Numerical Analysis for Anchoring Surrounding Rock of Thick and Soft Coal Roadway

Mem. Muroran Inst. Tech., 59（2009）69～72

Numerical Analysis for Anchoring Surrounding Rock of Thick and Soft Coal Roadway

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(Received 27 May 2009, Accepted 20 November 2009)

According to the surrounding rock stability type determined through fuzzy comprehensive evaluation, bolt and cable support parameters for thick and soft coal roadway were selected based on the engineering analogy method. Considering two conditions that the roadway was arranged along the roof and along the floor, the activity law of the roadway surrounding rock was simulated through Fast Lagrangian Analysis of Continua in Three Dimensions (FLAC3D) program. The results showed that the lower part of roadway walls in two layout forms has large displacement. When driving along the roof, the maximal floor heave is 3.2 times as many as that of driving along the floor. The roof control is important when the roadway is arranged along the floor. Comparing the surrounding rock deformation, the soft coal roadway arranged along the floor is beneficial to the roadway stability; and it is important to support the top and the lower part of walls.

Keywords: Soft coal, Roadway, Surrounding rock, Anchoring, FLAC3D

As an active support form, bolt support can change the mechanical properties of surrounding rock and form support system with surrounding rock to bring technical and economic benefits compared with traditional support methods(1). In mining engineering, bolting technology is applied for supporting the type *I* , type *II* and type *III* roadways, however, it is rarely used in the weak and disturbed roadways in China(2-5). Therefore, it is important to study the activity law of the soft coal roadways and analyze the effect of bolt (cable) support to decide reasonable roadways layout and support parameters.

1 ENGINEERING BACKGROUND

Zhengzhou Coal Group (Dengfeng) Jiaoxue NO.2 Mining Co., Ltd. is located in Baiping Town, Dengfeng City, Henan Province. The average thickness of soft coal seam mined is 4.6 m. The roadway level is +120m. The false roof is unstable, and the immediate roof is fine sandstone and medium sandstone with thickness of 7 ～ 12 m. The floor is mudstone and sandy mudstone.The roadway's surrounding rock stability is classified based on the geologic conditions through fuzzyevaluation, and bolting parameters is decided through engineering analogy method. The activity law of the roadway surrounding rock was analyzed through Fast Lagrangian Analysis of Continua in Three Dimensions (FLAC3D) program to provide the basis for the reasonable layout of roadway and the supporting pattern.

2 CLASSIFICATION OF SOFT COAL ROADWAY SURROUNDING ROCK STABILITY

In underground engineering, the key to confirm the measures of roadway drivage and support is the stability state of surrounding rock. According to geomechanics parameters, a subjection relation between target range and stability state is established

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based on fuzzy mathematics to objectively express the corresponding stability state of index value[4]. The clustering center is determined based the data of 58 roadway samples[5] and fuzzy comprehensive evaluation was used to classify the surrounding rock stability.

2．1 Evaluation set

The stability of gently inclined and inclined mining roadway surrounding rock in China is classified into five types: very stable, stable, medium stable, unstable and extremely unstable. The corresponding evaluation set *V* is denoted as follows.

$$V=\{\ \mathrm{I},\ \mathrm{II},\ \mathrm{III},\ \mathrm{IV},\ \mathrm{V}\}$$

2．2 Evaluation factors set

Classification indexes are the main effecting factors, 7 indexes are chosen to form the following set *U*.

$$U=\{\ \sigma_r,\sigma_c,\sigma_f,N,H,X,D\ \}$$
$$=\{55.278,\ 1.5,\ 28.8,\ 1.569,\ 593,\ 100,\ 20\}$$

Where $\sigma_r,\sigma_c,\sigma_f$ are the compressive strength of roof, coal seam and floor, respectively, MPa; *N* is the ratio of immediate roof thickness to mining height; *H* is the depth of roadway, m; *X* is the width of protecting coal pillar of roadway, m; *D* is rock mass integrity index, m.

2．3 Fuzzy comprehensive evaluation

In the fuzzy cluster analysis, each index needs to be weighted to distinguish its influencing extent to the stability of surrounding rock, so the weight vector of 7 indexes is as following.

$$\underset{\sim}{A}=[0.11,\ 0.03,\ 0.21,\ 0.11,\ 0.122,\ 0.3,\ 0.118]$$

The following fuzzy transformation is made in fuzzy comprehensive evaluation:

$$\underset{\sim}{B}=\underset{\sim}{A}\underset{\sim}{R}$$

The final evaluation result $\underset{\sim}{B}$ is expressed by fuzzy vector.

$$\underset{\sim}{B}=\ [b_1,b_2,b_3,b_4,b_5]$$

Where b_1, b_2, b_3, b_4, b_5 are respectively the membership degree of the roadway to clustering center, and the stability type of roadway is determined by the maximum of subjection degree. $\underset{\sim}{R}$ is fuzzy relation matrix.

$$R=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ \vdots & & & \vdots \\ r_{71} & r_{72} & \cdots & r_{75} \end{pmatrix}$$

Where r_{ij} is the membership degree that the factor can be evaluated as type *j* based on factor *i*; the line of *R* matrix is the single factor appraisal fuzzy vector of factor.

