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Strength and deformation behaviors of bedded rock mass under bolt reinforcement

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ABSTRACT

The mechanism of bolt support is an important topic in mining engineering and slope treatment. The artificial material and loading system were self-developed to study the influence of bedding cohesion and bolt number on the anchoring behavior of bedded rock mass. The results show that, both peak strength and elasticity modulus increase gradually with the increase of bedding cohesion and bolt number. The axial stress–strain curve of bedded rock mass under the reinforcement of bolts presents the features of strain-softening and secondary strengthening. Finally, anchoring behavior of bedded rock mass with different bolt numbers was simulated by using FLAC3D numerical program and the results were compared with the experimental results. This study can provide certain bases to the stability control and support design of bedded rock mass in roadway.

1. Introduction

In view of the exhaustion of shallow resources in recent years, the resource exploitation and space development gradually have been transferred to the deep earth [1–3]. Owing to the natural geologic process and excavation disturbance, there are many fissures, faults and holes in the deep rock mass. These flaws lead to the strength degradation of rock mass, which affects the stability of underground engineering [4–6].

Bolt support, as one of the most common support methods, has been widely applied in mining engineering, slope treatment, and so on. Bolt support has the advantages of high efficiency, low cost and easy operation [7–9]. Many experts devoted themselves to the mechanism of bolt support for years and made fruitful achievements. A series of uniaxial compression tests, splitting tests, and biaxial compression tests were conducted on the bolted rock-like specimens containing flaws by Li et al. to investigate the anchorage effect and coalescence process of rock mass [10–11]. The influence of the bolt tongue on the contact stress and the different anchoring mechanisms of the inflatable rock bolt in hard and soft rocks were revealed by Li [12]. Tan present a unified computational framework to study the mechanism of passive bolts reinforcement around a circular opening in strain-softening elastoplastic rock mass [13–14]. Chen and Li studied the influences of displacing angle, joint gap, and rock strength to the performance of rebar bolts and D-Bolts [15]. Cai et al. present a new analytical model considering the interaction behaviors between the grouted rock bolt and ground [16]. Based on a self-developed large-scale model experiment system (the dimension of specimen is 500 mm × 500 mm × 480 mm), the influence of joint angle on the anchoring strength and bolt axial force of jointed rock mass was investigated by Jing et al. [17]. Wang et al. present the effects of anchor on fractured specimens in splitting test simulated by DDARF method and the results were consistent with those of laboratory test [18].

The coal-bearing strata usually show a bedded feature. Meanwhile, deep roadway often appears the phenomenon of wall caving, which leads to bedded feature of surrounding rock mass [19–21]. In this study, rock properties of deep roadway in Pingdingshan No. 12 coalmine were taken as the reference, and the corresponding similar material was prepared to simulate the bedded rock mass. According to the self-developed loading system, the bedded rock mass specimens under bolt reinforcement were tested to investigate the influence of bedding cohesion and bolt number on the anchoring behavior of rock mass. Finally, FLAC3D was used to study the strength and failure behaviors of bedded rock mass with different bolt numbers.

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Table 1
Basic physical and mechanical parameters of sandy mudstone and artificial material.

Name	Compression strength (MPa)	Tensile strength (MPa)	Elasticity modulus (GPa)	Cohesion (MPa)	Friction angle (°)	Unit weight (kN/m^2)
Sandy mudstone	20–40	1.4–2.8	2.1–3.3	2.07	34.9	19–25
Artificial material	3.31	0.38	0.71	0.30	31.4	18.43

