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Research Article

Failure Characteristics and Control Technology of Surrounding Rock in Deep Coal Seam Roadway with Large Dip Angle Under The Influence of Weak Structural Plane

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Abstract

In view of the unsymmetrical large deformation and failure phenomenon that often occurs after the excavation and support of the deep large dip coal seam roadway with weak structural plane, the numerical simulation analysis and Engineering Application Research on the deformation and failure characteristics of its surrounding rock are carried out. The results show that the key position of asymmetric deformation is near the weak structural plane and the intersection of the roadway section and the inclined direction of the rock. On this basis, the " unsymmetrical high prestress pressure relief coupling control technology " is put forward, and the industrial test is carried out. The practice shows that the unsymmetrical coupling support technology can not only effectively solve the differential deformation of the surrounding rock, but also ensure the coordinated deformation of the support structure and the surrounding rock, thus improving the overall stability of the roadway, greatly reducing the repair rate of the roadway and saving the support cost.

Keywords: Weak structural plane; Deep roadway; Steep inclined coal seam; Numerical simulation; Asymmetric support technology

Introduction

In recent decades, with the depletion of shallow coal resources, coal mining has gradually entered deep areas. According to statistics, the reserves of coal seams with large dip angle account for 15% - 20%, and the annual output accounts for about 10% of the total output of coal in China. In order to meet the rapid development of China's economy, the proportion of deep steep seam in China's coal mining will increase year by year [1]. However, compared with the shallow coal seam, the geological conditions of the deep coal seam will be more complex. For this kind of large dip angle, especially for the deep coal seam roadway with the influence of weak structural plane, the support problem is increasingly prominent [2]. In this paper, based on the study of deep coal seam roadway with large dip angle under the influence of weak structural plane, the mechanism of unsymmetrical large deformation and failure is deeply analyzed, and the unsymmetrical high prestress pressure relief coupling control technology is put forward, which effectively solves the technical problems of support in this kind of roadway.

The Failure Characteristics of Asymmetric Large Deformation

The research results of many scholars at home and abroad on deep coal seam roadway with large dip angle show that the lithology of roof, two sides and floor of such roadway is often different, and the strata are easy to slide and move along the weak structural plane. The main deformation characteristics are as follows [3-8]:

Because of the non-uniformity of the overall stress on the surrounding rock of the roadway, its deformation and failure have typical asymmetry;

- Due to the large dip angle, the force of gravity along the bedding direction is obviously increased, and the influence of weak structural plane and working face between the strata, the rock mass is easy to slide and move along the inclined plane;
- The side and floor of the roadway often intersect with the inclined rock stratum, which leads to the serious phenomenon of side and floor heave.

It can be seen that the mine pressure of this kind of roadway is more violent, and the stress of the supporting components is obviously asymmetric. If the traditional symmetrical supporting system of anchor mesh cable is adopted, it is easy to cause the local supporting components to be damaged due to the excessive stress, thus causing the failure and instability of the overall supporting system. As a result, the roadway often needs to be renovated many times, and the renovated roadway still cannot meet the safety production demand of the mine, and the support cost is greatly increased. Therefore, it is urgent to find a safe and efficient support technology to solve such problems.

Simulation Analysis on the Process of Surrounding Rock Failure of Asymmetric Large Deformation Roadway

In order to understand the mechanism of unsymmetrical large deformation and failure of deep and steep seam roadway under the influence of weak structural plane, taking Dayuan coal 1201 working face as an example, the numerical simulation software FLAC3D is used to simulate the deformation and failure of surrounding rock of roadway under the condition of no support and original support respectively.

Engineering background

Dayuan coal mining field is located in the southeast wing of Ningwu coal field syncline, with a Northwest tendency in stratigraphic form. Among them, working face 1201 is located in the deep part of the well field, with a large dip angle (45° on average and 60° at maximum). It is greatly affected by structural forces and gravity, and the structure is relatively complex. The average buried depth of the mining roadway of 1210 working face is 800m, which is arranged along the coal seam floor. The roof strata of the roadway are claystone and sandstone, and the floor strata are sandy mudstone and mudstone, in which the false roof is claystone, which is easy to cross caving; there is weak structural plane between the false roof and the immediate roof, which is easy to separate and slip; the hardness of the roof, floor and coal seam are small. According to the in-situ stress test results, the maximum principal stress at -800m level in Dayuan coal industry is horizontal stress, which is 32.5MPa. The traditional symmetrical support form of "bolt net spray + anchor cable + steel belt" was used in the tunnel. At the beginning of the tunnel excavation, the local support components were damaged and failed, the floor heave of the tunnel was serious, and the two sides of the tunnel were deformed greatly. After many times of maintenance and repair, the tunnel still could not meet the needs of mine safety production.

Numerical model

According to the engineering geological conditions of Dayuan coal 1201 working face, the numerical simulation software FLAC3D is used to establish the numerical calculation model. Considering all factors, the inclination of rock stratum is taken as 45 degrees, and the model is simplified: the model size is 150m×50m ×80m, the section of mining roadway is straight wall semicircle arch, in which the straight wall height is 2.0m, the bottom width is 4.3m, and the net radius of semicircle arch is 2.15m. A contact surface is set between the pseudo roof and the direct roof to simulate the weak structural surface. The whole numerical model is divided into 77060 units and 87120 nodes. Boundary conditions of the model: the boundary around the model defines horizontal displacement, the boundary at the bottom of the model defines vertical displacement, and the top boundary of the model imposes a uniform load of 2.5×10 4×800= 20MPa equivalent to the gravity of the overlying strata (the burial depth is calculated as 800m). Considering the measured in-situ stress results, the lateral pressure coefficient is taken as 1.5. Cable element is used to simulate anchor rod and anchor cable, beam element is used to simulate reinforced joist, shell element is used to simulate concrete spray layer. The numerical calculation model is shown in Figure 1, and the physical and mechanical parameters of each coal seam and rock layer are shown in Table 1.

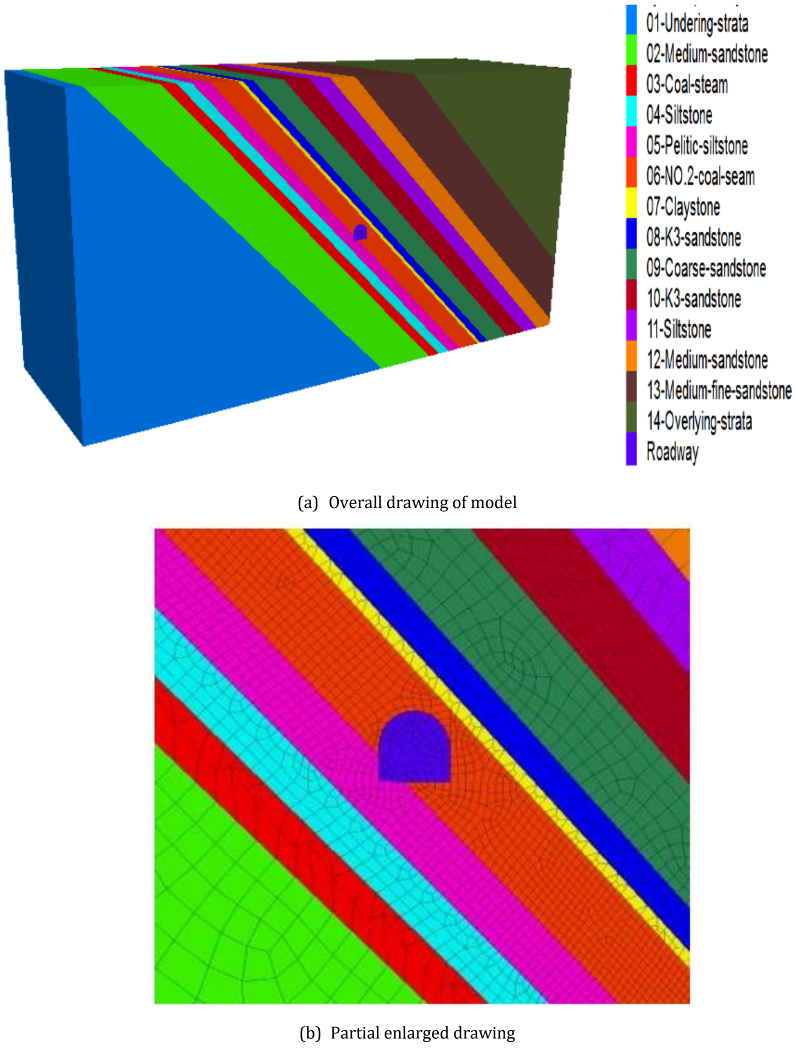


Figure 1: Numerical calculation model diagram.

