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Coupling effects of coal pillars of thick coal seams in large-space stopes and hard stratum on mine pressure

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A B S T R A C T

Concerning the issue of mine pressure behaviors occurred in fully mechanized caving mining of thick coal seams beneath hard stratum in Datong Mining Area, combined with thin and thick plate theory, the paper utilizes theoretical analysis, similar experiments, numerical simulations and field tests to study the influence of remaining coal pillars in Jurassic system goaf on hard stratum fractures, as well as mine pressure behaviors under their coupling effects. The paper concludes the solution formula of initial fault displacement in hard stratum caused by remaining coal pillars. Experiments prove that coupling effects can enhance mine pressure behaviors on working faces. When inter-layer inferior key strata fractures, mine pressure phenomenon such as significant roof weighting steps and increasing resistance in support. When inter-layer superior key strata fractures, the scope of overlying strata extends to Jurassic system goaf, dual-system stopes cut through, and remaining coal pillars lose stability. As a result, the bottom inferior key strata also lose stability. It causes huge impacts on working face, and the second mine pressure behaviors. These phenomena provide evidence for research on other similar mine strata pressure behaviors occurred in dual-system mines with remaining coal pillars.

1. Introduction

Major coal-bearing strata in China are of Jurassic system and Carboniferous-Permian. A mining area is generally explored as a simple system coal seam, and exploration of dual system coal seams is rare. As one of China's largest coal production bases, Datong mining area is of a typical dual system coal field for exploitation, and its coal seam is characterized with "hard coal, rock and roof" [1,2]. As Jurassic coal seam in Datong mining area has been completely mined, at present, exploration is being done mainly on the Carboniferous thick coal seam. Under the impact of hard strata interbedded between the two systems and the remaining coal pillars in the Jurassic mining goaf, there is a strong strata pressure behavior in exploration of the Carboniferous coal seam, which severely influences the safety of working face, and brings about many difficulties in safe and efficient production of mines. Strong strata pressure behavior in exploration of dual-system super high seam has been a problem demanding prompt solution in Datong mining area.

Many scholars have conducted related researches on the strong strata pressure behavior in exploration of the dual-system super high seam in Datong mining area. Yu Bin has come up with the jointed interaction mechanism of "coal pillar-overlaying rock movement" regarding the strong strata pressure behavior on the working face under the impact of the coal pillar in exploration of the dual system coal seams through studies; Chen Ying has studied movement and failure laws of the overlying strata under mutual impact in exploration of the double-system coal seams; it is clear that factors influencing the strong strata pressure behavior on the working face in the Carboniferous system mainly include: remaining pillars in the Jurassic mining goaf, mining impact in exploration of coal seam and hard strata interbedded between the two systems [3–6]. However, the previous researches did not cover breaking span of hard strata at the location of key stratum interbedded under the action of the coal pillar, and they could not explain precisely the couple effect of the coal pillar and hard strata interbedded between the two systems on the strong strata pressure behavior, so in this paper the hard rock interbedded in Tongxin mine field is studied to get the initial breaking and instability span of hard strata interbedded under the action of the coal pillar based on the thin and thick plate theory, thus getting the law of breaking and couple effect of the coal pillar and hard strata on

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the strong strata pressure behavior in mines, providing reference for study on the strata pressure behavior in similar "dual system" mines that have remaining coal pillars.

2. Project overview

Tongxin coal mine is typical in Datong mining area as a "dual system" mine field. A cluster of 9#, 11#, 12# and 14# coal seams are on the top, and exploration of 11#, 12# and 14# coal seams are mainly done. Coal seams that are relatively shallow embedded with hard roof (f = 8–10), small coal seam interval (7–19 m), coal seam dip angle at 3°-8°, minable seam thickness of 0.9–9.0 m have nearly been completely mined, with a lot of coal pillars remaining in the goafs. Now 3–5# coal seam is under exploration for the Lower Carboniferous system, which is 14.1–16.1 m thick, with an average of 15.0 m. According to the analysis of large numbers of drilling data on a mine field scale and the histogram of strata distribution on the "dual system" coal seam roof and floor: Carboniferous 3–5# seam are 140 m from the goaf of 14# coal seam, the Jurassic bottom. There is siltstone, fine-grained sandstone, and coarse sandstone, sandy and carbonaceous mudstone distributed between coal seams of the two systems, where sandy strata accounts for about 90–95%, mudstone and coal seam only account for 5–10%. Overlying strata between the two systems is in a layered distribution with few ups and downs and steady occurrence. Rock formation is mainly made of thick and hard sandstone with a lack of weak intercalated layers. With exploration continuing, there is a too long hard roof hanging above. It does not cave immediately, but when caving, it will cause massive pressure, reflected as strong pressure behavior on the Carboniferous working face support.

