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Mechanical analysis and selection of hydraulic powered supports in fully mechanized coal caving face

Zhang Shoubao, Qian Ruipeng, Xue Shanbin, Wang Zhiliu, Wang Yanfei and Wu Huankai

School of Resource and Safety Engineering China University of Mining and Technology (Beijing), Beijing, China

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ABSTRACT

In allusion to solving the dumping and down slide problems of the hydraulic supports in the 2313 full-mechanized coal face with large inclined angle in Geting mine, based on the geological and mining conditions, the strike and dip mechanical models of hydraulic support were established and analyzed. The results show that, under condition of no-restriction on the top of support, Anti-toppling and anti-skid measures of hydraulic supports should be taken in mining face with a dip angle more than 16 degree, furthermore, in 2313 face, the method of sliding advance of support should be done, and the minimal residual support force is 223kN in the process of advancing supports. The main basis for selecting hydraulic supports and the key influence factors of the dumping and down slide of supports were analyzed and compared, and the ZF4200/16/26 support was selected but it needs to be reformed. After applying supports with three technology improvements in 2313 face, the percentage of unstable supports reduces from 50% to 0%, the average height of roof caving reduced 75% and the depth of rib fall, 50%. So the safe and high-efficiency exploitation is achieved in the large inclined full-mechanized coal face with an average coal inclined angle of 36 degree and the maximum inclined angle of 51 degree.

Key words: Large inclined angle; fully mechanized caving support; comparison and selection of support; stability control; minimal residual support force

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INTRODUCTION

In recent years, with the sharp increase of coal production, the coal seams with easily mining conditions such as small inclination shallow buried depth and good roof and bottom will be dried up. The coal seams mining with large inclined angle became inevitable choice for the sustainable development of mining area or enterprise such as Yanzhou mining area, Xingtai mine, Kailuan mining area, Huainan and Huaibei mining area, etc. Since the 1980's, our country has committed to the development of large inclination device to solve the problem of safe and efficiency mining in deep inclined coal seams. With the progress of mining technology and mechanized in China, especially the development of the equipment of large inclined angle, full-mechanized mining in deep inclined coal seam has achieved initial success, such as Shandong Geting mine, Heibei Gequan mine, Kailuan tangshan mine, etc.[1~3]

For large inclined angle fully-mechanized (caving) face, guaranteeing stability of fully mechanized equipment is the important premise of working face safety and high efficient production. Because the hydraulic support accounted for 80% of the whole equipment weight and over 60% of the cost, the stability of hydraulic support is the fundamental problem in the deep inclined coal seam fully-mechanized (caving) face. In china, the coal reserve with large inclined angle approximately composes 1/5 of total reserves, while its production is less than 1/10 of the national coal production. The main reason is that the support-surrounding rock accidents in deep inclined face occurred frequently, especially the collapsing accident of support. Such accidents could lead to significant security problem of hidden danger and even cause personnel casualty accidents. The labor intensity of the workers is high, the working time is long, and the material consumption is more when dealing with the accidents. It seriously affects the normal production of working face and the safety of the workers. The practices showed that choosing a suitable hydraulic supports and maintaining its stability are the key links of large inclined fully mechanized (caving) technology[4~5].

In terms of contradistinction and selection of large inclined angle hydraulic support, theoretical research is little. Some scholars believe that support dumping and downslide is related to the dead weight of support, height of gravity center, supporting force, the base width and other technical parameters [6], but there is no specific theory analysis. In the study of the stability of hydraulic support in large inclined face , the Chinese scholars have achieved some results through the field practice, summed up a lot of effective measures to prevent support downslide, and accumulated useful experience in engineering[7~11].However, theoretical analysis is relatively few, some scholars analyzed the support stability against overturning, sliding and skew from the static view[12~16],but the stability of support in the process of moving has not been detailed researched. In this paper, strike and dip stability mechanical models of hydraulic support in deep inclined face have been established, through emphatically analyzing force condition of hydraulic support both in stationary and advancing support state, it gives out the main basis of support contradistinction and selection and the key influence factors of support instability. The appropriate technical measures to prevent supports dumping and downslide have been constituted and implemented according to the actual conditions. So the safe and high-efficiency exploitation is achieved in the large inclined full-mechanized coal face with an average coal inclined angle of 36 degree and the maximum inclined angle of 51 degree.