Table 1: Mechanical parameters of coal and rock.

Lithology	Thickness(m)	Elastic Modulus (GPa)	Poisson ratio	Cohesion (MPa)	Internal friction angle (°)	Density (kg/m³)
Undering strata	60	3	0.21	2.3	34	2500
Medium sandstone	12	3.9	0.18	3.3	35	2680
Coal seam	1	0.8	0.3	0.5	25	1400
Siltstone	2.6	2.2	0.22	1.26	33	2690
Pelitic siltstone	2.8	1	0.27	0.8	28	2090
NO.2 coal seam	5	0.8	0.3	0.5	25	1400
Claystone	0.8	0.9	0.29	0.6	26	1800
K3 Sandstone	2	1.4	0.22	2.1	32	2200
Coarse sandstone	8	1.8	0.23	1.2	31	2400
K3 Sandstone	5	1.4	0.22	2.1	32	2200
Siltstone	4.2	2.2	0.22	1.26	33	2690
Medium sandstone	5.3	3.9	0.18	3.3	35	2680
Medium fine sand-stone	13.2	2.1	0.31	2.2	33	2560
Overlying strata	42	3	0.21	2.3	34	2500

Original support parameters

The section shape of the mining roadway in working face 1201 is straight wall and semicircle arch, the width of the roadway is 4300mm, the height of the straight wall is 2000mm, and the net radius of the semicircle arch is 2150mm. The traditional symmetrical support method of "bolt mesh spraying + anchor cable + reinforced joist" is adopted. The specific support scheme is as follows:

Bolt support:

a. Top bolt: the model of the top bolt is BHR500, Φ 22mm × L2400mm left-hand threaded steel bolt. The row spacing between the bolts is 1000mm × 800mm, each row of the top bolt is 6, and the anchorage length is 1200mm. The bolt is installed vertically on the roadway roof.

b. Side bolt: the specification of side bolt is the same as that of top bolt. The row spacing between the bolts is 800mm × 800mm, with 3 bolts in each row. The distance between the bolts and the bottom plate is 300mm, 1100mm and 1900mm respectively. The anchoring method and length of the anchor bolt are the same as that of the top anchor bolt. The anchor bolt near the floor of the roadway side is installed obliquely with an angle of 15° and the direction is downward. The rest of the anchor bolts are installed vertically on the roadway surface.

Anchor cable support:

a. Top anchor cable: the roadway anchor cable is made of 1 × 19 high-strength and low relaxation prestressed steel strand with a diameter of 22mm. The length is 7300mm, the anchoring length is 3967mm, and the anchoring method is lengthening anchoring. The row spacing between anchor cables is 1100mm × 1600mm, with 5 cables in each row, all installed vertically on the roadway surface.

Matching accessory support: The anchor bolt tray shall be 150 mm × 150 mm × 8 mm high -strength adjustable center support plate and matching nuts. The anchor cable tray shall be 300 mm × 300 mm × 16 mm high-strength adjustable center support plate and matched lock. The horizontal connection component of anchor bolt adopts double reinforced joist with model of Φ 16 × 2200mm × 120mm, and the surrounding rock surface of roadway adopts diamond mesh with mesh size of 150 mm × 75 mm and diameter of 4 mm.

Primary shotcreting support: The surface of the surrounding rock of the roadway shall be sprayed with a concrete spraying layer with a thickness of 30-50mm. The concrete strength grade is C20.

The original support model is shown in Figure 2.

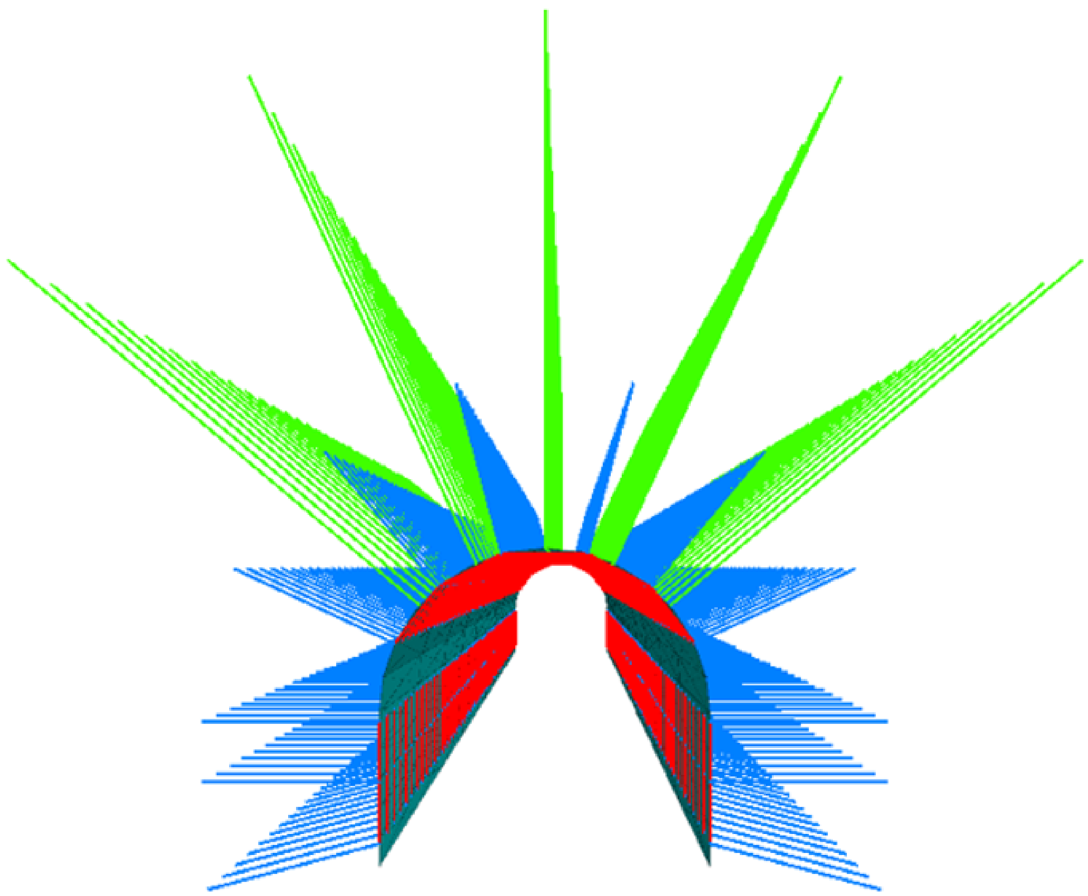
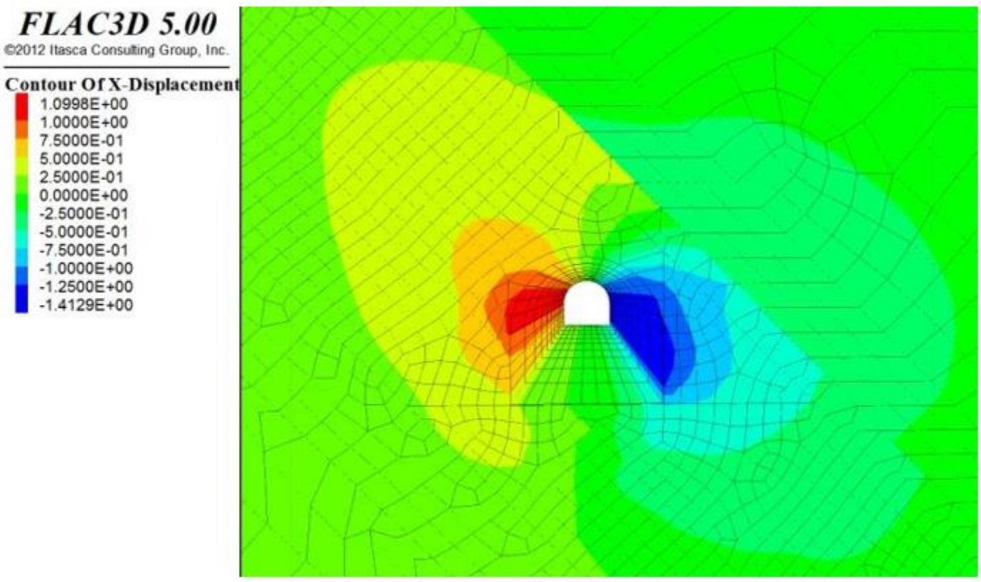


