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Roadway Support Technology with Sliding Cracking Surrounding Rock under Tectonic Stress

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Abstract: *The west ventilation roadway in Damoling Coal Mine in China suffered the serious impact of tectonic stress. The deformation of the roadway was observed and the asymmetric deformation behavior was analyzed. FLAC3D was used to simulate the distribution of the stress, displacement and plastic zone with the original support. The drawbacks of the original support scheme were deficient support resistance, no effect on the asymmetric deformation and no support effect on the floor. The improved support scheme named "symmetric integrated support technology using long anchors and anchor cables" was proposed. The new support suggested increasing the length of anchors, optimizing the interval of anchors, and installing anchors in the floor. The simulation results of FLAC3D verify the improved support scheme. The deformation data of the roadway after conducting the improved support scheme was obtained. The deformation value showed a remarkable decrease and the asymmetric deformation characteristic was improved obviously. The successful application of the supporting technology provides a reference for roadways with similar geological conditions.*

Keywords: *Asymmetric deformation; asymmetric integrated support; tectonic stress; sliding cracking surround rock*

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1. INTRODUCTION

Recent decades have witnessed a rapid increase of coal production in China. As a result, the shallow coal resource in most areas of China has been almost mined out. With the mining depth increasing, plenty of new problems triggered by the deep stress have frequently appeared(Hu and Dong, 2008; Wang and Liu et al., 2009; Lu and Dou et al., 2013; Qiao and Li et al., 2014; Kouame and Jiang et al., 2017), such as water inrushes, coal bumps and support problems et al. Among these problems, support problems occupy a large proportion. As one of the most sensitive factors of support, stress in deep strata brings much more difficulties to roadway support.

Numerous research efforts have been focused on the support problems in deep coal mines. In the aspect of deep soft rock roadway support, Li and Shan et al. (2012) analyzed the mechanism bolt-beam-net support. Chen and Meng et al., (2016) used bolt-grouting to control the deformation of deep soft rock roadway. Moreover, Kang and Lin (et al., 2015) proposed improved rock bolting support for roadways in soft strata. Sun and Wu et al., (2015) investigated the support failure of a soft-rock roadway in a deep coal mine. Meng and Han et al., (2016) studied the dynamic pressure effect on soft rock roadway. In the aspect of inclined roadway support, He and Jia et al. (2010) and He (2011) conducted physical modeling of different inclined rock roadway. Song and Lei et al. (2012) studied the parameters of the surrounding gently inclined roadway. In addition, water seepage effect (Ma and Li et al., 2015) and floor heave failure (Wang and Guo et al., 2015) of the inclined roadway were also studied. Besides the above aspects, roadway deformation influenced by geological structure was also a researched hotspot. Wang and Wang et al. (2000) summarized six characteristics of soft rock roadway deformation influenced by geological factors.

The above-mentioned research is beneficial to reveal the deformation characteristics and failure process of roadway with complex stress state. However, the deformation of roadway with cracking surrounding rock under tectonic stress has not been considered in detail. This paper analyses the asymmetric deformation characteristics of such a roadway in particular. According to the deformation characteristics, an improved support scheme named "Asymmetric integrated support technology using long anchors and anchor cables" was proposed. Numerical simulation and engineering application verify the new support scheme.

2. ROADWAY FAILURE CHARACTERISTICS UNDER TECTONIC STRESS

2.1. Engineering Background

Damoling Coal Mine is located in the southwest of Xinmi City, Henan Province, China. The west ventilation roadway in this coal mine is influenced seriously by the sliding structure and large reverse fault. This roadway is built in several medium sandstone and sandy mudstone layers with a depth of 600 m. Some small-scale geological structures, such as small faults and folds, lead to a poor integrality of the surrounding rock of the roadway. Overall, the west ventilation roadway is located in sliding cracking surrounding rock under tectonic stress.

