The Secondary Anchor-Cable Network Support Technology in Deep Soft-rock Roadway in Chaohua Coal Mine

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Abstract. To solve support problems in deep soft-rock roadway in Chaohua Coal Mine, main causes of instability of the original U-shaped steel supported roadway in deep Chaohua Coal Mine were analyzed by combining numerical simulation, theoretical analysis and practical applications. The instability of the original support is the consequence that the passive support cannot adapt to deformation of surrounding rocks in deep high-stressed soft-rock roadway and failure of the original anchor-cable net support is mainly caused by unreasonable support parameters. In this paper, the high-strength and high-stability secondary anchor-cable net supporting technology against deformation of surrounding rocks in deep soft-rock roadway was proposed. Specifically, the primary high-strength anchor-cable net support reinforces the surrounding rocks in roadway on time and forms an effective bearing structure with surrounding rocks. The secondary cable supplement support increases stability and bearing capacity of the bearing structure. The test results of 31 Dilian Roadway demonstrated that the proposed secondary anchor-cable net support technology can solve the support problems in deep soft-rock roadway in Chaohua Coal Mine effectively.

1.Introduction

With the continuous growth of mining depth, the support problems of deep soft-rock roadway become more and more prominent. Abundant deep researches on support technology to deep soft-rock structures have been reported in the world. Currently, more and more studies demonstrated that it is neither easy nor economic to control deformation of surrounding rocks in roadway completely through the single support. The secondary support technology is an effective mean to control the great deformation of surrounding rocks in deep soft-rock roadway. To solve great pressure and deformation of surrounding rocks and long self-stable time, it is recommended to adopting the support technology of “soft first and then rigid” during chamber excavation in deep soft rocks in the Huaibei Pangzhuang Mine. In this support technology, the primary support yielding was used to buffer the expansion pressure of surrounding rocks and the secondary support was employed to increase the support resistance to control deformation of surrounding rocks[1]. The Jiaozuo Coal Mining Administration and the China University of Mining and Technology cooperated in studying the soft-rock roadway and deemed that stress is in uneven distribution on surrounding rocks. Weak parts of the support structure failed firstly, which leaded to the overall failure of the roadway. Hence, the secondary composite support technology to key positions was proposed[2]. Based on the primary support failure in the Taoyuan Coal Mine, it is suggested to apply the secondary strengthened support technology which can reinforce the surrounding rocks and mobilize supporting ability of surrounding rocks fully[3]. In this paper, causes of buckling failure of deep soft-rock roadway with conventional support were analyzed in view of specific conditions in deep soft-rock roadway in Chaohua Coal Mine by combining

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associated research fruits. On this basis, the secondary support technology for deep soft-rock roadway under similar conditions was studied.

Currently, the -200m level is going to be mined out in the Chaohua Coal Mine and it is going to the -300m level gradually. The exploitation depth in the 31 Zone, a diphead mining area in the -300m level, has exceeded 500m. In particular, the buried depth of the 31 Dilian Roadway and 31 Zone in the bottom of the mining area even exceeds 700m. This mine is going to face with support challenges in deep soft rocks. The 31 Dilian Roadway connects three diphead areas which are important roadways of ventilation, workers and subsidiary transportation in the 31 Zone. Studying effective support technology to the 31 Dilian Roadway is of important significance to long-term stability of the deep soft-rock roadway and safety production of mines in the Chaohua Coal Mine.

In the measured geological profile during the roadway advancing, the 31 Dilian Roadway is in the roof rock stratum which is 0~15m away from the II-1 coal seam. Surrounding rocks of roadway are dominated by mudstone and sandy mudstone which have poor lithology. Moreover, there are geological structures and tremendous joint fissures in rocks in areas where the 31 Dilian Roadway lies in, resulting in the poor integrity of surrounding rocks.

