ARTICLE IN PRESS
ENGEO-04442; No of Pages 13
Engineering Geology xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Engineering Geology
journal homepage: www.elsevier.com/locate/enggeo

A case study on large deformation failure mechanism of deep soft rock roadway in Xin'An coal mine, China

Sheng-Qi Yang *, Miao Chen, Hong-Wen Jing, Kun-Fu Chen, Bo Meng

State Key Laboratory for Geomechanics and Deep Underground Engineering, School of Mechanics and Civil Engineering, China University of Mining and Technology, Xuzhou 221116, PR China

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 10 December 2016
Accepted 24 December 2016
Available online xxxx

Keywords:
Deep underground engineering
Soft rock
Large deformation
Failure mechanism
UDEC

ABSTRACT

Large deformation of soft rock roadway has always been a major difficulty in deep mining practices. This paper describes a case study of the failure mechanisms and stability control technology of deep roadway with soft rock mass in Xin'an coal mine in Gansu Province, China. Rock mass properties around the roadway are evaluated using geological strength index (GSI) based on the field data and the mechanical properties of intact rock specimens. The Universal Discrete Element Code (UDEC) software program is adopted to establish the numerical model of a ventilation roadway in Xin'an coal mine, and the micro-parameter calibration is conducted with the rock mass properties. The failure process of roadway under unsupported and primary support conditions is simulated; the deformation, stress and crack evolution characteristics were clearly illustrated. Failure first appears around the roadway surface because there is a high stress concentration around the roadway surface after excavation; the failure area propagates further into the deep surrounding rock as the stresses applied on the surface gradually decreases, finally resulting in a large zone of stress relaxation. There exists a large scale of tensile failure in the shallow rock, which leads to swelling and fracturing around the roadway. The primary support is low in strength with no support in the floor, which results in serious floor heave, side shrinking and roof subsidence. A new “bolt-cable-mesh-shotcrete + shell” combined support is proposed to support the ventilation roadway. The monitoring data in the experiment section show that the new support design successfully controls the large deformation of the roadway, which can provide helpful references for support designing of engineering in deep soft rock roadway.

1. Introduction

Approximately 60% of the discovered coal resources in China are buried deeper than 800 m, and the mining depth is increasing at a speed of 10–25 m per year with the exhaustion of shallow coal resources (He et al., 2005). Upon entering the stage of deep mining, the failure mechanism of soft rock roadways and the structures and mechanical properties of deep rock mass are significantly different from those of shallow rock mass. For example, the surrounding rock mass exhibits the characteristics of high in-situ stress, large and long duration deformation, etc. (Xie et al., 2015). A series of engineering problems with large rheological deformation then appear. Statistics indicate that deep soft rock roadways account for 28–30% of the annual total tunneling, but the repair rate of soft rock roadways is up to 70%. The maintenance cost exceeds the tunneling cost greatly, and many roadway instabilities occur because of improper support schemes that seriously affect mining production and safety. Therefore, the stability control of deep soft rock roadways has received much attention with increasing mining depth.

There are two difficult aspects in the stability control of deep soft rock roadways. On the one hand, the failure mechanism of soft surrounding rock under high in situ stress is not clear (Wang et al., 2000); on the other hand, limit supporting resistance could be provided by existing support, in other words, it is difficult to achieve sufficient supporting resistance with the planned supporting cost.

The main methods for studying the failure mechanism of deep soft roadway include theoretic analytical calculation, field testing (Shen et al., 2008), model testing (He, 2011; Meng et al., 2013) and numerical simulation. In recent years, various numerical simulations have been developed and adopted to analyze the instability mechanism of roadway. Compared with other research methods, the numerical method has many advantages such as low cost, high efficiency and repeatability. A wide range of case examples and different applications of the use of numerical methods show the feasibility of simulating the failure mechanism of roadway with the numerical method (Coggan et al., 2012). Gurocak et al. (2007), Kanik et al. (2015) and Yalcin et al. (2016) used different classification systems to characterize the rock mass and determine support systems, and the support systems were evaluated by

* Corresponding author.
E-mail address: yangsqi@hotmail.com (S.-Q. Yang).

http://dx.doi.org/10.1016/j.enggeo.2016.12.012
0013-7952/

numerical analysis to obtain a realistic and optimal design. Tang and Tang (2012) carried out a simulation with RFPA to simulate the floor heave processes of a swelling rock tunnel when exposed to high humidity. Mark et al. (2007) and Shen (2014) applied UDEC to simulate the failure mechanism of deep soft rock roadway, considering that high horizontal in situ stress is the major causes of roadway instability. The influence of stress, temperature and fault on a deeply buried roadway in Guqiao coal mine was simulated by FLAC3D basing on the thermal–hydro mechanical (THM) coupling theory (Kang et al., 2014). Li and Weng (2016) analyzed the influence of dynamic loading on the fracture process of surrounding rock in deep roadway. UDEC was adopted to simulate the process of roadway squeezing under mining-induced stresses (Gao et al., 2015), and the deformation phenomenon observed in the field were realistically produced in UDEC. Pellet et al. (2009) conducted a numerical simulation of the development of the excavation damage zone (EDZ) in deep underground roadway. These studies indicate that the instability of soft rock roadway is related to the excavation size, initial stress state, geological conditions, hydrology conditions, excavation and support method (Steiner, 1996; Dalgıc, 2002), etc. Due to the complex geological conditions and lithology differences of rock mass engineering, the failure mechanism of deep soft roadway remains to be revealed, especially for the process analysis of instability.

