial x^2} \quad (1)$$

In Eq. (1), D stands for stiffness of the plate, MPa, and $D=\frac{Eh^3}{12(1-\mu^2)}$, where E is the elasticity modulus, MPa; μ the Poisson ratio; h the thickness of the plate, m; ψ stands for deflection of plate, m, and $\psi = A\sin\left(\frac{m\pi x}{a}\right)$, where A stands for the constant quantity; and m is a positive integer greater than 1.

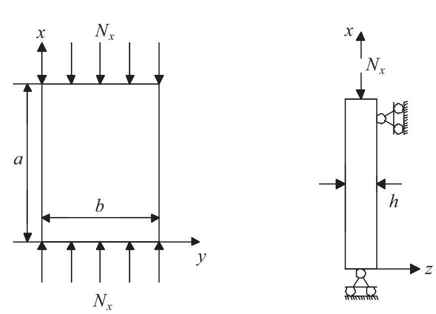
As the layer crack plate constantly meets the constraint conditions along the two free edges, i.e., $y = 0$ and $y = b$, if the size of the plate and elastic constant of materials are known, according to different integers m, the corresponding value of $(N_x)_s$ can be worked out. Taking $m = 1$, the buckling shape of the plate is a half-sine wave and the minimum instability critical load value $(N_x)_{min}$ can be obtained. The corresponding minimum critical compressive stress can be expressed as:

$$(\sigma_x)_{\min}=\frac{\pi^2h^2E}{3a^2(1-\mu^2)} \quad (2)$$

Eq. (2) shows that the instability critical load value of the plate is related to D (stiffness of coal and rock mass) and a (height of layer crack plate along the direction of the coal wall, m). With the increase of stiffness, the instability critical load value increases as well, making the plate less likely to be instable. At the same time, with the increasing height of the plate, the instability critical load value decreases, making the plate prone to buckle instability.

3. Mechanical analysis on defect anchorage in surrounding rocks affected by water seepage

Anchoring defect area exists between anchor bolt and anchor layer or anchorage and rock due to influencing factors, such as loose and broken rocks in the presence of water, invasion and corrosion of sandstone water, unevenly stir of resin cartridge and rock abscission layer, etc. Main failure types of resin bolting anchorage volume can be distinguished as follows: bonding failure, surrounding rock failure, rod body fracture failure and parts failure. Among them, bonding failure accounts for 80% of anchoring



(a) Parallel to the axial direction of roadway (b) Intersecting surface of siding-wall ("h" stands for the thickness)

Fig. 2. Mechanics model of thin rectangular plate with simply supported on both ends.