

Theoretical research on roof damage of the fully mechanized top-caving mining coal seam with deep dip angle

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ABSTRACT

In order to study the roof pressure of steep coal seams, it is necessary to establish a related mechanical model to analyze the roof breaking law. Based on a working face of SDIC Nileke Mine, a mechanical model of roof failure of deep dip angle coal seam for roof pressure and periodic roof pressure was built in the study. The model was analyzed in dip direction and along the advancing direction of the working face. Based on the stress analysis of the model, the formula for the distance of roof breakage was given. The stress, deformation, and failure discipline of complicated full mechanized top-caving coal seam with deep dip angle were studied, which also enriched the theory of roof damage. The research findings provide a theoretical basis for coal mine safety support, and it can be used as a reference for other similar research on the roof failure discipline of full mechanized top-caving coal seams with steep dip angle.

Keywords: steep coal seam; roof failure; model research

1. INTRODUCTION

The mechanical model was established based on the SDIC Nileke Mine N11 first mining face in the study, and the working face diagram is shown in Figure 1. Assume the roof material is homogeneous, continuous, and isotropic. According to production practice and related research (ZHANG, L. L. et al., 2012), the force of the working face's hydraulic support is much less than the weight of overburden, and only a part of the stratum will have a significant impact on the working face pressure which contributes to the roof deformation and fracture. It will form a pressure equalization arch when the face roof is broken, and the height of the arch is usually 4 to 8 times the mining height (GUO, S. et al., 2013). The roof load of mechanical model was 8 times the mining height of rock weight above the hydraulic support (LIU, J. Y. et al., 2010).

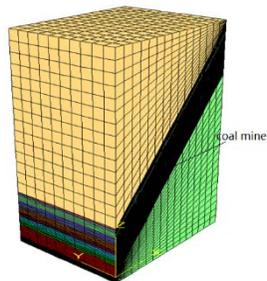


Figure 1: The working face schematic diagram.

2. MECHANICAL MODEL OF THE FIRST ROOF LOADING

Roof before first pressure can be treated as a four-side-fixed inclined plate (WANG, J. A. et al., 2010). The simplified model is shown in Figure 2. In order to calculate the stress distribution under the uniform load of the plate, the calculation was divided into two steps, which were analyzed in dip direction and along the advancing direction of the working face.

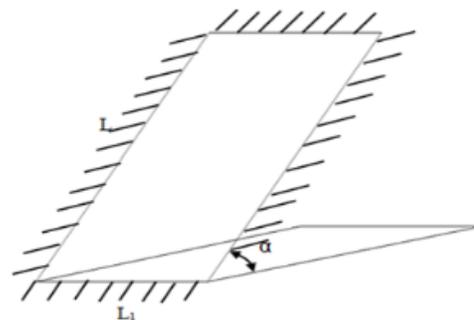


Figure 2: Model of four-side-fixed inclined plate.

2.1 Mechanical model along the direction of face advance

According to structural mechanics, the direction of face advance model was simplified and can be treated as girder with uniform load whose ends are both fixed (ZHANG, W. et al., 2006), as shown in Figure 3(a). Its bending moment is shown in Figure 2(b).

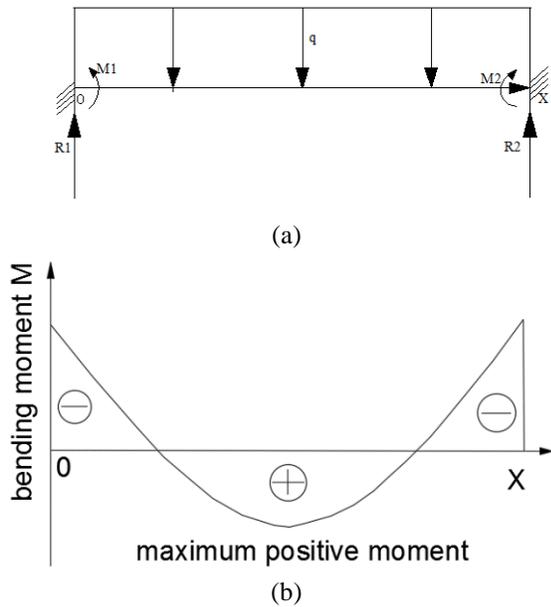


Figure 3: Bending moment distribution of fixed girder under uniform load in the advancing direction.

Fixed end bending moment (Timoshenko and Goodier,1951):

$$M_1 = -M_2 = -\frac{ql^2}{12} \quad (1)$$

End reaction of the girder ends: $R_1 = R_2 = ql/2$
Then:

$$M(x) = -\frac{qx^2}{2} + R_1x + M_1 \quad (2)$$

$$= -\frac{q}{2}\left(x - \frac{l}{2}\right)^2 + \frac{ql^2}{24}$$

In the above formula: q is uniformly distributed load, l is the beam length.