The roadway section is a semi-circular arch shape with two straight walls, shown in Fig.1. The original supporting method was bolting-wire mesh-shotcrete support. The size of anchors was 20 mm × 2000mm, with an inter-row spacing of 800 mm × 800 mm. The exposed length of anchors was 50 mm. Every anchor equipped with two volumes of resin anchoring agent. The anchoring agent type was CK2350. During the excavation process, the deformation of the roadway was so serious that U-shape steel sheds were used to strengthen support. The support parameters of U-shape steel sheds were shown in Fig.1. Nevertheless, the deformation of the roadway was still severe. The deformation of the walls reached 600 mm within one month, respectively. The deformation of the roof and the floor was also distinct. The support problem was urgent to solve.

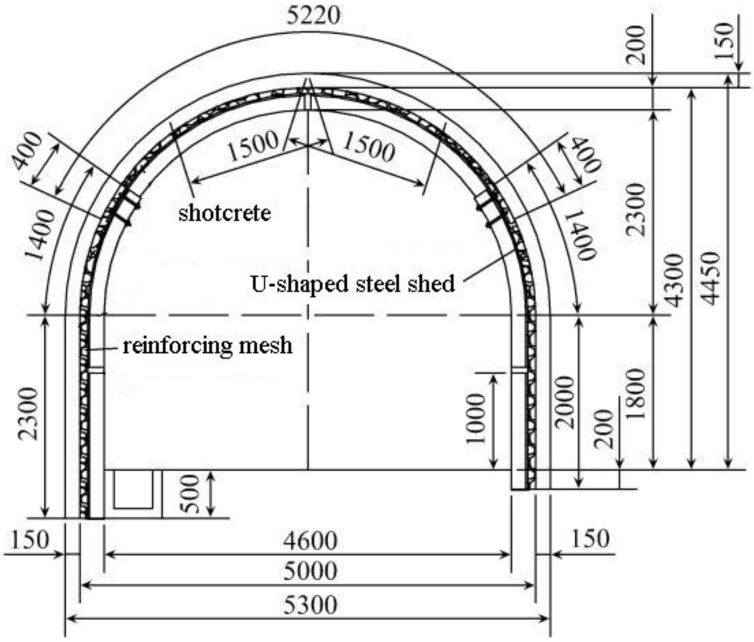


Fig1. *Original support method schematic diagram of the west ventilation roadway*

2.2. Asymmetric Deformation Characteristics of the Roadway

The support of U-shape steel sheds ignored the control of the floor, which leads to the stress release and large deformation in the floor. Taking the influence of the dip of supporting rock, the deformation characteristics of the two sides were different. Fig.2 shows the roadway deformation curve based on the measured data, the deformation position of the left side characterized at the wall and the arch, while that of the right side characterized at the floor and wall. The overall damage characteristics were large deformation of the wall, and asymmetric deformation of the floor and the arch.

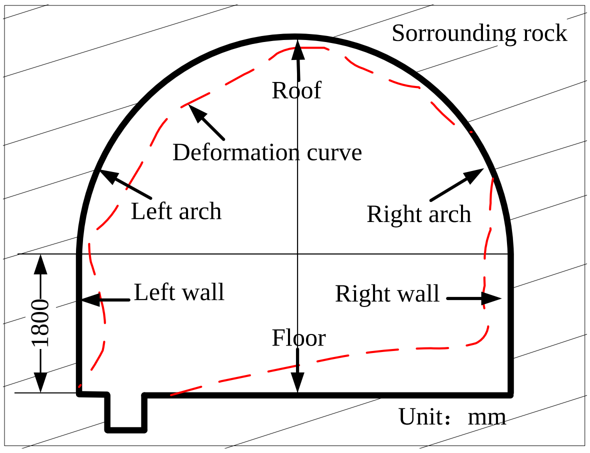
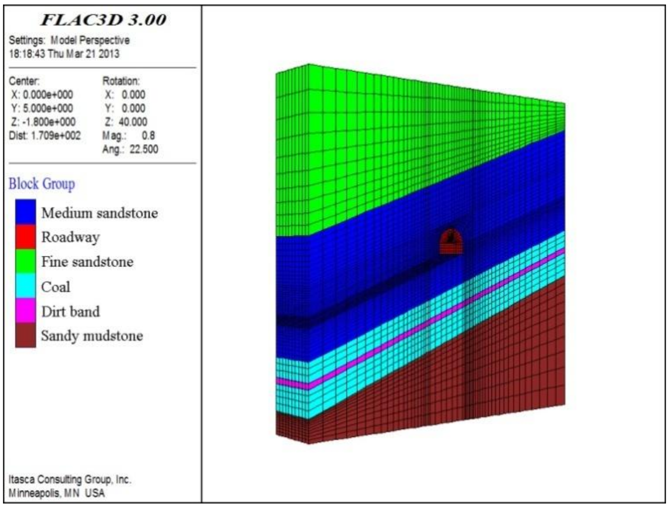


