International Journal of Mining Science and Technology 26 (2016) 417–422

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Top-coal deformation control of gob-side entry with narrow pillars and its application for fully mechanized mining face

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ARTICLE INFO

Article history:
Received 27 September 2015
Received in revised form 30 November 2015
Accepted 15 January 2016
Available online 15 March 2016

Keywords:
Fully mechanized top-coal caving
Narrow pillar
Gob-side entry
Top coal
Deformation control

ABSTRACT

A mechanical model to control the top-coal deformation is established in accordance with the structural characters of the gob-side entry surrounding rock for the fully-mechanic top-coal caving; the analytical solution of top coal roof-sag curve is deduced with Winkler elastic foundation beam model. By means of a calculating and analytic program, the top coal roof-sag values are calculated under the conditions of different supporting intensities, widths of narrow pillars and stiffness of top coal; meanwhile, the relationship between the roof-sag values and supporting intensity, width of narrow pillars and stiffness of top coal is analyzed as well. With the actual situation of the gob-side entry taken into consideration, the parameters of top-coal control are determined and a supporting plan is proposed for the top-coal control, which is proved to be reliable and effective by on-site verification. Some theoretical guidance and advice are put forward for the top-coal deformation control in gob-side entry for fully mechanized top-coal caving face.

1. Introduction

In the gob-side entry with narrow pillars, the abutment pressure is redistributed because of the subsidence rotary motion of roof strata [1]. The interaction and mutual influences among the top-coal, the narrow pillar, the integrated coal beside the roadway and the floor lead to the surrounding rock deformation and failure. As is known, the deformation amount of the roadway's sides is often larger than that of the roof and floor. Therefore, how to maintain the stability of the two sides of the roadway, especially that of the narrow pillar walls has been the focus of the research on the deformation and control of roadway driving along goaf [2–5]. Under the condition that the main roof acts on the surrounding rocks of the fully-mechanized caving roadway in a given deformation way, Gao et al. analyzed the deformation mechanism of roadway surrounding rocks [6–8]. However, there has been little research on the relationship between the top-coal deformation and supporting intensity, width of narrow pillars, and stiffness of top coal. Site investigations indicate that the analysis on the top-coal deformation and strained condition is of great significance to study the whole stability of fully-mechanized top-coal caving roadway with narrow pillars.

Based on the geological condition of the 3304 fully-mechanized top-coal caving face of a mine in Zaozhuang, the beam structure model of top-coal is established according to the general surrounding rock structure of the gob-side entry. By means of theoretical analysis, numerical calculation and field measurement, this paper studies the relationship between the caving top-coal deformation and its influencing factors, and puts forward the control method of the roof of caving top-coal of roadway along goaf with narrow pillars; meanwhile the relevant parameters are determined.

2. Top-coal stress and deformation analysis of roadway driving along goaf

2.1. Mechanical model of top-coal

One side of the gob-side entry for fully mechanized top-coal caving is the integrated coal beside the roadway while the other side is the narrow pillar. According to the key strata theory and the movement law of overlying strata on the goaf side of fully mechanized caving face, fracture, rotary and subsidence occur in the main roof after the immediate roof caving and sinking in the upper section of the working face; in the lower section, the lateral "voussoir beam" structure is formed in the coal mass, namely "the big structure" [9–14]. In this process, a fractured zone with a certain thickness is formed as the marginal coal mass is damaged;

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http://dx.doi.org/10.1016/j.ijmst.2016.02.008
2095-2686/

as the lateral abutment pressure is transferred to the integrated coal beside the roadway, the stress increasing zone is formed; and the stress decreasing zone is formed in the lower part of the big structure. This provides favorable conditions for the roadway driving along goaf where the forced deformation of surrounding rocks is small and easy to control. After the roadway driving along goaf, an organic whole is developed by the top-coal, the floor, the two sides, the narrow pillar and the anchor as the support object of the roadway, called "the small structure" [13,14]. The roadway support of gob-side entry driving focuses on maintaining the stability of the small structure. The relationship between the roadway driving along goaf with narrow pillars and the overlying strata structure is shown in Fig. 1.

The roof subsidence of roadway driving along goaf is mainly composed of the inelastic displacement caused by rock stress release of surrounding rocks in tunnel excavation process and the gravity of overlying strata. For the convenience of study, the inelastic displacement caused by rock stress release is ignored. According to the main roof activity rule, the top-coal of roadway driving along goaf is simplified to the beam structure, and its corresponding mechanical model is established and shown in Fig. 2. Taking the horizontal centerline of the top-coal as the axis, the goaf-side endpoint of top-coal as the origin O, the lateral direction of the integrated coal beside the roadway as the positive direction, we can set up the coordinate. Point A and point B stand for the two walls of the gob-side entry respectively; point C refers to the boundary of the deep stress concentrated zone of the top-coal; the top-coal strata is denoted by OD, and D refers to the random point which is far enough, and can not affect the calculation; the overlying strata stress on the upper part is $q_1(x)$; under the top coal, the narrow pillar, the gob-side entry and the integrated coal beside the roadway are respectively represented by OA, AB and BD, and their widths are l, L and $a + x_0$, respectively; they are acted jointly by the narrow pillar's holding power $q_2(x)$, support intensity p and the entity coal's holding power $q_3(x)$.