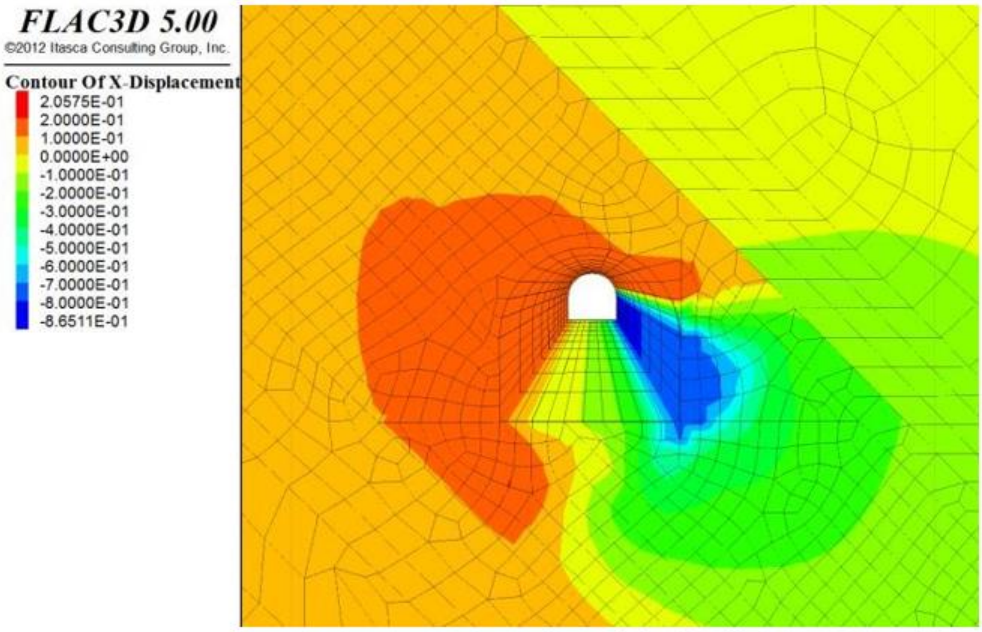
Figure 2: Original support model.

Analysis of simulation results

Figure 3 and Figure 4 respectively show the horizontal displacement cloud chart and vertical displacement cloud chart of the surrounding rock of the roadway under the condition of no support and original support. Figure 5 and Figure 6 are respectively the distribution diagram of the plastic zone of the surrounding rock and the shear displacement nephogram of the weak structural plane of the roof slate under the conditions of no support and original support.

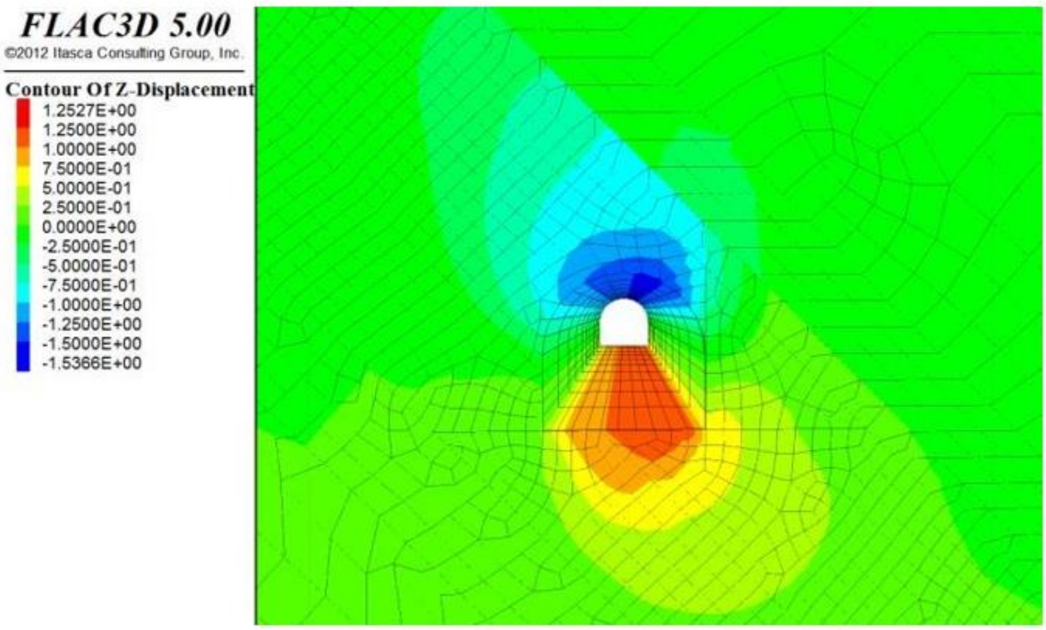


(a) Without support

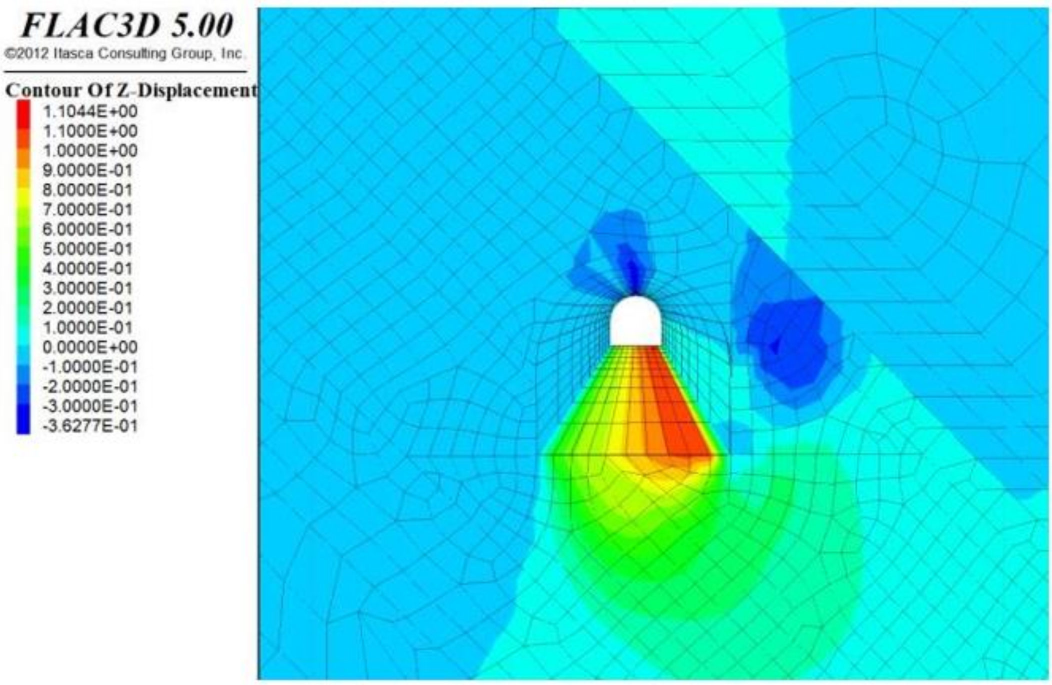


(a) Original support

Figure 3: Nephegram of horizontal displacement of surrounding rock of roadway.