Fig2. *Asymmetric deformation schematic diagram of the west ventilation roadway*

2.3. Numerical Simulation of Roadway Deformation

2.3.1. Modeling and parameter selection

FLAC3D is used to simulate the roadway deformation. The depth of the west ventilation roadway is 600 m. Similar to the engineering background; the roadway section was a semi-circular arch with a size of 5.4 m wide and 4.5 m high. The wall is 1.8 m high. To remove the boundary influence, the size of the model is set large enough, 60 m long, 10 m wide, and 60 m high, as shown in Fig.3. The whole model contains 39120 units and 44209 nodes. The four sides of the model can move horizontally, while the bottom of the model is fixed. The top of the model is the stress boundary based on the gravity of 600-meter-thick rock, with a vertical stress of 15 MPa.


FLAC3D 3.00
Settings: Model Perspective
18:18:43 Thu Mar 21 2013

Center:
X: 0.000e+000
Y: 5.000e+000
Z: -1.800e+000
Dist: 1.709e+002

Rotation:
X: 0.000
Y: 0.000
Z: 40.000
Mag.: 0.8
Ang.: 22.500

Fig3. *Flac^{3D} model schematic diagram*

Table1. *Model mechanics parameter value table*

Lithology	Bulk modulus / GPa	Shear modulus / GPa	Tensile strength / MPa	Cohesion / MPa	Friction angle / °	Density / kg/m^3
Fine sandstone	9.0	5.4	1.2	18.63	53.5	2.6×10^4
Medium sandstone	5.0	4.8	0.9	24.32	46.2	2.5×10^4
Coal	0.5	0.2	0.1	1.8	21	1.5×10^4
Sandy mudstone	0.1	0.4	0.2	2.1	32	2.54×10
Dirt band	0.1	0.002	0.1	0.05	15	1.5×10^4

2.3.2. Deformation simulation of the roadway

U-shape steel support is used in this model. The pressure coefficient is set 1.5 based on the in-situ stress test. The U-shape steel retractable shed is simulated by beam units. According to the parameter of the U-shape steel used in the engineering, the yield bending moment is set 71240 N·m.

