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Cable-truss supporting system for gob-side entry driving in deep mine and its application

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ABSTRACT

In order to solve the large deformation controlling problem for surrounding rock of gob-side entry driving under common cable anchor support in deep mine, site survey, physical modeling experiment, numerical simulation and field measurement were synthetically used to analyze the deformation and failure characteristics of surrounding rock. Besides, applicability analysis, prestress field distribution characteristics of surrounding rock and the control effect on large deformation of surrounding rock were also further studied for the gob-side entry driving in deep mine using the cable-truss supporting system. The results show that, first, compared with no support and traditional bolt anchor support, roof cable-truss system can effectively restrain the initiation and propagation of tensile cracks in the roof surrounding rock and arc shear cracks in the two sides, moreover, the broken development of surrounding rock, roof separation and extrusion deformation between the two sides of the roadway are all controlled; second, a prestressed belt of trapezoidal shape is generated in the surrounding rock by the cable-truss supporting system, and the prestress field range is wide. Especially, the prestress concentration belt in the shallow surrounding rock can greatly improve the anchoring strength and deformation resisting capability of the rock stratum; third, an optimized support system of "roof and side anchor net beam, roof cable-truss supporting system and anchor cable of the narrow coal pillar" was put forward, and the support optimization design and field industrial test were conducted for the gob-side entry driving of the working face 5302 in Tangkou Mine, from which a good supporting effect was obtained.

1. Introduction

In recent years, with the gradual depletion of shallow coal resources, the mining depth is increasing year by year, and more and more coal mines have entered the deep mining stage [1–4]. Besides, with the increase of mining mechanization degree and mining intensity, the cross-section of mining roadways also increases to ensure the normal production and transportation, which results in problems, such as supporting difficulty for deep gob-side entry with large section, large deformation of surrounding rock and unsatisfactory control effect of the traditional support forms becoming increasingly prominent [5,6]. Aiming at the problem of maintaining the surrounding rocks stability for this underground projects, scholars at home and abroad have carried out a lot of research and exploration, and to some extent have made some progress and achievements, among which, the cable-truss supporting system, due to its supporting superiority, has been gradually widely applied [7–12]. Zhao et al. emphasized the invalid mechanics of common bolt (cable) and support mechanics for the prestress truss cable in coal roadways with large cross section from the point of view of mechanics [13]. Yin analyzed the structural features of the prestressed truss-cable system, the transverse effect of the inclined cable and stress state of the tie-rod, and then established the "inverted triangle" load model that the tie-rod imposed on the roof surrounding rock [14]. Han et al. studied the truss-cable combination support mechanism in the coal roadway with compound roof and large mining height through theoretical analysis, field measurement and numerical simulation, and the truss-cable support parameters in the open-off cut were optimized [15]. Yin et al. investigated the different supporting mechanisms as well as advantages and disadvantages of the truss cable system and single cable by using theoretical analysis, numerical simulation and field trial. A novel technology of parallel-arranged supporting composed of truss cable and single cable with high prestress was proposed, and its composition structure, controlling mechanism

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and the stress distribution were also studied [16]. Yan et al. analyzed the deformation failure characteristics of the surrounding rock in large section coal roadways of deep mine combining with the field investigation, numerical simulation, theoretical analysis, field test and field monitoring. A surrounding rock controlling system called double-cable-truss (DCT) was put forward, and the composition structure, controlling mechanism and supporting superiority, stress field distribution characteristics of surrounding rock and the key supporting parameters were researched systematically [17,18].

However, throughout the academic literature at home and abroad, studies on supporting mechanism and control effect of cable-truss supporting system mainly focus on the theoretical analysis and field measurement, while the research through similar modeling test and numerical simulation has rarely been reported. Based on this, in our study, indoor similar modeling test was first conducted to investigate the deformation evolution of surrounding rock for the gob-side entry driving in deep mine under no support, common bolt support and cable-truss supporting system respectively. Then, the prestress field distribution features of the roof and side surrounding rock with single anchor cable support and cable-truss supporting system were compared and analyzed by the numerical simulation. Finally, taking the gob-side track transportation roadway of system mechanization mining face 5302# in Tangkou Mine as the engineering background, the optimized support form of "roof and side anchor net beam, roof cable-truss support and anchor cable of the narrow coal pillar" was put forward, combined with the deformation and failure characteristics and loose circle test results for surrounding rock of the gob-side entry driving under the original support form. Besides, key support parameters of the cable-truss supporting system were determined, and the field industrial test was successfully carried out, from which, stability of surrounding rock for the roadway during the support period was ensured.

