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Technical Note

Field investigation of long-term bearing capacity of strip coal pillars

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1. Introduction

A large number of unmined coal pillars are required in strip mining to support overlying strata, control surface subsidence, and protect surface infrastructures. Currently, strip mining still remains to be one of the main methods used for coal mining under buildings. The pillar strength or the bearing capacity is the key element deciding whether or not the coal pillar is capable of supporting the overlying strata and protecting surface buildings. The strength of the coal pillar is determined by its size, shape, surrounding environment, as well as other factors. Due to the fact that several factors are not always consistent or clear and some factors may not be measured easily, a prominent inconsistency is also shown in the strength of coal pillars [1]. In the past, researchers around the world have performed many studies on long-term pillar strength.

In 1911, the first empirical formula for coal pillar strength was presented by Bunting via testing the strength of anthracite blocks of different sizes and shapes [2]. Gaddy presented the relation between the strength of test blocks decreasing and the size increasing, and simultaneously the calculation formula for coal pillar strength with consideration of laboratory test values after testing the strength of coals with different sizes was also proposed [3]. Iannacchione et al. evaluated several theories of coal pillar strength after testing the actual coal pillar stress [4].

Based on the investigation and analysis of a large number of unstable coal pillars in South Africa, Salamon concluded that most successful coal pillar designs adopted the inversion method [5,6]. At the same time, after analyzing 23 unstable coal pillars and 20 stable pillars in India, a strength formula suitable for coal pillars with different ratios of width to height was presented by Loui and Sheorey [7]. As for studies performed in China, Xing monitored the stress of strip coal pillars in the Yeqing coal seam beneath the industrial square of Fengfeng No. 2 Mining Area, then systematically analyzed the distribution and its changes of the coal pillar stress [8]. Experimental research on the stress changes and stability of upper coal pillars during repeated strip mining was conducted by Wu [9]. The stresses of strip coal pillars in multiple coal seams under architectural complexes were observed in Hanqiao Coal Mine [10]. Jiang and Du observed the states of strip coal pillars in the Peicheng Coal Mine East No. 2 Mining Area [11]. Wei measured the deformation and stress distribution of room and pillar mined coal pillars [12]. After analyzing the stress of coal pillars under two-dimensional stress state based on SMP failure criteria of viscous materials, Zhu developed a formula for the ultimate strength of the pillars [13]. Using coals with different ratios of width to height in coal pillar models, the strength and deformation characteristics of coal pillars was analyzed by Zhang [14]. A theoretical study on pressure distribution, residual pressure, friction, coal pillar strength of model coal pillars was conducted by Lin [15]. Li suggested that the width of the stress limit balance area of reserved strip coal pillars based on elasto-plasticity theory [16]. Li, on the basis of mechanical models, theoretically studied the mechanical properties of coal pillars under the action of bearing pressure caused by goaf, the confining pressure at one side of roadway, and the pressure of upper strata after full caving has developed [17]. The effects of anchor reinforcement on the stability and bearing capacity of coal pillars were studied by Duan [18]. And the deformation of strip coal pillars under long-term stress by means of a borehole pressure gauge and displacement monitor was studied by Chen [19].

In general, a strip coal pillar always has certain strength and is hence capable of supporting overlying strata in the earlier stages. However, some coal pillars which were once stable may become

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unstable and collapse, leading to surface subsidence. American coal mines have suffered surface collapse due to coal pillar instability more than 100 years after construction. An abandoned mine in Scotland caused surface subsidence 118 years after it had been scrapped. The Wieliczka salt mine in Poland suddenly exhibited surface subsidence after 140 years of mining, resulting in the destruction of all surface buildings. Most unstable coal pillars in South Africa have suffered from surface subsidence after many years of mining [20]. These facts indicate that although the deformation of pillars becomes stable in short term, it may deteriorate after a long period of damage accumulation, leading to unstable failure in the coal pillar or seam roof. Therefore, the long-term bearing capacity of the strip coal pillar is a key factor in determining whether or not the safety of surface structures (buildings) in the mining area could be maintained for a long period of time.

In this study, the strip mining of Shandong Daizhuang Coal Mine was used as the experimental site to measure the bearing capacity of a strip coal pillar at different depths of a pillar during or after mining. In this way, the complicated effects of various factors on the strength and bearing capacity of the coal pillar are skillfully avoided. In addition, the study is also attempted to determine the actual bearing capacity of the strip coal pillar at different pillar depths. The results are of practical significance for the optimal design of strip coal pillars for long-term stability.