(1) Stress analysis

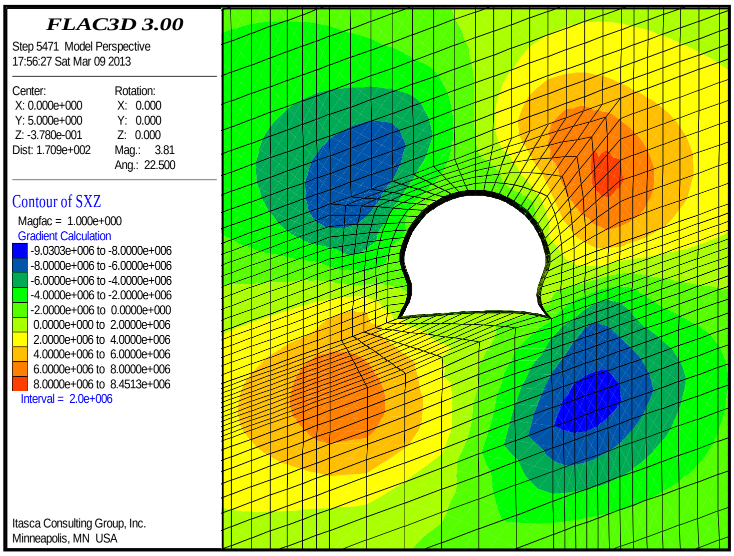
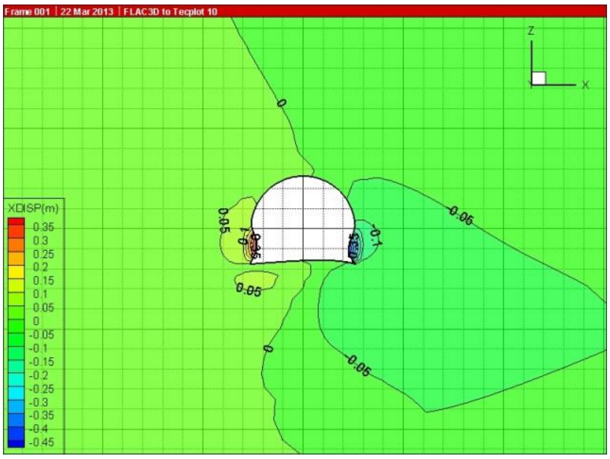


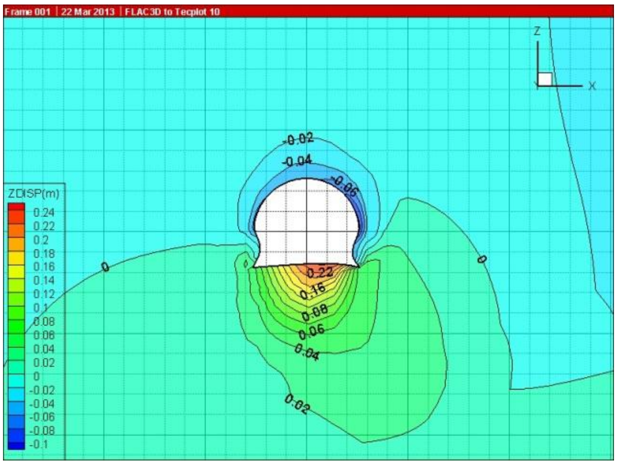
Fig4. *Shear stress distribution of the roadway*

Fig.4 shows the shear stress distribution nephogram and isoline. The shear stress state shows an obvious asymmetric behavior. In the left side of the roadway, stress concentration is located at the left arch part and stress decrease is located at the left floor. Nevertheless, the stress state on the right side is the opposite. Stress decrease appears at the arch part, and stress concentration appears at the right floor.

(2) Displacement analysis



(a)



(b)

Fig5. *Displacement distribution of the roadway with the original support scheme. (a) Displacement in the X direction. (b) Displacement in the Z direction*

From the view of the deformation of U-shape steel, the simulation results almost accord with the measured deformation data. U-shape steel sheds are able to control the shear deformation of the shallow surrounding rock. But the shortcomings of low support stiffness and poor coordination are obvious as well. As exhibited in Fig.5 (a), the deformation of the wall was rarely evident, which reaches 350 mm. The deformation of the right side was slightly larger than that of the left side. In the Z direction (shown in Fig b), the displacement of the floor was serious, reaching 240 mm. The floor heave value on the right side is larger than that on the left side. The subsidence of the roof is not obvious.

Overall, the deformation of the wall leads to the damage of U-shape steel sheds. Then the integrity of U-shape steel sheds is damaged. As the U-shape steel sheds provide no support with the floor, the floor heave is rarely serious. The floor heave and the wall displacement form a mutual improvement and vicious circle until the roadway failure happens.