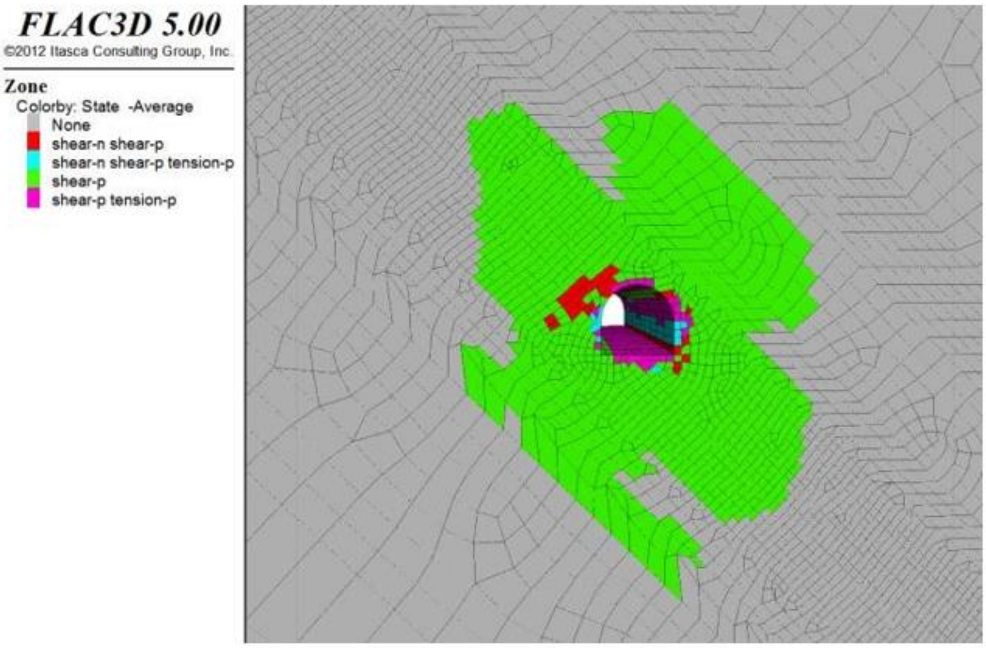


(a) Without support

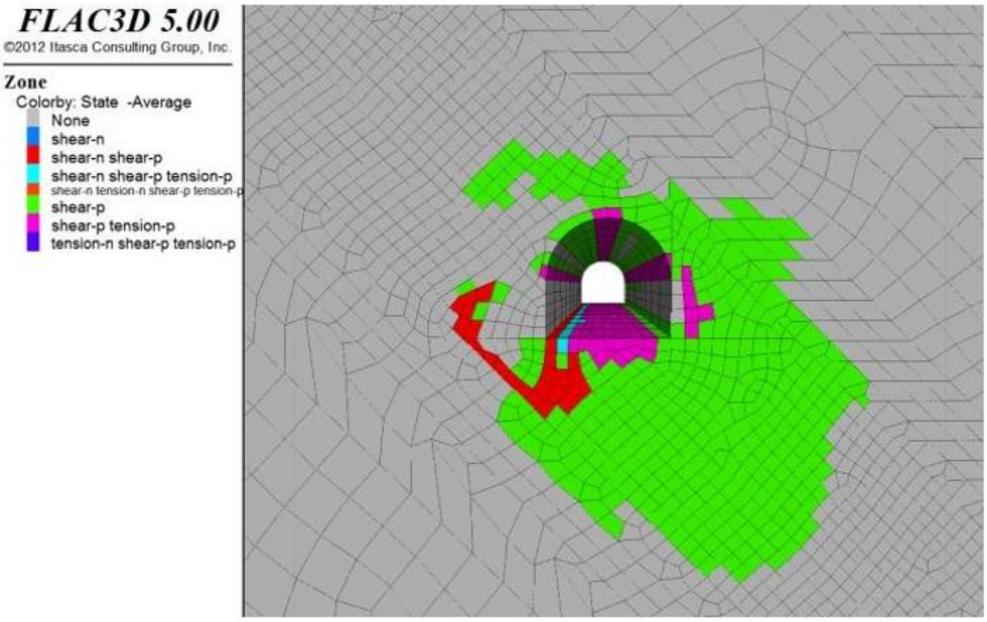


(b) Original support

Figure 4: Nephegram of vertical displacement of surrounding rock of roadway.



(a) Without support



(b) Original support

Figure 5: Distribution of plastic zone in surrounding rock of roadway.

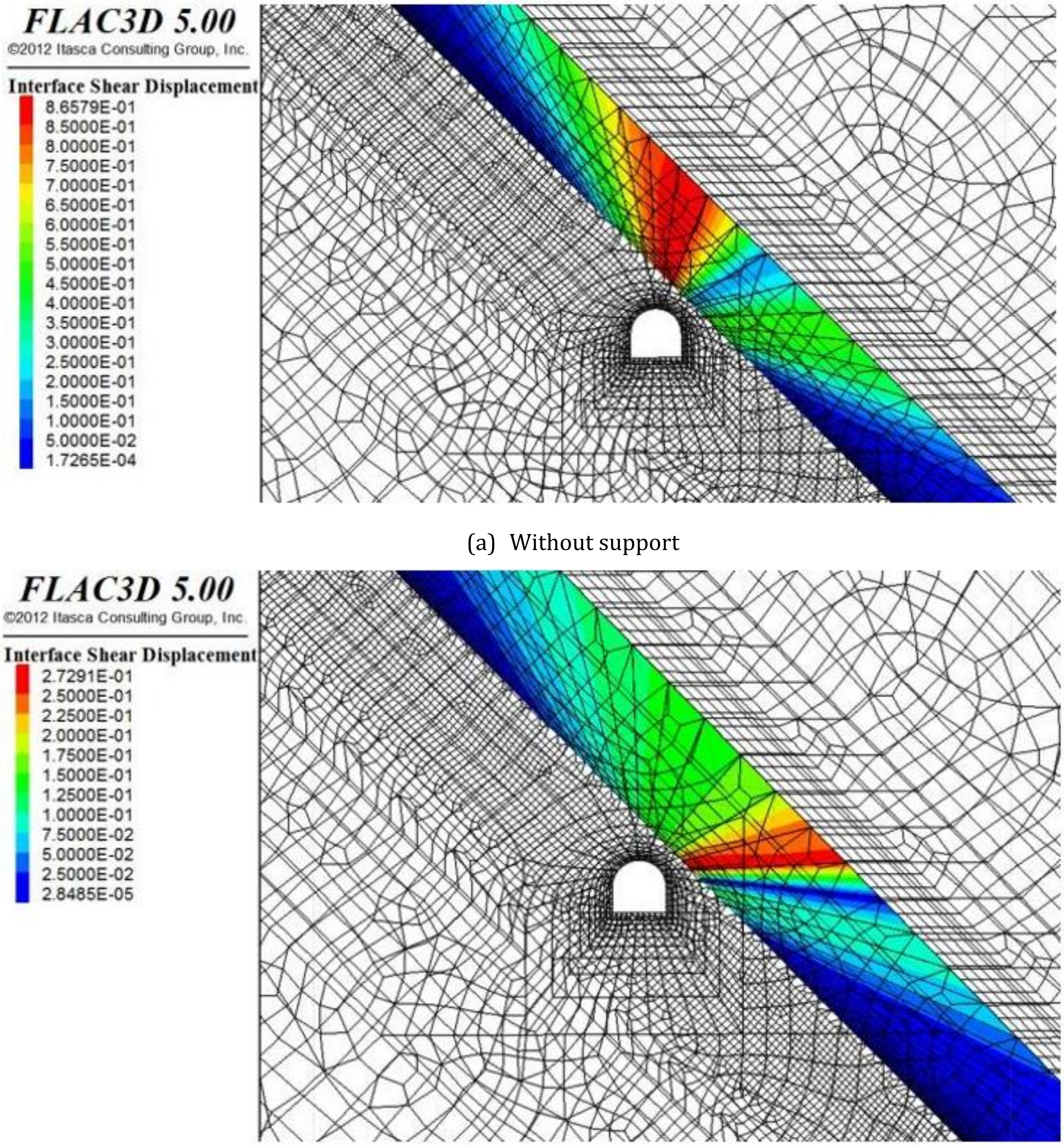


Figure 6: Nephogram of shear displacement on weak structural plane of roadway roof strata.

From the displacement point of view, it can be seen from Figure 3 and Figure 4 that the deformation of the surrounding rock of the roadway shows obvious asymmetry under the condition of no support. The maximum displacement of the left side is concentrated near the left shoulder of the roadway, that is, the intersection of the roadway section and the inclined direction of the rock stratum, with the value of 1100mm; the maximum displacement of the right side is concentrated near the lower right side of the roadway, with the value of 1413mm; the subsidence of the roof is on the right side Obviously larger than the left side, the maximum subsidence reached 1537mm; floor heave was serious. Due to different lithology of floor strata (argillaceous siltstone on the left side and coal seam on the right side), floor heave was obviously shifted to the right side, with the maximum value of 1253mm.