At present, controlling the large deformation of soft surrounding rock in high in situ stress environments is still a hot and challenging issue. Many studies and engineering practices have been performed on the control technology of deep soft rock roadway, and many achievements have been obtained. Based on the existing research and applications, control technologies can be categorized as three basic methods: (1) rigid passive support acting on the roadway surface such as brickwork, U-shaped steel supports (Jiao et al., 2013; Zhao et al., 2015), concrete-filled steel tubes (Gao et al., 2010), etc.; (2) active support acting on the roadway surface and internal surrounding rock, such as prestress bolts and cables (Kang, 2014); (3) methods that improve the physical mechanical properties and stress state of surrounding rock, such as grouting (Wang et al. 2005), pressure relief, etc. These research results established the basis of further research in the control technology of deep soft rock roadway. Many practices have proved that it is difficult to realize control of large and long-duration deformation in soft surrounding rock by using a single and simple support method. It has also been proved that the combination of different supporting methods is an effective way to solve the supporting problem in deep soft rock roadway. The "bolt-cable-mesh-shotcrete + square confined shotcrete arch" support scheme was adopted to solve the large rheological deformation problem in Zhaolou coal mine (Li et al., 2015b); the support scheme of "bolt-mesh-U-steel arch-shotcrete-grouting-cable" has succeeded in solving the severe extrusion and floor heave in the main haulage roadway at the +850 m level of Qujiang coal mine (Yu et al., 2015); Liu et al. (2011) proposed a sub-step supporting method and optimized "bolt-mesh-grouting" support method for the south wing rail roadway of Guqiao coal mine; "bolt-cable-net-spray + floor bolt" asymmetric coupling support can effectively reduce deformation in the key area of the roadway in Xingcun coal mine (Sun et al., 2014).

Although many effective control methods of deep soft rock roadway have achieved a significant effect, the existing support scheme is not completely applicable to other engineering for its own geological characteristics. For example, the common "bolt-cable-mesh-shotcrete" support was used in the reinforcement of the main roadway of Xin'an coal mine in the early stage. Serious deformation appeared less than one month after the support, and it failed to control the large deformation after several repairs. To solve such a problem, this paper presents a case study on failure mechanisms and control technology of deep soft rock roadway. The rock mass properties were carefully calibrated with GSI by using the field data and laboratory results. A numerical simulation with UDEC was performed to investigate the evolution process of deformation, stress and cracking after excavation, and a "bolt-cable-mesh-shotcrete + shell" support scheme was proposed to support the roadway. Simulations and field tests were also conducted to evaluate the control effect of new support scheme on large deformation.

2. Engineering property of deep underground soft rock tunnel

2.1. The engineering status

The Xin'an coal mine is in Pingliang city in China's Gansu province (Fig. 1a). The site grade level is +1255 m, and the shaft bottom level is +535 m, and the grade level of the main development roadways is 700 m to 900 m. The arrangement of main roadways is shown in Fig. 1b. The surrounding rock of the main ventilation roadway is mainly composed of mudstone and sandstone with an inclination of 10 degrees, and the detailed strata histogram is illustrated in Fig. 2. The roadway is excavated in the strata of sandstone, and the cross section of the roadway is a semicircular arch, with width and height of 4.8 m and 3.9 m, respectively. The primary support system of the "bolt-cable-mesh-shotcrete" support is shown in Fig. 3.

2.2. Rock mass properties

The effect of rock mechanical properties on roadway stability is obvious, and the mineral components of rock have a decisive influence on rock mechanical properties. To provide a reference for the following numerical simulation and supporting design, X-ray diffraction and uniaxial compression tests are carried out for onsite rock specimens to understand the mineral components and mechanical properties of surrounding rock in Xin'an deep roadway.

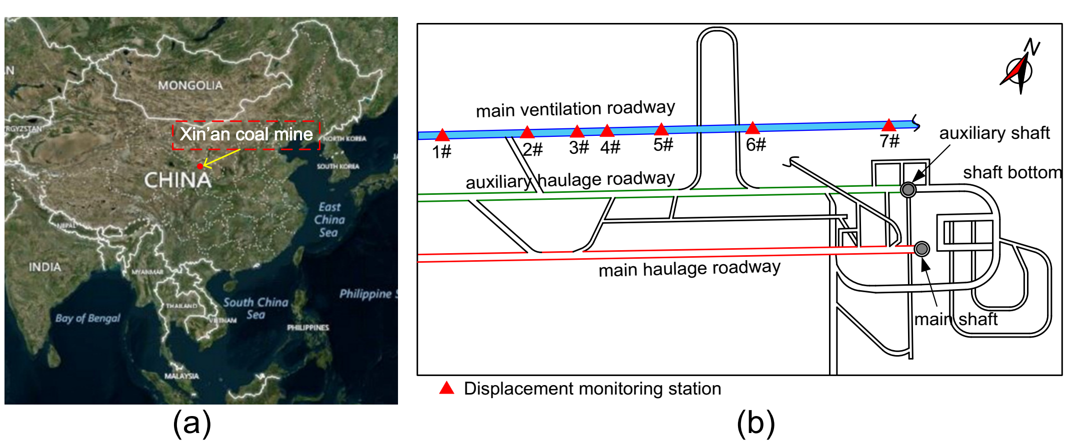

Fig. 1. (a) Location of the Xin'an coal mine, Gansu, China. (b) Plan view of the main roadway in the shaft bottom of Xin'an coal mine.

Please cite this article as: Yang, S.-Q., et al., A case study on large deformation failure mechanism of deep soft rock roadway in Xin'An coal mine, China, Eng. Geol. (2016), http://dx.doi.org/10.1016/j.enggeo.2016.12.012