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Short communication

Criteria of support stability in mining of steeply inclined thick coal seam

Wang Jin-an [a,b,*], Jiao Jun-ling [a]

[a] School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China
[b] State Key Laboratory of Education Ministry for High Efficient Mining and Safety of Metal Mines, China

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1. Introduction

The level slice cutting or pseudo inclined slice cutting method associated with top coal caving mining is usually used in extraction of steeply inclined thick coal seams. A layout of short wall working face is simple and the support stability is easily guaranteed. However, the width of the mining face is limited by the thickness of the coal seam. As a result, the mining efficiency is low, due to a high ratio of the amount of roadway excavation to the amount of coal production. Therefore, how to take advantages of longwall mining to enhance the efficiency and safety of mining in steeply inclined coal seam becomes a key issue.

As well known, the roof caving and movement, gravity traction and other factors directly affect the stability of supports in steeply inclined thick coal seam. The supports are prone to sliding or toppling along a steeply inclined working face .[1-3] In order to solve the problems of support instability, comprehensive technical measures and researches have been performed regarding different aspects, such as curving layout of the longwall working face,[4] support connection,[5-7] and interaction between support and roof and floor strata[8–10] etc. Kong and Jiang [11,12] studied the reasonable supporting resistance and obtained the relationship between the roof structure and support working resistance for a general top caving mining face. They also proposed quantitatively the expression of the “support- surrounding rocks” relationship under three kinds of roof structure model in top caving mining face. Wu et al.[13–15] analyzed the relationship between masonry structures of overlying rock strata and support stability, they put forward the stability criterion of the ‘roof-support-floor’ system (R–S–F model). Xie[8] studied the layout of longwall working face and pointed out that ‘nonlinear bifacial’ face layout is the key technology to ensure the support stability in steeply inclined thick coal seam. In addition, the varying of supporting resistance with time[9], the mechanical analytic model of support[16,17] and the non-uniqueness of supporting resistance[18,19] have been studied.

Dongxia Coalmine is located in Huating coal field, Gansu province of China, where folds are the major tectonic structure. Mining panel 37220 is seated at the eastern wing of syncline with dip angles ranging from 34° to 62° (an average value of 52°). The thickness of coal seam No. 6–2 is 19.8 m. The working face is at depth between 603–657 m with an inclined length of 93 m and a strike length of 1036 m. The geological characteristics of major overlaying rock strata and the coal seam are summarized in Table 1. According to in situ stress measurement by using core covering method, the orientation of the maximum principal stress is approximately 18°/258° (dip/azimuth angle), that is almost perpendicular to the strike of the coal seam. The maximum principal stress and minimum principal stress increase linearly with the depth as follow:

* Corresponding author at: School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China.
E-mail address: wja@ustb.edu.cn (W. Jin-an).

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Table1
Characteristics of coal seam and surrounding rock strata.

Stratum	Rocks	Thickness/ m	Character description
Main roof	Sandstone	> 10	Gray white, massive and hard texture
Immediate roof	Silt sandstone、Mudstone	1–2.3	Mainly silt mudstone, grey mudstone and partially light gray siltstone
False roof	Oil shale、Carbon mudstone	0.16–0.86	Dark gray carbonaceous mudstone, partially clipping with coal line and dark grey oil shale
Coal seam	Coal no. 6–2	19.8	Black, shiny, massive structure with asphalt, bright coal and semi bright fine coal, joint development, brittle, easily broken. There are two layers of gangue of carbonaceous mudstone and white siltstone in the coal seam
Immediate floor	Coal 6–2 (meddle)	9–10	Black, shiny, asphalt and massive structure long flame coal
Main floor	Sandstone	> 5	Grey argillaceous sandstone

$$\sigma_{h,\,max} = 0.0446H + 0.7211$$

$$\sigma_{h,\,min} = 0.0302H + 0.2851 \qquad (1)$$

$$\sigma_v = 0.0265H + 0.6704$$

where $\sigma_{h,max}$, $\sigma_{h,min}$ and σ_v are the maximum principal stress, the minimum principal stress and vertical (intermediate) stress, respectively. Herein, the maximum principal stress $\sigma_{h,max}$ at depth of 603–657 m in Dongxia coalmine reaches 27.6–30.0 MPa, and the ratio of $\sigma_{h,max}/\sigma_v$ is about 1.67, indicating that the tectonic stress is dominant in Huating coalfield.