Under the condition of original symmetrical support, although the deformation of surrounding rock of the roadway has been controlled to some extent, the deformation is still large and shows obvious asymmetry. Among them, the maximum displacement of the left side is still concentrated near the left shoulder of the roadway, with a value of 206mm; the maximum displacement of the right side is obviously further shifted to the lower right side of the roadway, with a value of 865mm; the maximum subsidence of the roof is mainly concentrated in the roadway At the right shoulder of the roadway and the top of the roadway, the value is 363mm; the floor still has a serious floor heave phenomenon, the distribution rule is the same as that without support, and the maximum value is 1104mm.

From the perspective of plastic area distribution, it can be seen from Figure 5 that under the condition of no support, the overall distribution of plastic area is large, showing a typical asymmetry. Among them, the plastic area at the lower left and upper right of the roadway is relatively prominent, with the damage depth of about 6.8m at the lower left and 7.3m at the upper right. At the same time, the shear damage at the left shoulder of the roadway (i.e. the intersection of the roadway section and the inclined direction of the rock stratum) is relatively serious. Under the original support condition, the distribution range of the plastic area at the left side and the roof is significantly smaller than that without support, but the overall distribution is significantly smaller The distribution still shows typical asymmetry. Among them, the plastic area of the upper left and right sides of the roadway roof is relatively prominent. The damage depth of the upper left side is about 4.1m, and the damage depth of the right side is about 5.0m. At the same time, part of the left side of the roadway is connected with the plastic area of the floor. No matter what kind of working condition, the roadway floor shows obvious tensile failure characteristics. Based on the analysis of the slip and dislocation of the rock strata near the weak structural plane of the roadway roof, it can be seen from Figure 6 that the maximum value of the shear displacement on the weak structural plane of the roadway roof is located directly above the roadway roof, with a value of 0.87m, and the slip and dislocation of the rock strata of the roadway roof are mainly concentrated above the roadway roof; The shear displacement value on the weak structural plane of the roof slate layer of the roadway is significantly reduced under the constraint of the original support structure. The maximum value

is located at the right shoulder of the roadway, and its value is 0.27m. Moreover, the staggered sliding interval of the roof strata of the roadway is mainly concentrated near the right shoulder of the roadway.

Analysis of the Mechanism of Asymmetric Large Deformation and Failure

Based on the data of numerical simulation, field investigation and field measurement of ground stress and structure distribution, the failure mechanism of surrounding rock in deep coal seam roadway with large dip under the influence of such weak structural plane can be summarized as the following:

Failure mechanism of slip and dislocation of weak structural plane

Due to the long-term tectonic movement of natural rock mass, there are various directional and non-directional weak structural planes, and the strength, deformation and failure of rock mass are mainly controlled by these weak structural planes. Under the secondary stress caused by the excavation of the roadway, the weak structural plane of the roof slate layer produces slip and dislocation, which changes the lateral pressure exerted on the surrounding rock of one side of the roadway, and then causes the destruction of the surrounding rock of the roadway. The larger the slip and dislocation deformation, the greater the impact on the deformation and failure of the surrounding rock of the side of the roadway close to the weak structural plane. At the same time, the location of the maximum shear slip of the weak structural plane directly determines the distribution of the overall deformation of the roadway. Therefore, due to the influence of the weak structural plane on one side of the roadway, the deformation and damage of the upper right and lower right side of the roadway roof are significantly greater than other parts.

Asymmetric failure mechanism of rock structure and lithology

Because of the influence of rock occurrence in this area, the rock structure and lithology on both sides of the roadway show a high degree of asymmetry. Under the same stress condition, the internal stress of the surrounding rock on both sides of the roadway will show asymmetry, which will cause the asymmetric deformation and damage of the surrounding rock. Especially at the intersection of the roadway section and the inclined direction of the rock stratum, due to the different lithology and structure, the deformation and failure of the left side of the roadway and the floor show a typical asymmetry.

Deep high stress tensile shear failure mechanism

Because of the large depth of the tunnel and the influence of the structural stress, the surrounding rock of the tunnel is often in a high stress environment. After the excavation of the tunnel, the stress is redistributed. Although the high stress develops to the depth of the surrounding rock, the surrounding rock on the surface of the tunnel suddenly changes from the original stable three-way stress state to the unstable two-way stress state, so that the strength of the surrounding rock is relatively reduced, the stress of the surrounding rock is relatively increased, and the surrounding rock is prone to tensile failure (such as roadway floor under the action of high horizontal stress on both sides) or shear failure (such as one-way lateral pressure caused by slip and dislocation of weak structural plane) under this high stress state.

Control Technology of Unsymmetrical Large Deformation Failure

Unsymmetrical high prestress pressure relief coupling control technology

Engineering practice and research results show that [9-13], for the deep coal seam roadway with large dip under the influence of weak structural plane, because the weak structural plane between the roof strata of the roadway is easy to move and separate, the roadway is located in a large ground stress, and the inclined direction of the rock layer and the roadway section are prone to generate concentrated stress, which leads to the failure of the local support components in the traditional bolt mesh cable support, and then causes the damage of the whole support system of the roadway. The traditional support cannot effectively control the harmful deformation of the roadway, and the roadway repair frequency is high, and the maintenance effect is poor.

Therefore, in order to solve the problem of unsymmetrical large deformation support in deep coal seam with large dip under the influence of this kind of weak structural plane, the unsymmetrical high prestress pressure relief coupling control technology is proposed. The control idea of the technology is as follows:

- Asymmetry: strengthen the support near the weak structural plane of the roof rock layer of the roadway and the intersection of the inclined direction of the rock layer and the roadway section. The support of other parts is normal, and the overall support is asymmetric;
- High prestress: the main role of high prestress support is to control the expansion deformation of the separation, sliding, crack opening and new crack generation of the surrounding rock in the anchorage area which can make the surrounding rock in compression state, restrain the occurrence of bending deformation, tension and shear failure of the surrounding rock, and make the surrounding rock become the main bearing body. At the same time, the prestressed bearing structure with high rigidity is formed in the anchorage zone, which can prevent the separation of strata outside the anchorage zone, especially near the weak structural plane, and improve the stress distribution in the deep part of the surrounding rock;
- Pressure relief: the pressure letting support refers to the support measures that can closely stick to the surrounding rock or penetrate into the rock mass, effectively exert the self-supporting capacity of the surrounding rock, allow the surrounding rock to deform and damage to a certain extent, even when the whole movement is made with the strengthened rock mass, it can still ensure a considerable support resistance. Generally, by adding pressure relief device (such as pressure relief ring or double bubble pressure relief pipe, see Figure 7 for details) to anchor rod and anchor cable, bird's nest anchor cable with large elongation and good expansion performance (as shown in Figure 8) is adopted to relieve and release the high stress near the surrounding rock of roadway by allowing a small amount of common deformation of support components and surrounding rock, so as to improve the stress environment of surrounding rock of roadway.

