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The caving and sliding control of surrounding rocks on large coal roadways affected by abutment pressure ☆

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ABSTRACT

For the caving and sliding control of roadways with large cross-section, thick mudstone roof and abutment pressure influence, the cable truss system is proposed and its support mechanism is thoroughly analyzed in this paper. Furthermore, according to the geometric size and ground pressure conditions on field coal roadways Nos. 101, 102 and 103 in Xinyuan Coal Mine, three types of cable truss support systems are designed for obtaining the optimum cable truss support system. Then the corresponding parameters for each support design are determined by use of the numerical simulation method, and three kinds of support systems are put into practice. The field observation results show that roof should be effectively controlled by the normal cable truss structure consisting of two long cables and one connector, and both coal sides can be protected by the simplified cable truss structure composed of two short cables and one channel bar. Finally, the optimal support system is gotten which is much better than the other two support designs in rock deformation control effect and economic profits.

1. Introduction

In recent years, with the increment of the coal demand year by year, the coal mining depth and width turn to be larger, however, lots of accidents mainly containing caving and sliding of the surrounding rocks on roadways have frequently taken place, which are especially on complex coal roadways, such as thick mudstone roof, abutment pressure influence, large cross-section and soft roadways. According to the roadway accidents statistic in the year 2010 in China, the number of accidents from the above mentioned complex roadways has amount to 90% in total accidents. Lots of researchers have explored the supporting theory and corresponding field tests on complex roadways. Liu and Lu (2000) researched the mudstone softening mechanism which was affected by the water; Yao et al. (2008) got the following controlling countermeasures which contained reasonable hydrophobic, saving water and high pre-stress bolt and cable supporting; Yang et al. (2011) researched the roadways deformation mechanism with thick mudstone roof and put forward a set of controlling method which included enclosing the surrounding rock, improving the stratum strength and adopting inclined cable. For the roadways supporting affected by abutment pressure, Kang et al. (2009) put forward the whole cross-section and high pre-stress cable supporting technology; Ying et al. (2009) proposed the supporting technology with abnormal draining section, bolt and cable support and adopting different nets for three stages; combined with the analogous complex conditions, He et al. (2011, 2010a) studied the cable truss supporting technology.

However, the complex roadways in Xinyuan Company of Yangmei Group in this paper have the comprehensive characters of large cross-section, thick mudstone roof, abutment pressure influence, and caving accidents happened during the drilling and supporting period. Moreover, the corresponding supporting research results are few, so it is imperative to propose the effective methods and choose the typical roadways to have the supporting tests. Aiming at the roadways deformation and broken characters, developing a set of reasonable and practical supporting system is important to ensure the roadways safety, and then greatly reduce the accidents rates of roadways. In this paper, three types of cable truss systems are put forward, thoroughly analyzed on theoretically and tested underground.

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2. Cable truss supporting system analysis

The cable truss is a set simple supporting structure which is composed of two inclined cables and one connector (He et al., 2010b). The cable truss supporting system is a comprehensive structure which has the corn of cable truss and the other supporting structures containing bolt, single cable, etc. Combined with the parameters optimization of supporting scheme by software simulation and the coal roadways condition, the final supporting scheme is formed and then tested. The cable truss has experienced the development from bolt truss, simple cable truss, cable truss, high pre-stress cable truss to cable truss system (Liu et al., 1998, 2005; Kang and Wang, 2007; Zhao et al., 2007).

2.1. Engineering background for the type of supporting system

The excavation cross-section of roadways turns to be larger and larger in China. Meanwhile, plenty of roadways roof are composed of thick mudstone or other soft stratum, which have no stable anchoring points. Moreover, some roadways are suffered from twice or more times abutment pressure. When choosing the normal I beam to support, it may bring the high strength, low working speed and weak loading force, which may lead to abscission layer for roof or serious deformation. When choosing the conventional bolt or cable support, there exists the large roof subsidence, especially in the middle of the roof, and the whole supporting structure could not be formed, which may lead to roadways accidents such as roof caving or coal sides sliding.

The cable truss supporting system could ensure the roadways safety mainly depending on two supporting stages. The first stage adopts the high strength bolt or cable support and forms the support structure. On the basis of the first stage supporting, the cable truss structure is applied to the roof or coal sides to strengthen the supporting properties. During the roadway supporting and service periods, two sets of supporting structures make coordination function and form the whole cable truss supporting system, which guarantee the roadway safety and the surrounding rock stable.