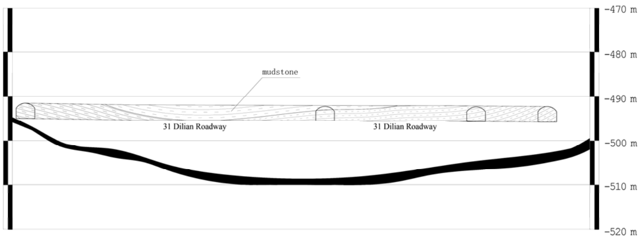


Fig. 1. Geological profile of the 31 Dilian Roadway

2.Failure characteristics of the originally supported roadway

The 31 Dilian Roadway had a straight-walled arc section and had two supporting structures: U-shaped steel support and anchor net. The U-shaped steel support chose the 36U steel support and Φ16×8000mm anchor cable reinforcement was applied every 2m at the springing line and arc top of the roadway. The anchor net was formed by common Φ18×1800mm architectural deformed steel bars at the interval of 800×800mm. Since the roadway suffers serious deformation soon after the supporting construction, anchor cables with beams were supplemented at side and arc top of the roadway. Anchor cables used Φ15.24×8000mm steel strands and six anchor cables were placed on each section. Two anchor cables were set at two sides at an interval of 2,000mm, respectively. Another two anchor cables were placed at the arc top at the interval of 2,500mm. The distance between different sections is 2,000m.

Internal state of roadway surrounding rocks was observed by the borehole peep. According to observations on surface deformation of roadway surrounding rocks, the deformation failure characteristics of the 31 Dilian Roadway are summarized as follows:

In the U-shaped steel supporting structure, there's serious internal displacement and obvious heaves at sideways. Evident low-resistance slippage occurs between the supporting fashioned iron and the fashioned iron, which leads to support failure. Surrounding rocks at the roadway armpits are in loose arrangement and crushed, and the crushing depth exceeds 8m. The spray-layer cracking and falloff are developed soon after the anchor net support is used, followed by accelerating internal displacement of surroundings at two sideways and accompanied with obvious heaves. Later, strong internal displacement of surrounding rocks at different roadway positions is formed and the roadway section narrows uniformly. There are uniformly distributed microcracks in surrounding rocks in the range of 0~8m at sideway feet. In the roadway armpits, fissures which are wide and in dense distribution mainly distribute in surrounding rocks in the range of 0~2m. A separation layer is developed at the depth of about 2m in roof surrounding rocks of the roadway. Surrounding rocks in the depth of 0~2m witness dense development of fissures, but surrounding rocks in deeper than 2m remain highly integral.

3.Analysis of causes of the original support failures

3.1 Causes of the original U-shaped steel support failure

Causes of the original U-shaped steel support failure were analyzed according to the failure characteristics of the roadway. On the one hand, the supporting structure to the straight-walled arc section has high bearing capacity at the top, resulting in the small deformation at the arc top throughout the exploitation process. Sideways also remain highly stable in the early period, which is attributed to the short straight wall and support resistance of the anchor cables at the springing line to control surrounding rock deformation in time[4,5]. However, the supporting structure at roadway armpits has low bearing capacity and cannot provide a support resistance positively to control surrounding rock deformation. As a result, the breach of surrounding rock deformation in the roadway is formed under high stress in deep positions. On the other hand, the buckling failure of the supporting structure at roadway armpits leads to gradual expansion of the surrounding rock crushing areas to the sideways, thus causing failures of the anchoring bearing structure composed of anchor cables at sideways and the U-shaped steel support. Consequently, the supporting structure at sideways is broken, which further leads to the overall failure of the roadway.

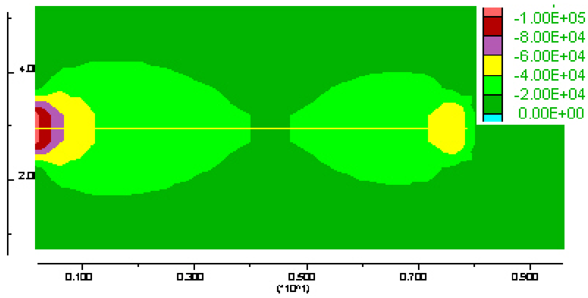
Based on above analysis, the U-shaped steel support belongs to a passive support. It has absent deformation of surrounding rocks and poor bearing capacity of the support structure. In deep soft-rock roadway, surrounding rock stress is high. Since there are great differences in stability at different arc roadway positions, surrounding rocks often present uneven deformation after the roadway advancing, which further causes uneven loading on the support. The uneven loading on the support will decrease the bearing capacity of the support significantly. Hence, the U-shaped steel support in deep soft-rock roadway cannot control surrounding rock deformation effectively since it cannot adapt to deformation of roadway surrounding rocks and develop the bearing capacity fully. In a word, it shall provide enough support resistance to surrounding rocks in deep soft-rock roadway in order to control strong deformation of surrounding rocks effectively.