1 Field problems and its causes

In Geting 2313 fully-mechanized face, the coal strength is low, joint fissures is many, the average angle of the coal seam is 36°,the maximum angle is 51°, the average thickness of coal is 6.5m, false-inclined longwall retreating comprehensive caving mining method is used, coal-cutting height is 2.2m, caving height is 4.2m.The serious roof accidents and hydraulic supports dumping accidents occurred during the trial mining in the face which used ZF5600/16.5/26 type caving support. 50% of the supports had dumped and slid seriously, lots of caving coal had intruded into the supports. It caused working face off production, increased maintenance cost and engineering quantity, furthermore, it will pose threat to workers and affect the mine safety and efficient production.

Through field research and analysis, it was obtained that during the fully mechanized coal caving at large inclined angle coal seam in Geting mine, the main reasons of roof fall and support dumping accident in support-rock system are as follows:

1) The coal in Geting mine has low strength, many joint fissures and large inclined angle. Due to the sliding force of the top coal on the hydraulic support along the direction of working face is larger and the disturbance in the process of moving support and coal caving，the working face easily occur rib fall of coal wall and the leakage of coal and rock. If the face met faults or is during the period of the pressure change of working face, the roof leakage is frequent, which causes the downslide and vicious cycle of roof leakage risk.

2) In Geting fully-mechanized caving face, some supports are used many wears, due to the aging of mechanical parts and hydraulic system's long-term work, there may be problems of mechanical components damage or the leaking of hydraulic system, it will lead to the failure of support and the problem of roof control reliability, thus the normal operation of mining face support and supporting quality is affected.

3) The coal seam in Geting mine have many faults, collapse columns and a large inclination which changes significantly. The roof and floor relief is strong. The above factors caused the top coal breaks, the support can't fully connect the roof, and bottom coal should be left when coming across small faults. Such factors lead to the base of the support subside losing stability. When it comes across major fault in the existing production process, new cutting hole has to be cut, and the support need to move to the new cutting hole, which reduces the production speed and coal production, and hinders mine production and development.

4) Large angle full-mechanized coal face caving support with complex stress state, suffering big inclination force will lose stability when in non-support state or free state caused by roof fall or support failure. Base of the support will down slide and fall forward when the top beam is restricted by adjacent support. Support is easy to fall down or works abnormally during the period of the pressure changes of working face, due to the movement of roof and floor.

5) It's difficult and dangerous to exploit and manage the large inclined angle full-mechanized coal face, which requires high on mechanical equipment adaptability. Staff works in bad environment, so they can't observe and operate the equipment effectively and it's difficult to adjust the position and state of the support. Because the support will be unsupported and disturbed during the caving coal process, roof fall and falling support in full-mechanized coal face can't be solved, and what's worse, large-scale roof fall and support dumping will occur, although top-caving fully mechanized supports have the device of anti-skid and safely guarded.

6) The dead weight of original support is heavy. It's difficult to adjust the support in normal ways, when the state of the support goes wrong in the large inclined angle full-mechanized coal face. And that the heavier the support is, the more likely the support to slide, and the support of the coal face is more likely to slide and fall down.

2 Mechanism model establishment and analysis of supports

2.1 Transverse mechanical model of the support

According to the production situation of 2313 fully mechanized coal caving face, the gap between support beam is small, there are constraints between the side guard plate of support beam , but the gap between the support base is large, and easily influenced by the conveyor sliding, to a great extent, the downslide of the support is mainly the downslide of the base, furthermore leading to the trend of support upward dumping, the point of base reaction force is at the O point , take O as the origin of coordinates establish Cartesian coordinate system , along the tendency is x axis and vertical seam direction as y axis. The transverse support force model can be simplified shown in Figure 1.