2.2. The mechanism of cable truss supporting system

The new type of cable truss is a positive support to strength surrounding rock, as is shown in Fig. 1. Without applying the pre-tightening force, the roof has large subsidence and the inclined cables load the force. Depending on the high pre-tightening force, a strengthening layer is formed in the middle of the roof, which improves the anti-deformation property and decreases the abscission layer between the above strata. Along with the roof subsidence, the applied force continues to increase and the corresponding force loaded by cable truss decreases, and the roof has some displacement, so the cable truss is in a new stable stage.

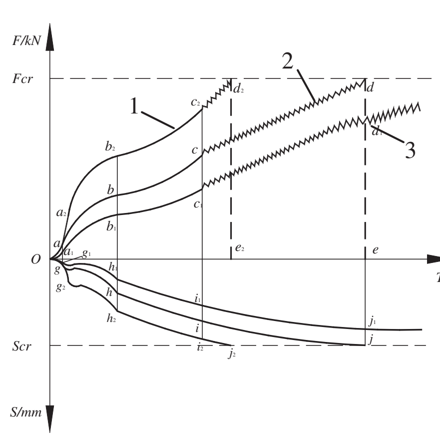

Fig. 1. Supporting mechanism of cable truss system (1-conventional cable truss; 2-cable truss supporting system; 3-low pre-stress cable truss).

Until the surrounding rock stress increases again, the cable truss could experience the above analogous working, and the loaded force continues to change, which also could improve the tension stress and make the roof surrounding rock increase the loading ability. The cable truss system changes from the stable, decreasing pressure force and stable state, and the working situation will develop to the max tension stress of the cable. Along with the surrounding rock stress increases once more, the loading force on the cable truss also increases and the whole cable truss is in a critical state, and then the system develops to break off suddenly in the weakest point.

3. Three sets of cable truss supporting system analysis

Based on the above analysis, three sets of cable truss supporting system are put forward, which consist of the bolt, cable and cable truss combining supporting in squeeze or cross, short cable and cable truss combining supporting system.

3.1. The bolt, cable and cable truss combining supporting in squeeze

In the view of the roof supporting, the bolt, cable and cable truss are set in squeeze. In the supporting system, the cables could get into the stable strata, which improve the loading properties of the deep stratum. Meanwhile, the soft and break stratum in the shallow surrounding rock could be strengthened depending on the high pre-stress bolt supporting, which decreases the abscission layer and roof subsidence. The type of supporting system is combined with different structures, however, the shortcomings of the system are the large discrepancy of the stiff and strength property between the cable and bolt, which may lead to different deformation for roof stratum and unable to form the whole supporting structure.

3.2. The short cable and cable truss combining supporting system

Considering the high strength short cable and cable truss combining supporting, the shallow and deep roof surrounding rock form the corresponding whole structures after applying the high pre-stress into the system respectively. Meanwhile, as the supporting coordination makes good function, the whole supporting properties of the system could improve along the roadway supporting and control the roof well.

3.3. The bolt, cable and cable truss combining supporting in cross

As the tension stress in the middle of the roof is large, the bolt, the type of system of cable and cable truss combining supporting in cross is proposed. In this supporting system, the single cable is arranged in the middle of the roof or nearby, and the truss cable is the strengthening supporting. Compared with the whole cable supporting system in the roof, the supporting speed of this type of system is faster, but the whole supporting performance is weaker, which especially needs effective supporting parameters.

4. The numerical simulation and field application of cable truss supporting systems

4.1. Numerical calculation model building

According to the elastic and plastic theory, it is five times zones to determine the corresponding boundary of the model. In the *x*-axial direction, the left distance of the roadway No. 101 is 28.5 m, and the right distance of the No. 103 is 30 m. The whole calculation model is 116 m × 60 m, and the underground depth of the simulation roadways is about 560 m, so the rock stress is about 13.72 MPa. Considering the factors such as geological condition, rock strata properties and occurrence state, the model is done by stratum arrangement, joints division, and applying constraint conditions. The coal and strata mechanical parameters are shown in Table 1, and coal and strata distribution of the model is shown in Fig. 2.