3.2 Causes of the original anchor net support failures

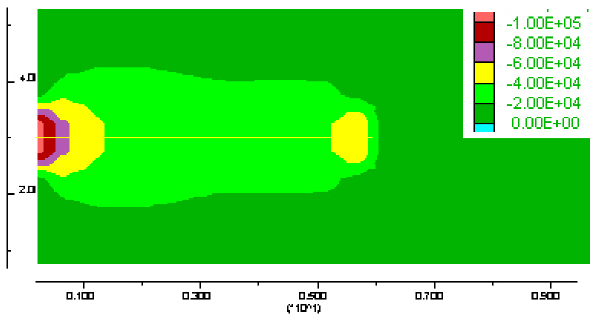
According to existing research results and failure characteristics of the original supported roadway, it concluded that unreasonable support parameters are main causes of failure of the original cable net support.

On the one hand, there are inadequate length and strength of anchor bars. The original support used short Φ18×1800mm anchor bars and the anchoring bearing structure formed in surrounding rocks of roadway is thin. Moreover, the anchor bars have small diameter and low strength as well as preload. They form weak compressive resistance to surrounding rocks in the anchoring zone and the bearing arc formed by anchor bars in superficial surrounding rocks has low bearing capacity.

On the other hand, the anchor cable length mismatches with preload and diameter. Although the original support has Φ15.24×8000mm anchor cables at sideways and arc top of the roadway, the anchor cables are short and have small diameter as well as low preload. The FLAC simulated distribution of the preload field[6,7] which is formed by 8m and 6m long anchor cables with 9T preload in soft rocks is shown in Fig.2. Although the distribution depth of preload formed by 8m anchor cable is small, the stress distribution zones are discontinuous and zero-stress regions are observed in the middle of the anchor cable, indicating the poor positive supporting effect of the anchor cable to surrounding rocks in the middle of anchor cable. Although the distribution depth of preload formed by 6m anchor cable is only limited within 0~6m, the distribution width is higher than that formed by 8m anchor cable. Besides, preloads which are generated at two ends of anchor cable superpose in the middle of anchor cable, so the distribution region of preload becomes an integral. The anchor cables offer a certain positive support to surrounding rocks at different depths. Therefore, given the same preload and fixed length of anchor cable at ends, the longer anchor cable contributes the more obvious of the preload effect and the poor performance of anchor cables in positive supporting. Therefore, mismatching between anchor cable length in the original support and the preload size and diameter may cause failure of supplemented anchor cables after the basic support to enhance support structures[8]. The original support develops grading bearing of two support structures and then breaks one by one.



8m



6m

Fig. 2. Distribution of preload from different lengths of anchor cable in surrounding rocks

4.Secondary anchor-cable net support technology

4.1 Mechanism

Based on above analysis of causes of the original support failures, on the one hand, controlling the strong deformation of deep soft-rock roadway under the comprehensive effect of high stress and the complicated structural stress has to form a supporting structure with certain strength in superficial surrounding rocks timely and effectively, aiming to maintain the three-way stress state of deep surrounding rocks and prevent expansion of the plastic region of surrounding rocks after roadway advancing. On the other hand, structural compensation shall be adopted at weak points of the bearing structure according to the bearing characteristics of the support structure in superficial surrounding rocks[9,10] in order to increase stability of the support structure. Moreover, the coupling effect between the compensation support and basic support shall be considered to prevent grading bearing and successive failures of two support structures. Hence, it is suggested to control deformation of deep soft-rock roadway in Chaohua Coal Mine by using the secondary anchor-cable net support technology. The primary support uses the anchor net support with strong preload[11] to support surrounding rocks in the roadway timely and effectively and give full development of bearing capacity of surrounding rocks. In superficial surrounding rocks, the support and surrounding rocks form a reliable support structure. The secondary support uses the preload anchor cable with high strength and small pore diameter for the sake of structural compensation to the support structure. It makes full use of bearing capacity of deep surrounding rocks in the roadway and can increase the bearing capacity and stability of the support structure. Therefore, the strong deformation of surrounding rocks in the roadway could be controlled effectively.

4.2 The secondary anchor-cable net support program in 31 Dilian Roadway

Based on the above mechanism of secondary anchor-cable net support technology and specific geological conditions of the 31 Dilian Roadway, a numerical simulation on the surrounding rock controlling effects under different support parameters was carried out. The optimal support parameters for the secondary anchor-cable net support technology in the 31 Dilian Roadway are proposed: the primary high-preload anchor net support uses Φ20×3000mm anchor bars at an interval of 800×800mm. It can make the anchor bars and surrounding rocks form a high-strength support structure. Based on further increased support strength, the secondary compensation support uses Φ18.9×6500mm anchor cables as compensation supports to roadway structures with poor bearing capacity stability. It can improve stability of the support structure which is formed by the anchor net and surrounding rocks significantly.