The coal seam was extracted in two layers separately. Working face 37220-1 is the first layer of mining with a thickness of 10 m. The fully mechanized top-coal caving mining technique is employed, where the cutting height is 3.0 m and the top coal caving height is 7.0 m. The mining face is laid in a nonlinear bifacial manner along the inclination that is composed by an inclined straight plane, a curving section and a horizontal plane. As shown in Fig. 1, the steeply working face in the lower region is transited from an inclined straight plane to a horizontal plane through a curving section. Such a layout of working face resolves an abrupt transition from the steeply inclined supports to level end-supports. Also, it improves significantly stability of the supports as a whole along the inclination of coal seam.

The working face is equipped with four column shield supports (ZF5000/17/28) .[20] As shown in Fig. 2(a), the basic support has a weight of 17 t with a height of 2.8 m and a width of 1.5 m. The supporting force at installation can reach 3958 kN, and the maximum supporting capacity is 5000 kN. As shown in Fig. 1, three transitional supports are placed in the horizontal section numbered as 1#–3#; 23 basic supports are installed in the curving section, numbered upward, respectively, by 1#–23# (supports from 1# to 15# transitionally incline from level to the angle of 25° with an increment angle of 1.67°, and supports from 16# to 23# incline gradually to 52° with an increment angle of 3°). 36 basic supports are installed on the inclined straight plane with the inclination angle of 52°, and numbered upward by 24#–59#, respectively.

In the initial mining stage, when the working face 37220-1advanced 6.5 m from the open cut, a small scale roof collapse occurred along the face wall ahead of supports 28# and 29#. The caved size is 2.5 m × 1.5 m × 1.2 m. A successive larger scale collapse of the roof stratum occurred after the supports were moved forward. The collapsed roof coal buried the mining face up to support 25#. From the position of support 12# in the mining face, the collapse of roof coal and the working face developed and enlarged up and forward, giving rise to a huge funnel shaped cave space with the maximum width of 4 m and the maximum height of 11.6 m (Fig. 3). The supporting system from the middle to the up region of the working face was completely destroyed. As like a *domino effect*, toppling and gripping of the supports severely took place.

The essential reasons of the accidental collapse and support instability are majorly as follows:

(1) Failure of surrounding rocks. The structure of coal seam no. 6–2 is complicated, and lamination and joints are densely developed in the brittle coal seam. Under a high tectonic stress

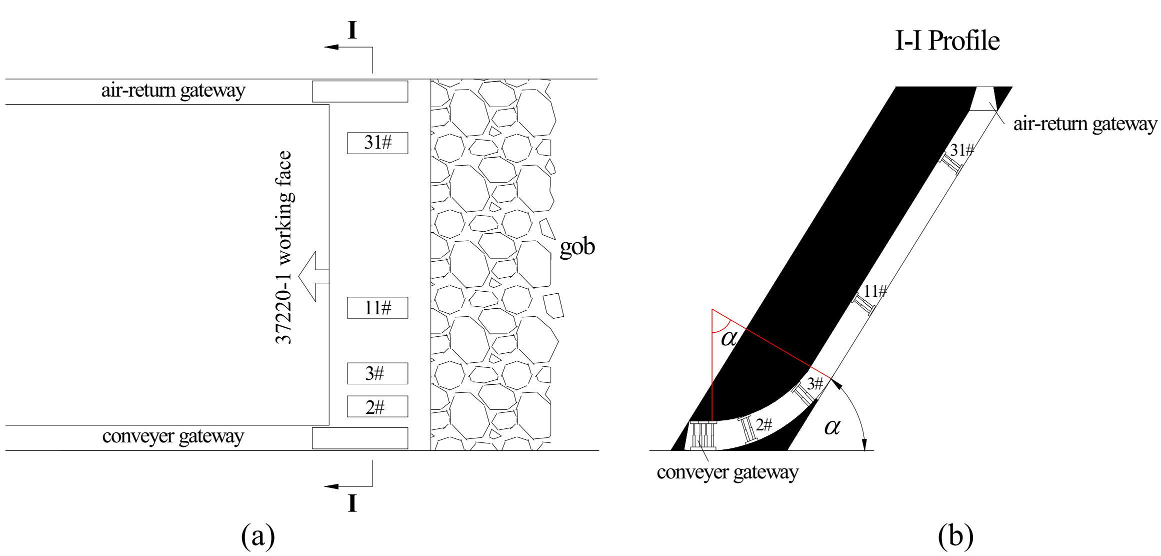

Fig. 1. Layout of the working face (a) On coal seam plane; (b) On inclination profile.