4.2. Simulation process and results

It mainly combines orthogonal test with Flac software simulation, especially to the supporting parameters for three roadways, which contain bolt and cable diameter, length, distance between two rows, spacing, the angle between the cable or bolt and horizontal direction, etc., as is shown in Fig. 3. On the basis of the simulation, the final three sets of cable truss supporting parameters are determined according to geological and production conditions of the field roadways.

The corresponding supporting parameters are determined, and the type I cable truss system is applied to roadway No. 101. The diameter of the cable is 17.8 mm, and the section length inside the drill hole of the cable is 8.0 m, the angle between truss cable and horizontal is 70°.The diameter of roof bolt is 20 mm, the length is 2.5 m, and the distance between two bolts and the space are

Table 1
Mechanical parameters of the 3# coal and strata.

Materials	Density kg/m^3	Shear modulus/Pa	Bulk modulus/Pa	Bond force/Pa	Internal friction angle/(°)	Tensile strength/Pa
Gray black sandy mudstone	2450	8.00e9	1.25e10	1e7	31	1e6
Gray fine sandstone	2660	2.12e10	3.91e10	1.53e7	34	6.03e6
Gray black sandy mudstone	2450	8.00e9	1.25e10	1e7	31	1e6
Gray medium sandstone	2600	2.43e10	4.12e10	1.67e7	36	6.93e6
Black sandy stone	2500	8.30e9	1.30e10	1.1e7	31	1e6
3#coal	1400	9.00e8	1.89e9	2.52e6	28	8.5e5
Gray sandy stone	2500	8.15e9	1.30e10	1.15e7	31	1e6
Siltstone	2663	1.131e10	1.648e10	2.09e7	40	3.87e6
Gray fine sandstone	2660	2.12e10	3.91e10	1.53e7	34	6.03e6

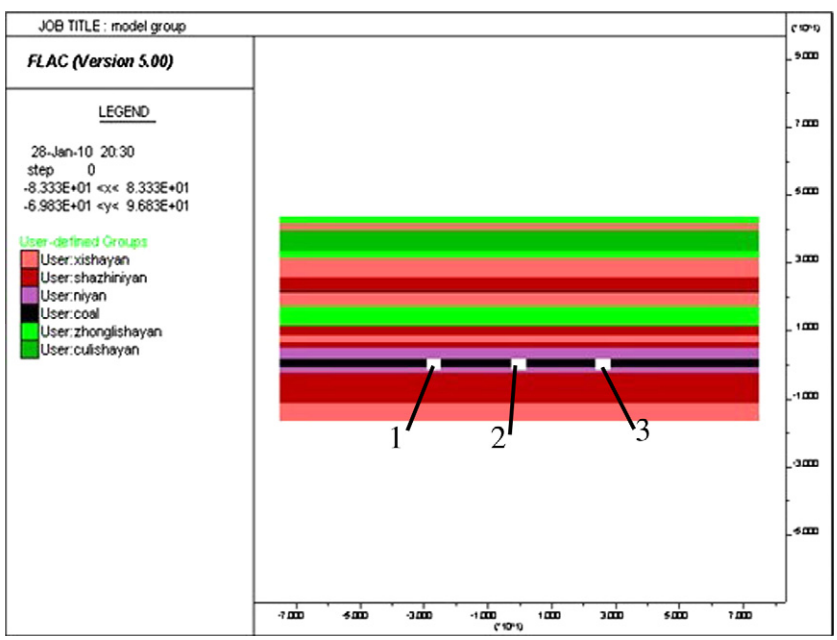

Fig. 2. The coal and strata distribution of the model. (1-roadway No. 101; 2-roadway No. 102; 3-roadway No. 103.)

