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Research Article

Bolt-anchor Combined Supporting Based on the Limiting Equilibrium in Food Mineral Substance Base

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Abstract: Based on theory of the limit equilibrium and FLAC3D numerical simulation, optimization analysis on the support of 3401 gate road in Sanhekou food mineral substance base. Optimization processes are mainly to make numerically simulate about non-supporting state, the original state support and optimized supporting design three conditions, getting the change of the stress fields, the displacement fields and the plastic zone. The results showed that the optimized supporting design can better control the deformation of surrounding food and stress distribution. Meanwhile, the ground pressure monitoring on the scene can also verify the rationality of the optimized supporting design. It provides Sanhekou food mineral substance base and other similar food mineral substance bases theoretical and applied guidance.

Keywords: Food mineral substance base, FLAC3D, ground pressure monitoring, numerical simulation

INTRODUCTION

In the recent half a century, bolt support technology in our country has become more mature. However, the theory of food mineral substance base support has been stagnant (Kang, 2002). As the limit equilibrium theory is widely used in slope stability analysis (Duncan, 1996), some scholars also apply the theory to the design and optimization of the food bolting parameters (Cheng, 2003). In addition, as the rapid development of computer technology in recent years, the computer numerical simulation method has been rapidly developed. In solving practical engineering problems, the FLAC3D numerical simulation technology combined with limit equilibrium theory, calculation of the bolt support parameters by limit equilibrium theory and simulated analysis of the optimized supporting parameters by FLAC3D. Getting the change of stress fields, displacement fields and plastic zone compared with the actual monitoring results to achieve the optimal supporting parameters.

Sanhekou food mineral substance base 3401 working area food seam roof has high strength because lithology is given priority to with sandstone and two food seams are hard. And the current support is in good condition, supporting parameters is larger. In this thesis, the main application of the theory of limit equilibrium method to optimize the supporting parameters and simulated analysis is mainly to analyze unsupported design, state of the original supporting and optimized supporting design three conditions by FLAC3D numerically simulated. At the same time, the optimized design scheme for monitoring, to ensure the reliability of the optimized scheme, also achieves optimization on the economy.

MATERIALS AND METHODS

Status of test base:

Status of geology: Sanhekou food mineral substance base is located in the Jining City. Food seam structure is simple, stable and the whole recoverable. Its roof and floor lithologic as follows (Table 1).

Status of 3401 gate road the original support: At present, Sanhekou food mineral substance base supporting mainly use the bolt-mesh- anchor support. The anchor is mainly adopt equal strength thread steel bolt, Ø20×2400 mm; Row spacing between roof bolt is 700×800 mm and row spacing of the base's sides is 700×800 mm. Roof and non-mining surface sides use 10# wire diamond mesh while mining surface sides use double resistance plastic mesh. Roof bolt connection is with w steel belt and the base's sides are Ø14 mm mesh reinforcement. Each section has a root anchor cable which using Ø17.8×7000 mm steel strand and the row spacing of 2.4 m.

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Table 1: Lithologic characteristic of the 3401 food roof and floor

The name of the roof and floor	The name of the rock	Thickness (m)	Lithologic character
Main roof	Medium grained sandstone	5.30	Most of quartz, contact with the lower flush
Immediate roof	Siltstone	2.70	Dark gray, thick layer, silt structure, jagged fracture, with a few pieces of fossil plants, as the top horizontal bedding downward that the shale content reduce.
Food	3401 food	5.31	Gloss black asphalt, step-like fracture, banded structure, most of light food, type semibright food endogenic fracture, accidentally see pyrite tuberculosis
Immediate bottom	Mudstone	0.55	Thick black layer, argillaceous structure, flat fracture, soft, rich in plant roots.
Main bottom	Thin sand mud interbed	10.50	Gray, thin - layer, siltstone and mudstone interbedding structure, flat fracture, horizontal wavy texture development, containing a small amount of iron.

