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A new cable truss support system for coal roadways affected by dynamic pressure

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ABSTRACT

The support of coal roadways is seriously affected by intense dynamic pressures. This can lead to problems with large deformation of the roof and the two side walls of coal roadways. Rapid convergence of the walls and roof, a high damage rate to the bolts and cables, or even abrupt roof collapse or rib spalling can occur during the service period of these coal roadways. Analyzing the main support measures used in China leads to a proposed new cable truss supporting system. Thorough study of the entire structure shows the superiority of this design for roadways suffering under dynamic pressure. A corresponding mechanical model of the rock surrounding the cable truss system is described in this paper and formulas for calculating pre-tightening forces of the truss cable, and the minimum anchoring forces, were deduced. The new support system was applied to a typical roadway affected by intensive dynamic pressure that is located in the Xinyuan Coal Mine. The results show that the largest subsidence of the roof was 97 mm, the convergence of the two sides was less than 248 mm, and the average depth of the loose, fractured layer was only 6.12 mm. This proves that the new support system is feasible and effective.

1. Introduction

The total coal production in 2010 was 3.25 billion tons in China. This is 2.35 times as much as that in 2001 and 1.09 times that produced in 2009. Although this increasing production ensures the growth of the national economy it is difficult for many coal mines to balance between mining and excavation activity. This is especially true for supporting roadways affected by dynamic pressure two or more times [1–4]. The common characteristics of deformation in these roadways include rapid breaking, large roof subsidence, convergence of both side walls, and frequent damage of conventional bolt and cable supports. As time passes, the roadway is prone to abrupt caving or rib spalling accidents [5,6], as illustrated in Fig. 1a. This directly threatens the safety of the workers and renders subsequent repair of the roof collapse difficult and unsafe because of the large area involved, see Fig. 1b.

The support measures applied to mining gateways repeatedly affected by dynamic pressure consist of: (1) Combining supports with bolts, cables, and U-shaped steel; (2) Lengthened resin anchors and supports together with high strength bolts and cables; (3) Excavation of unconventional roadway sections and grouting for reinforcement of the cables; (4) And, highly pre-stressing the entire short cable support around the cross-section [7–12].

Although these support methods have been used in the coal fields, the first and third methods are so trivial in their results that adopting U-shape steel supports or additional grouting just decreases the excavation speed and then changes the balance of effort between actual mining and ancillary excavation.

Intensive dynamic pressure on the roadway when the second method is used leads to results that are far from universally successful. For instance, many roadways are affected by dynamic pressure in the Xinyuan Coal Mine and suffer large deformation and damage. This includes some steel bands breaking up, serious roof subsidence, bolts pulling out, and supporting plates dropping down, among other things. Despite all these deformations the roadways are still brought to a passive situation by immediate repairing after excavation. Occasionally a cycle of excavation and repair results.

Comprehensive consideration of these support measures suggests the last has the best effect on roadways affected by dynamic pressure, especially for many intensive coal roadways.

From the viewpoint of support economics, however, the costs are significantly increased and this method is difficult to put into practice in a wide range of situations.

A new cable truss support system is proposed and analyzed herein that will safeguard the security of a roadway affected by intensive dynamic pressure and will reduce the cost of support. These facts will make it widely applicable.

2. A new cable truss support system

2.1. Key structure and supports

Fig. 2 shows the supporting structures including the cable truss system, bolt truss system, and a simple form of cable truss system

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(a) Roof collapse of a roadway (b) Treatment of a roadway after caving

Fig. 1. Broken roadway and subsequent treatment.

with joint steel [13–18]. Pre-tightening forces have been increased from no pre-tightening force to a low pre-tightening force, then to a high pre-tightening force. The new cable truss support system includes highly pre-stressed cables of a relatively small diameter, resin anchors, connectors, and lock sets. The cables in this system go through the roof obliquely and are then anchored with a suitable resin bonding agent. About one and a half hour later the outside cable should be immediately locked with an arc connector after applying the high pre-tightening force.

