Stabilization Control Techniques for a Roadway in Deep High-Stress Soft Surrounding Rock

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Abstract - **In order to solve the instability of roadways in deep high-stress soft rock, this paper proposed four supporting schemes for controlling the deformation of surrounding rock by using the horizontal roadway of -980m level refrigeration underground chamber in Xinhe Mining. Grouting and full section anchoring support, grouting and enclosed U36 steel support, grouting + enclosed U36 steel and full section anchoring support, and grouting + enclosed U36 steel + full section anchoring + masonry lining are proposed to control the deformation of surrounding rock according to the specific conditions of the mine. In view of the field engineering geological analysis, combined with laboratory tests, field monitoring, theoretical analysis and numerical simulation, the mechanism of deformation instability and supporting measures were studied. The numerical simulation results show that the grouting and enclosed U36 steel + full section anchoring support is more ideal, and achieved good economic and technical results.**
Keywords - **Soft rock roadway, Deep high stress, mine pressure monitoring, curve fitting**

With the continuous increase of the depth of coal mining, coal production process has encountered a series of outstanding problems. Expansion of soft rock is particularly prominent. When the rock mass is disturbed, especially when the water is in the water, the lithology changes greatly. This has a huge expansion pressure on the construction of the building, and seriously affect the stability of the project. Deep mining is different from the shallow mining conditions, especially in the deep part of the extremely complex geological structure, soft rock high stress, weak and broken surrounding rock conditions of mining. It is very difficult to maintain the roadway in the deep conditions, and it will put forward higher and more stringent requirements for supporting design.

In view of the deep roadway support problem, domestic and foreign experts and scholars have conducted a lot of research, and achieved a series of results, However, the research on the problem of the chamber supporting of soft broken surrounding rock in deep mine is few. In view of the current situation of coal, coal enterprises to bear repaired for many times repeated investment. Therefore, to explore deep weak broken surrounding rock of chamber deformation instability mechanism, in search of economic reasonable supporting technology become the urgent need to resolve important issues.

I.ENGINEERING SURVEY

With a burial depth over 1,000 meters, the horizontal roadway of Xinhe Mining's -980m horizontal refrigerating chamber is under high stresses and, due to other complicating factors, the roadway deformation would be great and the support would be very challenging. The -980 horizontal chamber is subject to a maximum principal stress of 28.41~28.66MPa, which is nearly horizontal, forming an included angle less than 20° with the horizontal plane. The uniaxial compressive strength of the rock is 20.24MPa, as established in a direct rock jacking test, making shear failure highly probable, and the tensile strength is 2.25MPa; the rock is generally of poor strength. This region is characterized by high ground stress levels yet the surrounding rock is of poor

strength, with the ground stress being 1.40~1.42 times the uniaxial compressive strength of the surrounding rock. High ground stress and low surrounding rock strength are therefore found to be the major causes leading to roadway deformation and destabilization.