RESULTS AND DISCUSSION

Optimization analysis based on theory of the limit equilibrium: At present, there are many bolt support controlling surrounding food, mainly including suspension theory, composite beams, composite arch theory, surrounding food loose circle theory and the theory of limit equilibrium, especially the latter two theories are very similar to some extent (Huang and Liu, 2014). Considering the feature about 3401 mineral substance base area of roof surrounding food, thence we make the choice of limit equilibrium theory to optimize support parameters.

Optimization of the support parameters: There are many factors of optimizations of the support parameters. The main on the Sanhekou 3401 working face crossheading support is to optimize the length of the anchor cable, especially the length of the rock bolt and row spacing and discuss the limit equilibrium radius calculation formula according to the site conditions as follows:

$$R = a[\frac{(K_1 g\rho H + K_2 C\cot\varphi)(1-\sin\varphi)}{p_i + K_2 C\cot\varphi}]^{\lambda} \quad (1)$$

This formula is a theoretical solution of elasticity theory and homogeneous medium. However, in actual production process, combined with the scene of the situation, each parameter values can be comprehensive selecting through the experimental comparison, especially the size of the internal friction angle and agglutinating power. In order to ensure safety, all the parameters usually choose the most unfavorable factors. To 3401 working area in this thesis, R is the limit equilibrium radius, m; the depth of the H takes 400m and the quality of volume ρ is 2.5t/m3; pi is support resistance, MPa; Mining influence coefficient $K1$ takes 1.6; the correction coefficient about mechanical parameters of rock mass $K2$ takes 0.4; agglutinating power C takes 8Mpa; internal friction angle φ takes 31°. Theory of radius a takes the smaller one during the equivalent radius of and circumscribed circle radius and the value of the equivalent radius can be determineral substance based as follows:

$$r_s = k_s\left(\frac{S}{\pi}\right)^{1/2} \quad (2)$$

where,

r_s = The equivalent radius of base
S = The practical sectional area and where takes 13.68 m^2
k_s = The cross-section correction coefficient (Yu *et al.*, 2013) and where takes 1.2.

The formula (2) shows that the equivalent radius of is 2.51 m and the circumscribed circle radius by graphic method is 2.66 m, taking the theory radius of 2.53 m.

Take every parameter into the formula (1) and the limit equilibrium radius R = 4.36m, so it is concluded that the limit equilibrium depth of deep surrounding food, $h = R - a$ = 4.36-2.51 = 1.85m.

Usually the length of the rock bolt consists of limit equilibrium depth of deep surrounding food, the exposed length of rock bolt and the anchorage length. Combined with the 3401 status, we take anchorage length $L1$=0.3m, the exposed length of rock bolt $L2$ = 0.1m, which can get the total length of the rock bolt: $L = L1+h+L2$ = 0.3+1.85+0.1 = 2.25m, take 2.2m. According to the theory of strong support food sidewall about SHAN Renliang (Dong, 2001), so in order to enhance the stress of the two sidewalls, we take two sides rock bolt length 2.4 m. In addition, the top and the bottom bolt extraversion 30°and the both sides of the roof bolt are also extraversion 30°.

Optimization of the length about anchor cable: In theory, the length of the anchor cable has the same calculation method with bolt. But in the process of base, support anchor cable is used to maintain more mining dynamic pressure and the dynamic pressure is influenced by many factors, so the length of the anchor cable calculation can't be calculated by a theoretical formula. According to actual condition, we take the anchor cable into the stability of rock, so as to give full play to the anchor cable. For the present 3401 working surface gateway, the process of its tunneling to reserve 2 m of the top-food and the roof has 3m sandstone which density and strength is high. But the top of the bedding from the horizontal should contain a small amount of sediment, so the contact area and food seam are prone to slide off and reduce its stability. According to the present supporting conditions expected length (2 m), so the length of the anchor cable is about 5.3 m (Reserve top-food lengths + the lengths of the stability of strata + protruded lengths + anchorage lengths).