Trough fuzzy relation matrix calculation and fuzzy transformation, the remark vector *B* is as follows.

$$B=[0.195,\ 0.238,\ 0.169,\ 0.241,\ 0.157]$$

According to maximum membership degree law, the surrounding rock is unstable and belongs to type IV. Based on engineering analogy, bolting parameters were selected as shown in Fig.1.

The bolts were made of deformed steel bar, and the specification of roof bolt and side bolt are Φ18 mm×1800 mm and Φ18 mm×1600 mm, respectively. The cable specification is Φ18 mm×8000 mm, and the spacing between cables and the distance between rows are 1600 mm and 800 mm, respectively.

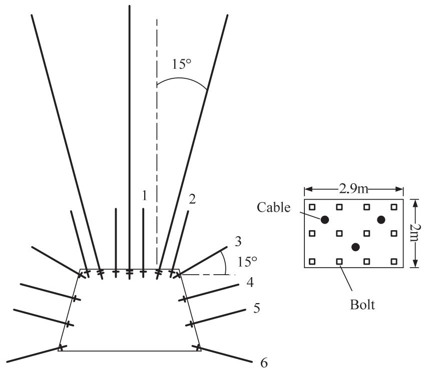


Fig.1 Layout of bolt and cable

3 NUMERICAL CALCULATION

3．1 Numerical model

Considering two conditions that the roadway was arranged along the roof and along the floor, respectively, we establish model to analyze the activity law of surrounding rock based on Mohr-Columb strain-softening model.

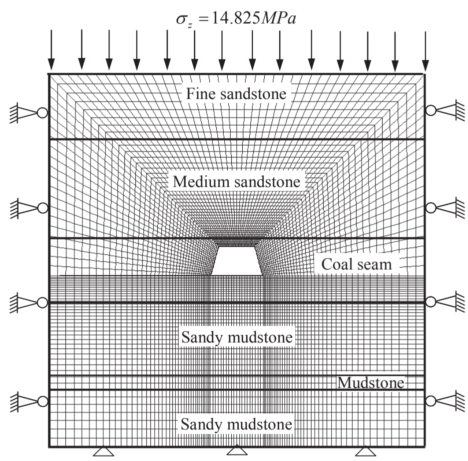


Fig.2 Numerical model

The size of three-dimensional model is 30 m (x) × 30 m(z) ×2 m(y). The roadway section is trapezoid whose upper edge is 2.9 m, lower edge is 4.2 m, height is 2.4 m, and the origin is located at the center of trapezoid.

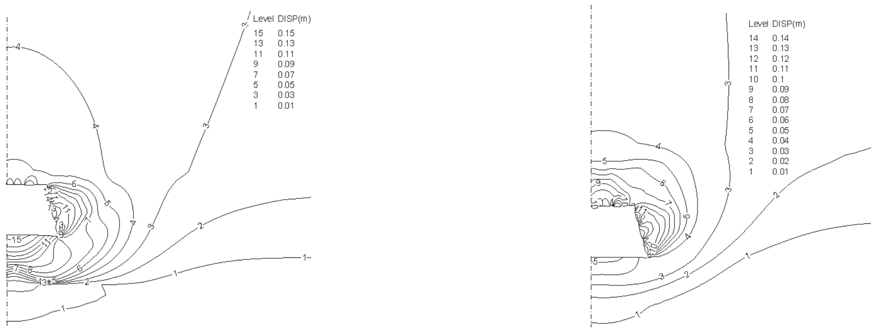
The mining depth is 593 m. Rock strata bulk density is 25kN/m^3 and the vertical stress caused by gravity was put on upper boundary. The stress and constraints of the model is shown in Fig.1. The mechanical parameters of surrounding rock are shown in Table.1.

Table 1 Mechanics parameters of surrounding rock

Lithology	Bulk density/(kg·m^{-3})	Bulk modolus/GPa	Shear modolus/GPa	Tensile strength/MPa	Cohesion/MPa	Friction angle(/°)
Fine sandstone	2580	4.47	2.18	0.6	1.36	35
Medium sandstone	2633	4.40	1.84	0.66	1.25	30
Coal	1447	0.8	0.4	0.3	0.5	23
Sandy mudstone	2563	4.74	2.71	0.5	0.8	26
Mudstone	2575	3.07	1.66	0.45	0.7	24
Sandy mudstone	2563	4.74	2.71	0.5	0.8	26

3．2 The result of numerical simulation and analysis

（1）Analysis of total-displacement



(a) Roadway arranged along the roof (b) Roadway arranged along the floor

Fig.3 Total-displacement-contour map of surrounding rock

According to the symmetry of model, the total-displacement of the right half of surrounding rock was analyzed.