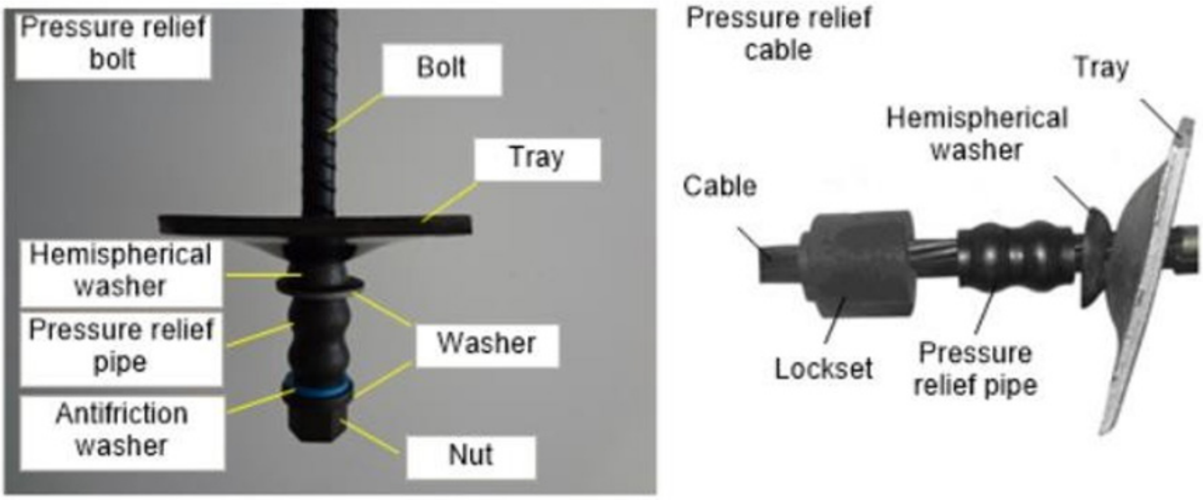
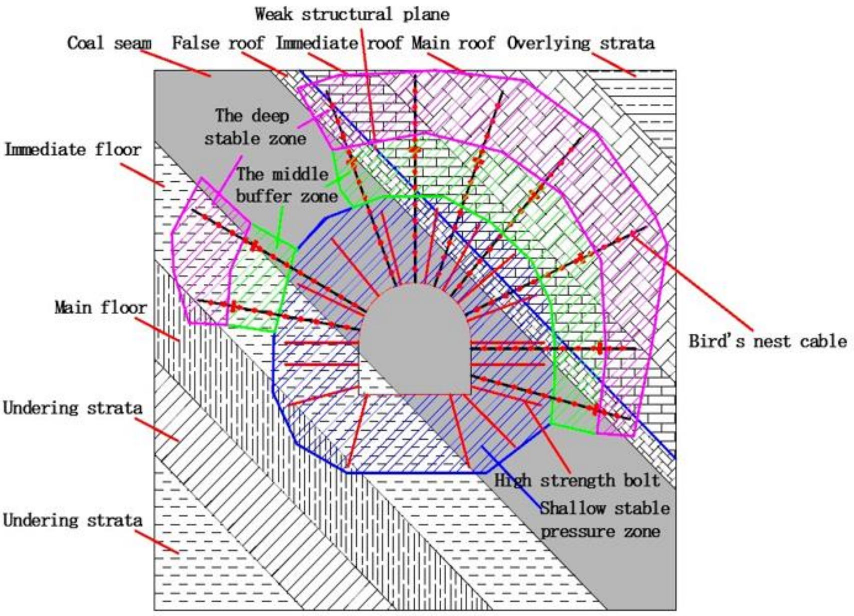


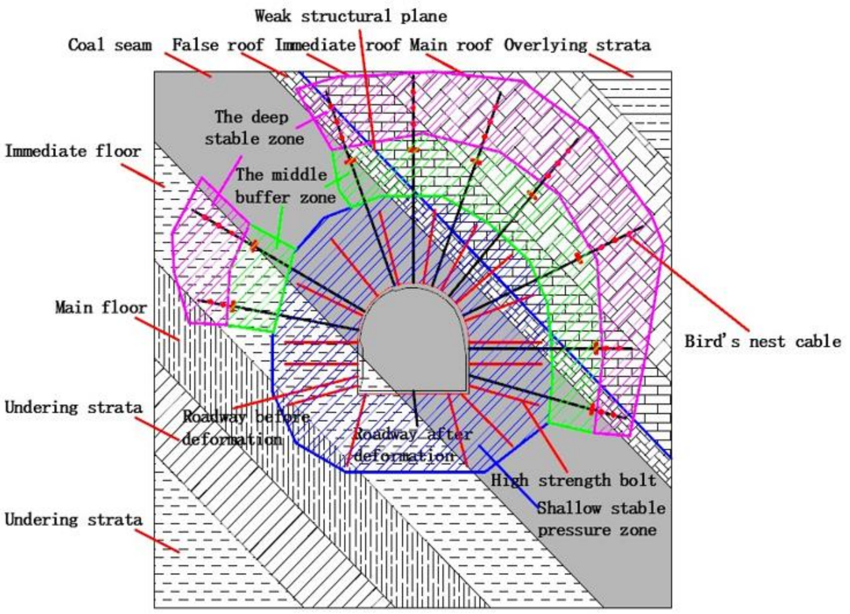
Figure 7: Structure diagram of yield bolts (cables).

Figure 8: Structural sketch of bird's nest anchor cable.

The main principle of the technology is shown in Figure 9. After the excavation of the tunnel, firstly, the high prestressed anchor rod is used to form a mutually connected and overlapping pressure stress zone in the shallow part of the surrounding rock, in which the key parts are reinforced, i.e. the shallow stable pressure zone shown in the figure; secondly, the bird's nest anchor cable with good pressure performance (good elongation) and guarantee the anchoring effect is used to anchor the whole shallow bearing structure zone to the deep stability of the surrounding rock in the fixed rock stratum, the deep stable zone shown in the figure is formed; at the same time, the bird's nest in the free section of the bird's nest anchor cable can be stretched along with the common deformation of the surrounding rock and the support body, so as to release the high stress in the surrounding rock and make the roadway in a low stress environment, so as to play a pressure relief buffer role, that is, the middle buffer zone in the figure. The purpose of this technology is to reasonably utilize the interaction of surrounding rock structure and supporting components, reduce the high stress around the roadway and increase the pressure release performance of supporting components, and realize the asymmetric high prestress pressure release coupling support for this kind of asymmetric large deformation roadway. Finally, a safe and economic asymmetric support technology system is formed.



(a) Before deformation



(b) After deformation

Figure 9: Schematic diagram of asymmetrical high prestress pressure relief coupling control technology.

Analysis on the control effect of unsymmetrical high prestress relief coupling technology

In order to verify the rationality of unsymmetrical high prestress relief coupling control technology, taking Dayuan coal 1201 working face as an example, the numerical simulation software FLAC3D is used to simulate and analyze the surrounding rock support effect under the condition of unsymmetrical high prestress relief coupling control technology.

The numerical calculation model and the mechanical parameters of surrounding rock are the same as before. The supporting parameters of "unsymmetrical high prestress and pressure release coupling" of roadway are as follows:

Bolt support:

a. Top bolt: the model of the top bolt is BHR500 left-hand threaded steel bolt with specification of Φ22mm×L2800mm. The top bolt is arranged asymmetrically. The spacing between the top bolts on the non-mining side is 800mm×800mm. The spacing between the top bolts on the mining side is 1000mm×800mm. There are 7 bolts in each row. The anchorage length is 1200mm. The bolts are installed vertically on the roadway roof.

b. Side bolt: the parameters of side bolt are the same as the original support, but the length of anchor rod changes from 2400mm to 2800mm.

c. Bottom bolt: the bottom bolt is arranged in an asymmetric way. The row spacing between the bottom anchor bolts on the non-mining side is 500mm×800mm, three in each row (one on the mining side and two on the non-mining side). The horizontal distance between the anchor bolts on both sides near the roadway side and the roadway side is 300mm, and the inclination is 15°. The anchor r od on the non-mining side is 45°. The anchoring method and length of anchor bolt are consistent with that of top anchor bolt.

Pressure relief device shall be added for all anchor bolts.

Anchor cable support: All cables are made of 1 × 19 strands of high-strength and low relaxation prestressed steel strand with a diameter of 22mm. The whole cable body is equipped with a new type of bird's nest cable which can be stretched freely.

a. Top anchor cable: the top anchor cable is arranged in an asymmetric way. The row spacing between the top anchor cables on the non-mining side is 900mm × 1600mm, with a length of 9300mm. The row spacing between the top anchor cables on the mining side is 800mm × 1600mm, with a length of 6300mm and 9300mm, with 7 cables in each row, with a length of 3967mm. The anchoring method is lengthening anchoring, which is installed vertically on the roadway surface.

b. Side anchor cable: the anchor cable is only arranged on the non-mining side of the roadway, with a spacing of 1000mm × 1600mm and a length of 6300mm. There are two cables in each row. The anchor length and anchor method are the same as the top anchor cable. The anchor cable near the bottom plate is installed at an angle of 15°, and the rest are installed vertically on the roadway surface.

Pressure relief device shall be added to all anchor cables.

Matching accessory support: Channel steel is used as the longitudinal connection component of anchor cable, and other parameters are the same as the original support.

Primary shotcreting support: Same as the original support

Floor reinforcement support [14]: The bottom of the roadway floor shall be undercover first, then the stone cushion shall be laid for leveling, and finally the concrete floor construction shall be carried out. The thickness of the concrete floor is 300 mm, and the concrete floor construction shall reach the design height of the roadway after completion. During the construction, the concrete with different strength grades (C20 and C30) is used for pouring the roadway floor with different lithology.