The roof pressure from support P(resultant is P),support weight G, the squeeze force p_{up} and p_{down} of the adjacent supports from up and down, supports attain the support form floor r(resultant is w_1),the counter-setting pressure of supports q(resultant is w_2),the friction force of supports from roof and floor is in the equilibrium state. The roof of inclined coal seam moves along a curve which is close to the direction of gravity, so the roof pressure of supports is not entirely along the direction of gravity, however, in order to facilitate the discussion ,regard it as a curve which is approximately along the direction of gravity.

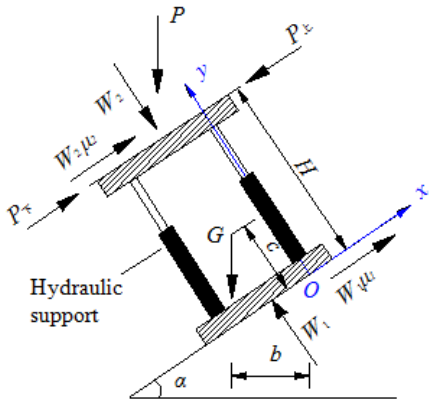

Fig.1 Inclination direction mechanical model of large angle full-mechanized caving support

1) Stability analysis of anti-dropping about supports

It is assumed that the supports do not slide, only consider the instability of dumping. Taking support as the research object, obtained by the equilibrium conditions:

$$\sum F_{xi} = P_{down} + W_1\mu_1 + W_2\mu_2 - (P+G)\sin\alpha - P_{up} = 0 \quad (1)$$

$$\sum F_{yi} = W_1 - W_2 - (P+G)\cos\alpha = 0 \quad (2)$$

In this equation, u_1 and u_2 are the friction coefficient between floor, roof and supports.

Regard M_{kn} as torsion moment that prevent supports from falling, thus:

$$M_{kn} = Gb - W_2 m_2 H + P_{up} H + P\sin a\, H - P_{down} H - (W_1 - W_2)(B/2) \quad (3)$$

$$b = (B/2)\cos a + c\sin a \quad (4)$$

In this equation, b is the horizontal distance between the direction of support gravity and upper edge of support base, H, B, c respectively for the height of the support, the width of support base and the height of support's center of gravity.

The formula (1), (2), (3) and (4) simultaneous obtain:

$$M_{kn} = Gc\sin a - W_2 m_2 H + P\sin a\, H + (P_{up} - P_{down})H - P\cos a\,(B/2) \quad (5)$$

Support is in static equilibrium, namely when roof fall s empty or support does not touch roof, the interaction between the support and initial resistance support is zero, if support does not incline, we need to satisfy the condition:

$$\tan a_1 = (B/2)/c \quad (6)$$

In this equation,α_1 is the critical angle of support transverse falling.

Support is in dynamic equilibrium, when support is moved, we should choose low-position shield top-caving support with light weight, lower center of gravity height and larger base width, and use the method of sliding advance of the support, increase the coefficient of friction between support and coal-rock mass and so on, which is beneficial for preventing support falling.

2) Support stability analysis of anti-dumping
If keeping support from down sliding, we need to exert a skid-resistance F_{kn},making $\mu_1=\mu_2=\mu$，then:

$$F_{kn} = 2W_2 + (P_{down} - P_{up}) + (P + G)(m\cos a - \sin a) \quad (7)$$

According to the above equation, support sliding is most associated with support weight, setting load, interaction among supports, roof pressure, face dip and the coefficient of friction between support and coal-rock mass and so on

Support is in static equilibrium, when roof falls empty or support does not touch roof, the initial resistance of support and the interaction between the supports is zero, regarding α_2 as the support critical slide angle, thus:

$$a_2 = \arctan m \quad (8)$$

Support is in dynamic equilibrium, when support is moved, the smaller F_{kn} is, the easier preventing support inclining is, so preventing support inclining can be realized by improving setting load and the coefficient of friction between support and coal-rock mass, decreasing support gap, improving mutual restriction ability among supports