2. Engineering situation

The gob-side track transportation roadway of system mechanization mining face 5302# in Tangkou Mine has a design length of 1600 m and the buried depth of about 990 m. The size of the roadway section is rectangular with 5 m in width and 4 m in height, and the reserved narrow protection coal pillar has the width of 5 m, with the roadway driving along the floor of the coal seam 3#. The average thickness of coal seam is 4.8 m. The immediate roof and main roof for the roadway are mudstone and siltstone respectively with the thickness of 3–6.2 and 4.6–6.5 m, and similarly, the immediate floor and main floor are also mudstone and siltstone with the thickness of 1.4–2 and 1.5–26.3 m respectively. The physical and mechanical parameters for different rock stratums are listed in Table 1. Supporting difficulties for the roadway are characterized by the following points: (1) the roadway layout in the coal pillar with high abutment pressure, (2) large cross section of the roadway, (3) soft coal seam with low strength, (4) composite stratums in the roof with a great difference in stiffness. In the initial roadway excavation period, both the deformation and damage of surrounding rock for the roadway were extremely serious with the common bolt support, and development trend of the surrounding rock deformation was still not stable after several renovations for the roadway, with the maximum roof subsidence of 1.2 m and extrusion deformation between the two sides of 2.2 m. Besides, abnormal mining pressure phenomena occurred during the roadway driving and maintenance period, with the sound of "coal blasting". Bolt plates at the roof-side corners were universally deformed and dropped off, and tensile failure for several bolts and anchor cables were also taken place, as shown in Fig. 1.

Loose circle of surrounding rock for this roadway was measured and analyzed to study the real damage situation in the inner surrounding rock by using the strata borehole camera measurement system. Three testing sections (1#, 2#, 3#), located at the position of 15, 25 and 40 m ahead of the mining face respectively, were arranged. The borehole depth in the roof and side surrounding rock is 2.54–3.84 and 2.41–3.32 m respectively, and specific test results are presented in Fig. 2. The loose circle thickness for the entity coal side, narrow coal pillar side and the roof is 1.36–1.57, 2.06–2.20 and 0.95–0.98 m, respectively and belongs to moderate-to-large loose circle, unstable surrounding rock with large loose circle and relatively stable surrounding rock with moderate loose circle.

3. Physical model test of reasonable support structure

3.1. Similar materials

The geometric similarity ratio $C_L = 40$ was chosen based on section size and buried depth of the roadway, empirical prediction of excavation-induced influence range and size of the experiment frame. Therefore, the size of modeled roadway is 125 mm in width and 100 mm in height, and the sketch map of the modeling experiment is shown in Fig. 3, in which, the overburden pressure was realized by using the external force compensation method.

In the experiment, the pure and uniform river sand was chosen as the aggregate, and sedimentary rock mass was simulated by heating and melting the paraffin to cement the aggregate. This kind of similar materials has the advantages of short production cycle, stable mechanical properties (not affected by the humidity change) and the reusable property, and good elastic–plastic behavior of the similar materials is suitable for the simulation of mine pressure and deformation characteristics for the mining roadway [19]. Mica powder was used to simulate the weak surfaces between various rock stratums.

By referring to the previous research experience of our group, the river sand and paraffin were compounded by using the mass ratio based on the strength of the similar materials. The average unit weight γ_m of the tested similar material is 1.6×10^4 N/m^3, from which, both bulk density similarity ratio C_r of 1.4 and intensity similarity ratio $C_R (C_R = C_L C_r)$ of 56 were obtained, and the proportion of the river sand and paraffin in the similar materials to simulate the coal seam, mudstone and siltstone was finally ensured to be 100:4, 100:7 and 100:8 respectively. In the model

Table 1
Physical and mechanical parameters of rock stratums.

Lithology	Uniaxial compressive strength σ_c (MPa)	Tensile strength σ_t (MPa)	Elastic modulus E (GPa)	Cohesive strength c (MPa)	Poisson ratio μ	Unit weight γ (10^4 N/m^3)
Roof siltstone	92.41	5.86	78.51	4.88	0.28	2.60
Roof mudstone	63.08	4.02	41.22	4.32	0.20	2.67
Coal seam3#	19.25	0.88	11.02	1.68	0.43	1.42
Floor mudstone	65.89	4.41	45.64	4.32	0.29	2.63
Floor siltstone	71.19	4.33	36.40	4.88	0.31	2.60

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