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Theoretical analysis of support stability in large dip angle coal seam mined with fully-mechanized top coal caving

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ABSTRACT

Support stability is one of the problems in mining at large dip angle coal seams with fully-mechanized top coal caving. Support stability such as anti-dumping, anti-slip, and anti-rotation at support tail assembly were analyzed on the basis of the mechanic model of large dip angle coal seam along face dip and strike. The relations between each factor and stability were researched, which shows that firstly, the support stability was negatively correlated with dip angle along the face dip, secondly, higher top caving means lower anti-rotation at support tail assembly, and thirdly, with initial support force and working resistance of support enhanced, the support anti-slip, and anti-rotation at tail assembly can rise significantly. Along the strike, support strike critical tilting angle is proportional to dip angle, mining height, support weight, support width, and support force. Similarly, support strike critical slip angle is positively correlated with support force, friction coefficient of the roof, and metal support. According to the results of the mechanical analysis, support stability in large dip angle can rise efficiently and support slipping, dumping, and rotation can be avoided by selecting proper technological methods such as enhancing initial support force appropriately and choosing fit-designed support.

KEYWORDS: large dig angle; hydraulic support; stability

1. INTRODUCTION

Fully-mechanized caving is the current development direction of mining, especially large dip angle mining. Hydraulic support is the key equipment in fully-mechanized caving (Zhizeng et al, 2010). The efficiency and safety will rise if support stability can be ensured. Under the influence of dip angle, the working load of the working face supporting system will decrease while external load resulting in support system instability will increase. Also, the probability of support slipping at the working face and extrusion between supports will be raised. The stability of hydraulic support is one of the problems in mining in large dip angle coal seams with fully-mechanized top coal caving (Zhiyan, 2007). Before this paper, the fracture mode of large inclined seam roof (Changyou et al., 2014), the support stability (Fengfeng et al., 2014), and the working resistance of support (Buzilo et al., 2010) were researched, mainly choosing supports and wall rock as the study objects at large dip coal seam. These studies and mainly focused on support stability along the face dip. The support stability in strike needs to be researched further.

In this paper, the hydraulic support is selected as the study object and its stability is analyzed via judging the anti-dumping, anti-slip and tail anti-rotation along the face dip and strike.

2. STABILITY ANALYSIS OF HYDRAULIC SUPPORT AT LARGE DIG ANGLE ALONG FACE DIP

2.1 Anti-dumping stability analysis of support along face dip

The complexity of the stress of the support at the working surface is caused by the complex ore pressure in large dip angle caving. The stability of hydraulic support can be affected by the dig angle, degree of crushing, support moving technology, mining and caving process, and hydraulic support structure and properties (Yuan et al., 2008; Changxi, 2014).

To analyze the stability of hydraulic support, a mechanical model was built in which the hydraulic support was assumed to be under uniform load. The hydraulic support mechanical model of anti-dumping along the face dip is shown in Figure 1.

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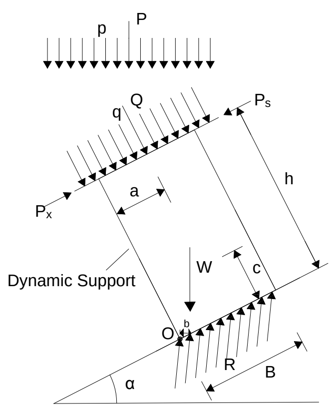


Figure 1: The hydraulic support mechanic model of anti-dumping along face dip.

When the large dip coal seam is mined, the actual movement of the roof is a curve that is close to the direction of gravity, and the force of the roof is also close to the direction of gravity, just as in Figure 1. Considering the simplification of the mechanical model, it is simplified to the gravity direction in this paper. During the mining period, the hydraulic support is inclined to the pressure P, which is also influenced by the support gravity W, the extrusion pressure P_s, P_x, initial support force q, and the supporting force R. The simplified model is shown in Figure 2. When the support is stable, the mentioned force should be in the mechanical equilibrium.