The support program is introduced as follows:

1) The Φ20×3000mm left-handed non-longitudinal deformed steel bars are used at an interval of 800×800mm in the primary high-preload anchor net support and the preload is set 5T. To control heaves effectively, the height between the bottom anchor bars and the base plate shall be no higher than 300mm and anchor bars shall fixed downward by 15°. The arrangement of anchor bars is shown in Fig.3. Each anchor bar uses 2 pieces of Z2350 resin cartridges. The 140×140×10mm A3 steel drum tray is adopted. Besides, the Φ8mm high-tensile steel bar network is used and ladder beams of high-tensile steel bars are placed circumferential along the roadway.

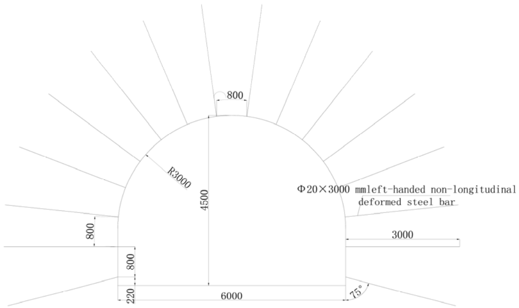
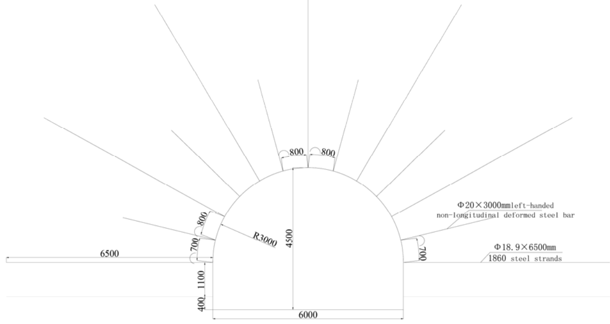
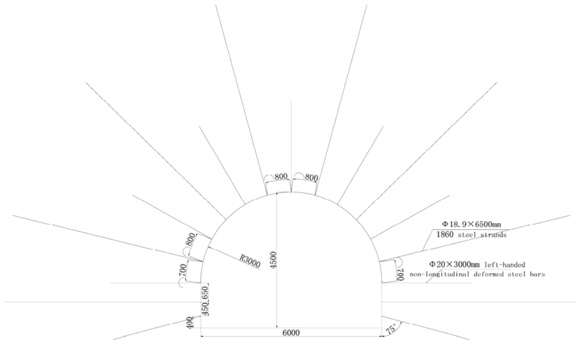


Fig. 3. Primary support section (Unit: millimeter)

2) Primary spraying is performed to the roadway after the primary support, which is to achieve a good molding of the roadway for secondary support. The secondary support is applied at a delay of 10m to the primary support. Two support sections are used (Fig.4(a) and Fig.4(b)). The section A and Section B are placed alternatively and the distance between two sections is 800mm. After secondary spraying to the roadway after the secondary support, the spraying layer shall not be too thick. It only has to cover metal components and prevent rusting of metal components.



a. Secondary support section A



b. Secondary support section B

Fig. 4. Secondary support sections (Unit: millimeter)

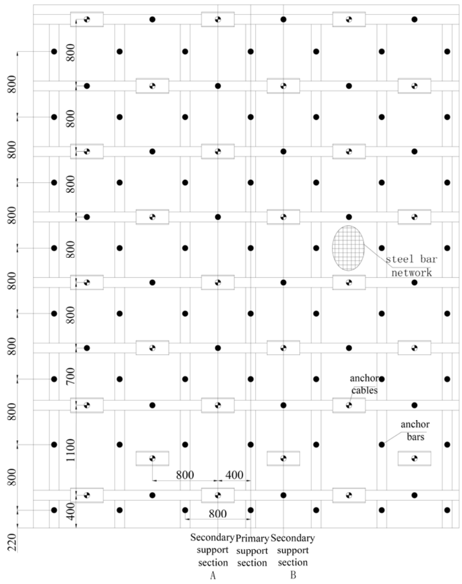


Fig. 5. Lateral view of the secondary anchor-cable net support in the roadway (Unit: millimeter)

Anchor bars and accessories in the secondary support are same with those of the primary support. Anchor bars are placed at an interval of 1100×1600 mm at sideways and at an interval of 1600×800 mm at top. The anchor cables use Φ18.9×6500mm 1860 steel strands. The anchor cables are placed at an interval of 1100×800 mm at sideways and at an interval of 1600×800 mm at top. Preload of anchor cables shall be no lower than 9T and each anchor cable uses 4 pieces of Z2350 resin cartridge. The 400mm long 18# box iron is used as the tray. Ladder beams of high-tensile steel bars are placed axially along the roadway to connect anchor bars and anchor cables of the sections A and B in the secondary support.