2.2 The longitudinal mechanical model of the support
The longitudinal mechanical model of the support is simplified to be figure 2,F_1, F_2 are respectively single front and back support holding power;θ_1,θ_2 are respectively included angle between floor normal and front, back-support. θ_3 is gob shield level included angle.W_3 is the gravity of smashed coal-rock mass on the gob shield, kN，$W_3\cos\alpha$ is the positive pressure which acts on gob shield,kN; $W_3\cos\alpha\mu_3\cos\theta_3$ is the gob shield friction force from smashed coal-rock mass, kN；T_1 is the support pulling force, kN.
Amuse G_1 as the gravity of roof beam,kN; l_{g1} is the arm of force from G_1 which acts on O_1,m；G_2 is the gravity of shield beam,kN; l_{g2} is the arm of force from G_2 which acts on O_2,m；Because false-inclined angle of work face is very small, $G_1\cos\alpha$ and $G_2\cos\alpha$ are respectively projection from G_1 and G_2 which is along the floor normal direction.

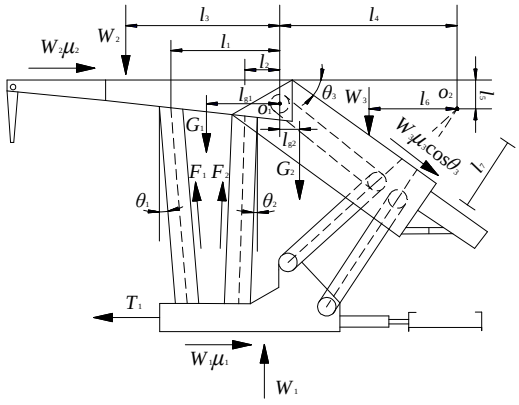

Fig. 2 Longitudinal mechanical model of full-mechanized caving support

As figure 1 is shown, we should keep each component of the support steady to make support steady when moving it. At first, taking roof beams as free body and O_1 as fulcrum, based on the balanced condition, $\sum Mo1=0$，then:

$$W_2 l_3 + G_1 l_{g1}\cos\alpha = 2F_1 l_1\cos\theta_1 + 2F_2 l_2\cos\theta_2 \quad (9)$$

Secondly, taking roof beams and shield beams as of free body, and O_2 as fulcrum, based on the balanced condition $\sum M_{o2}=0$,then：

$$W_2(l_3+l_4) + W_3 l_6\cos\alpha + W_3\cos\alpha\mu_3\cos\theta_3 l_7 + G_2 l_{g2}\cos\alpha = 2F_1(l_1+l_4)\cos\theta_1 + 2F_2(l_2+l_4)\cos\theta_2 + W_2\mu_2 l_5 \quad (10)$$

In this equation, γ as the bulk density of loose coal-rock mass, D as the length of the shield beams, θ_3 as the included angle between shield beams and horizontal direction, B as the width of the support, h as the height of the caving loose coal-rock mass ,then：

$$W_3 = \gamma \square D\cos\theta_3 \square B \square h \square \cos\alpha \tag{11}$$

1) The stability analysis of anti-dropping about supports

In order to avoid the immediate roof breaking and leaking which make support falling in the process of moving support, workers should make the support touch the roof when moving it. According to equation 5, in the case that no measure is adopted to prevent support dumping, if the support is moved forward with the sliding force from the roof , the minimum requirement is:

$$W_2 = Gc\sin a / m_2 H \tag{12}$$

Combined (9),(10),(11,) and (12) come to a conclusion, when moving support, in order to avoid support dumping, the minimal residual support power of the front, back leg are respectively F_{m1}、F_{m2}:

$$F_{m1} = \frac{\gamma \square D\cos\theta_3 \square B \square h\cos^2\alpha \square l_2(l_6 + l_7\mu_3\cos\theta_3) + G_2 l_{g_2} l_2\cos\alpha}{2(l_2 - l_1)l_4\cos\theta_1} - \frac{G_1 l_{g_1}\cos\alpha(l_2 + l_4)}{2(l_2 - l_1)l_4\cos\theta_1} + \frac{Gc\sin\alpha(l_2 l_4 - \mu_2 l_2 l_5 - l_3 l_4)}{2(l_2 - l_1)l_4\mu_2 H\cos\theta_1} \tag{13}$$

