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Research on the Stability of Waterproof Coal Pillar in Steep Seam under Aquifers

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Abstract After the steep coal seam being mined, the overlying coal and rock collapses and forms “three zones”, which may threaten the coal mine production. In the mine design, the length of confirming fault waterproof pillars is largely decided by height of water conducting zone, rather than the stability of coal pillar itself. While the unstability of the reserving waterproof pillar can cause large-scale caving, even leading to the invalidation of waterproof pillar. Thus, it is of great importantance to analyse the stability of waterproof pillar itself. This paper has deduced the limit value formula of the unstability of coal pillar by establishing mechanical model, then took Zhaogezhuang for example to calculate the limit value of waterproof pillar by using this theoretical model. It turned out that this formula for calculating the size of waterproof pillar can also meet design requirement after compared with the values calculated by the method of FLAC^{3D} numerical simulation software,and has engineering guiding significance.
Keywords steep seam, waterproof pillar, waterproof pillars caving, FLAC^{3D} software

Introduction

Underground mining can caused damage by overburden strata moving. Once sweeping high layered aquifer may be result in waters flowing in underground, and threaten to coal mine production and safety (Dong and Hu 2007).There are complex reasons for the failure of waterproof coal pillar in steep coal seam other than flat seam and gently inclined coal seam(Wu etal 1994, Zhao 1991, Zhang et al. 1999).There is of great significance on the study of stability of reasonable waterproof coal pillar in steep seam (Wu and Shi 1990, Deng 1991).

Rules of waterproof pillars caving in steep coal seam

The caving mechanism analysis of steep coal seam mining

After the steep seam was mined, the roof rock curved and caved, the caving rock fell, then free space formed in the upper part of the mined-out area.When the height of the caving zone reaches a certain value, the upper pillar easily occurs instability under gravity. According to the characteristics of steep caving, a mechanical model which is shown on fig. 1 is established.

The main controlling factors of preventing coal pillar from breaking with rock is the pressure from roof, cohesive force and friction coefficient on the surface of the rock mass. In order to calculate the limit of size of coal pillar, this paper analysis the stress of steep rock and coal seam. As shown in fig. 1, the free space in the caving zone can be regarded as a horizontal mining area. The effect of lateral regional coal pillar can be divided into two parts: BCDE is the area directly affected by caving zone (blue), ABC is the area directly affected by caving zone (green). The width of free space in caving zone is $H_m/\cos\alpha$,where: H_m is caving zone height α is seam dip, M is the normal exploitation of coal seam thickness, H is the depth from surface.

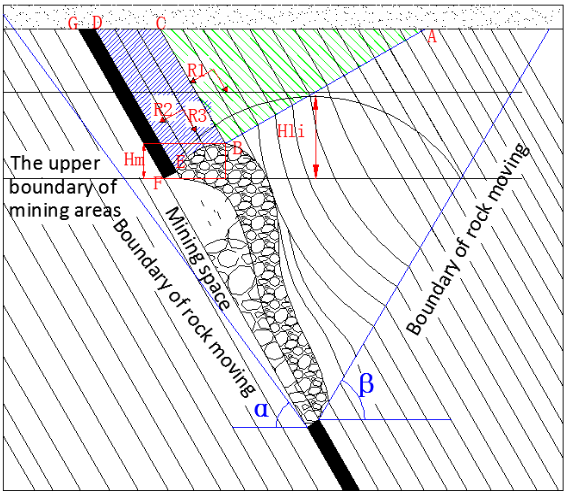

Fig.1 *Stress analysis of coal pillar*

Coal pillar which may cause surface collapse can be seen as an object located on the surface of the inclined plane. BCDE is a trapezoid, whose bottom length is L_1, top length is L'_1 and height is H_m/cosα. After the couple balance and friction balance analysis of coal GDEF and rock BCDE, ABC, L_1 and safety factor k can be obtained by the following formulas.

$$L_1 = \frac{H_m}{\cos\alpha}\sqrt{\frac{3\gamma'}{\gamma}} \quad (1)$$

$$k = (\sqrt{3} + ctg\alpha)f \quad (2)$$

where f is coefficient of friction between the pillar and rock. It is evident from the second equation that the pillar will not slip as long as cut safety factor k >1.0, equivalently，the coefficient f>0.6.

Waterproof pillar tilted steeply inclined length calculation

Based on geological and mining conditions and functional conservation and energy conversion, this paper choose the following empirical formula to calculate the height of the caving zone in in steep inclined strata (Yang 1981).

$$H_m = B\sqrt[4]{\mathrm{K_p LbmK / rcos}\alpha} \quad (3)$$

Where: B is comprehensive coefficient; K_p is tensile strength of rock(according to experiments), seams take values 0.1MPa generally and rock take values 1-3MPa; L is horizontal projection length of the working face; b is the width of trend (calculation on initial weighting interval of main roof);r is bulk weight; α is angle of inclination; K is the fragmentation coefficient (1.3 - 1.7).