When working face along the advancing direction's mining distance is l , the uniformly distributed load of girder is

$$q = \gamma Hl \quad (3)$$

q is the uniformly distributed load of the girder along the dip direction of the face, γ is the density of overburden, H is the overburden thickness, l is the length of the girder.

When the stress of the rock σ reaches the tensile strength of the rock, roof fracture will occur, then:

$$\sigma = -\frac{M_{max}}{\omega} = -\frac{M_{max}}{\frac{bh^2}{6}} = -\frac{\frac{24}{6}M_{max}}{bh^2} = \sigma_t \quad (4)$$

In the above formula: ω is the beam bending section coefficient, b is the width of the beam, and h is the ply. When combining equation (3), the length of roof breakage formula is:

$$l_1 = \sqrt[3]{\frac{4bh^2\sigma_t}{\gamma H}} \quad (5)$$

According to the SDIC Nileke Mine field data, $\gamma=25 \text{ kN/m}^3$, $H=32 \text{ m}$, $b=1 \text{ m}$, $h=8 \text{ m}$, $\sigma_t=8 \text{ MPa}$, then $l_1=13.7 \text{ m}$.

According to the results, when the face advanced to about 13.7 m, around 6.8 m the top plate in the goaf will fracture.

2.2 Mechanical model along the dip direction of face

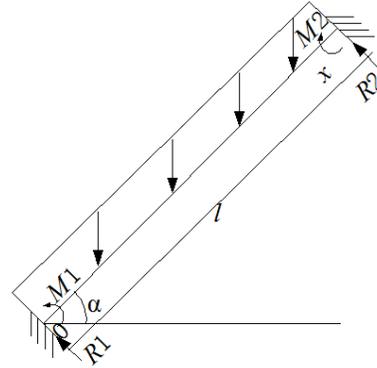


Figure 4: Force distribution of the girder along the dip direction of face.

The uniformly distributed load was decomposed into two mutually perpendicular loads one of which is perpendicular to the axis of the girder and the other along the axis. First, calculate the tensile stress generated by the load which is perpendicular to the axis of the girder; then calculate the tensile stress generated by the axial load; the total tensile stress is the sum of the two.

(1) Perpendicular to the axis of the girder

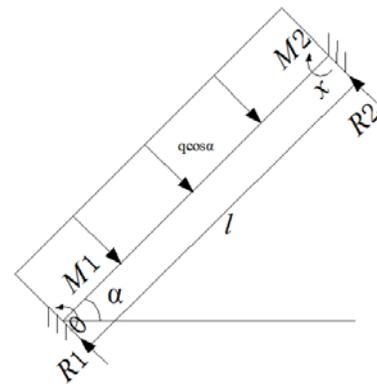


Figure 5: Force diagram of a section perpendicular to the axis of the girder.

Based on the analysis, the bending moment perpendicular to the axis of the girder is (WANG, J. A. et al., 2010):

$$M(x) = -\frac{q}{2} \cos \alpha \left(x^2 - lx + \frac{l^2}{6}\right) \quad (6)$$

M is the girder's axial moment, q is the uniform load, α is the angle of the girder, l is the length of the girder.

(2) Along the girder axis

Stress at both ends along the girder axis:

$$R'_1 = R'_2 = \frac{ql}{2} \sin \alpha \quad (7)$$

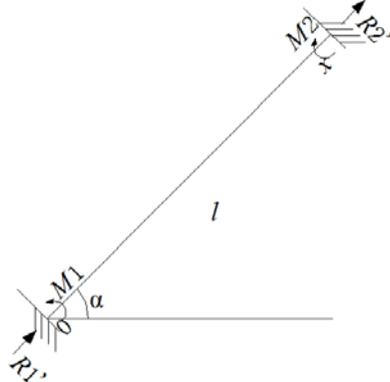


Figure 6: the axial stress of the girder along the dip direction.

$$N(x) = R'_1 - qx \sin \alpha = \frac{q}{2} \sin \alpha (l - 2x) \quad (8)$$

N is the axial tension of the girder, q is the uniform load, α is the angle of the girder, l is the length of the girder.

The stress distribution of the girder along the dip direction:

$$\sigma(x) = -\frac{M(x)}{\omega} + \frac{N(x)}{A} \quad (9)$$

And $\omega = bh^2/6$, $A = bh$.

Then:

$$\sigma(x) = \frac{3q \cos \alpha}{bh^2} \left(x^2 - lx + \frac{l^2}{6}\right) + \frac{q \sin \alpha}{2bh} (l - 2x) \quad (10)$$

σ is the stress of the girder, q is the uniform load, α for the inclination of the girder, l is the length, b is the width, h is the thickness of the girder.