$$F_{m2} = \frac{\gamma \square D\cos\theta_3 \square B \square h\cos^2\alpha \square l_1(l_6 + l_7\mu_3\cos\theta_3) + G_2 l_{g_2} l_1\cos\alpha}{2(l_1 - l_2)l_4\cos\theta_2} - \frac{G_1 l_{g_1}\cos\alpha(l_1 + l_4)}{2(l_1 - l_2)l_4\cos\theta_2} + \frac{Gc\sin\alpha(l_1 l_4 - \mu_2 l_1 l_5 - l_3 l_4)}{2(l_1 - l_2)l_4\mu_2 H\cos\theta_2} \tag{14}$$

2) The stability analysis of anti-sliding about supports

According to the equation (7), in the case that no anti-sliding step is adopted, the minimum support requirement that keep support moving with sliding force from roof is:

$$W_2 = G(m\cos a - \sin a)/2 \tag{15}$$

Combined (9), (10), (11,) and (14) come to a conclusion, in the process of moving the support, if support do not dump, the minimal residual support power of the front, back leg are respectively F_{m1}、F_{m2}:

$$F_{n1} = \frac{\gamma \square D\cos\theta_3 \square B \square h\cos^2\alpha \square l_2(l_6 + l_7\mu_3\cos\theta_3) + G_2 l_{g_2} l_2\cos\alpha}{2(l_2 - l_1)l_4\cos\theta_1} - \frac{G_1 l_{g_1}\cos\alpha(l_2 + l_4)}{2(l_2 - l_1)l_4\cos\theta_1} + \frac{G(\mu\cos\alpha - \sin a)(l_2 l_4 - \mu_2 l_2 l_5 - l_3 l_4)}{4(l_2 - l_1)l_4\cos\theta_1} \tag{16}$$

$$F_{n2} = \frac{\gamma \square D\cos\theta_3 \square B \square h\cos^2\alpha \square l_1(l_6 + l_7\mu_3\cos\theta_3) + G_2 l_{g_2} l_1\cos\alpha}{2(l_1 - l_2)l_4\cos\theta_2} - \frac{G_1 l_{g_1}\cos\alpha(l_1 + l_4)}{2(l_1 - l_2)l_4\cos\theta_2} + \frac{G(\mu\cos\alpha - \sin a)(l_1 l_4 - \mu_2 l_1 l_5 - l_3 l_4)}{4(l_1 - l_2)l_4\cos\theta_2} \tag{17}$$

In summary, when moving the support, in order to avoid support dumping and sliding, the minimum F_1、F_2 are respectively the minimal residual support power of the front, back leg:

$$F_1 = \max\{F_{m1},\ F_{n1}\} \quad F_2 = \max\{F_{m2},\ F_{n2}\} \tag{18}$$

3 Main basis of support selection and comparative analysis

According to dumping and sliding accident of support in 2313 large inclined angle fully mechanized coal caving face, a field research is made between ZF4200/16/26 and ZF5600/16.5/26 type hydraulic supports, main parameters of two types are as follows:

Table 1 Comparison of main technical parameters of support

The type of support	Weight（kN）	The height of gravity center（m）	Side guard plate stroke（mm）	The minimum remaining holding power（kN）		support working resistance（kN）
				Front	Back	
ZF4200/16/26	125	1.35	55	189	223	4200
ZF5600/16.5/26	185	1.60	43	301	334	5600

1）The weight of the support. The height of gravity center, the width of the base, according to the equation (1) and (3) ， with the weight of the support G, the height of gravity center c and the width of the base B ， M_{kn} and F_{kn} increasing, it goes against anti-dumping and anti-slipping. So, we had better choose the low caving support with the lighter weight, lower focus height and larger base width.ZF4200/16/26 support belongs to low caving hydraulic support. Compared with ZF5600/16.5/26 support, it is

60KN lighter than latter, and 0.25m lower about height of gravity center, so the former is steadier.

