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Characteristics of deformation and stress distribution of small coal pillars under leading abutment pressure

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ABSTRACT

Based on the engineering project on a small coal pillar of 12,521 working face roadway in Xieqiao Coalmine, data regarding surface displacements of the coal pillar, deep displacements and mining stress have been collected and analyzed. The results show that macroscopic transverse fractures of the inner coal pillar are developed within 2–4 m of the roadway surface, which is located outside the coal pillar anchorage zone. There is a displacement of 530 mm at the monitoring point in the 6 m deep zone of the pillar. Transfer of the fracture zone is found in a small coal pillar and the fractures within 3–4 m of the coal-rock zone from the roadway surface undergo propagation and closure of cracks which means this fracture zone is transferred from 3–4 m outside the roadway to only 2–3 m from the roadway surface. In the monitoring zone, vertical and horizontal stresses increase with a feature that shows that acceleration in the deep zone of the pillar is greater than that in the shallow zone. Furthermore, the acceleration of vertical stress is also greater than that of horizontal stress with a peak value in the 4 m zone. The research findings provide a reference for the regulation of a reasonable width of coal pillar in coalmines and optimal control design of surrounding rock.

1. Introduction

Currently, adopting small coal pillars to protect an adjacent roadway is a conventional methodology of coal mining in China. Thus, the width of a pillar is a key issue for the stability of a roadway and the recovery coefficient of a coal resource which means that a reasonable width of pillar will ensure that the adjacent roadway can meet the needs of safe coal production after mining effects on the working face. The stability of the roadway and pillar involves many factors such as engineering geomechanics characteristics, physical mechanics properties of coal-rock, stress environment and support method. Thus, roadway deformation failure can be investigated through measurement of stress and displacements and this method can effectively analyze dynamic disasters in coalmines in China [1–4]. The bearing structure of the surrounding rock for a roadway is analyzed and it is proved that enhancing support resistance can control the deformation of the surrounding rock. Theoretically, the stability of a roadway in deep coalmines can be improved by adopting small pillars and high strength anchor bolts [5–7]. Simulation of the depressurization effect utilizing boreholes in areas of stress concentration in small coal pillars have been carried out and the development of fractures in rock under different conditions for roadway excavation. A reasonable width of pillar under that condition is regulated and a critical width criterion is proposed [8–12]. Fracture mechanics and plastoelasticity mechanics models have been employed to investigate the distribution of strip pillar stress, and of displacements and stress in small pillars. The findings provide a theoretical basis for the stability of narrow coal pillars and control technologies of surrounding rock [13–15]. Field tests for failure evolution of coal pillars have been implemented under different support conditions and the results show that there is a saddle-shaped asymmetric failure in small pillars [16]. A study concerning the stability and safety of small pillar extraction at shallow depths has been carried out. Relative factors have been taken into consideration, especially the stress state in long wall mining working faces [17,18]. By applying the numerical simulation method, coal pillar stress under dynamic mechanical state has been analyzed and the safety assessment of the coal bump risk during extraction has been conducted. Therefore, an acceptable research approach for stress state and safety of deformation failure is proposed [19,20].

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2. Engineering conditions

Alongside the ventilation roadway of 12,521 working face in Xieqiao Coalmine, the small coal pillar has a width of 7 m and the depth of this pillar is about 660 m below ground level. Bolt and cable support parameters are shown in Fig. 1. Specifically, there are 6 anchor bolts with a model $\phi 20\text{—}M22\text{—}2500$ mm and a 3 m M3 steel band and 8# metal mesh in the coal pillar area. Besides, the bolts are utilized with 3 resin cartridges of Z2360. The layout space is 700 mm × 900 mm.

Basically, a reasonable width of a coal pillar is determined by the stress environment and physical mechanics characteristics of coal-rock. A small coal pillar will undergo multiple mining effects from roadway excavation and coal mining, both in the last mining working face and the adjacent working face as shown in Fig. 2. The pillar is fixed by anchor bolts and metal mesh in both sides and another roadway alongside the pillar is filled by gangue for avoiding coal gas accumulation. Additionally, piles of caving waste rock in the gob are accumulated. Thus, the movement of coal pillar towards the gob is limited. As for monitoring points, owing to the existence of a dip angle of about 15°, a multi-point extensometer is arranged in the pillar line at a height of 1.2 m from the floor as shown in Fig. 2. Considering the entire stress environment, the pillar only causes displacement in the negative direction of both *X* and *Y* axes, not in the positive direction of these two axes.