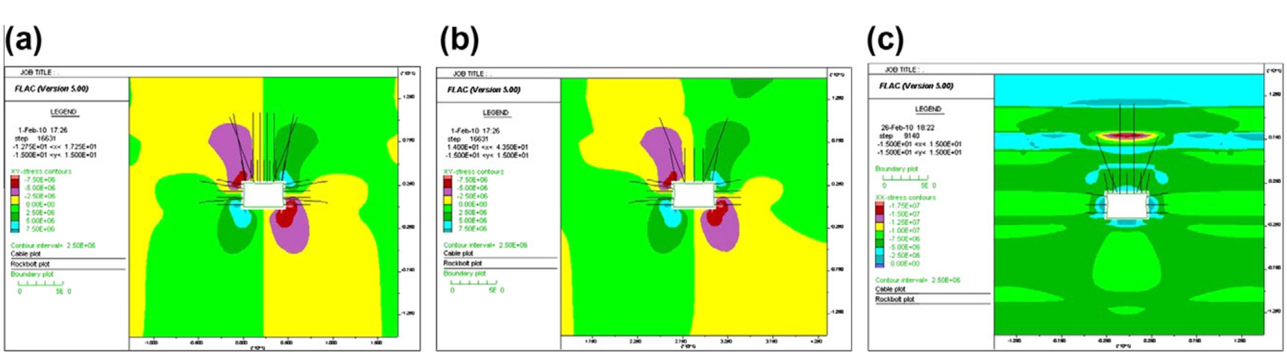

Fig. 3. The horizontal stress distribution for different trial systems (a) the type I; (b) the type II; (c) the type III.

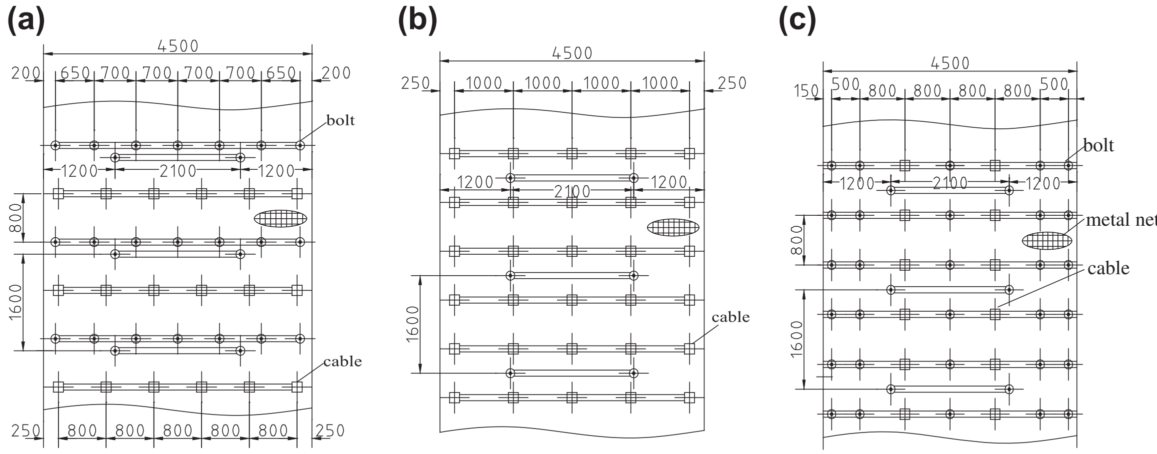

Fig. 4. The roof supporting systems for three roadways (unit: mm) (a) the type I; (b) the type II; (c) the type III.

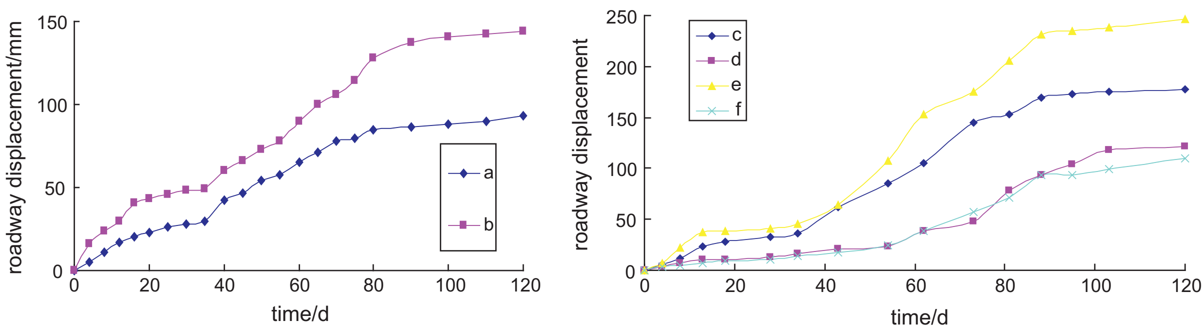

Fig. 5. The surrounding surface displacement (a) The type I; (b) The type II and type III (a, c, and e – convergence of both sides; b, d, and f – convergence of both sides roof subsidence).

respectively 0.7 m and 0.8 m. For the single cable, the diameter is 17.8 mm, the length is 8.3 m, and both of the space and distance between two cables are 0.8 m. For the coal sides supporting, the bolt diameter is 20 mm and the length is 3.0 m. Besides, the simple cable truss system is adopted with cable and channel steel, and the chose cable is 5.3 m long with the same diameter.