(3) Plastic zone analysis

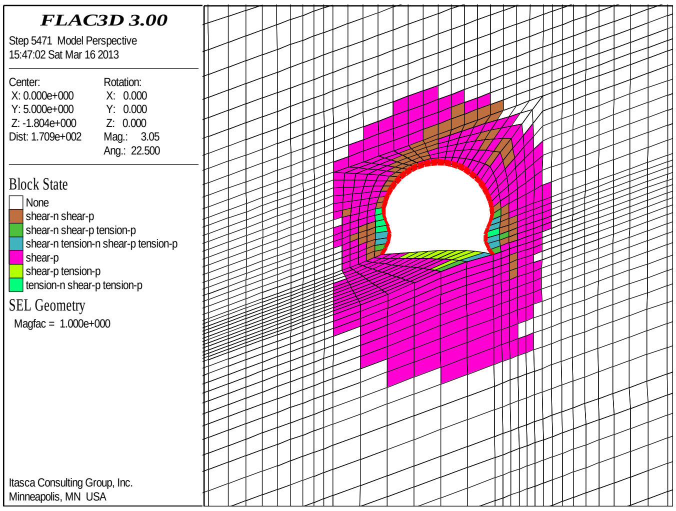


Fig6. *Plastic zone distribution of the roadway*

Fig.6 shows the plastic zone distribution of the west ventilation roadway. The tensile failure zone and shear failure zone of floor and wall are distinct. The plastic zone of the roadway surrounding rock has sizable space, especially the plastic zone in the floor. It discloses that the floor and wall are the weak part of the U-shape steel support system. The large displacement of floor promotes the deformation of the wall, which leads to the failure of the U-shape steel sheds support system.

Given the above, U-shape steel sheds are not fit for the asymmetric displacement of roadway with sliding cracking surrounding rock. The support system cannot provide enough support resistance during roadway deformation. The support ability of U-shape steel is not made full use. The deformation of floor and wall forms a vicious circle. These characteristics result in the failure of the support system.

3. IMPROVED SUPPORT SCHEME OF THE ROADWAY

According to the asymmetric deformation characteristics, the support scheme should be improved in the following aspects. Firstly, the shear deformation of the arch and wall should be controlled. Secondly, the support of the floor should be strengthened to control the floor heave. Thirdly, the support equipment in some weak parts should be strengthened to fit the asymmetric deformation.

3.1. Support Scheme Optimization

A new support scheme named “Asymmetric integrated support technology using long anchors and anchor cables” was proposed. The detailed improvements are described below. (1) The section shape keeps the same, while the size of the roadway increases slightly, 5100 mm wide, 4350 mm high. The increased size is reversed for the deformation. (2) The length of anchors is increased to 3 m to control the shear deformation of the shallow surrounding rock. (3) Anchors with enough stiffness are installed in the floor to prevent floor heave. (4) The spacing of anchors and anchor cables are adjusted in different sides to fit the asymmetric deformation. The improved support scheme is shown in Fig.7.