The optimized support model is shown in Figure 10.

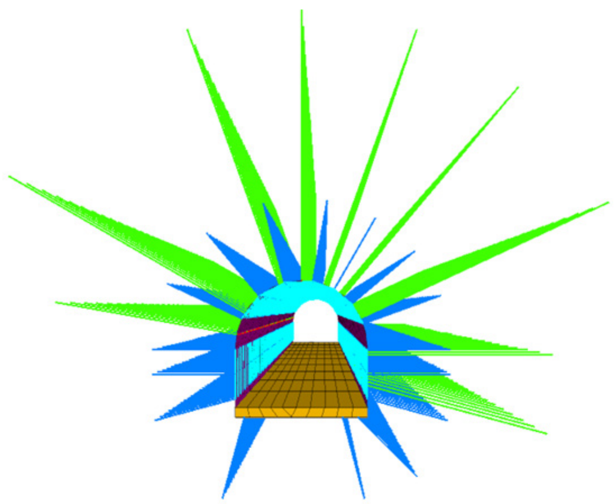
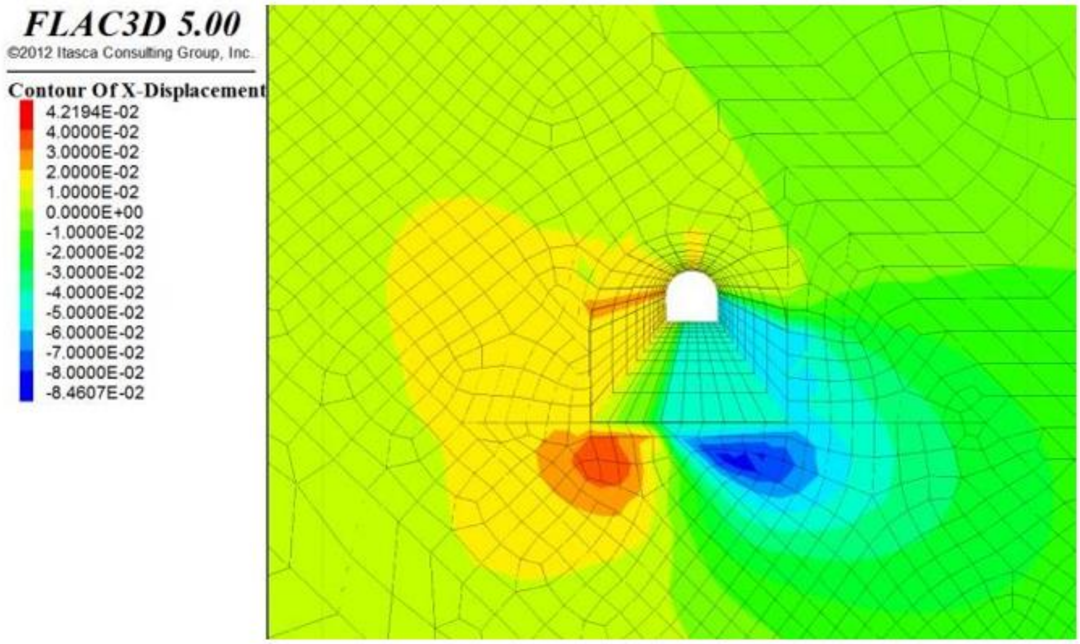
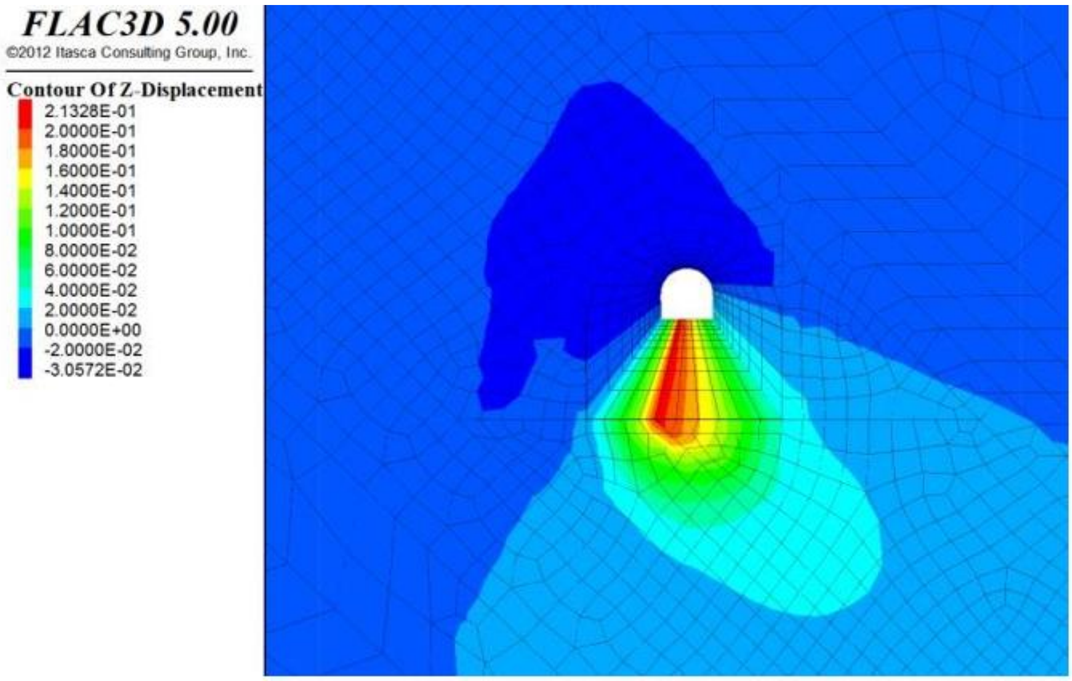


Figure 10: Optimized support model.

Figure 11 and Figure 12 are the displacement nephogram of surrounding rock and the distribution diagram of plastic zone under the optimized support condition respectively. Figure 13 shows the nephogram of shear displacement on the weak structural plane of roadway roof under the optimized support condition. Table 2 shows the statistical table of surrounding rock deformation and other indicators under the original and optimized support conditions (both are maximum values).



(a) Horizontal displacement



(b) Vertical displacement

Figure 11: Nephogram of displacement of roadway surrounding rock.

Figure 12: Distribution of plastic zone in surrounding rock of roadway.

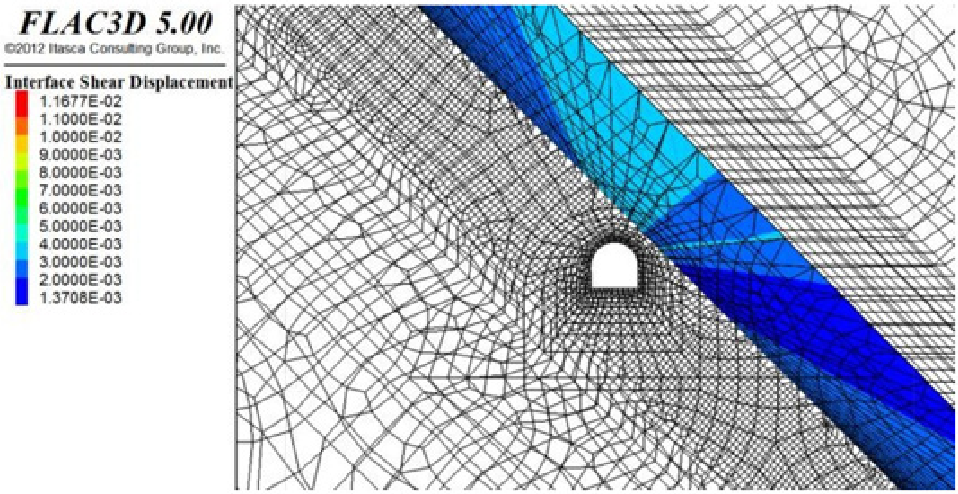


Figure 13: Nephogram of shear displacement on weak structural plane of roadway roof strata.

