Study on Coupling Relationship Between Surrounding Rock Deformation and Support Parameters in Deep Roadway

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Abstract: Surrounding rock in deep mine will exhibit discontinuous large deformation characteristics under high geo-stress, so the rationality of the anchor-net support parameters will directly affect the tunnel support effect. In this paper, the relationship between wall rock around tunnel in deep mine deformation and support parameters of deep roadway is studied by FLAC numerical simulation. The travelling roadway of 11501 coal face in a mine is taken as the research background. Five bolt lengths (2.4m, 2.6m, 2.8m, 3.0m and 3.2m) and 5 kinds of the inter-row spacion of anchor rod (0.6m×0.6m, 0.65m×0.65m and 0.7m×0.7m, 0.75m×0.75m, 0.8m×0.8m) are designed based on the initial support scheme of the tunnel. The effect of 25 combinations of bolting support are analyzed. After, 6 kinds of anchor cable length schemes (5.5m, 6m, 6.5m, 7m, 7.5m, 8m) are designed for research. Finally, the coupling relationship between the support parameters of the anchor (cable) and the deformation of the surrounding rock is obtained. The research results provide reference for the scientific design of the roadway support under similar conditions.

1. Introduction

According to reference [1] and [2], the deep tunnel in the high stress, high ground temperature, high permeating press geological environment makes the surrounding rock ductile and rheological, and the failure mechanism also changes from shallow brittle failure to deep quasi-static failure, so the deformation of the deep tunnel is difficult to control. According to reference [3] to [8], many scholars in China have proposed the deep tunnel coupling support technology by studying the relationship between the support body and the surrounding rock deformation. With the universality of deep shaft mining in recent years, the coupling support technique is widely used due to its good support effect, and it can also be combined with other support technique to enhance the stability to support [9]. The coupling support effect is affected by many factors, and the support parameters can directly affect the support effect. However, in many of its studies, the research on the coupling relationship between the support parameters and the surrounding rock deformation of the roadway is not comprehensive enough. KangHongpu[10] made a comprehensive analysis of the pre-stressed anchor bar support parameters but he did not involve the anchor cable. According to reference [11] and [12], other scholars mostly optimized the support parameters, but they did not deeply analyze the relationship between the support parameters and the wall rock. In this paper, the numerical simulation is used to analyze the relationship between different supporting parameters and the coupling degree of surrounding rock deformation based on the support of 11501 working face haulage roadway in a mine, and the effect of
deep tunnel support is evaluated.

2. Material and Methods

2.1 Engineering background

The background of this paper is the 11501 working face of a mine with an elevation of -1060.5m to -955.7m. The coal mining conditions are simple and the thickness is about 1.6m. The surrounding rock where the working face of haulage roadway mainly includes siltstone, fine sandstone, mudstone. The immediate roof of the tunnel is mudstone with an average thickness of 5.2 meters and compressive strength of about 38 MPa. The main roof is siltstone with an average thickness of 1.6 meters, and the compressive strength is about 61 MPa. The main floor includes mudstone, siltstone and fine sandstone. The immediate floor is mudstone with an average thickness of 0.8m, and the local phase is siltstone. The physical and mechanical parameters of the rock formation are shown in Table 1.

| rock formation        | K(GPa) | G(GPa) | c(MPa) | φ(°) | (MPA) | ρ(kg/m³) |
|-----------------------|--------|--------|--------|------|-------|----------|
| Argillaceous sandstone| 2.8    | 2.5    | 1.3    | 36   | 0.8   | 2788     |
| lime mudstone         | 1.6    | 1.4    | 0.8    | 33   | 0.73  | 2732     |
| mudstone              | 4.1    | 3.6    | 0.7    | 30   | 0.84  | 2716     |
| coal                  | 0.8    | 0.3    | 0.75   | 30   | 0.06  | 1350     |
|Fine sandstone        | 7.9    | 5.4    | 3.12   | 24   | 1.31  | 2890     |
|siltstone              | 8.6    | 6.2    | 2.7    | 40   | 1.54  | 2792     |

2.2 deformation characteristics of the roadway

2.2.1 Initial support parameters of roadway. The section of the haulage roadway is rectangular, with a section width of 5000mm and a height of 3200mm. The tunneling is along the bottom of the coal seam roof. The initial support method of the roadway is anchor bolt and cable joint support: roof bolt diameter 22mm, length 2.8m, inter-row spacing 750×750mm; high strength roof cable diameter 22mm, length 6.3m, inter-row spacing 1000×750mm. The anchor cables are alternately arranged in 3 or 4 rows; the side bolt parameters are the same as the roof bolt parameters.