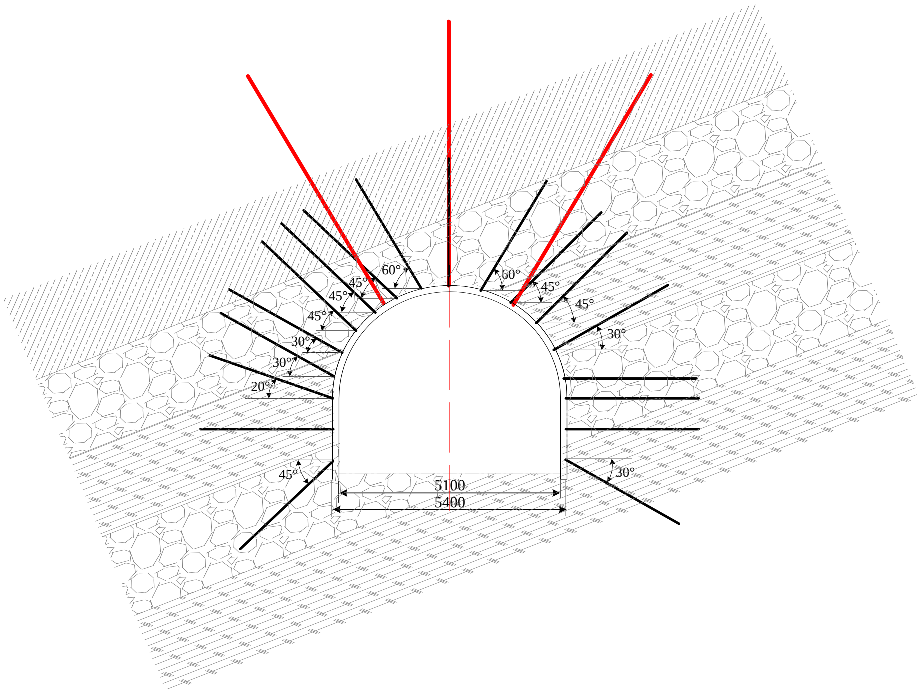


Fig7. *Improved support scheme of the west ventilation roadway*

3.2. Simulation of the Improved Support Scheme

On basis of the model built in section 2.3, the support method is replaced by the proposed "Asymmetric integrated support technology using long anchors and anchor cables". The distribution of stress, displacement, and plastic zone distribution are analyzed below.

(1) Stress analysis of the improved support

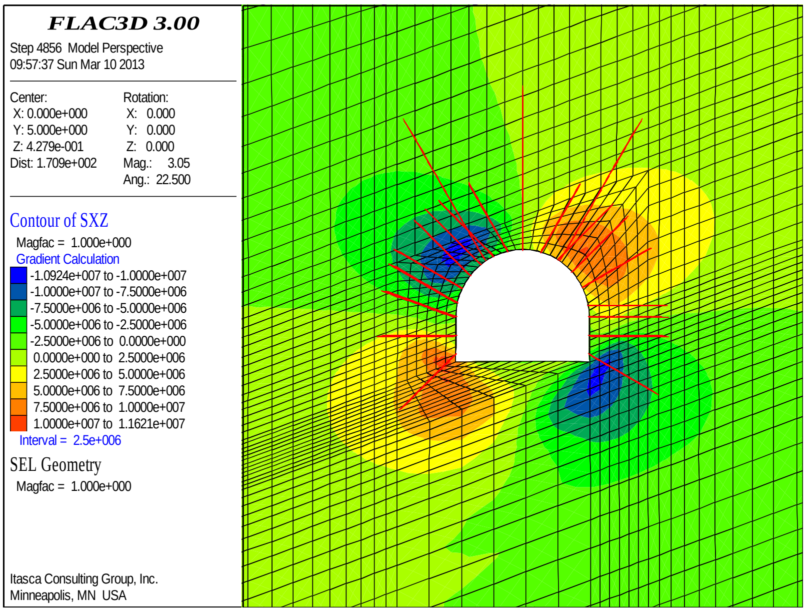
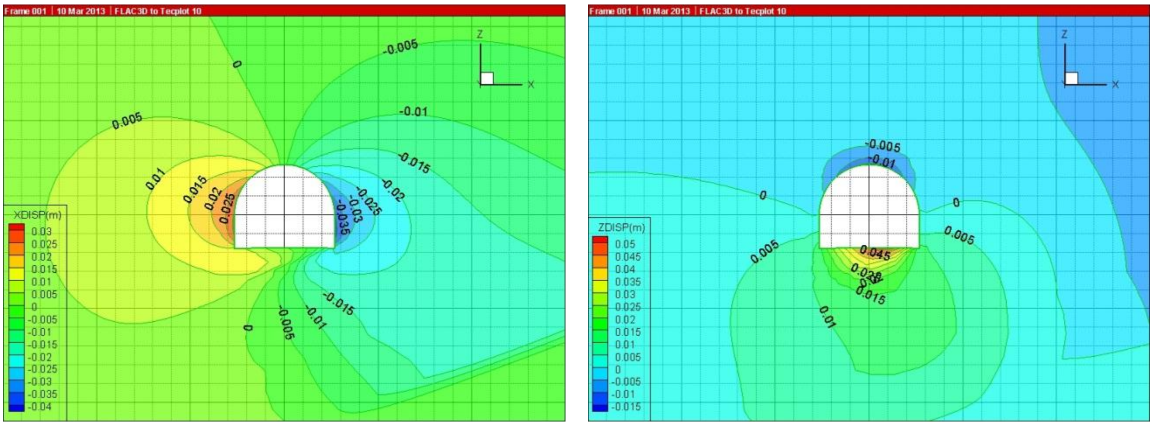