3. Study on initial breaking span of hard strata interbedded between the dual systems

3.1. Determination of the key stratum interbedded between the two systems and analysis of the mechanical model

When there are many rock strata contained in the overlying rock in the mine field, those wholly or partly control activities of rock mass are called key stratum, while the former are known as primary key stratum and the latter known as inferior key stratum for activities of the rock strata [7]. It will be of great importance in studying characteristics of overlaying rock movement and the law of strata pressure behavior to locate the key stratum. In the study, the effective range for computation of key stratum, namely the distance between strata of the two systems is 140 m. According to the discriminating requirements of the key stratum and based on the drilling data, it is identified that the key stratum between the two system include one inferior key stratum and one primary key stratum, which are fine sandstone (9.8 m thick) at a distance of 11.51 from the roof of 3–5# coal seam and medium-fine sandstone (53.65 m thick) at a distance of 42.73 m from the roof of 3–5# coal seam [8].

According to the reality of working face of 3–5# coal seam and a lot of field practice, a simplified mechanical model for the key stratum between the two systems is set up [9,10] (Fig. 1).

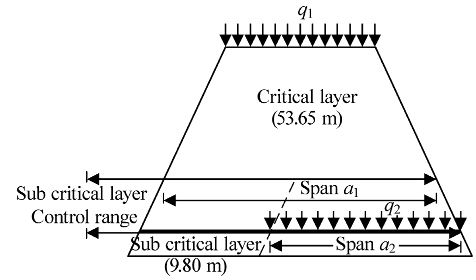

Fig. 1. Mechanical model of interlayer rock.

Along with upside Jurassic 11# and 14# coal seams completely mined, rock strata spacing coal seams as well as 12# coal seam break and connect to the broken roof of 11# coal seam, forming a broken roof group (Fig. 2).

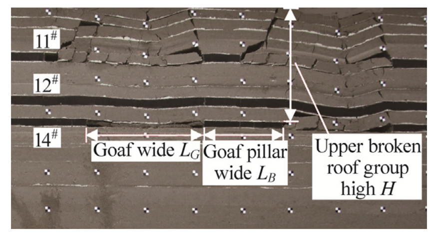

Fig. 2. Breaking roof group structure.

For the remaining coal pillar in the goaf of 14# coal seam at the Jurassic bottom, due to its location at the bottom of the three mining seams, it will bear cumulative stress of the upper remaining coal pillar and most of the load of the broken rock roof group, besides concentrated stress brought about exploration of this coal seam. Let the goaf of the Jurassic 14# coal seam be L_G wide, coal pillar be L_B wide, upper broken roof group be H high, the load collection degree of the coal pillar shall be [11–13]:

$$q_{\text{coal}} = \frac{\left[(L_B + L_G)H - L_G^2 \cot\alpha/4\right]\gamma}{L_B} \tag{1}$$

where γ represents the volume weight of the rock strata at kN/m^3.

This formula is applicable when the broken roof group height H and the goaf width L_G comply with $H > L_G\text{cot}\alpha/2$.

According to the key stratum theory, the unit area loading of the overlying rock controlled by the primary key stratum is:

$$q_0 = \frac{E_1 h_1^3 \sum_{i=1}^{n} \gamma_i h_i}{\sum_{i=1}^{n} E_i h_i^3} \tag{2}$$

where E_i is the elasticity modulus of stratum i; h_i is the thickness of stratum i; γ_i is the volume weight of stratum i; and n is the number of strata controlled by the primary key stratum.

Suppose s_1 is a primary key stratum; s_2 is inferior; the load q_1 on s_1 is the sum of the load q_{coal} of remaining coal pillar in 14# coal seam and the self load q_0 of its controlled overlying rock, i.e.,

$$q_1 = q_0 + q_{\text{coal}} \tag{3}$$

The load on the inferior key stratum is the self load q_2 of its controlled overlying rock, subject to the calculation formula the same as that of q_0.

3.2. Formula for solution of the initial breaking span of the key stratum interbedded between two systems

Breaking span of the roof is traditionally studied based on the "beam" theory, using a mechanical model of linear load with fixed beams at its both ends. This model provides a high accuracy in shallow beam mechanical analysis, but for Datong mining area where the mine roofs are thick and hard, the roof rock beam is not suitable for shallow beam range compared with its span, so it will be of great significance to study breaking span of the dual system hard roof in Datong mining area based on the "plate theory".

With the mining roof regarded as a plate, along with the coal mining face advancing, the roof boundaries are simply supported