II. FLAC³ᴰ NUMERICAL SIMULATION

2.1 Establishment of three dimensional numerical model

In light of the field situation and the actual circumstances, a model of 50m×10m×40m in dimensions was created, for which the field ground stresses were simulated by applying external forces to the surface of the model. Given the ground stress testing results, the numerical simulation was performed using a vertical external load of 24.8MPa and a horizontal external load of 28.5MPa. For the simulation, the constitutive model was based on Mohr-Coulomb theory.FLAC³ᴰ three-dimensional model is shown in Figure 1.
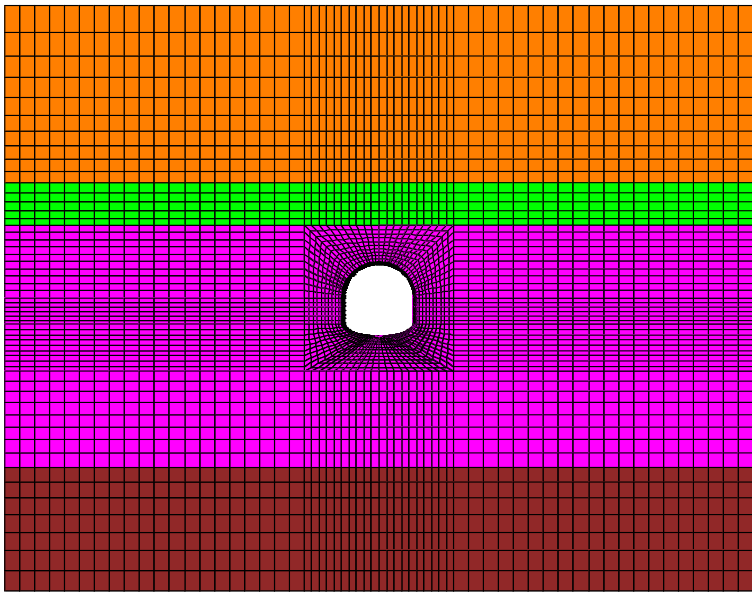

Fig. 1 numerical model diagram

The physical and mechanical properties and parameters of the rock material were made available using a tri-axial compressive test on a laboratory MTS rock servo testing machine. Results are shown in Table 1. Basic mechanical parameters of bolt and U36 steel as shown in Table 2,3.

Table 1 Rock mechanical parameter table

name	density /kg/m^3	Tensile /MPa	cohesion /MPa	Internal friction angle /°	Shear modulus /GPa	Bulk modulus /GPa
Mudstone	2400	2.25	1.5	30	2.65	3.5
Sandstone	2550	3.1	2.6	27	3.34	4.6

Table 2 Mechanical parameter table of anchors

name	Elastic modulus /GPa	tensile /kN	prestress /kN	diameter /mm	cohesion /(kN/m)	Internal friction angle /°	rigidity /MPa	Outer circumference /mm
figure	200	130	60	20	2000	30	17	110

Table 3 Mechanical parameter table of U36

model	Sectional area/cm^2	theoretical weight /(kg/m)	Inertia moment /cm4	Elasticmoduls/GPa	Tensile rigidity /kN	Flexural rigidity /(kN·m^2)
U36	44.69	35.87	928.65	200	9.138×10^5	1857.3

2.2 Numerical simulation of supporting structure

The numerical simulation of the following four kinds of supporting methods are carried out for the -980 level refrigeration chamber of New River mining industry

(1)Solution I full-section anchoring (anchored cable) support and grouting mode, Supporting parameters:Φ20×2200mm full thread steel bolt,anchoring spacing 800×800mm， Φ21.8mm×6200mm(1*17 strands) anchored cable spacing 800×1600mm。

(2)Solution II Grouting+enclosed U36 section steel+full-section anchoring (anchored cable)steel support model. Supporting parameters：U36 Steel shed and Closed bottom arch，Spacing shed 800mm，Pouring concrete anti bottom arch.

(3) Solution III Grouting+enclosed U36 section steel+full-section anchoring (anchored cable). Supporting parameters:U36 Steel shed and Closed bottom arch，Spacing shed 800mm，Pouring concrete anti bottom arch；1000mm lengthening anchorage，Φ20×2200mm full thread anchor rod @800×800mm, and Φ21.8mm×6200mm (1*17 strands) tendon，anchoring

(4) Solution IV: Grouting+enclosed U36 section steel + full-section anchoring (anchored cable) + masonry crown. Supporting parameters： U36 steel shed ，anchoring spacing 800×800mm + closed bottom arch；Φ20×2200mm full thread anchor rod @800×800mm, and Φ21.8mm×6200mm (1*17 strands) tendon，anchoring spacing 800×1600mm. 500mm thick reinforced concrete masonry crown, with reinforcement Φ20mm @300* 300mm.