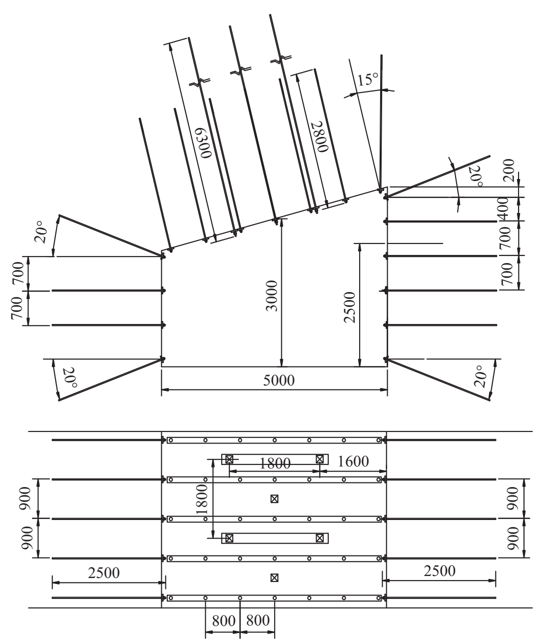

Fig. 1. Bolt and cable supporting parameter of roadway.

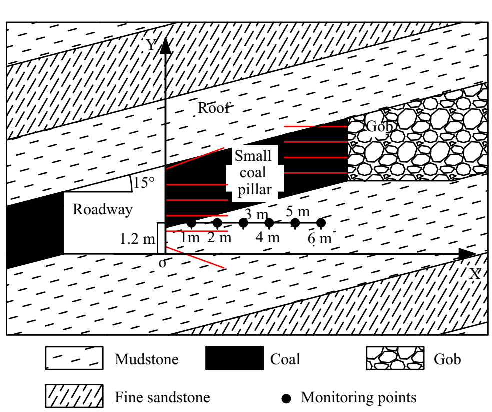

Fig. 2. Sketch map of small coal pillar.

3. Monitoring point layout and scheme

The whole length of the monitoring line is 14 m and surface displacement, inner coal-rock displacement and stress are recorded by setting monitoring equipment in the coal pillar as shown in Fig. 3.

Firstly, the monitoring line is far away from the working face at a distance of 240 m. Data on surface displacement, inner coal-rock displacement, vertical stress and horizontal stress are collected with a frequency of one recording per two days. The forward speed of the working face is about 6–8 m per day and when the distance is less than 100 m, the recording frequency is changed to once per day.

4. Deformation analyses of small coal pillar

Surface deformation monitoring points and inner displacement monitoring equipment are designed in the same section of the roadway. With a height of 1.2 m from the floor, a multi-point extensometer is utilized and surface displacement is calculated by the crossing methodology. In fact, the width of the pillar is 7 m and the monitoring line is about 6 m from the surface to the inner zone of the pillar. The monitoring distances from the surface of the pillar are 1 m, 2 m, 3 m, 4 m, 5 m and 6 m respectively, as shown in Fig. 3.

Based on the data of displacement from the surface, the curve of the relationship between surface displacements, volume and distance from the working face are shown in Fig. 4. Furthermore, according to data from the multi-point extensometers, 6 curves between different monitoring points and the distance from the working face are shown in Fig. 5.

From Fig. 4, it is shown that the displacement of the surface of the pillar is about 697 mm after mining effects from the leading abutment pressure. Additionally, data from multi-point extensometers are relative displacements from the surface of the pillar. The values of the 1 m and 2 m points are too small which means that the range of the 1–2 m pillar from surface has the same movement as the surface. The displacement data for 3 m, 4 m, 5 m and 6 m are greater than that of 1–2 m of the pillar indicates that many fractures developed in the pillar which ranged from 2 m to 6 m of the inner pillar. However, the specific number and degree of fractures are indistinct.

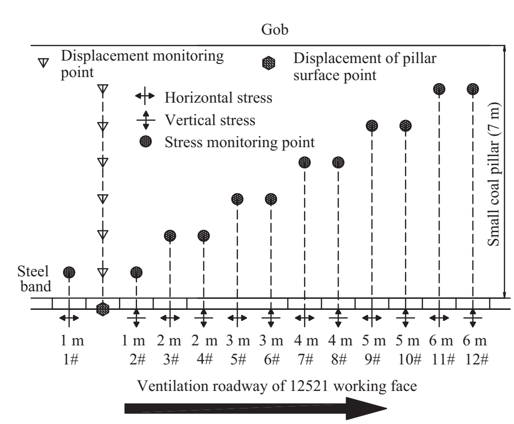

Fig. 3. Installation and layout of monitoring equipment for coal pillar.