Fig8. *Shear stress distribution of roadway with new support scheme*

Fig.8 shows the shear stress distribution of the roadway with the new support scheme. The improved support scheme is able to unite the support equipment and surrounding rock to a system. Compared with the stress distribution in the original support scheme, the stress concentration of the improved support scheme in the roof and floor shows a remarkable decrease. The position of the stress concentration is effectively controlled in the shallow surrounding rock.

(2) Displacement analysis of the improved support



(a) (b)

Fig9. *Displacement distribution of the roadway with the improved support scheme. (a) Displacement in the X direction. (b) Displacement in the Z direction*

The displacement distribution of the improved support scheme is shown in Fig.9. In the X direction, the largest displacement is reduced to 35 mm. Compare the deformation of the both sides, we find the value of the right side is slightly larger than that of the left side. In the Z direction, the position of the largest displacement value has moved to the central part from the left side. The largest displacement value of floor heave is reduced to 45 mm from 220 mm. As for the roof, the largest displacement value increases slightly to 10 mm. The effect of the improved support scheme is remarkable and the asymmetric deformation presents an outstanding improvement.

(3) Plastic zone analysis of the improved support

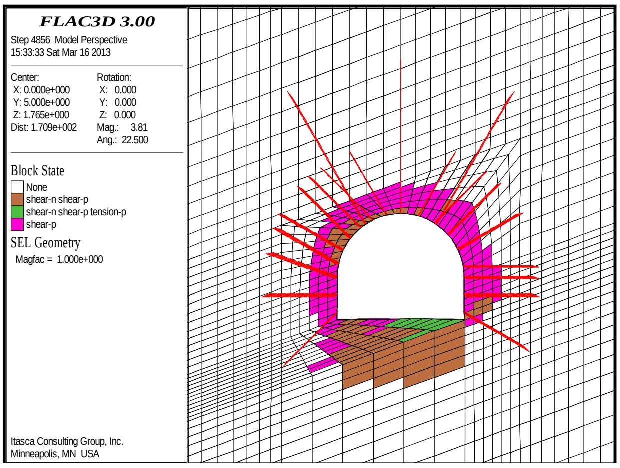


Fig10. *Plastic zone distribution of the roadway with the improved support scheme*

The plastic zone distribution is shown in Fig.10. Compared with the original support scheme, the plastic zone of the improved support scheme occupies a smaller range. The most remarkable change appears in the floor. The damage depth in the floor presents a prominent decrease, which shows that the high-strength anchors have effective control for the plastic zone in the floor. As for the wall and arch part, the damage zone shrinks obviously as well. Increasing the length of anchors has a beneficial effect on preventing the damage of deep surrounding rock. From the view of controlling the asymmetric deformation, the damage zone shows a more balanced distribution of the two sides, which indicates the anchors and anchor cables arrangement plays a significant role in balancing the deformation. In general, the improved support scheme can effectively prevent the large deformation and asymmetric deformation.

4. ENGINEERING APPLICATION

The improved support scheme was conducted in the west ventilation roadway. To verify the support effect, the roadway deformation was observed at a distance of 360 m from the ventilation shaft. The observation lasted for 45 days. Fig.11 and Fig.12 show the measured data of one observed point.

Fig.11 shows the deformation of every part of the roadway, including the roof, floor, two arches and two walls.

