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The reasonable breaking location of overhanging hard roof for directional hydraulic fracturing to control strong strata behaviors of gob-side entry

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1. Introduction

Strong strata behavior such as significant deformation and rock burst often occur in gob-side entry of longwall panel under hard roof, which affects the safe and efficient mining of coal mines. On one hand, the vertical and lateral abutment pressure (static pressure) in the safety pillar and the gob-side entry are large due to overhanging hard roof over the gob of the adjacent working face, which causes the strata behaviors such as floor heave and large deformation. On the other hand, due to the high strength, great thickness and good integrity of the hard roof, considerable elastic energy can be stored in the hard roof. When the stored elastic energy reaches the maximum and is abruptly released, dynamic disasters such as rock burst occurs. The hard roof is hanging over the gob during the active working face was being mined, the impact load caused by the periodic breaking of the hanging roof leads to the larger advanced abutment pressure (dynamic pressure)[1,2]. The superposition of the advanced abutment pressure and the lateral abutment pressure[1,3] speeds up the deformation rate of the entry and increases the probability of strong strata behaviors. Typical strong strata behaviors occur in the gob-side entry in Tongxin coal mine Datong mining area before the working face is mined. The coal wall and floor of the entry heaved and cracked. During the mining period, single hydraulic props bent and toppled, or sank into the floor under the effect of the upper load. In extreme situation, the height of the entry in the front support section decreased to 1.5 m from 3.5 m in a very short time.

Field practices show that, the strong strata behaviors of the gob-side entry can be solved by directional hydraulic fracturing to cut hanging hard roof. Compared with traditional blasting technology[4,5], the hydraulic fracturing technology has advantages of large controlling range of single bore hole, low energetic disturbance, long operating distance, and can be used in high gassy coal seam[6,7]. In directional hydraulic fracturing, the hanging hard roof is pre-split along a key plane. Then the hanging roof rotates and slips to the gob. The overburden strata over the gob also cave. As a result, the load of the overhanging roof and the overburden strata supported by the coal pillar is transferred to the gob area, and partial load of the coal pillar is released. The general stress state becomes uniform by releasing the stress in the coal pillar and increasing the stress in the gob. Besides, considerable elastic energy is stored in the hard roof under the effect of surrounding rock stress, weak plane can be generated in rock by hydraulic fracturing to lower the integrity of the roof, and decrease the probability of dynamic disasters.

Field tests show that it is very important to control the breaking location of the overhanging hard roof for hydraulic fracturing; different breaking location of overhanging roof has a great influence on the breaking effect of the hanging roof and stress redistribution. There are few researches on controlling large deformation in gob-side entry by directional hydraulic fracturing. The movement of the roof and the distribution of stress before and after hydraulic fracturing has not been studied systematically. The reasonable criteria theory for fracturing location of the hanging roof to guide the field construction is not established. Intensive researches are required in all these problems above.

2. The bearing capacity of the gob-side entry under overhanging hard roof

Hard roof usually has high strength and good integrity. The hanging roof area can even reaches tens of thousands square kilometers. Hanging roof over the gob of the adjacent mined working face will also

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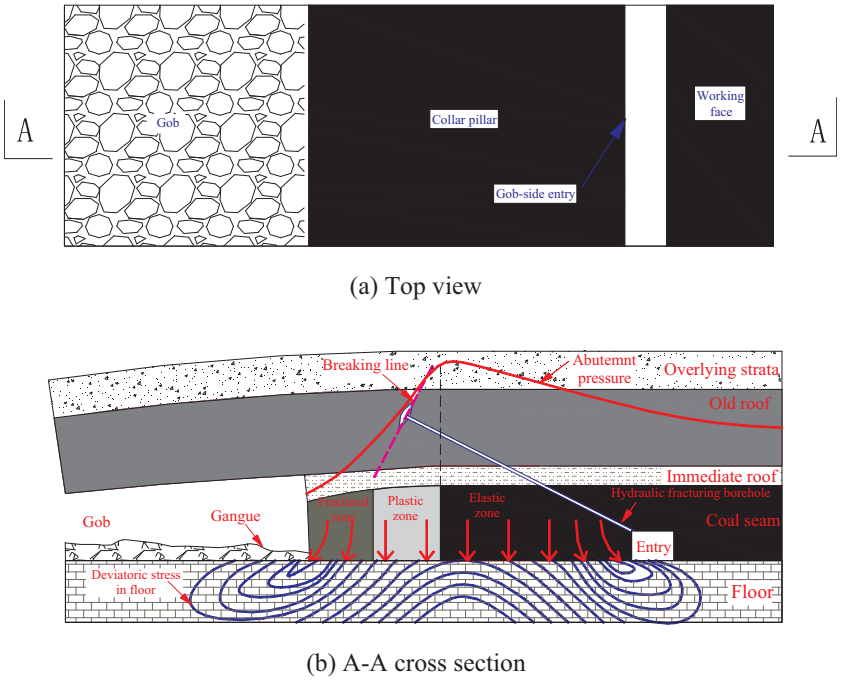

(a) Top view

(b) A-A cross section

Fig. 1. Characteristics of the static load of the gob-side entry under overhanging hard roof.

occur, and the hanging distance is a few tens of meters beyond the coal pillar. Under the compression of the overburden strata, enormous energy is stored in the hard roof.