Optimization of the anchor cable spacing: According to the bolt support design method in limit equilibrium zone (He, 2004), the derivation formulas of the anchor cable spacing is as follows:

$$b = \frac{nY_1 + B\gamma\Delta^2 \tan\varphi \tan^2\left(45 - \frac{\varphi}{2}\right)}{\gamma\Delta\left[B - \Delta\tan\varphi\tan^2\left(45 - \frac{\varphi}{2}\right)\right]} \quad (3)$$

where,

b = The anchor cable spacing and the unit is m.

B = For width of the where takes 3.8 m.

Δ = For calculating the thickness of the disturbed area, by type, the anchor cable to overburden height is 1.83 m.

γ = The volume mass of food seam in the limit equilibrium zone, according to the experimental area geological conditions for $\gamma = 2.8$t.

Y_1 = The yield limit load about anchor cable, which is 22t. According to the experiment, the overburden of internal friction Angle $\varphi = 39°$.

Through the type, this thesis can conclude that $b = 50.565/17.744 = 2.85$ m. Considering the rock properties of the Sanhekou 3401 mining area, as well as the anchoring and exposed length, the anchor cable is Ø17.8×5300 mm steel wire production and the spacing is 2700 mm.

Integrated, after optimizing, roof adopts strong rebar anchor, such as Ø20×2200 mm and the spacing from 900×900 mm. The food sidewall adopts strong rebar anchor too, such as Ø20×2400 mm and spacing is 900×900 mm. In addition, the top and the bottom bolt extraversion 30° and the both sides of the roof bolt are also extraversion 30°. The anchor cable adopts Ø17.8×5300 mm steel wire production and the spacing is 2700 mm. Other conditions don't change.

OPTIMIZATION ANALYSIS FOR NUMERICAL SIMULATION

Establishment of a model of numerical simulation: The numerical simulation in this thesis is based on engineering geological condition of Sanhekou food mineral substance base 3401 gate food and the model domain is of 30×30×30m, which is divided into 133500 cells and 110174 nodes. The FLAC3D model for this simulation is set up as shown in Fig. 1 and the model of excavation is shown in Fig. 2.

The displacement of lateral horizontal and bottom is limited in this model: The upper surface was applied with 20 MPa load, simulating the boundary of upper overlying strata's deadweight; According to the rock triaxial compression test and uniaxial compressive test in laboratory, the physical mechanical calculation parameters of the rock mass of food mineral substance