The mechanical environment of the fully mechanized top-coal roadway driving along goaf with narrow pillars differs from that of general mining roadways [15,16]. After mining in the upper section, the stress relaxed zone is formed above the gob-side entry; meanwhile the stress concentrated zone appears with the increase of the stress on the two sides of the overlying strata. Thus the quadratic function is employed here. Due to the rotation of the main roof, the narrow pillar enters the plastic state with the bearing capacity dramatically reduced, while the stress concentration on the integrated coal beside the roadway rises higher. The stress concentration coefficient of the BC side of the integrated coal beside the roadway is set as α_1, and that of the top-coal of narrow pillar OA as α_2. The overburdened pressure upon AB above the roof of roadway driving along goaf is regarded as the uniform load, and the relative rock stress coefficient is α_3. Because the roadway excavation has less impact on the top-coal CD side of the virgin coal

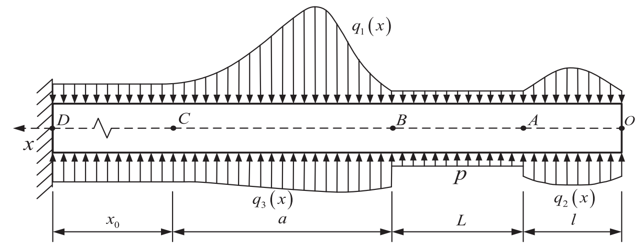

Fig. 2. Mechanical model of the top-coal of roadway driving along goaf with narrow pillar.

face, the load subjected is still the overlying strata gravity $\gamma_2 H$, where γ_2 is the average weight, N/m^2; and H is the thickness of the overlying strata (m) which can be seen as the buried depth. Therefore, the overlying strata stress $q_1(x)$, which is acted on the top-coal can be represented by the following piecewise function:

$$q_1(x) = \begin{cases} \frac{4(\alpha_3-\alpha_2)\gamma_2 H}{L_0^2}\left(x - \frac{L_0}{2}\right)^2 + \alpha_2\gamma_2 H, & 0 \leqslant x < l \\ \alpha_3\gamma_2 H, & l \leqslant x < l + L \\ \frac{4(1-\alpha_1)\gamma_2 H}{a^2}\left(x - L_0 - L_1 - \frac{a}{2}\right)^2 + \alpha_1\gamma_2 H, & l + L \leqslant x < l + L + a \\ \gamma_2 H, & l + L + a \leqslant x < +\infty \end{cases} \quad (1)$$

If the coal mass is taken as the isotropic elastic body, the supporting effect of the narrow pillar and the integrated coal beside the roadway on the top-coal can be conducted as the elastic foundation [17]. So

$$q_2(x) = -k_1 w(x), \quad 0 \leqslant x \leqslant l \quad (2)$$

$$q_3(x) = -k_2 w(x), \quad l + L \leqslant x < +\infty \quad (3)$$

where k_1 and k_2 are the Winkler foundation coefficients reflecting the bearing capacity of the coal-rock mass under the top-coal, which is related with the mechanical properties of the side coal mass and the height of the roadway. Due to the roof subsidence, the two sides enter the plastic state from the coal wall to the coal mass. The side surrounding rocks constantly squeeze and crush the inside roadway, which leads to the reduction of the bearing capacity of the coal-rock mass. The Winkler foundation coefficients go down consequently and then the curve subsidence of the roof is enlarged. In addition, the top-coal of the gob-side entry is affected by the support intensity p, and the whole top-coal is affected by its own gravity $\gamma_1 h_1$, where γ_1 refers to the unit weight of the coal mass, N/m^2; and h_1 is the thickness of the top-coal, m.

The resultant force, which is called the equivalent load $q(x)$, is composed of the overlying strata stress, the side coal mass' holding power, the supporting intensity and the self gravity being acted on the top-coal. It can be represented by Eq. (4):

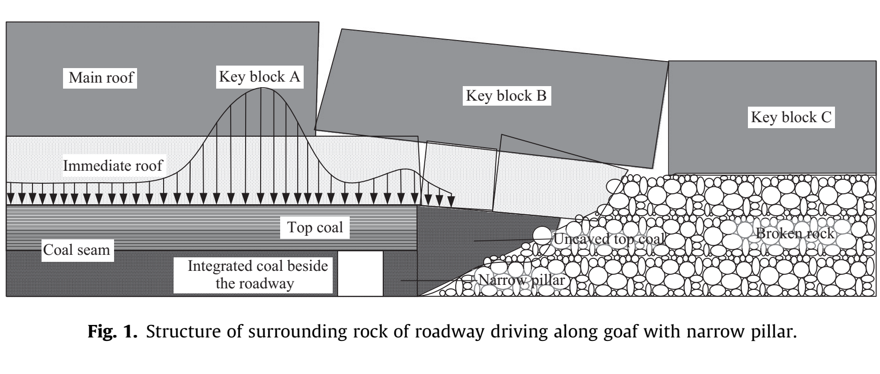

Fig. 1. Structure of surrounding rock of roadway driving along goaf with narrow pillar.