The type II trial system which combines with the short cable and cable truss is used to roadway No. 102, and the corresponding supporting parameters are as follows: the single cable is 4.3 m long, the diameter is 17.8 mm, and the row and space distance are respectively 0.8 m and 1.0 m; for the coal sides supporting, the bolt is 3.0 m long, the corresponding diameter is 20 mm, and both of the row and space distance are 0.8 m, besides, the simple cable truss supporting system is used to one side which is nearby the coal pillar, and the chose cable is 5.3 m long with the same diameter.

The type III trial system is applied to coal roadway No. 103 and the corresponding parameters are as follows: the truss cable is 8.5 m long, the diameter is 15.24 mm, the angle between cable and horizontal direction is 70°, and the row distance is 0.8 m. The roof bolt is the same row with the cable, the bolt diameter is 20 mm, the length is 2.4 m, and both of the row and space distance are 0.8 m; the single cable in the roof is 10.3 m long, the diameter is 21.6 mm, and the row and space distance are respectively 0.8 m and 1.6 m. For the coal sides supporting, the bolt is 2.4 m long, the diameter is 20 mm, and the row and space distance are respectively 0.8 m and 1.0 m.

4.3. The field supporting tests

The designing cross-section of three coal roadways for supporting tests is triangle, which is 4.5 m wide and 3.0 m high. After determining the concrete supporting parameters, three types of cable truss supporting system are put into practice on roadways Nos. 101, 102 and 103, and the field supporting schemes are shown in Fig. 4.

To compare with the roadways supporting effects, the abscission layer and roadways displacement of three roadways are monitored after adopting three sets of supporting systems. From the perspective of roadways displacement, as is shown in Fig. 5, the supporting effect between type I system and type II system is basically identical, but the roof subsidence and convergence of both sides of type III supporting are respectively amount to 110 mm and 246 mm. Meanwhile, the roof abscission layer of the deep and shallow stratum from type II system is less 20 mm, but the type I system could reach 67 mm, which is shown in Fig. 6. By comparison with two

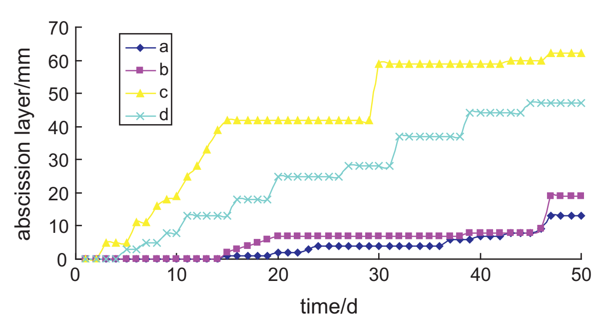

Fig. 6. The comparison on abscission layer with two cable truss systems (a and c – the shallow basic point; b, and d – the deep basic point; a and b stand for abscission layer of type II; c and d stand for abscission layer of type I).

cable truss systems, the former has better effect than the later on controlling the surrounding rock of the roof roadway. According to the comprehensive analysis and comparison, the type II supporting system combined with short cable and cable truss could effectively control the complex roadways with characters of soft surrounding and affected by dynamic pressure.

5. Conclusions

(1) The main supporting methods about the large cross-section, thick mudstone roof and suffering from dynamic pressure roadways are analyzed. Combined with the support problems in Xinyuan Company of Yangmei Group, the cable truss supporting system is proposed and the corresponding engineering background and support principal are studied.
(2) Three sets of cable truss supporting systems are put forward and researched on theoretically, and the key parameters of three sets of supporting are optimized on the basis of the orthogonal test and numerical simulation.
(3) According to the analysis results, the final schemes are respectively got field test on roadways Nos. 101, 102 and 103. From the perspective of whole supporting effect, the type II supporting system has low roof abscission layer and roadway deformation, which is superior to the other supporting systems.

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