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Instability mechanism and control technology of soft rock roadway affected by mining and high confined water

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ABSTRACT

Based on deformation and failure characteristics of the second belt conveyor roadway at level II of Zhuxianzhuang coal mine, laboratory experiments, numerical calculation and field test were adopted to analyze the composition and microstructure of mudstone, the law of mudstone hydration and its strength weakening induced by water, the characteristics of surrounding rock deformation and failure under the action of confined water. Results showed that montmorillonite clay minerals accounted for as much as 76% of mudstone, with a large number of pores existing in the microstructure. Besides, as the molecular structure of montmorillonite changed, mudstone microstructure damage occurred with the macroscopic manifestation of its rheological instability. Weakening degree of confined water on residual strength of mudstone was almost 50%. The instability mechanism of soft rock roadway caused by high confined water is that surrounding rock circulates the process of "fracture-seepage-mud ding-closed" twice, which weakens its strength and leads to roadway instability. A combined support technology, namely the, "high-toughness sealing layer + hollow grouting cables + full-length anchoring bolts with deep borehole" was proposed. Based on field observation, the soft rock roadway was controlled effectively, which also verified the effectiveness of new control technology for surrounding rock.

1. Introduction

As the depth of mining coal seams increases, the complexity of geology for roadways in coal mines rises, which, to some extent, causes a variety of issues on roadway stability, such as soft rock roadway. In recent years, support technology for soft rock roadway, especially soft rock roadway affected by high confined water, has become a very critical and complex engineering problem in many coal mines in China [1]. Many scientific researchers have made a lot of investigation in this area.

As for the property of soft rock, early in the 1950s, Norrish et al. researched mechanical expansion of montmorillonite in soft rock, who started the research of mechanical property for soft rock [2]. He et al. adopted a self-developed experiment system to carry out water absorption testing of soft rock. According to the experiment system, the scanning of electron microscope (SEM) and X-ray techniques, the hydrophilic characteristics can be divided into two stages in time series [3]. Li and Chen et al. put forward a nonlinear power function creep model that well reflects the rheological characteristics of deep soft rock under different stress status and reveals time-dependence and stress-dependence of mudstone creep rate [4,5]. Zhu et al. pointed out that water content is an essential factor to mechanical properties of rock creep and the relationship between water content and rock creep characteristic was discussed [6,7]. Other experts studied adsorption properties of clay mineral and water characteristics among different clay layers [8–12]. He Bing put forward solution formula of water content and obtained absorption and diffusion constant by fitting data, as well as the relationship curve between expansion strain and water absorption based on the investigation results of Yew and Chenevert and mudstone hydration test [13–15]. In terms of control technologies of soft roadway, Zhang et al. analyzed fracture development of surrounding rock within excavation influence zone and proposed relevant technologies (grouting, high strength cable and anchors) as well as critical design parameter (grouting hole depth, anchor spacing and grouting time) [16]. Li et al. thought that the key for roadway stability with mudstone roof affected by water was to control the fracture development and prevent the development of fracture zone beyond the anchoring zone [17]. Aimed at the deterioration of bearing capacity for mudstone roof affected by water, Yao et al. proposed the combined technology of water

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control technology and high pre-tightening force anchor bolt-cable-mesh technology [18]. Valko et al. carried out Kachanov and Pekins–Kern–Nordgren damage model [19] to simulate the damage and crack process of rock with hydro-fracturing. Yang et al. established the coupling model (seepage field and damage field) of fracture rock and adopted it into the mechanism of seepage failure for slope [20–23]. Liu et al. listed some water inrush accidents in coal mines and analyzed the mechanism of water inrush as well as proposed the grouting for water plugging and the drainage for the decrease of water pressure [24]. However, up to now, previous researches basically focused on the property of soft rock and roadway support, and little work has been done on the coupling effect of mining-induced stress and seepage on roadway instability on the basis of field. In this study, we take the background of the roadway located in level II of Zhuxianzhuang coal mine with a lot of faults and high confined water pressure and water content. Its dramatic deformation and instability occurred with the initial support scheme (bolt + spraying concrete + U-section steel with filling behind support + grouting after excavation). This paper attempts to analyze the natural composition and microstructure of mudstone from the field, the law of hydration and strength weakening of mudstone affected by water, and deformation and failure characteristics of surrounding rock under the action of confined water. In the end, based on analysis, the instability mechanism of soft rock roadway affected by mining and high confined water pressure is revealed, and new strengthening roadway control technologies is put forward, which shows the excellent effect in the field.