The simulation model of the four schemes is shown in Fig. 2
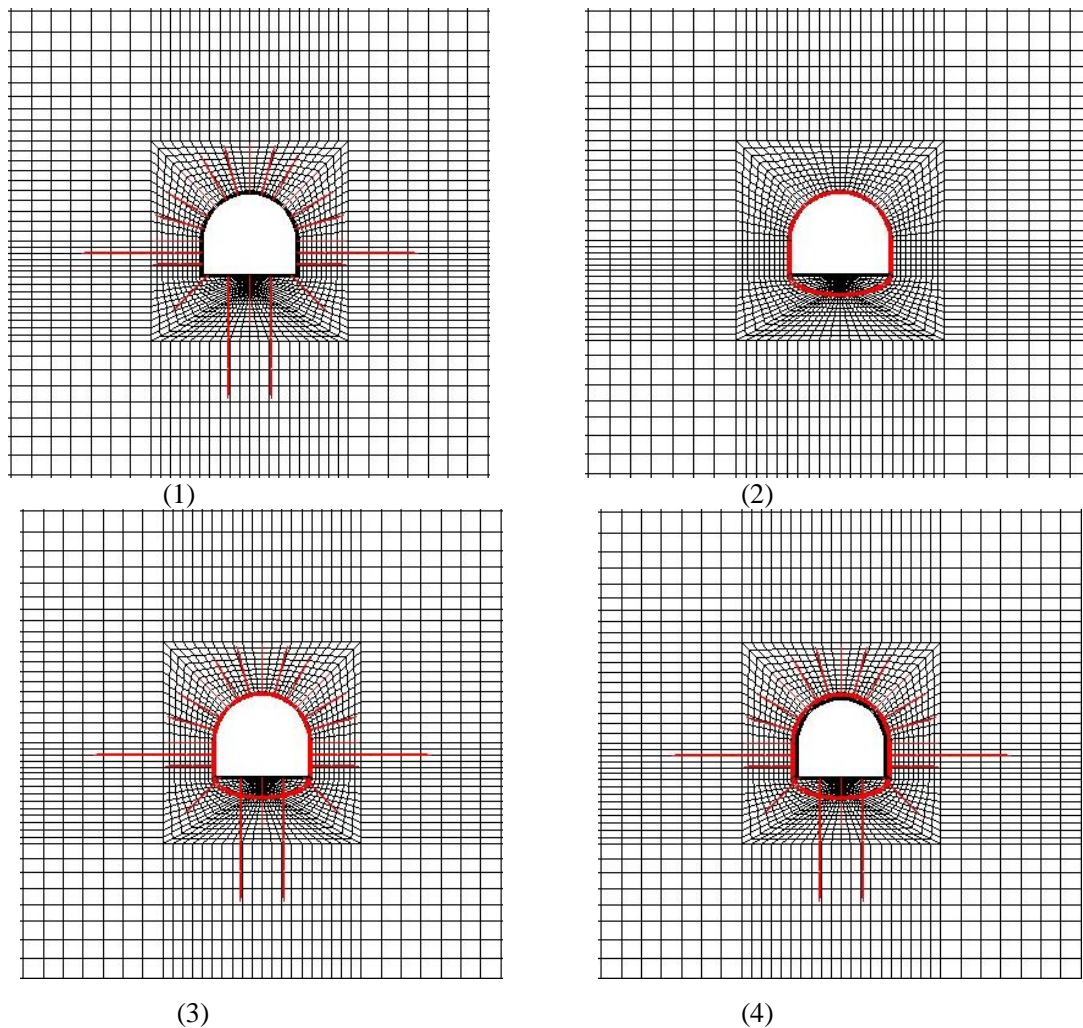