4.3 Support effect

After the above support program is constructed, observation stations are set in the roadway adjacent to the Dilian Roadway and pump chamber at 10m away from the entrance of the pump chamber in order to test the support effect. The roadway surface displacement is observed. The variations of roadway surface displacement at the observation stations after the secondary support are shown in Fig.6. Obviously, the maximum displacement of the roof and baseboard is 73mm and the maximum displacement of two sideways is only 51mm. Surrounding rocks in the roadway become stable at about 1.5 months. The average moving rate of the roof and baseboard is about 1.62mm/d, and the average moving rate of two sideways is about 1.13mm/d. Besides, the displacement speeds at roof, baseboard and two sideways are approaching to 0.

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Meanwhile, state of rock mass in surrounding rocks is observed by the borehole peep instrument in order to further test the support effect and test the effect of support in controlling surrounding rocks. According to observation results, surrounding rocks at more than 3m depth are maintained basically stable after 9 months of the secondary anchor-cable net support, accompanied with few cracks in rock mass. Although there are cracks in surrounding rocks within the depth of 0~2m, these cracks are narrow and rock bulks contact very closely under the high-strength anchor-cable net support although rock masses are crushed significantly. This indicates that the support improves the stress state of surrounding rocks in the roadway and increases the bearing capacity of surrounding rocks. States of roof surrounding rocks at 3m and 2m depth are shown in Fig.6.

According to above observation results, the surrounding rock deformation in the 31 Dilian Roadway after the secondary anchor-cable net support is controlled effectively.

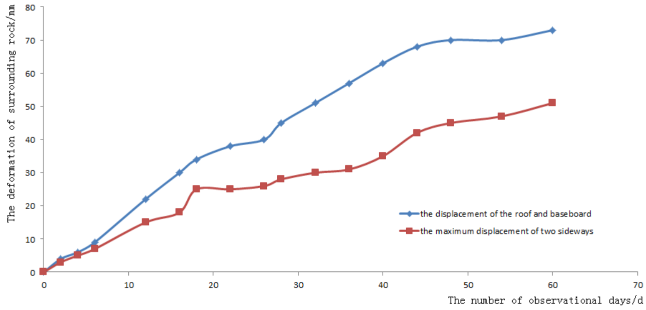
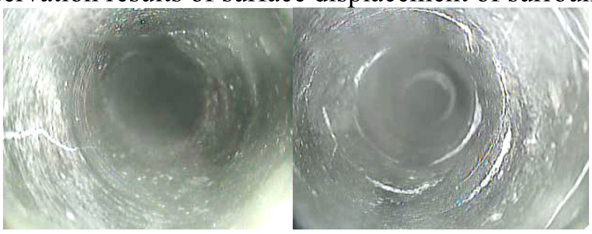


Fig. 6. Observation results of surface displacement of surrounding rocks



3m 2m

Fig. 7. State of rock mass in surrounding rocks in supported roadway

5.Conclusions

(1) Analysis on causes of the original support failure in deep soft-rock roadway of Chaohua Coal Mine demonstrates that the U-shaped steel support can neither support surrounding rocks positively nor develop the bearing capacity of surrounding rocks. The anchor net support shall cooperate with surrounding rocks in the roadway to form an effective support bearing structure. The anchor cable reinforced support shall be able to increase strength and stability of the support structure.

(2) In the 31 Dilian Roadway in Chaohua Coal Mine, the primary anchor net support uses Φ20×3000mm left-handed non-longitudinal deformed steel bars with a preload of higher than 5T to reinforce surrounding rocks of roadway in time and form an effective bearing structure with surrounding rocks. The secondary support reinforces the bearing structure formed after the primary support by Φ18.9×6500mm anchor cable with 9T preload. The maximum displacement at roof and baseboard is controlled at 73mm and the maximum displacement at two sideways is only 51. This reflects that the proposed secondary anchor-cable net support technology controls deformation of surrounding rocks in deep soft-rock roadway effectively.

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