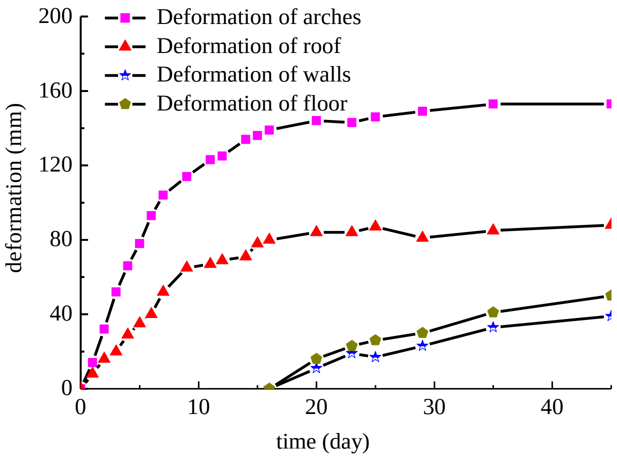


Fig11. *Deformation curves of different parts of the west ventilation roadway*

In the aspect of the arch deformation, the deformation increased sharply in the first 10 days. The deformation reached 114 mm during this period. From Day 10 to Day 25, the deformation speed slowed down with a deformation value of 35 mm. After Day 25, there was almost no increase in the arch deformation. The total deformation of the arch was 154 mm. The roof deformation showed a similar trend. Namely, drastic deformation in the first 10 days (65 mm), stable deformation from Day 10 to Day 25, and almost no deformation after Day 25. The total deformation of the arch was 91 mm. As for the deformation of two walls and the floor, the measurement points were arranged on Day 15 and the total deformation were 39 mm and 51 mm, respectively. Compared with the deformation with the original support scheme, the deformation of the whole roadway decreased sharply.

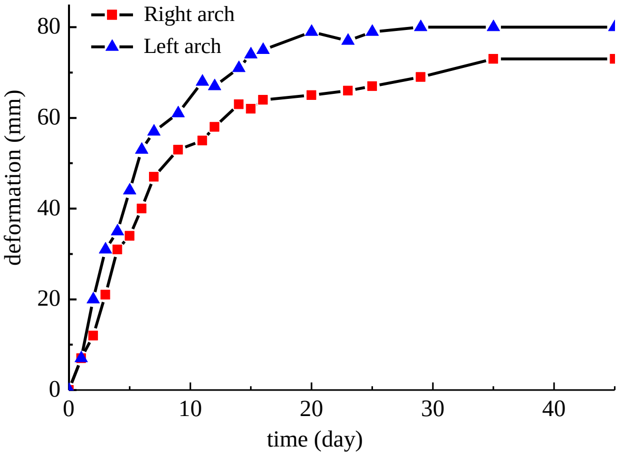


Fig12. *Deformation curves of two arches of the west ventilation roadway*

Fig.12 shows the comparison of the deformation of two arches. Two curves show a similar development process. On the whole, the right arch showed a larger deformation than the left arch, 81 mm versus 73 mm. But the total values have little difference. The asymmetric deformation has been effectively improved through the new support scheme.

5. CONCLUSION

This paper takes the asymmetric roadway deformation of a coal mine as the engineering example. The shortcomings of the original support were analyzed and the improved support scheme “Asymmetric integrated support technology using long anchors and anchor cables” was proposed. The following conclusions can be obtained:

- The deformation of the west ventilation roadway with sliding cracking surrounding rock under tectonic stress showed an asymmetric characteristic. The deformation of the left side focused on the left arch and wall, while the deformation of the right side focused on the right arch and floor.

- The U-shape steel support has the following drawbacks: insufficient support resistance, no effect on the asymmetric deformation and no support effect on the floor. These deficiencies led to the roadway support failure。
- The improved support scheme “asymmetric integrated support technology using long anchors and anchor cables” was proposed. This support scheme fits well with the asymmetric deformation characteristic and controls the roadway deformation effectively.

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