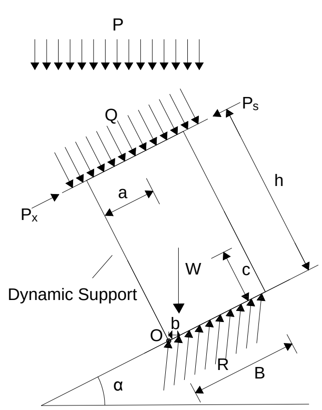


Figure 2: The simplified hydraulic support mechanical model of anti-dumping along face dip.

In the process of mining, the component force on each support changes. When the point of resultant force on the support is beyond the contact surface between the support base and floor, the support will dump. When the support along the face dip is at critical equilibrium state, it means that reaction force, of the floor to the support, should be on the point O, and each overturning moment and anti-overturning moment caused by every component force of the support to point O should meet the torque limit equilibrium.

Hence, we can write:

$$P_S h+Ph\cdot sin\alpha=P_X h+p\cdot\frac{B}{2}cos\alpha+Wb \qquad (1)$$

$$b=\frac{B}{2}\cdot cos\alpha-c\cdot sin\alpha \qquad (2)$$

h: height of the support
B: width of the support base
b: horizontal distance between gravity direction and edge of support base
c: height of centre of gravity

Due to formulation (2), horizontal distance between gravity direction and edge of support base b has negative correlation with the dig angle α. When the horizontal distance between gravity direction and edge of support base b and anti-dumping torque increases, the height of centre of gravity c , height of the support h and dumping torque of support decreases, and the stability of the support can be enhanced.

2.2 Anti-slip stability analysis of support along face dip

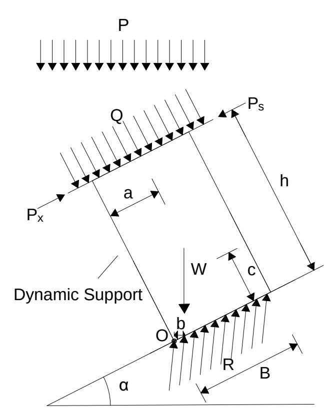


Figure 3: The simplified hydraulic support mechanic model of anti-slip along face dip.

As in Figure 3, the anti-sliding stability of support along the face dip is mainly by the influence of its own gravity W and roof pressure P, whose component force play a main role in causing the support slipping down. To ensure the anti-slip stability of support along the face dip, anti-slip fore F_{kh} must be greater than slip force F_h.

$$F_{kh}\geq F_h$$

Which means

$$[(W+P)\cos\alpha+Q]\cdot f \geq (W+P)\sin\alpha+(P_S-P_X) \quad (3)$$

F_{kh}: anti-slip force

f: coefficient of kinetic friction

According to the formulation, the existence of the initial support force increases the anti-slide force, and does not increase the downward force. So, the anti-slide capacity of the support can be significantly improved if the initial support force is improved.

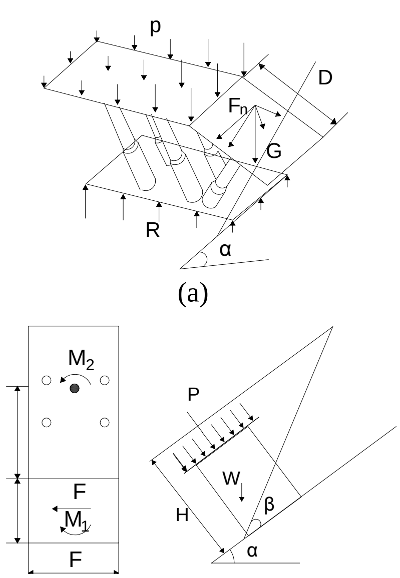
Assuming that the support is only influenced by its own gravity, and the initial support force and the roof pressure are zero. Due to the equation mentioned, we can know:

$$Wf\cos\alpha \leq W\sin\alpha \text{ and } \tan\alpha \geq f \quad (4)$$

The related research shows that the friction coefficient of metal and coal seam is 0.35-0.40 (ZHIYAN, 2007). From the formulation, we can draw the conclusion that the support will slip if the dig angle is more than 15° (tanα is greater than the friction coefficient of metal and coal seam). As a result, the anti-slip measures should be taken if the dig angle is beyond 15°.