The coal pillar width of the gob-side entry usually ranges from few to several meters. However, the supporting capacity of the coal pillar is limited. The load of the overburden strata is transferred to the coal pillar through the overhanging roof, resulting in different integrities in different part of the coal pillar. The coal pillar can be divided into fractured zone, plastic zone and elastic zone (Fig. 1(b)). The coal pillar and gob side entry are under large lateral abutment pressure.

General shear failure of the floor occurs due to the load of the hard roof transmitted to the floor through the coal pillar[8,9]. It also results in the floor rock turning into plastic flow state. Meanwhile, the floor is compressed continually by the coal pillar and the hard roof, leading to large deviatoric stress in the floor at the two sides of the coal pillar[10–12]. The floor is crushed and squeeze under great deviatoric stress. Various degrees of floor heave occurs in the gob and the gob-side entry at the two sides of the coal pillar.

3. Control principle of the breaking location of the hanging roof for directional hydraulic fracturing

The purpose of directional hydraulic fracturing for hanging hard roof in gob-side entry is to transmit the load of overburden strata to the gob as much as possible under the precondition of ensuring safety, through which the stress relief and stress transfer can be achieved and the stress intensity and stress concentration of the gob side entry and coal pillar can be weakened.

Compressed by the overhanging hard roof, fractured zone and plastic zone exist in the coal pillar near the gob, due to which the overall strength is low. If the breaking plane of the overhanging roof is moved toward the gob from the edge of the coal pillar (Fig. 2(a)), hanging roof with large area will rapidly slip or fall immediately after it breaks. Because there is no coal pillar under the hanging roof to support as a buffer, impact load will form and leads to dynamic disaster. The accumulated gas in the gob can even be squeezed out suddenly. Due to the curve and bed separation of the hanging hard roof, the effect of the directional hydraulic fracturing to break the overhanging roof cannot be ensured. Regarded as a cantilever, a maximum deflection of the hanging hard roof exists along the hanging roof. The location of the maximum deflection is generally related with the width of the fractured zone and the plastic zone in the coal pillar, specifically related with the stiffness of the coal pillar and rock strata of roof. The breaking plane of overhanging roof moved or shifted towards the inside of coal pillar is defined as the “internal offset distance”. If the fracturing location is properly moved towards the inside of coal pillar (Fig. 2(b)), i.e., the breaking location of the hanging roof is above the coal pillar, so, the released overburden load increases, and the width of the coal pillar under the broken roof increases. Correspondingly, the effective width of the coal pillar of the gob-side entry decrease. When the width of the coal pillar under the broken roof reaches a critical value, the broken hanging roof will rotate slowly and the plastic zone of the coal pillar is weakened further. Then the entire broken hanging roof will slip onto the gob and contact with the gangue tightly, forming a steady support structure. In this condition, not only the load of the roof is relieved, but also the dynamic disasters are eliminated. After the breaking position is moved toward the coal pillar properly, the curvature of the roof above the breaking location reaches the maximum, and the tensile stress also reaches the peak value. Hence, the breaking effect of the hanging hard roof by hydraulic fracturing is enhanced. From the construction point of view, the breaking location of the hanging roof should not be in the bed separation zone of the roof over the gob, which ensures the effect of directional hydraulic fracturing. The internal offset distance should not be too long (Fig. 2(c)), otherwise, the fractured roof cannot cave and contact with the gangue. As a result, an optimum breaking location of the overhanging roof exists theoretically for directional hydraulic fracturing in gob-side entry. In practice, to ensure that the stress state of the gob-side entry is the optimum, the fracturing location of the overhanging roof is determined based on the propagation law of directional hydraulic fractures and the site construction conditions.

It should be noted that with the breaking of the overhanging roof, part of the coal pillar near the gob will necessarily be crushed. Thus the integrity and effective width of the coal pillar decreases, and the stress over the coal pillar and the gob-side entry is transmitted toward the gob. The integrity and stress distribution of the surrounding rock and the gob-side entry should particularly be paid attention after the