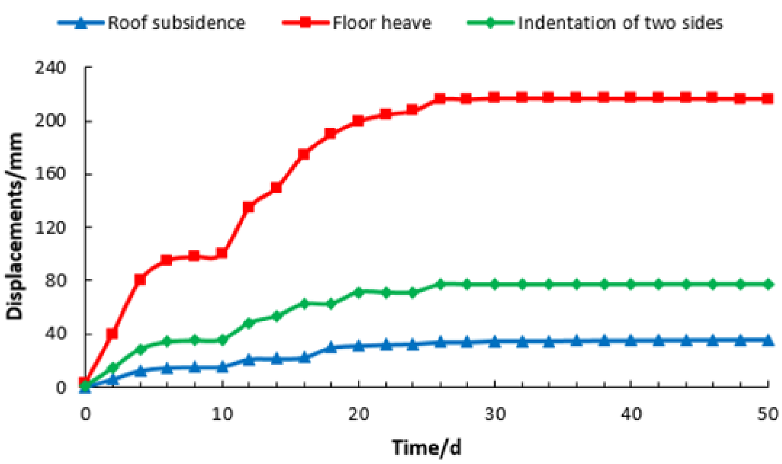


Figure 14: Displacement time curve of roadway surrounding rock.

Table 2: Statistical table of deformation index of surrounding rock of roadway.

Support scheme	Left side indent/ mm	Right side indent/ mm	Roof subsidence/mm	Floor heave /mm	Shear displacement of weak structural plane /mm
Original support	206	865	363	1104	270
Optimized support	25	55	31	213	5

It can be seen from the simulation results that the deformation of surrounding rock and the range of plastic zone are not only effectively controlled, but also distributed symmetrically. Among them, the maximum value of horizontal displacement is transferred to the deep part of the floor, the maximum displacement of the left side is 25mm, the maximum displacement of the right side is 55mm, and the maximum displacement of both sides are located in the middle of the roadway side; the maximum value of roof subsidence is 31mm, which occurs in the upper part of the roadway to the left, and the maximum value of floor heave is about 213mm, which is located in the middle of the floor. The range of plastic zone has been improved obviously. There is almost no plastic zone in the roof, only a small amount of plastic zone in the two sides, only a certain range of plastic zone in the floor, and the failure depth is about 3.8m. At the same time, the sliding and dislocation of the roof strata of the roadway are effectively controlled. The maximum shear displacement on the weak structural plane of the roof strata of the roadway is located at the upper right side of the roadway, which is about 5mm.

It can be seen from table 2 that the supporting effect of the optimized supporting scheme is far superior to that of the original one, which further explains the rationality of the asymmetric high prestress let pressure coupling control technology. The optimized scheme not only effectively controls the key parts of the roadway that are easy to lose stability and damage (i.e. the parts near the weak structural surface of the roadway roof and the intersection of the roadway section and the inclined direction of the rock), but also makes the roadway The whole displacement deformation and plastic area of surrounding rock are controlled within the allowable scope of the project, and the displacement deformation is distributed symmetrically, and the deformation of all parts of the tunnel almost reaches a stable state at the same time.

Engineering Application Effect

The above research results have been applied in the later construction project of 1201 working face. According to the real-time monitoring curve of the deformation and time change of the surrounding rock of the roadway (as shown in Figure 14), after the excavation of the roadway, it has successively gone through the initial stage of severe deformation (0-10 days), the middle stage of slow deformation (10-30 days) and the later stage of stable deformation (30-50 days), respectively corresponding to the rapid adjustment period of the surrounding rock stress of the roadway, the period of coordinated deformation between the support and the surrounding rock and the surrounding rock of the roadway Stress stability period. Among them, the subsidence of roadway roof is 36mm, the floor heave is 217mm, and the two sides' indentation is 78mm, which is basically consistent with the numerical simulation results.

The application of the results further verifies the correctness of the unsymmetrical high prestress pressure relief coupling support theory, which not only realizes the purpose of the coordinated deformation and support of the roadway support components and the surrounding rock of the roadway, but also solves the support problems of such roadway, and meets the requirements of the mine safety production.

Conclusion

Through the study of the failure mechanism and control technology of the surrounding rock of the deep coal seam roadway with large dip under the influence of weak structural plane, the following conclusions can be drawn:

- The surrounding rock of this kind of roadway often has the characteristic of large deformation and failure under the action of typical high stress, that is, the key part (i.e. near the weak structural plane of the roadway roof and the intersection of the roadway section and the inclined direction of the rock stratum) first loses stability and the overall deformation presents asymmetry.
- The existence and effective control of weak structural surface of roadway roof is very important for the support of the whole roadway. This kind of roadway should give priority to strengthening the support of surrounding rock near the weak structural surface, and at the same time, make the support components meet the requirements of flexible yielding and anti-coordination.
- It is necessary to strengthen the unsymmetrical coupling support control measures for the asymmetric distribution characteristics of the surrounding rock lithology structure of the roadway, especially for the intersection of the roadway section and the inclined direction of the rock stratum.
- The engineering application results show that the unsymmetrical differential deformation of surrounding rock and the instability of key parts can be effectively controlled by using the unsymmetrical high prestress pressure relief coupling control technology, and the overall stability of the roadway can also be greatly improved.

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Conflict of Interest

No conflict of interest.

References

1. Yang Huapeng (2019) Coal situation development report analysis of great changes and development trend of coal industry in New China in 60 years.
2. Hongwei Wang, Yaodong Jiang, Sheng Xue, Lingtao Mao, Zhinan Lin, et al. (2016) Influence of fault slip on mining-induced pressure and optimization of roadway support design in fault-influenced zone [J]. Journal of Rock Mechanics and Geotechnical Engineering 8(5): 660-671.
3. Dong Yuxi (2019) Research on asymmetric deformation mechanism and control technology of roadway in inclined soft coal seam [D]. China University of mining and technology.
4. Wu Yongping, Jiepanshi, Ren Shiguang (2010) Analysis of spatial asymmetric structure characteristics of surrounding rock in large dip seam mining [J]. Journal of coal industry 35(2): 182-184.
5. Wu Hai (2014) Evolution law of non-uniform deformation and stability control of deep inclined rock roadway [D]. China University of mining and technology.
6. Kulatilake PHSW, Wu Qiong, Yu Zhengxing, Jiang Fuxing (2013) Investigation of stability of a tunnel in a deep coal mine in China [J]. International Journal of Mining Science and Technology 23(4): 567-577.
7. Yang Zengqiang, Liu Chang, Tang Shichuan, Dou Linming, Cao Jinglong (2018) Rock burst mechanism analysis in an advanced segment of gob-side entry under different dip angles of the seam and prevention technology [J]. International Journal of Mining Science and Technology 28(6): 891-899.
8. Hu Shaoxuan (2018) Study on stability analysis and control technology of surrounding rock of roadway in steep seam [D]. China University of mining and technology.
9. Hu Shaoxuan, Ma Liqiang, Guo Jinshuai, Yang Peiju (2018) Support-surrounding rock relationship and top-coal movement laws in large dip angle fully- mechanized caving face[J]. International Journal of Mining Science and Technology 28(3): 533-539.
10. Xiao-meng Li, Zhan-bo Cheng (2015) Safe Effective Key Mining Technologies of Fully Mechanized Caving Face in Steeply Dipping Seam[C]. International Informatization and Engineering Associations, Atlantis Press. Proceedings of 2015 International Conference on Management Science, Education Technology, Arts, Social Science and Economics (MSETASSE 2015).
11. Xie Shengrong, Li Erpeng, Li Shijun, Wang Jinguang, He Chongchong, et al. (2015) Surrounding rock control mechanism of deep coal roadways and its application[J]. International Journal of Mining Science and Technology 25(3): 429-434.
12. Ma Rui, Li Guichen, Zhang Nong, Liu Cong, Wei Yinghao, et al. (2015) Analysis on mechanism and key factors of surrounding rock instability in deeply inclined roadway affected by argillation and water seepage[J]. International Journal of Mining Science and Technology 25(3): 465- 471.
13. Zhang Bei, Cao Shenggen (2015) Study on first caving fracture mechanism of overlying roof rock in steep thick coal seam[J]. International Journal of Mining Science and Technology 25(1): 133-138.
14. Wang Meng, Guo Guanlong, Wang Xiangyu, Guo Yu, Dao Vietdoan (2015) Floor heave characteristics and control technology of the roadway driven in deep inclined strata [J]. International Journal of Mining Science and Technology 25(2): 267-273.