2.3 Anti-rotation stability analysis of support tail along face dip

When using low caving coal process, the possibility of skew angle at the support tail should be considered. In the processing, the component force of caving coal will affect the support tail beam. If the anti-torque is less than the torque, the tail beam will rotate and result in support skewness. The anti-rotation mechanic model of support tail beam is shown in Figure 4.



(b) (c)

Figure 4: The anti-rotation mechanic model of support tail beam.

The torque and anti-torque, which are generated by the twisting force Fn and the anti-twisting force, should be kept in balance. This ensures that the dynamic support won't rotate.

The gravity of the coal mass G, which is acting on the cover of the support beam, the torsional force of the shield beam F_n, which is the component in the coal seam dip direction of the sliding friction force that the coal mass acts on the cover beam, and the torque of the shield beam M_1 are calculated as follows:

$$G=lBH\rho \quad (5)$$

$$l=D\sin\theta \quad (6)$$

$$F_n=Gf_2\cos\alpha\,\sin\theta\,\cos\beta \quad (7)$$

$$M_1=F_n(L+l/2) \quad (8)$$

f_1: coefficient of kinetic friction

$\alpha+\beta$: stopping angle

f_2: the friction coefficient of coal mass and shield beam

L: the distance from the base of the outer support to the geometric center

l: the projection length of the cover of the support beam

H: coal rock mass height

D: tail beam length

Q: density of bulk coal rock mass

Furthermore, we can know:

$$M_1= Gf_2(L+l/2)\cos\alpha\,\sin\theta\,\cos\beta \quad (9)$$

When the friction force F_{kn}, which is generated by the pressure between the support, the floor and the roof interacts with F_n, the torsional force acting on the shield of the support beam, support to rotate point is influenced by the roof pressure and pillar working resistance, and the distance L (from geometric center of the support to the outer edge of the base) is related with the roof pressure distribution and pillar working resistance. The related research shows that the working resistance of the support is generally greater than that of the rear column (Zhongming et al, 2004). As is shown in Figure 4, due to the measurement of working resistance of the support column, and assuming the roof pressure in the roof has a linear uniform distribution, the model can be simplified to the mechanical equilibrium model of the load on a simply supported beam, and the position of the equivalent action can be determined.

Anti-rotation moment M_2 of the friction force between the base and the top plate is used to obtain the integral of the uniform load friction torque. We can know:

$$M_2=\left(\frac{2P+W\sin\alpha}{4}\right)L_g f_3 \quad (10)$$

L_g: length of beam

f_3: coefficient of kinetic friction between the support and the top floor

Conditions to ensure no skew is $M_1 \le M_2$, torsional stability coefficient is K_3.

$$K_3 = M_2/M_1 = \frac{(2P+W\sin\alpha)L_g f_3}{8Gf_2(2L+l)\cos\alpha\,\sin\theta\,\cos\beta} \quad (11)$$

From the analysis of the K_3, when caving height is increased, the tail bracket torsional stability coefficient is a nonlinear decreasing trend. When the support working resistance increases, K_3 shows a linear increasing tendency. Hence, the working resistance of the support is significantly affected by increasing the anti-rotation stability of the support and the torsion of the support.

3. STABILITY ANALYSIS OF HYDRAULIC SUPPORT AT LARGE DIG ANGLE ALONG STRIKE

3.1 Anti-dumping stability analysis of support along strike

The stability of hydraulic support is a common problem in the mechanical mining of large dip angle coal seam in the inclined direction of the working face. In fact, the hydraulic support is influenced by the angle of the coal seam, and the stability of the hydraulic support is also influenced by the trend of the direction of the slope and the angle of the back (Dongsheng et al., 2013; Panshi et al., 2012).