The superiority of the new cable truss support system can be generalized as follows. The force is applied in two directions, providing a long and relatively soft linear shearing force along with firm bolting points locked along with roof deformation. Salient points are:

- The support system reinforces both in the vertical and horizontal directions, which switches the stress from two directions into a balanced stress state;
- The cable is much longer than a conventional bolt so the supported region is also larger. Meanwhile, the superior extension provides a powerful shearing assistance;
- The linear contact between the outer section of the cable and the roof provides a uniform force on the shallow surrounding rock;
- The bolt points are located in regions deep in the roof and coal sides so spalling can be prevented and the roof is stabilized;
- As the support system deforms it will gradually lock and, thus, can control larger roof displacements.

The main support styles using bolts or cables in the coal fields in China are listed, compared, and analyzed in detail in Table 1.

In conclusion, the cable truss is superior compared to the conventional cable and the bolt truss. The conventional cable has a larger support range, which could harmonize the shallow and deep stratum during excavation and service periods. Bolt trusses tie the roof to the support structure in a horizontal direction as roof subsidence occurs, which can control roof deformation to a degree. The cable truss system replaces the bolt and bar with the cable and the connector respectively. This allows larger pre-stress to be applied than in the bolt and truss method and results in a higher strength for the whole system. Hence, the cable truss system provides greater supporting to complex roadways than can the conventional cable and bolt truss.

2.2. A mechanical model of the rock surrounding a cable truss support

The friction forces between the outer section of the cable and the shallow surrounding rock of the roof, and between the inner section of the cable and deep surrounding rock, are small after applying pre-tightening force in the cable truss support system. These forces can be omitted during calculations and analysis. However, the intersection between the cable and the intermediate roof bears a considerable force. The locally effective stress on the roof is included in the mechanical model of the surrounding rock and cable truss support as shown in Fig. 3. The calculations of anchoring and pre-tightening forces in the support designed for field applications are given by Eq. (1).

$$\frac{P}{2} \leqslant F_1 \cdot \cos\left(\beta - \frac{\pi}{2}\right) \tag{1}$$

$$P_1 = P_2 = P/2 = q_0 a/2 \tag{2}$$

where P is a vertical force, N; F_1 the friction force inside the inclined cable, N; β the obtuse angle between the horizontal and the inclined cable; and q_0 the uniform stress, N/m^2.

Furthermore, following Fig. 4, the relationship between the pre-tightening force, F, and the friction force, F_1, is obtained from:

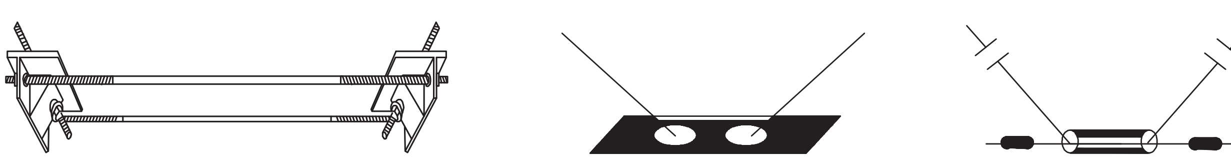
$$F_1 = F - \kappa \cdot 2F\cos\frac{\beta}{2} \tag{3}$$

where κ is the friction coefficient.

Then, substituting F_1 from Eq. (3) gives:

$$F \geqslant \frac{P}{2\left(1 - 2\kappa\cos\frac{\beta}{2}\right)\cos\left(\beta - \frac{\pi}{2}\right)} \tag{4}$$

Now suppose the rock inside the cable truss is under a uniform load. Then the pre-tightening force should exceed the horizontal force that arises from the combed effects of the ground stress and the vertical load:



(a) Bolt truss (b) Simple cable truss with joist steel (c) Conventional type of cable truss

Fig. 2. Schematic diagrams showing bolt or cable truss systems.