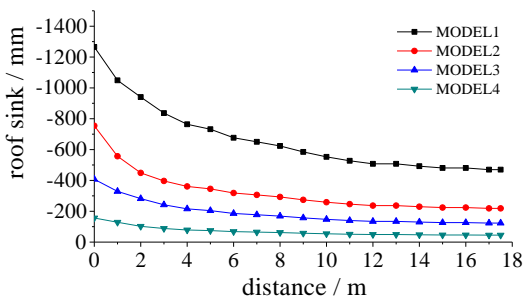| (1) | (2) |
| (3) | (4) |

Fig. 2 Simulation Scheme

III.ANALYSIS OF NUMERICAL SIMULATION

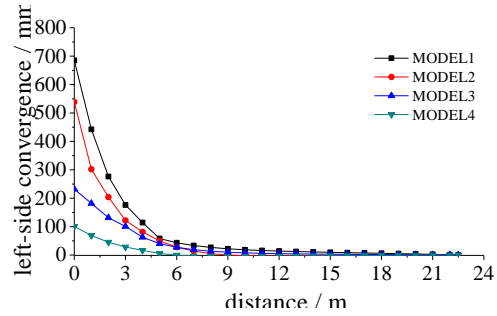### 3.1 Analysis of displacement evolution law after excavation

Different types of post-excavation support were simulated. The patterns of vertical displacement and settlement evolution as subsequently simulated for the roof, the left side wall, and the floor of the roadway under different conditions are shown in Fig. 3.

From Fig. 3 it is found by comparing the roof settlement amounts that the four models behave in a similar pattern in roof settlement, with a minimal influence experienced from excavation when the distance is at 10m; the four solutions produce a roof settlement of 1279.8mm, 795.6mm, 400.7mm, and 214.3mm respectively. Model I produces the largest settlement among the four m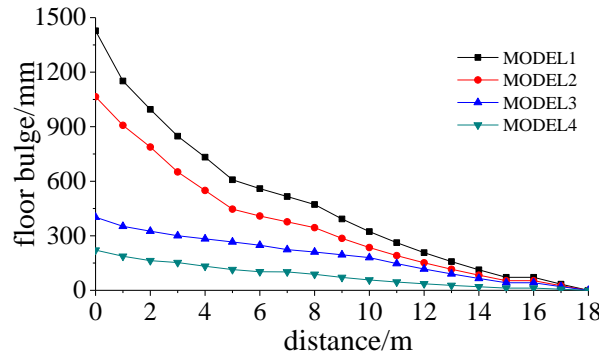odels, and the roadway will be surrounded by extremely unstable rock; the subsidence of the model III or IV is relatively small, and the stability of the surrounding rock is in accordance with the requirements .The left side wall develops a maximum displacement of 685mm, 538.7mm, 211.2mm, and 100.5mm respectively in the four support solutions. The displacement in the left side wall tends to stabilize down from 8m away outwards, where the influence of excavation is less; model III or IV, the displacement is relatively small, and the change of displacement is same.It is clear from the floor displacement variation that the floor heave is maximum in a scope from the cutting face to a level 14m below the roadway bottom; the four models have a maximum floor heave of 1427.5mm, 1064.8mm,332.2mm, and 241.3mm respectively, but the influence of excavation becomes minimal when the distance exceeds 14m.

（a） Roof subsidence evolution curve

（b） roadway's sides Close evolution curve

（c） Evolution curve of bottom drum

Fig. 3 Displacement curves of surrounding rock after tunnel excavation

3.2 Analysis of the evolution law of stress after excavation

Fig. 4 shows the post-excavation surrounding rock stress evolution pattern. As is evident, excavation may influence the roof rock stress within a range up to 9m, with Model I having the largest influence variation (up to 3.1Mpa). In Model III, the stress variation is relatively small, as low as 0.9MPa. The post-excavation stress variation in the left side diminishes with the distance and the effect of excavation becomes minimal when the distance reaches 10m, Model I producing a stress variation of 3.0MPa, the largest of the four models. The stress variation, 1.0MPa, occurs in Model III.The floor rock stress varies in a similar pattern to the roof or the left ride, and 11m is found to be the critical distance, beyond which the influence