When roadway was arranged along the roof, the maximum roof between bolt 1 and bolt 2 was 70 mm, the maximum floor heave was 150 mm, the convergence between roof and floor was close to 220 mm, the maximum rib displacement were 140 mm, 130 mm and 140 mm between bolt 3 and bolt 4, bolt 4 and bolt 5, bolt 5 and bolt 6, respectively.

When roadway was arranged along the floor, the maximum roof subsidence between bolt 1 and bolt 2 was 130 mm. The maximum floor heave was 50 mm. The convergence between roof and floor was 180 mm. The maximum rib displacement was 140 mm, 130 mm and 130 mm between bolt 3 and bolt 4, bolt 4 and bolt 5, bolt 5 and bolt 6, respectively.

The above result showed that the deformation of roadway wall were severe whether the roadway was arranged along the roof or along the floor. If the roadway is arranged along the roof, the floor leave would become larger, and if the roadway arranged along the floor, the roof subsidence would become larger. However, the absolute amount of roof convergence is not out of control. When the roadway was arranged along the floor, the convergence between roof and floor decreased by 18.2%, and the maximum wall displacement decreased 2.4%. It is beneficial to control the deformation of roadway arranged along floor.

（2）Analysis of floor heave

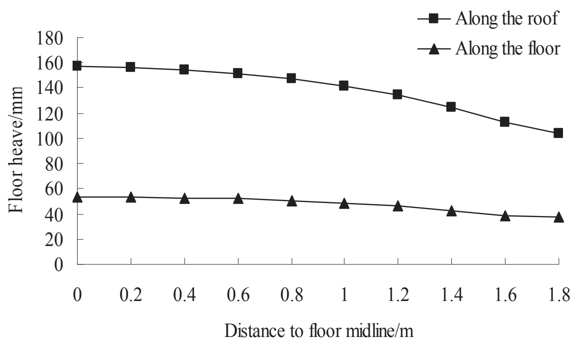


Fig.4 Floor heave of measuring points

Fig.4 shows the floor heave of measuring points arranged along roadway floor. The maximal floor heave of roadway driven along roof was more than 3 times larger than that of roadway driven along the floor due to the stable sandy mudstone floor.

（3）Analysis of surrounding rock separation

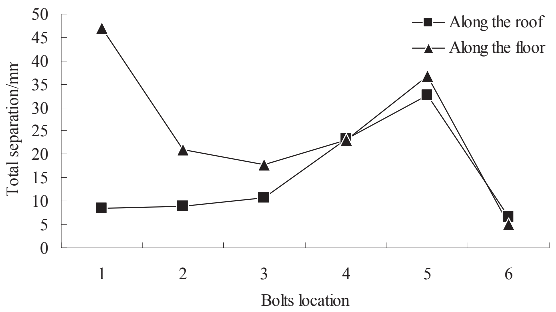


Fig.5 Total separation between two measuring points close to bolt junction

The separation was measured through measuring points arranged on the front end and the back end of bolt to estimate the effect of bolting and the surrounding rock stability. Fig.1 shows the numbers and location of bolts, and Fig.5 shows the total separation between two measuring points, which indicates that the maximum separation occurred at bolt 5 which is about 0.84 m far from the lower part of walls. So it is important to support the lower part of walls. Although the subsidence of roadway arranged along the floor was more than that of roadway arranged along the roof, its absolute amount was relatively small. The sandstone roof had a little effect on the control of the subsidence.

4 CONCLUSIONS

(1) According to the geomechanical condition the surrounding rock of soft coal roadway is classified through fuzzy comprehensive evaluation. The supporting parameters of bolt and cable were selected based on the engineering analogy method.

(2) Reasonable roadway arrangement and control features of surrounding rock was simulated and analyzed through FLAC3D program. Under the condition of bolt and cable support, the soft coal roadway arranged along the floor is beneficial to the roadway stability, and it is important to support the top and the lower part of walls.

ACKNOWLEDGMENT

This study was funded by Science Fund for Distinguished Young Scholars of Henan province (094100510006) and Key Programs for Science and Technology Development of Henan Province (072102240029). The authors appreciate the scientific support of Zhengzhou Coal Group (Dengfeng) Jiaoxue NO.2 Mining Co., Ltd and Henan Polytechnic University.

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