2.2.2 Analysis of roadway deformation. After the tunnel was excavated, the deformation of the wall rock around tunnel was observed by the "double cross" method. The observation results are shown in Fig. 1. It is concluded that the roadway deformation tends to be gentle after 38 days, and it is basically stable after about 50 days. The deformation of the floor is about 186 mm, the deformation of the roadway's sides is about 200 mm, and the deformation of the roof is about 210 mm. The deformation of the roadway is large because of the horizontal and perpendicular stresses.

![Fig.1. Accumulated curve of deformation of roadway surrounding rock](image1)

![Fig.2. Distribution of rock formations around the roadway](image2)
2.3 Model construction and support parameter simulation scheme

2.3.1 Model construction. The coal seam dip angle of the 11501 working face is 3°~9°, which belongs to the nearly flat seam. Therefore, the model is established in the horizontal state with the FLAC3D numerical simulation software. The haulage roadway section of the working face is 5.0m wide and 3.2m high. According to the Saint-Venant principle, the influence range of the roadway excavation is about 3~5 times of the excavation space, so the size of the model grid is 60m×30m×65m, the roadway is excavated in the center of the model.

2.3.2 Simulation scheme of bolt and cable support parameters.

(1) Design scheme of bolt parameters
There are many factors affecting the bolt support effect, but the most significant effect on the bolt support effect is the length of anchor pole and inter-row spacion. When the anchor is long, the surrounding rock of the fracture zone can be better anchored on the deep stable rock layer to improve the stability of the surrounding rock of the anchorage zone [13], but the longer anchor will increase the difficulty of construction and installation. When the anchor is short, due to the shorter anchoring section and the rod body, the anchorage may be insufficiently anchored to cause instability of the surrounding rock. When the density of bolt arrangement is fixed, the residual strength of anchorage body will be greater than the peak strength of rock mass, but the cost of roadway support will be increased, and the support workload will be increased, too, which will affect the stiffness of bolt.

According to the construction site and engineering analogy method, the lengths of 5 sets of bolts are selected: 2.4m, 2.6m, 2.8m, 3.0m and 3.2m; the inter-row spacion is also selected as 5 sets: 0.6m×0.6m, 0.65m × 0.65m, 0.7m × 0.7m, 0.75m × 0.75m, and 0.8 m × 0.8 m. The two sets of support parameters were cross-combined to obtain 25 sets of numerical simulation results. The analysis analyzed the optimal set in 25 groups, and then analyzed the different anchor rope parameters.

(2) Design anchor rope parameter
The anchor rod and the anchor cable are complementary in the supporting function[14], the anchor rod and the surrounding rock forming an anchor, and the anchor cable suspends the anchoring solid on the stable rock layer to achieve the purpose of supporting the large deformation of the roadway. The key factors affect the anchoring effect are the anchor rope length and arrangement position. Appropriate length of anchor rope can increase the stability of surrounding rock stability, and the length of anchor rope is selected by equal growth method. Six groups of different lengths are selected based on the length of common anchor rope, which are: 5.5m,6m, 6.5m, 7m, 7.5m and 8m. By analyzing the surrounding rock deformation and the perpendicular stress distribution, the optimal support length is obtained in the length of 6 groups of anchor rope.

Usually, the arrangement distance of the anchor rope is about twice that of the anchor rod, and the odd-numbered and even-row cross arrangements. The numerical modeling experiment analysis of the supporting effect of the top anchor cable arrangement is as follows: 3 or 4 anchor rope are arranged in each row, inter-row space is 1200×750mm, and the anchor cable is 750mm from the upper corner of each row.

3 Results

3.1 Coupling relationship between bolting parameters and surrounding rock deformation.
The results of FLAC 3D simulation bolting are shown in Table 2 and Table 3. Different anchor rod lengths and different inter-row spacion result in different plastic zone ranges and different surrounding rock deformation. For further analysis, the single-factor analysis of the length of anchor rod and the inter-row spacion is carried out to obtain a clearer relationship between the surrounding rock and the bolting parameters, as shown in Fig.2-5.
Tab. 2. Range of plastic zone of surrounding rock with different lengths of anchor rod and inter-row spacing (m).

| length of anchor rod /m | inter-row spacing/m | 0.6×0.6 | 0.65×0.65 | 0.7×0.7 | 0.75×0.75 | 0.8×0.8 |
|------------------------|---------------------|--------|-----------|--------|-----------|--------|
| 2.4                    |                     | 3.2    | 3.3       | 3.4    | 3.5       | 3.6    |
| 2.6                    |                     | 3.1    | 3.2       | 3.2    | 3.3       | 3.5    |
| 2.8                    |                     | 2.8    | 3.0       | 3.0    | 3.1       | 3.4    |
| 3.0                    |                     | 2.7    | 2.8       | 2.8    | 3.1       | 3.2    |
| 3.2                    |                     | 2.6    | 2.6       | 2.7    | 2.9       | 3.1    |

Tab. 3. Deformation of surrounding rock with different lengths of anchor rod and inter-row spacing (mm).