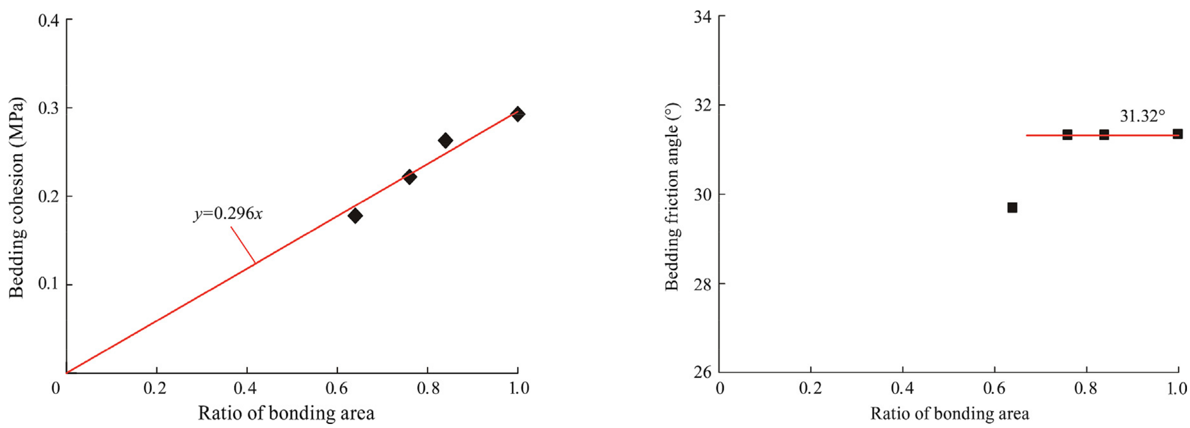

Fig. 1. Effect of the ratio of bonding area on the bedding cohesion and bedding frictional angle.

2. Experimental material

2.1. Artificial material of rock

In this paper, river sand, cement and land plaster are selected to prepare the artificial material to simulate the sandy mudstone in Pingdingshan No. 12 coalmine. According to the tentative tests, the ratio of 3:0.6:0.4 for the above three materials was determined. Table 1 lists the basic physical and mechanical parameters of sandy mudstone and the prepared artificial material.

2.2. Bedding simulation

Teflon film is chosen to simulate the bedding plane in rock mass. Owing to the weak bonding power between Teflon film and cementing material, the bedding mechanical behavior can be adjusted by the laying area of Teflon film. Fig. 1 shows the effect of the ratio of bonding area on the bedding cohesion and bedding frictional angle, in which, the ratio of bonding area is defined as the ratio of the non-bedding area to the total area. With the increase in the ratio of bonding area, the bedding cohesion increases gradually, presenting a linear feature. However, the bedding friction angle generally remains a constant value (31.32°) except for the ratio of bonding area of 0.64.

2.3. Support material

Fig. 2 shows the support materials, including bolt, steel strip, bolt plate and nut. The bolt is simulated by the 6061-T6 aluminium bar with the diameter of 6 mm in this study. The yield load and failure load of this aluminium bar are 6.00 kN and 7.25 kN respectively. The steel strip has the length of 240 mm, the width of 50 mm and the thickness of 0.6 mm. The bolt plate is the square steel plate with the side length of 30 mm and thickness of 1.5 mm.

3. Experimental method

The rock mass specimens are designed as a cuboid shape, with the width of 150 mm, the thickness of 150 mm and the height of 300 mm. Five bedding planes are evenly prepared in the rock mass, with the bedding distance of 25 mm. In this paper, four different levels of bedding cohesion (i.e. 0 MPa, 0.06 MPa, 0.12 MPa and 0.18 MPa) are experimented to study the influence of bedding cohesion on the strength and deformation behaviors of bedded rock mass.

The bolts are arranged in the prepared rock mass specimens, which are perpendicular to the bedding planes, as shown in

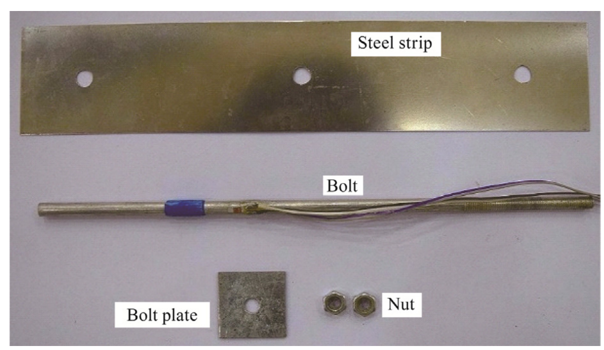

Fig. 2. Support materials.

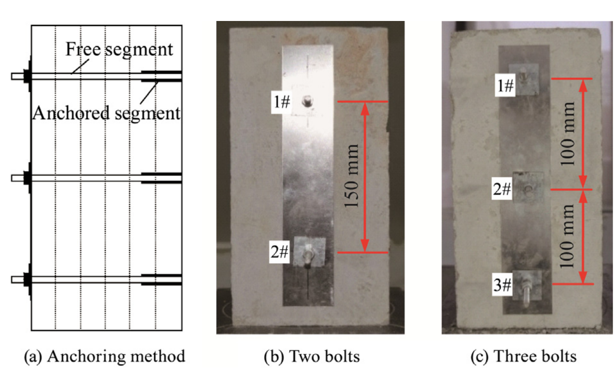

Fig. 3. Bolts arrangements.