of excavation becomes minimal; Model III produces relatively small stress variation. After analysis of the displacement and stress evolution pattern of the models corresponding to the four solutions, and reference to the actual economic and technical solution，III has been retained as the optimal choice.
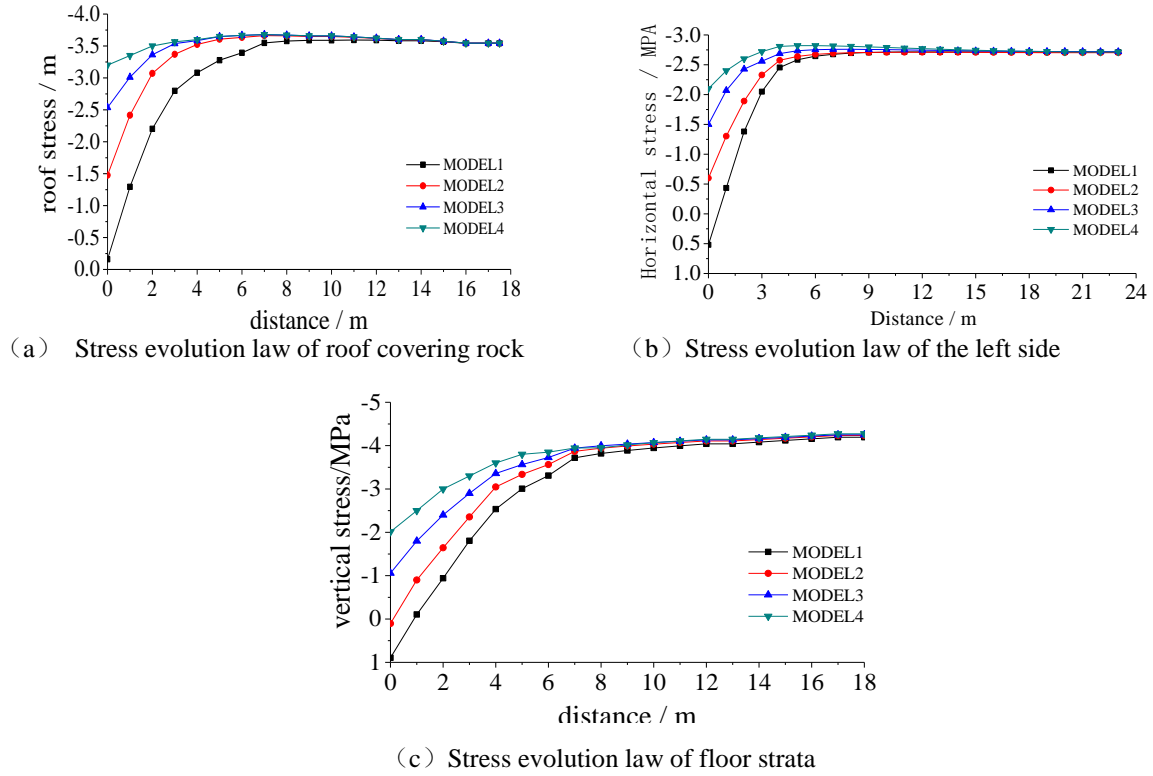

（a）Stress evolution law of roof covering rock

（b）Stress evolution law of the left side

（c）Stress evolution law of floor strata

Fig. 4 Stress evolution law of surrounding rock after tunnel excavation

IV. ENGINEERING APPLICATIONS

From the geotechnical condition, the monitored roadway deformation and failure patterns, and the FLAC^{3D} numerical analysis and practical economic and technical conditionsof different support solutions for Xinhe Mining's -980m refrigerating chamber, it arrives that the optimal support solution is grouting + enclosed U36 section steel + full-section anchor (anchored cable).The supporting scheme is shown in Figure 5.