| length of anchor rod /m | inter-row spacing/m | 0.6×0.6 | 0.65×0.65 | 0.7×0.7 | 0.75×0.75 | 0.8×0.8 |
|------------------------|---------------------|--------|-----------|--------|-----------|--------|
| 2.4                    |                     | 415.3  | 418.2     | 425.6  | 459.2     | 468.3  |
| 2.6                    |                     | 383.5  | 389.5     | 391.6  | 403.7     | 434.6  |
| 2.8                    |                     | 367.9  | 374.8     | 377.6  | 387.2     | 423.4  |
| 3.0                    |                     | 359.7  | 363.1     | 369.4  | 378.5     | 412.3  |
| 3.2                    |                     | 341.8  | 329.4     | 356.5  | 363.9     | 389.4  |

It can be seen from Fig. 2 that when the length of the anchor rod is constant, the plastic zone of the wall rock around tunnel increases with the increase of the inter-row spacing. Fig. 3 shows that the plastic zone size tends to decrease with the increase of the anchor rod length when the inter-row spacing is constant. Fig. 4 shows that when the anchor rod length is constant, the deformation of the surrounding rock increases with the increase of the row spacing between the anchors. Fig. 5 shows that when the inter-row spacing is constant, the deformation of the surrounding rock shows a decreasing trend with the increase of the anchor rod length.
The curve of Fig. 3 to Fig. 6 is fitted and analyzed to obtain four relations:

Fig.3 is fitted: \( y = 0.13x + 2.67, R^2 = 0.8802 \) \( (1) \);
Fig.4 is fitted: \( y = 0.14x + 3.6, R^2 = 0.9423 \) \( (2) \);
Fig.5 is fitted: \( y = 12.34x + 349.16, R^2 = 0.7916 \) \( (3) \);
Fig.6 is fitted: \( y = -21.58x + 463.24, R^2 = 0.8566 \) \( (4) \).

The relations (1), (2), (3), (4) can theoretically analyze the influence of bolting parameters on the wall rock around tunnel. Through theoretical analysis, the length of the bolt is! 2.6m, and the spacing is the 0.75m×0.75m can be well coupled with the surrounding rock of the roadway to achieve the coupling support effect.

3.2 Coupling relationship between anchor rope support parameters and surrounding rock deformation.

The simulation results show that the deformation of the surrounding rock decreases gradually with the anchor rope length. In Figure7 shows as the length of anchor rope increases, the variation of deformation tends to be gentle. The interval of the anchor rope length of 6m and 6.5m is the transition period.

Mathematical fitting analysis of the curves of Fig.7 yields one relations: Fig. 7 is fitted: \( y = -1.4943x + 143.95, R^2 = 0.9836 \) \( (5) \). Through the calculations of equations (5) and combined analysis, the anchor rope length of 6.2m can achieve the best effect, and can be well coupled with the wall rock around tunnel.

4.Discussion

Coupling support [15] is based on the analysis of the support mechanism of different supporting
structure. The joint support method is used to make the interaction between different supporting structure form complementary advantages, and the self-supporting ability of wall rock can be fully utilized to achieve the purpose of controlling surrounding rock deformation. The key to coupling support is to fully release the nonlinear energy accumulated in the surrounding rock and maximize the self-supporting ability of the wall rock.

By adjusting the strength and stiffness of the support structure and supporting it in a reasonable time, the surrounding rock and the supporting structure work together to make the surrounding rock load distribution after the support uniform and continuous deformation. The experiment proves that the wall rock around tunnel still has strong bearing capacity after the plastic zone. The proper deformation of the surrounding rock can release the nonlinear energy of some internal accumulation. The surrounding rock deformation should be fully released without destroying the bearing strength of the surrounding rock itself, and support can be implemented to achieve strength coupling.

There are many factors affecting the coupling of anchor and surrounding rock deformation in stiffness and structure. This paper mainly selects several common key factors such as bolt length, spacing, cable length and anchor cable arrangement to analyze the coupling relationship between support and deformation of rock. On this basis, considering the other influencing factors comprehensively, it is worthwhile to study the coupling effect of bolt support and surrounding rock deformation.

5. Conclusions
In this paper, the coupling relationship between surrounding rock deformation and support parameters of roadway in deep roadway coupling support technology is studied.

(1) From the field observation, the deformation law of wall rock around tunnel in deep is known and the roadway is greatly affected by horizontal and perpendicular stresses.

(2) In order to fully study the influence of support parameters, 5 sets of anchor rod length parameters and 5 sets of inter-row spacing parameters were set up, and 25 sets of bolt support schemes were cross-combined. Based on this, six sets of anchor rope length parameters are set for research.

(3) By analyzing the FLAC 3D simulation results, the variation of surrounding rock deformation with the length of the bolt and the spacing between the rows is obtained, and the relationship between the length of the anchor cable and the deformation of the surrounding rock is obtained too.

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