2. Structural model of surrounding rocks in strip mining panels

According to the mine ground pressure theory and spatial structural models of surrounding rocks in mining panels [21] during strip mining, the roof of the goaf will not collapse, or only the immediate roof will collapse, but the main roof will remain if the mining width is small and the roof is solid, as shown in Fig. 1. The spatial structural model of the strip mining panel forms the patterns shown in Fig. 1(a) and (b). If the support systems at the two sides of the strip coal pillar remain in place and are not dismantled, the strength of the coal seam is much larger with little or no failure occurs in the coal pillar edges. In this case the strip coal pillar would be able to support the weight of the overlying strata, as shown in Fig. 1(a). If the support systems at the two sides of the strip coal pillar are removed and the strength of the coal seam is lower, the coal pillar edges may collapse within a certain distance, as shown in Fig. 1(b).

At this time, the collapsed parts of the coal pillar will no longer take any load, while the weight of the overlying strata over the collapsed parts will be transferred to the central section of the coal pillar.

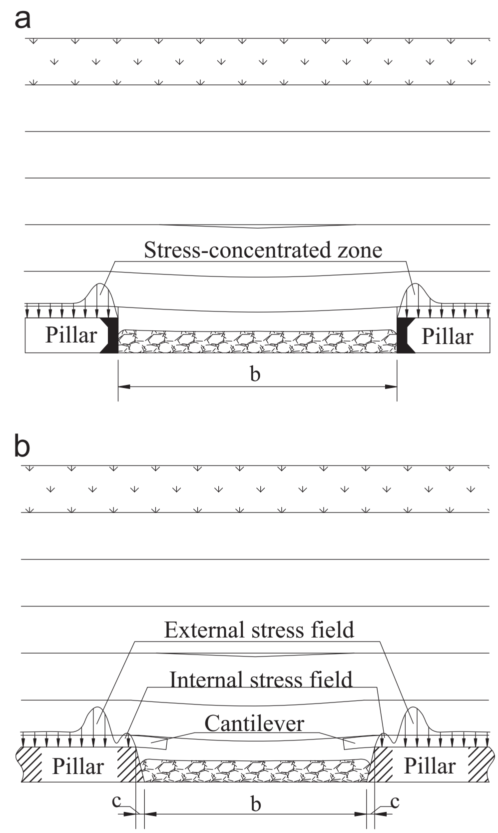

Fig. 1. Structure model of surrounding rocks in strip mining panel with small mining width.

3. Field measurements for the long-term bearing capacity of strip coal pillar

Direct field measurements of the long-term bearing capacity of strip coal pillar may mainly assist in avoiding the complexity of numerous influential factors. At present, most monitoring methods are not able to monitor the coal pillar in the goaf for a long period of time, nor are they able to monitor the coal pillar directly.

Long-term monitoring is conducted in strip coal pillar by means of connecting borehole pressure gauges with a data cable (as shown in Fig. 2), thus the disadvantages of the previous monitoring methods may be avoided [22]. This monitoring method is implemented as follows: (1) Drill into the coal pillar at a location of about 150 m to the panel stop line, leaving 1 m spaces between the drill holes, then drill a number of holes in a row and number them as No. 1, No. 2, etc. (2) Install a pressure gauge in each drill hole. Each drilling pressure gauge monitors the pressure of a certain location of the pillar. Connect all the pressure gauges in a series, convert the pressure signals to electric signals, and then transmit them to the monitoring subunit. (3) Transmit the signals captured by the subunit to the ground monitoring host via a downhole telephone line, then convert the signals to pressure data. (4) During the installation of the instruments, care needs to be taken to avoid damaging the pressure gauges which located under the mining supports when pushing the working face moves over the installation location.

During the overall measuring process, it is important for the automatic collection of instruments to ensure that the data is accurate and the data collection frequency is high, so that the subtle changes in the stress of coal pillar can be picked up. The system is also able to determine the true situation of the coal pillar by means of directly monitoring the additional pressure of the coal pillar, and to confirm the long-term stress change in strip coal pillar in the goaf which is of assistance to studying the state of coal pillar over a long period of time.

4. Calibration and correction of the drilling pressure gauge

The drilling pressure gauge is the fundamental unit and an important tool of the monitoring system. After the mining, the coal pillar will take on additional stress. The reading of the pressure gauge over additional stress has reached a certain degree after the coal pillar deformation and therefore the borehole deformation concedes with the reading of pressure gauge. If only the mechanical deformations of the coal pillar are to be observed, the pressure gauge reading may be used directly. If the force value