When the first weighting, periodic weighting, and roof fall occurs in the mining process, the roof becomes more and more fragmentary due to stress increasing, and the roof will trend to be downward. At the same time, under the influence of the inclined angle, the lateral stress of the support will also be increased, which greatly reduces the stability of the large dip angle coal seam. The mechanic model of support along the strike in the processing of downhill-mining was built to analyze the support stability of anti-slip and anti-dumping.

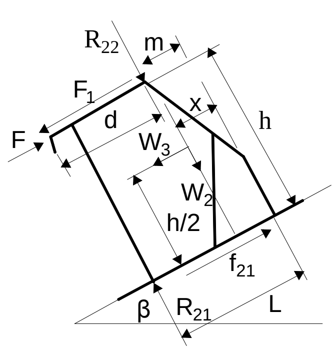


Figure 5: The support mechanic model of anti-dumping along strike when downhill-mining.

Figure 5 shows the support mechanic model of anti-dumping along strike when downhill-mining. According to the mechanical equilibrium conditions, we can know that:

$$f_{21}-F_1+F=W_3 \quad (12)$$

$$R_{21}=W_2+R_{22} \quad (13)$$

$$f_{21}=\mu R_{11} \quad (14)$$

$$R_{22}(L-M)+(F-F_1)h+2W_2L/3-W_3h/2=0 \quad (15)$$

Solving that equation, the critical tilting angle of the support along strike β:

$$\beta = arcos\frac{3h\sqrt{N-36M^2}-24LM}{N\cos\alpha} \quad (16)$$

In the equation：

$M=LR_{22}+Fh-F_1h-R_2m$; $N=W(16L^2+9h^2)$

W_3: The component force of the support gravity W, which is parallel to the surface along the seam to the bottom of the support direction

F_1: Lateral force of roof

F: Support force of coal wall to support

μ: Friction coefficient between the support and the rock

d: length of the beam

m: The distance from the base of the outer support to the geometric center

L: length of support base

x: the distance from the center of gravity to the base of the support，$L/3$。

Due to the equation, in the process of mining, if the broken roof trends to slide, the roof lateral force F_1 along strike has a negative correlation with the critical slipping angle. The critical angle is proportional to the dig angle, mining height, support weight, width, and support force.

3.2 Anti-slip stability analysis of support along strike

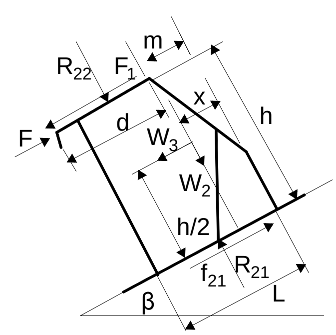


Figure 6: The support mechanic model of anti-slip along strike when downhill-mining.

According to Figure 6, we can know the equations:

$$f_{21}-F_1+F=W_3 \quad (17)$$

$$R_{21}=W_2+W_{22} \tag{18}$$

$$f_{21}=\mu R_{21} \tag{19}$$

So, the critical slip angle α:

$$\alpha=\arccos\left(\frac{\mu F_1-\mu F-\mu^2 R_{22}+\sqrt{W^2(\mu^2+1)-(F_1-F-\mu R_{22})^2}}{(\mu^2+1)W\cos\beta}\right) \tag{20}$$

As a conclusion, raising the support force, or the friction coefficient between the support and the roof or floor, could lead to the increasing of critical slip angle. The support stability of anti-slip could be enhanced. Also, decreasing the support weight or the angle of the coal seam strike could have the same results.

4. CONCLUSIONS

(1) The mechanical model of anti-dumping, anti-slip and anti-rotation at the support tail along the strike at the large dig angle coal seam is established. When the dig angle of coal and caving height rises, the stability and anti-rotation at the support tail decreases. Also, it is significant to enhance the stability of anti-slip and anti-rotation by raising the initial support force and working resistance.

(2) The anti-dumping and anti-slip mechanic model was built and the equations of dumping angle and slip angle of support along the strike were derived.

5. ACKNOWLEGEMENT

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