International Journal of Mining Science and Technology 24 (2014) 799–804

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Deformation control of asymmetric floor heave in a deep rock roadway: A case study

Sun Xiaoming [a,b,*], Wang Dong [a,b], Feng Jili [a,b], Zhang Chun [a,b], Chen Yanwei [a,b]

[a] State Key Laboratory of Geomechanics and Deep Underground Engineering, Beijing 100083, China
[b] School of Mechanics and Civil Engineering, China University of Mining & Technology, Beijing 100083, China

ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form 26 April 2014
Accepted 17 June 2014
Available online 14 November 2014

Keywords:
Deep rock roadway
Asymmetric floor heave
Numerical simulation
Asymmetric reinforced support

ABSTRACT

In order to control asymmetric floor heave in deep rock roadways and deformation around the surrounding rock mass after excavation, in this paper we discuss the failure mechanism and coupling control countermeasures using the finite difference method (FLAC^{3D}) combined with comparative analysis and typical engineering application at Xingcun coal mine. It is indicated by the analysis that the simple symmetric support systems used in the past led to destruction of the deep rock roadway from the key zone and resulted in the deformation of asymmetric floor heave in the roadway. Suitable reinforced support countermeasures are proposed to reduce the deformation of the floor heave and the potential risk during mining. The application shows that the present support technology can be used to better environmental conditions. The countermeasures of asymmetric coupling support can not only effectively reduce the discrepancy deformation at the key area of the surrounding rock mass, but also effectively control floor heave, which helps realize the integration of support and maintain the stability of the deep rock roadways at Xingcun coal mine.

1. Introduction

There is considerable interest in stability control of deep soft rock roadways with increasing mining depth in a deep complex mechanical environment [1–6]. By entering the stage of large nonlinear plastic deformation, the failure mechanism of soft rock roadways is significantly different from that of hard rock roadways. For example, the surrounding rock mass of deep inclined rock roadways exhibits the characteristics of prone-asymmetric deformation. This unfortunately makes the support technology available for shallow roadway to be unsuitable for deep soft rock roadways [3,7–9]. It is consequently required, from theoretical and experimental standpoints, to provide alternative design rules for the deformation control of deep soft rock roadway using nonlinear continuum mechanics after analyzing in situ underground stress field and strata conditions [10–13]. The goal is to efficiently and reasonably control such asymmetric deformation, which often appears in deep soft rock roadways, in order to accommodate safe mining and ensure the stability of surrounding rock masses [14–16].

In this study, under the specific engineering geological conditions of an air-return rock roadway at the −1186 m level at Xingcun coal mine, stability control of the surrounding rock of the inclined rock roadway was investigated using the finite difference technique (FLAC^{3D}). Suitable reinforced support countermeasures were proposed to reduce the deformation of the floor heave to eliminate potential risk during mining. The applications showed that the proposed support technology can be used to improve control of the stability of deep soft rock roadway under complex mechanical and environmental conditions.

2. Failure characteristics of the old support system

2.1. Project overview

Xingcun coal mine is in the Shandong southwest rift tectonic zone, in which the air-return roadway is at the −1186 m level in the region. The length of experimental roadway is 100 m, which in turn passes through the aluminous mudstone of Shihezi Formation, hoary sandstone, and gray black sandstone of the Shanxi Formation. The dip angle of the strata is about 10°. The roadway passes through three faults including F57-2, F57, and DF22. From the viewpoint of lithological information, the geological structure at this coal mine is rather complicated. The old support system used at the coal mine lead to asymmetric heave with large deformation of the floor, which seriously influences the routine work of ventilation and pedestrian travel in the mining zone.

---

* Corresponding author. Tel.: +86 13801166205.
E-mail address: sxmcumtb@163.com (X. Sun).

http://dx.doi.org/10.1016/j.ijmst.2014.10.011
2095-2686/© 2014 Published by Elsevier B.V. on behalf of China University of Mining & Technology.