V.MINE PRESSURE MONITORING

Following the support works of the -980m refrigerating chamber that couple grouting and anchoring, the roadway was monitored for its floor to bottom narrowing amount and its roadway's sides narrowing amount using a crisscross pattern of monitoring points.Monitoring results are shown in figure 6.

VI.CONCLUSIONS

(1) With the help of FLAC3D software, an insight was provided into the mechanical properties of the surrounding rock in the excavation of a Xinhe Mining's roadway in deep hi-stress soft rock. Deep Roadway Influenced by excavation, and the front end of roadway surrounding rock are plastic failure，Destroy the first from the key parts (such as corner of roadway's sides，bottom corner, etc.) and then to the entire roadway instability；The deformation and failure of the surrounding rock of the road is obviously larger than the two side and the top plate.

(2) The more distant away from the cutting face, the less is the deformation in the roof, the left side wall and the floor, for which the critical distance of influence is 10m, 8m, and 14m respectively; the stress value stabilizes down as the distance from the free face increases, the critical distance in this regard being 9m, 10m, and 11m respectively for the roof, the left side wall, and the floor.
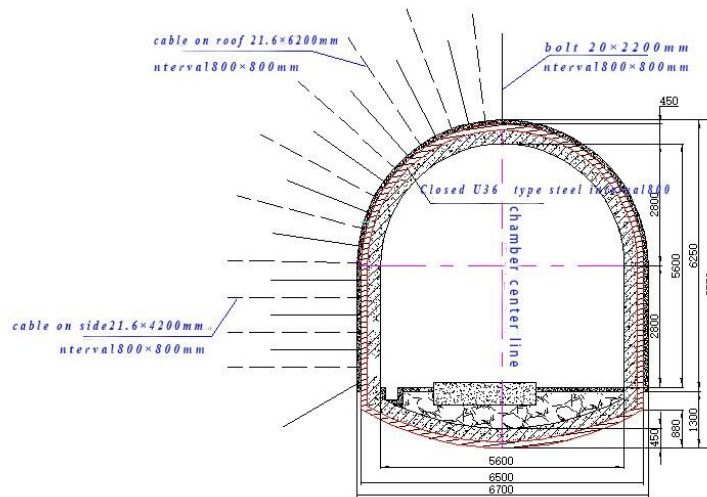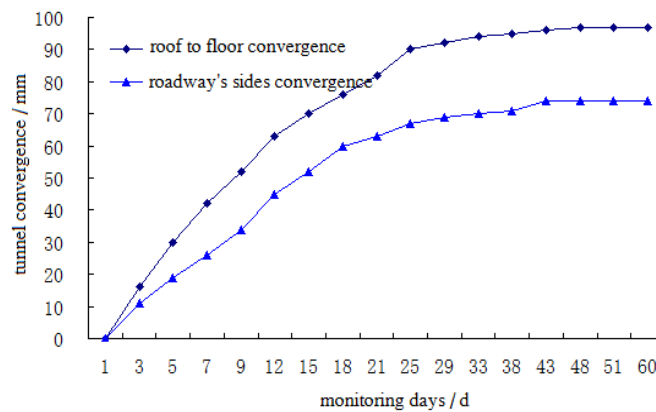
Fig. 5 bolting and grouting support scheme

Fig. 6 displacement of roadway surrounding rock

(3) Four support solutions have been proposed to control surrounding rock deformation having regard to the actual coal mine conditions, they are: grouting + full-section anchoring support, grouting + enclosed U36 section steel support, grouting + enclosed U36 section steel + full-section anchoring support, and grouting + enclosed U36 section steel + full-section anchoring + masonry crown. The solutions were compared for their performance and economic technical conditions of the century in the coal mines, subsequently, grouting + enclosed U36 section steel + full-section anchoring was retained, which provided optimal support parameters.

(4) The surrounding rock deformation pattern of the test section as monitored in real time during normal service attested to the efficacy of grouting + enclosed U36 section steel + full-section anchoring in controlling the deformation of a roadway in deep hi-stress soft rock.

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