2) The minimum residual support. According to the equation (5), when moving the support, in order to avoid support dumping and slipping, we must remain a certain amount of holding power, but it is hard to control residual support power in practice. So it is better to make the minimum residual support power as small as possible. Based on the production condition and support technical parameter, combined (14),(16),(17) and (18) come to a conclusion, the minimum residual support power of the front, back leg for ZF4200/16/26 support are smaller than ZF5600/16.5/26 support, so it is easier to adjust the position state of former support when moving it.

3）Support strength. By calculating, support strength of ZF4200/16/26 hydraulic support 0.87MPa＞face calculations supporting strength 0.43MPa＞the largest average support strength 0.39MPa,so it can meet the demand of working face supporting strength.

4）Support side guard device. The side plate of support not only ensures preventing gangue well, good sealing performance, but also increases the transverse constraint between supports, that is P_{up} and P_{down}, the side guard ability of adjacent supports plays an important role in preventing support from dumping especially when the roof above supports caving empty. Head beam of support ZF4200/16/26 has an appropriate width and side plate of the support has a travel of 55mm, thus support gap can be adjusted effectively. This property can not only prevents the top-coal leakage, but also improves supports interaction force, which is advantageous to anti-toppling and anti-skid of the support.

5）The integrity of the system. Supports should match with other devices, such as conveyor, cutting coal machine, etc. and the coordination between supports should be paid attention to.

Through the comparison analysis of supports, 2313 large inclined angle fully-mechanized caving work face should choose the lighter deadweight, low center of gravity height and larger base width ZF4200/16/26 type of low caving hydraulic support. For this hydraulic support, B = 1.5 m, c = 1.35 m, bring them into the formula (6) and calculate, the critical inclination of the support dumping is 29°.Combining with the conditions of coal mining face, the friction coefficient μ among the roof, floor and support is 0.28, bring them into the formula (4) and calculate, critical gliding angle for 15.6°.So, critical inclination of the support dumping in a state of instability is 15.6°. While the average angle of 2313 large inclined angle fully-mechanized caving face is 36°,so we must take measures to prevent the support toppling and skid.

4 Anti-toppling and anti-skid measures of support and practical effects

Modified transformation of hydraulic support is mainly used to prevent the support from skiding. Concrete design and parameters are as follows:

1）The square plate at the back of the support base is installed sleeve inside of which is installed rotatable trunnion. Every two supports share a Ø 100 mm jack which is fixed in trunnion and adjust the angle of the support.

2）The base of support at middle of the working face is installed in trunnion. Every 3~5 supports, there is a antiskid cylinder(diameter 140 mm, stroke 700 mm) which is used to adjust conveyor to prevent gliding conveyor driving support to glide.

3）Every 5 ~ 10 erect a compression bar cylinder, the top of cylinder is installed on the support canopy, the lower end of the cylinder can elongate to press on the relay bar. The cylinder can make the relay bar close to the base and ensure the plate is not up warping, then it prevent conveyor linked to relay bar from side tumbling.

The specific effect of the design is shown in figure 3.

① bottom adjusted cylinder ②Pull the rear conveyor device ③compression bar cylinder ④Pull the front conveyer device

Fig 3 3-d sketch of modification design of hydraulic support

In the aspect of geometrical state control, supports should be moved one by one from up to bottom in time, the relay bar should be

oriented in the whole process in order to reduce the gap between relay bar and base. Keep pressure between supports and roof when advancing support in order to prevent supports is in the free state. After advancing supports, side plate jack should be controlled in time to reduce the gap between supports canopy in order to keep restraint between adjacent supports and improve the stability of the support system of working face.

In the aspect of coal mining technology, large inclined fully-mechanized caving work face should be adjusted to pseudo-inclined to reduce the true dip of the face. The operation of shearer should be regulated strictly to prevent mining height being too high. The speed of coal-cutting should be accelerated. we should make full use of the process characteristics and adopt measures to control rib spalling and leakage of the coal and rock in order to keep integrity and stability of support-surrounding rock system.