2. Engineering condition of experimental roadway

2.1. Geology condition

Second belt conveyor roadway is located at level II in the south of Zhuxianzhuang coal mine. The depth and length are almost 700 m and 1025 m respectively. Within the whole area of roadway excavation, there are total eight faults including four large faults, of which the throw is above 5 m. The largest fault is F19. Limestone water of Taiyuan group is located beneath this roadway and there are 12 limestone layers beneath −680 m. As shown in Fig. 1, the first and second limestone layers are thin, and their water content is less, while the third and fourth layers are thick with plenty of water. The roadway is located under the 10th coal seam and above the first limestone layer.

2.2. Initial support scheme

The intial support scheme of this roadway is anchoring + shotcreting + 29# U-shape steel frame with filling behind it + lagging grouting. The detailed excavation procedure is that the 50 mm initial shot concreting is carried out after blast excavation firstly. Next, the bolts are implemented with two resin capsules for each bolt, of which the type is GM22/2800-490, and the pretension force is more than 80 kN and the torsion is over 300 N m and the space is 800 mm × 1000 mm. Besides, 29# U-shape steel with filling behind it is adopted with the space of 500 mm and the lap length of 500 mm. Each lap joint is connected by specially-made steel hook and is tightened by two limit clamps and one double-groove clamp. The torsion of clamp nut is over 300 N m. Φ10 mm reinforced back bars are adopted to support roof, sides and floor. Then, C20 concrete is sprayed once more, and the ultimate thickness of shotcrete is up to 150 mm. Finally, grouting is carried out with the space 2000 mm × 2000 mm, behind the heading faces 150–200 m. The grouting bolt is made by the utilization of Φ20 mm × 2000 mm steel pipe.

Generally, the whole process of support is as follows: initial spraying → roof bolts installation → back bar installation → sides' bolts → 29# U-shape steel installation → twice spraying → grouting bolts installation → grouting.

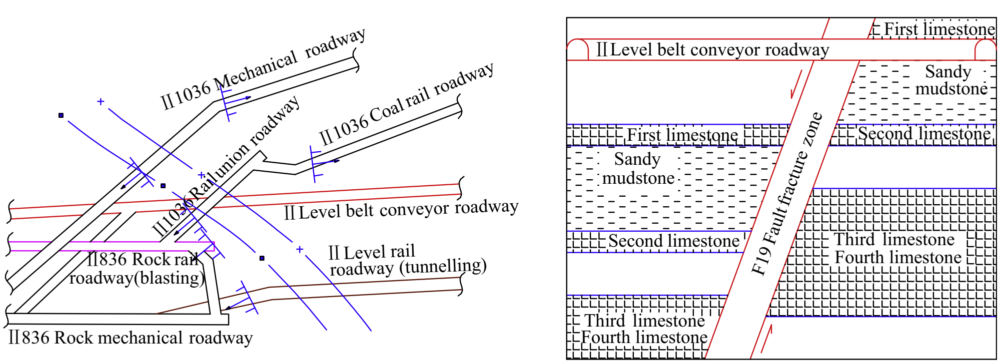
2.3. Characteristics and process of instability for the roadway

From May 2009, bottom heaves occurred four times, and they were caused by the coupling effect of mining and seepage of the first and second limestone water with high pressure. As a consequence, convey capacity was almost zero and it affected mining safety. After the fourth heaving floor, the deformation was serious with water inrush content of 2–3 m^3/h. The largest heaving floor was approximately 1.1 m with severe argillization which means that the stable bearing structure cannot be formed timely, as shown in Fig. 2.

3. Instability mechanism of roadway

The part of roadway is affected by the faults and its surrounding rock is mudstone which is weakened by the water. With the

Fig. 2. Roadway instability.



(a) Plane graph (b) Profile graph

Fig. 1. Location for the roadway and geology characteristics.