Assuming:

$$\sigma(x) = \frac{3q \cos \alpha}{bh^2} \left(x^2 - lx + \frac{l^2}{6}\right) + \frac{q \sin \alpha}{2bh} (l - 2x) \leq \sigma_t \quad (11)$$

According to the SDIC Nileke Mine field data, $\gamma=25 \text{ kN/m}^3$, $H=32 \text{ m}$, $b=1 \text{ m}$, $h=8 \text{ m}$, $L=15 \text{ m}$, $\sigma_t=8 \text{ MPa}$, $\alpha=45^\circ$, then $x_1=20.5 \text{ m}$, $x_2=87 \text{ m}$.

According to the results of the analysis above, the middle of the roof in the advancing direction will break when the exposure length is 13.7 m along the

advancing of the working face, while the roof, which is about 20.5 m to 87 m apart from the bottom, will break in the dip direction.

3. MECHANICAL MODEL OF THE PERIODIC ROOF PRESSURE

Roof periodic pressure can be treated as a three-side-fixed inclined plate. A simplified model is shown in Figure 7. After first roof pressure, the calculation method of inclined plate's stress distribution under uniform load is the same as first roof pressure's when along the working face advancing distance to L_1 .

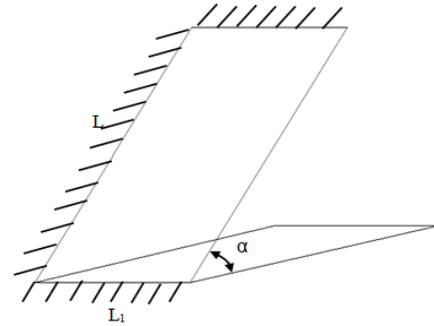


Figure 7: Model of three-side-fixed inclined plate.

3.1 Mechanical model along the face advance direction

A free-body diagram of the hanging stick along the face advance direction when the roof exposure length is l is shown in Figure 8.

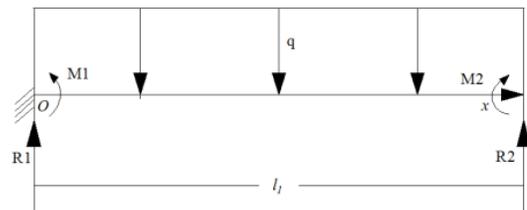


Figure 8: Free-body diagram of the cantilever along the face advance direction.

The formula of uniform load (q) is as shown in equation (3).

The bending moment of the cantilever:

$$M(x) = \frac{qx^2}{2} \quad (12)$$

Then:

$$\sigma_{min} = -\frac{M_{max}}{\omega} = -\frac{M_{max}}{\frac{bh^2}{6}} = -\frac{\frac{ql^2}{2}}{\frac{bh^2}{6}} = \sigma_t \quad (13)$$

In the above formula: σ is the stress of the beam, σ_t is the tensile strength of rock, ω is the beam bending section coefficient, b is the width of the beam, h is the ply, and l is the length of the cantilever. Combined with equation (3), the distance of roof breakage formula is:

$$l = \sqrt[3]{\frac{bh^2\sigma_t}{3\gamma H}} \quad (14)$$

According to the SDIC Nileke Mine field data, $\gamma=25 \text{ kN/m}^3$, $H=32 \text{ m}$, $b=1 \text{ m}$, $h=8 \text{ m}$, $\sigma_t=8 \text{ MPa}$, and $l=5.97 \text{ m}$.

According to the results, around 2.99 m of the top plate in the goaf will fracture when the face advances to about 5.97 m after first roof pressure.

3.2 Mechanical model along the dip direction of face

The mechanical model of the girder along the dip direction of the face is the same as Figure 4, and the way of analysis is also the same as first roof pressure in section 2.2.

We can get an inequality using equation (11).

According to the SDIC Nileke Mine field data, $\gamma=25 \text{ kN/m}^3$, $H=32 \text{ m}$, $b=1 \text{ m}$, $h=8 \text{ m}$, $L=15 \text{ m}$, $\sigma_t=8 \text{ MPa}$, $\alpha=45^\circ$, then $x_1=21.9 \text{ m}$, $x_2=88.9 \text{ m}$.

According to the results of the analysis above, the middle of the roof in the advancing direction will break when the exposure length is 5.97 m along the advancing of the working face, while the roof, which is about 21.9 m to 88.9 m apart from the bottom, will break in the dip direction.

4. CONCLUSIONS

The mechanical model of roof damage when first roof pressure and periodic roof pressure was built in this study based on the beam bending theory of elastic mechanics. The model was analysed in the dip direction and along the advancing direction of the working face. Based on the stress analysis of the model, the formula for the distance of roof breakage was given. Combined with field data, the range of the working face roof fracture was calculated.

The results of the study provide a reasonable hydraulic support scheme for the mine, and provide a theoretical basis for mine safety support.

5. ACKNOWLEDGEMENT

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