2.2. Failure characteristics of the old support system

The lithological formation, structure and mechanical properties of the surrounding rock mass were not fully considered in the application of the old support scheme which was simply to adopt a symmetric support form of bolt-net-spray without any measures for the floor of the roadway, which resulted in asymmetric heave with large deformation of the floor. From the in situ investigation, failure deformation of the air-return roadway at the −1186 m level had the following characteristics under the old support scheme:

(1) Serious asymmetric failure with the characteristics of heave appeared in the partial floor of the roadway. Deformation of the roadway was anisotropic in form. In the Jurassic aluminous mudstone significant asymmetric heave appeared in the floor with a maximum deformation of 1000 mm with large inclination, which seriously impacted upon the use of the roadway.
(2) Serious asymmetric subsidence appeared in the partial roof of the roadway. In the aluminous mudstone, it was found that there were a series of failure phenomena such as asymmetric large downward deflection in the roadway, shear rupture of the shotcrete layer in the vault, distortion of steel net, and fracture failure of some rock bolts.
(3) Extruded plastic deformation occurred locally in the spandrel and side walls of the roadway.

3. Failure mechanism of the old support system

3.1. Numerical model

From the engineering geological conditions and in-situ investigations, the size of the numerical model was set as length × width × height = 100 m × 40 m × 40 m. In order to simulate the initial underground stress due to the overly rock mass on the model, uniformly distributed forces of 31.6 MPa, 31 MPa, and 45 MPa along the directions of weight load, horizontal load, and roadway respectively, were applied on the corresponding surfaces of the model, except for the base which is fixed. The materials and mesh of the engineering geological model are shown in Fig. 1. The mechanical parameters of the rock masses used in the present numerical model are given in Table 1. The mechanical response was calculated using the finite difference method (FLAC^{3D}).

3.2. Parameters of the old support system

The cross-section of the roadway consists of straight walls and a semicircular arch, with an arch radius of 2100 mm and straight wall length of 1600 mm. The bolt-net-spray symmetric support form was used at the start of the excavation. The support parameters used are as follows:

(1) Bolt: Rebar bolt was used with a diameter of 20 mm, length of 2000 mm, and row spacing of 800 mm × 800 mm, and arranged in a radial pattern. End anchorage was adopted as the fastened form of the bolt. Each hole was applied by resin anchoring of MSCK2535 and MSK2550.
(2) Welded steel mesh: Welded steel was used with a diameter of 6.0 mm, grid size of 100 mm × 100 mm, and hook connection.
(3) Shotcrete: the thickness of the first spraying of concrete was 50 mm, and the thickness of the second spraying was 100 mm, in which the compressive strength of concrete was 20 MPa.

The old reinforced support is as shown in Fig. 2.

3.3. Analysis of the numerical simulation

In the case of the old reinforced support system, after extraction for 100 m, the maximum compressive stress zone on the cross-section transfers continuously to the inner part of the floor rock mass, especially to the left side of the floor (see in Fig. 3a). Shear stress continues to develop in the deep surrounding rock mass and the area of stress concentration is further enlarged (see in Fig. 3b). Major deformation of the roadway concentrates over the floor, especially at the left part of the floor shown in Fig. 3c. From the distribution of the plastic area (Fig. 3d), it is readily observed that the plastic zones on the left corner and right side of the roadway are clearly enhanced. It is also shown from Fig. 3 that, even in the case of the old reinforced symmetric support system, stress response of the surrounding rock mass appears to emerge as an asymmetric distribution in the surrounding rock mass of the roadway.

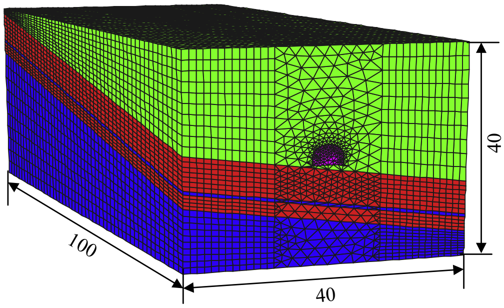

Fig. 1. Materials and mesh of engineering geological model.

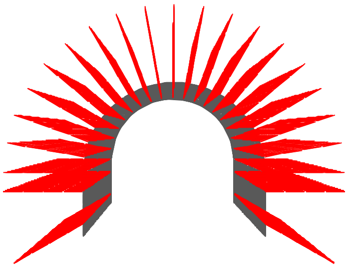

Fig. 2. Old reinforced support.

Table 1
Mechanical parameters of rock masses.

Rock	Bulk modulus (GPa)	Shear modulus (GPa)	Friction angle (°)	Cohesive strength (MPa)	Tensile strength (MPa)
Aluminous mudstone	2.083	1.483	20.0	0.175	4.35
Hoary sandstone	5.170	3.583	21.0	0.250	6.95
Gray-black sandstone	5.017	4.417	26.0	0.410	8.41
Sprayed concrete	1.125	1.100	22.5	0.200	0.15