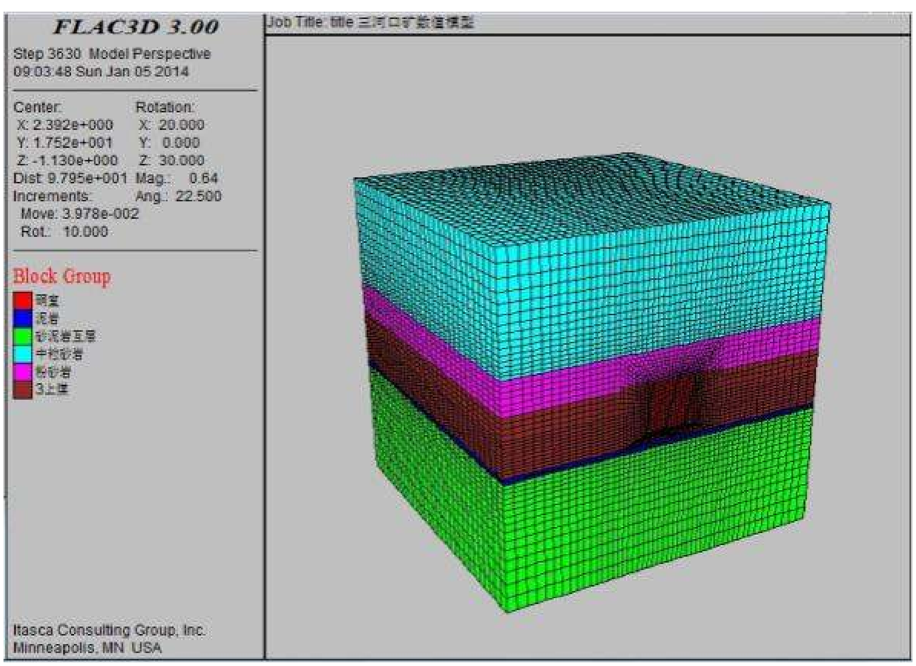

Fig. 1: FLAC3D three-dimensional numerical simulation model

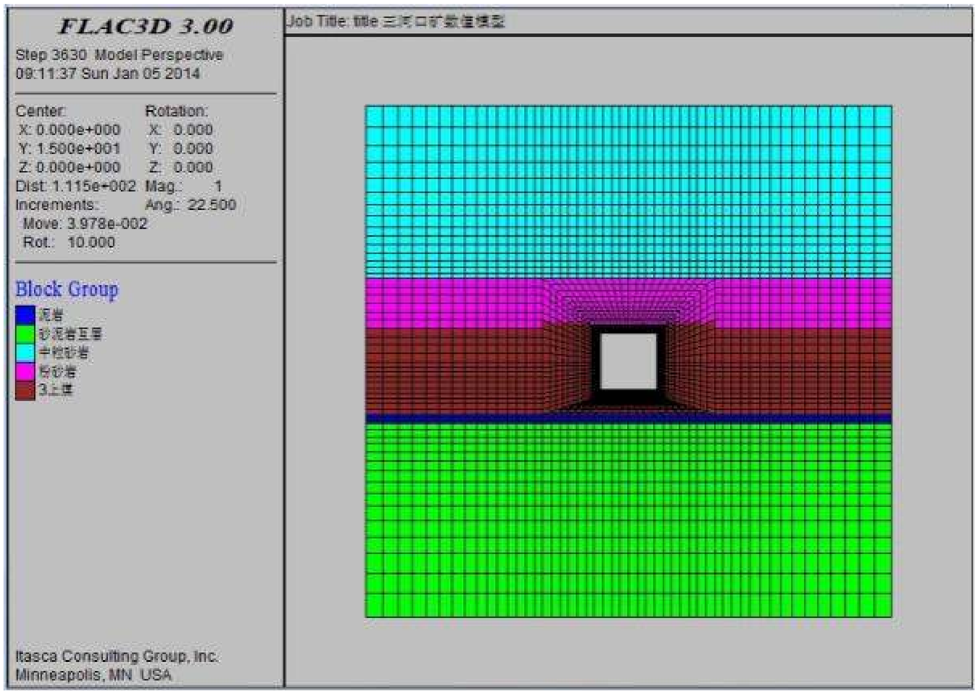

Fig. 2: FLAC3D three-dimensional numerical simulation model of excavation

Table 2: Numerical simulation of parameter table

Lithology	Density /kg·m^3	Bulk modulus /GPa	Shear modulus /GPa	Internal friction angle/°	Cohesion/MPa	Tensile strength /MPa
The grain of siltstone	2530	4.8	3.5	34.3	14.53	3.6
Siltstone	2510	8.4	5.3	39.0	18.30	7.8
Food	1450	2.8	1.4	31.0	2.08	1.8
Mudstone	2130	2.2	1.7	32.0	5.01	2.1
Thin Sand Mud Interbed	2060	3.3	1.6	33.6	10.61	6.6

base take value as Table 2, MohrCoulomb failure criteria are widely used as failure criteria, revealing the influence of support parameters of base to surrounding food deformation and developmental condition of plastic zone.

CONCLUSION

This thesis used field examples as the research object, by the method of combining limit equilibrium theory and FLAC3D numerical simulation cross heading support parameters, optimizing crossheading supporting parameters of Sanhekou 3401, by which can we get the actual results and also ensure the theoretical rigor.

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