The determination of parameter B, n in calculation can use the following formula(4)(Luo 2012):

$$B = H_m\sqrt[4]{\mathrm{K_p LbmK / rcos}\alpha} \quad (4)$$

The formula selects several parameters, most of which comes from the test results. Fragmentation coefficient is selected by the variation of lithology, whose calculation program is not complex. The main task is to combine geological exploration stage results with mining conditions.

Based on the data of No. 2137 working face, in Zhaogezhuang, K_p selects values 1 MPa, L selects values 31.4 m, b selects values 12 m, r selects values 2.6 t/m^3, K selects values 1.4 m selects values 11.2 m, Plugging the above parameter into formula(3), (4)to calculate H_m, then substituting H_m into formula(1). NO.2137 working face of Zhaogezhuang is west to 13 levels , which is in steep inclined strata. Thickness of coal seam exposed is 9.57-12.5 m and average thickness is 11.2 m. Average dip angle is 73°. According to calculation, the reserved inclined length of coal pillar of Zhaogezhuang coal mine needs 66.57 m.

FLAC^{3D} numerical simulation of waterproof coal pillar

FLAC^{3D} was used to do the simulation analysis for this working face(Yang F 2006) (Huang QX1998). The results are shown on figure 2 to 3.

On the basis of the volumetric strain simulation results, overburden deformation zonation in No.2137 working face is shown in fig.2. The plastic zone distribution of No. 2137 working face is shown in fig.3.

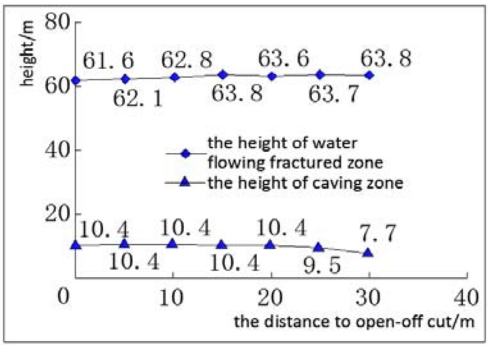

Fig.2 Overburden deformation zonation in face No.2137 working face

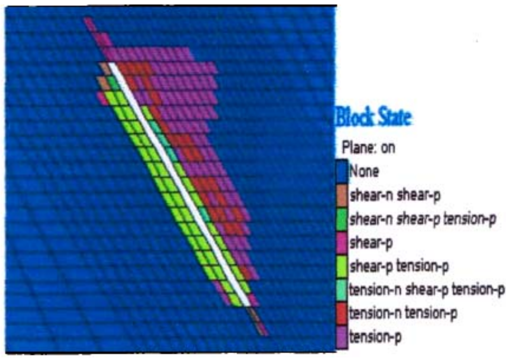

Fig.3 The plastic zone distribution of 2137 working face

The simulation results show that the maximum height of caving zone is 11.2 m and water conducted fractured zone is 63.8 m, when deeming the maximum height of water flow fractured zone as the height of waterproof coal pillar, the inclined length of waterproof coal pillar is 66.7 m.In the In the actual production, the work has realized safety mining under the protection of the 62.75 m waterproof coal pillar. Using the caving mechanism formula of the mining in deeply inclined coal seam, the large value is 66.57 m, which is close to the results of numerical simulations. Since the No. 2137 working face has been proved safe mining and the setting reasonable, it can conclude that the theoretical formula meet the design requirements.

Conclusions

(1) Great changes have taken place in coal mining geological conditions, the establishment of empirical formula or method applied to new conditions is needed. On the basis of considering the stability of coal pillar itself, limit height of pillar instability is deduced through the establishment of mechanical model. Comparing with the value calculated by numerical simulation software FLAC^{3D}, the result is basically same, which shows that the theoretical derivation and numerical results are correct.

(2) When the safety waterproof of pillar is $L_1 = \frac{H_m}{\cos\alpha}\sqrt{\frac{3\gamma'}{\gamma}}$, there cut safety factor will be $k = (\sqrt{3} + ctg\alpha)f$. As long as the friction coefficient f > 0.6 between coal and rock pillar and the shear safety factor k > 1.0, waterproof pillar will not slip and keep stable.

(3) The No. 2137 working face of Zhaogezhuang, confirming 66.7 m inclined length of waterproof pillar, has been proved safe. The theoretical derivation is 66.57 m, which is very close to the confirming value, besides, the theoretical result has a certain safety factor. In a word, the derivation formula has a engineering guidance value.

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