ZF4200/16/26 type hydraulic support is applied in 2313 large inclined fully-mechanized caving work face and the anti-toppling and anti-skid measures are implemented. The stability of hydraulic support is good and the accident of toppling and glide of support doesn't happen which influence the production. Maximum inclination deflection angle of support's column is 8°upward to 2°downward. The height of caving and the depth of rib spalling have been decreased by 75% and 50% respectively.

CONCLUSION

1) The main reasons for falling and downslide of support in the original fully-mechanized caving work face are developmental joint fissure, complex geological conditions of coal seams and the unreasonable chose of support.

2）The critical stable angle of support and the calculation method of minimum residual support power are obtained by analyzing the longitudinal and transverse stability of support on the base of mechanical model of hydraulic support which we established. It also points out that keeping pressure between supports and roof to advance supports is advantage to keep dynamic balance, the smaller minimum residual support power of hydraulic support in large inclined fully-mechanized caving face in the process of moving supports, the more convenient adjustment and the supports can keep stable more easily .

3）Structure technique parameters such as deadweight of support, height of center of gravity and width of base are the important indicators of the compared selection of large inclined angle fully-mechanized hydraulic support. The lighter weight, the lower center of gravity height and the wider base are more advantage to support anti-dumping and anti-sliding.

4）The critical dumping inclination of the ZF4200/16/26 type hydraulic support in 2313 large inclined angle fully-mechanized caving work face is 29°. The critical sliding angle of support is 16° while the average angle of coal seam is 36°,so the three technical reconstruction measures have been taken to prevent the support from dumping and sliding have obtained good effect.

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REFERENCES

[1] WU Yong-ping. Study on dynamics controlling basis of system "R-S-F" in steeply dipping seam mining [D].Xian: Xi'an University of science and Technology, **2003**.
[2] TU Shi-hao, YUAN Yong, LI Nai-liang. *Journal of Coal Science & Engineering* (China), **2008**, (03): 382-385 .
[3] YANG Ren-shu, ZHU Xian-lei, GUO Dong-ming, et al. *Coal Science and Technology*, **2010**, 38(3): 8-11
[4] YIN Guang-zhi, LI Xiao-shuang, GUO Wen-bing. *Chinese Journal of Rock Mechanics and Engineering*, **2010**, 29(S1): 3336-3343.
[5] WANG Zhi-peng, YAO Wei, WEI Jian-ping. *Coal Science and Technology*, **2009**, 37(5): 15-82.
[6] YUAN Yong, TU Shi-hao, DOU Feng-jin, et al. *Journal of Mining & Safety Engineering*, **2008**, 25(4): 430-434.
[7] KE Chang-qing, LI Yan-song, CHEN Yu-bo. *Coal Mine Machinery*, **2012**, 33 (1): 223~224.
[8] MIAO Jian-hua. *Safety in Coal Mines*, **2011**, 43(3): 172~174.
[9] XU Tao. *Coal Science and Technology*, **2007**, 35(9): 58~62.
[10] ZHENG. Wei-qiang. Research on priventie fall and resistie skid for rgent-inclining synthetic minins hydraumatic supporting[D]. Xian：Xi'an University of science and Technology, **2007**.
[11] XIE Sheng-rong, HE Fu-lian, YANG Hong-zeng, et al. *Advanced Materials Research*, **2011**, Vols. 243-249: 2039-2043.
[12] ZHANG Zhi-yan. *Journal of China Coal Society*, **2007**, 32(7): 705-709.
[13] MA, Li-qiang,ZHANG Dong-sheng, ZHANG Cheng-guo, et al. *Advanced Materials Research*, **2011**, v160-162: 1524-1530.
[14] ZHANG Wei, ZHANG Dong-sheng, ZHAO Yong-shu. *Applied Mechanics and Materials*, **2012**, v101-102: 1105-1108.

[15] ZHAO Xiao-dong, WANG Hai-long. *Journal of China Coal Society*, **2012**，37(5): 731-736.
[16] YUAN Yong. Stability control mechanism of support surrounding rocks at fully mechanized mining face with great cutting height[D]. Xuzhou, China University of Mining & Technology, **2011**.