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Model test study on surrounding rock deformation and failure mechanisms of deep roadways with thick top coal

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ABSTRACT

The deep roadway with thick top coal is a typical roadway difficult to support in deep mining project, and resolving this sophisticated problem to control the stability of surrounding rock is of great significance in safety production of coal mines. In order to explore the surrounding rock deformation and failure mechanisms of such deep roadways, with Zhaolou coal mine in Juye mining area of China as the engineering background, a large-scale geomechanical model test was carried out. The displacement and stress evolution laws of surrounding rock supported by the pressure relief anchor box beam system were researched. Meanwhile, the related results validate and analyze main failure characteristics and mechanisms of the surrounding rock by comparing with field test.

1. Introduction

China produces the most coal in the world. With the rapid development of the national economy and state higher attention to energy strategies, the demand for coal, primary energy in China, has significantly increased in recent years. As shallow resources decrease, coal mining gradually tends to deep resources. Under the influences of high *in-situ* stress, high permeability, high geotherm, and strong mining disturbances in deep complex geological conditions, roadway supporting in such seriously broken surrounding rock is of huge cost and difficulty. In fact, at the beginning of the 20th century, deep soft rock supporting as a worldwide difficulty was brought up and discussed. In particular, roadway supporting is always a major problem in coal mine production and construction, as presented by He and Sun (2004). Data shows that the thick coal seam accounts for approximate 45% of China's total coal reserves and production. As a typical roadway difficult to support in the thick coal seam, the deep roadway with thick top coal is easy to produce roof accidents endangering coal mining safety owing to the thick top coal and the resulting wide range of the surrounding rock failure zone, long-lasting deformation, and serious roof separation or convergence after roadway excavation. Therefore, it is significant to study the failure mechanism of surrounding rock in deep roadways with thick top coal and propose advanced roadway supporting technologies to resolve the surrounding rock control problem in such roadways are of great significance in coal mine safety production.

In general, the following approaches to analyzing the stability of underground caverns have been widely adopted: theoretical analysis, numerical simulation, geomechanical model test, and engineering analogy. Theoretical analysis (Sharan, 2003; Cohen et al., 2009, and Fraldi and Guarracino, 2010) and numerical simulation (Jing and Hudson, 2002; Addenbrooke et al., 1997, and Eberhardt, 2001) are more popular than model tests in economy and convenience. However, in case of complex geotechnical problems, they need to be simplified but then fail to fully describe the complex field geological conditions while geotechnical model tests can directly reflect the physical and mechanical phenomena of the under-study system and quantitatively or qualitatively reflect the rock mechanical characteristics and interaction effects with related engineering structures. Hence, the model test can make up the inadequacy of theoretical analysis, numerical simulation and field tests, and is a classic method in underground engineering research. Meguid et al. (2008) proposed the experiment method and principle in view of the geological model test on underground tunnels in soft rock; Tetsuo et al. (1996) researched the mechanical behaviors of jointed rock masses around an underground opening under excavation using a large-scale geological model; Zhu et al. (2010) made a true triaxial model by piling up and bonding precast model

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blocks and conducted model tests on the stability of Shuangjiangkou hydropower station cavern groups; Li et al. (2005) analyzed the stability of Xiluodu hydropower station cavern groups through three-dimensional geomechanical model tests and compared the results with numerical simulation results; Huang et al. (2012) systematically studied the instability and failure patterns of tunnels with weak interlayers through model tests; Chen et al. (2014) researched the dynamic failure process around a circular cavern in hard and brittle rock under the high and increasing natural stress conditions. However, the experimental studies mentioned above focused on traffic tunnels, hydropower stations and so on. The model tests on the surrounding rock deformation and failure mechanisms and supporting technologies of deep roadways with thick top coal have not been conducted.

As a newly ascertained oversize coal field, Juye coal field retains the largest coal deposit in eastern China. Zhaolou coal mine is located in the central part of Juye coal field. The roadways in this mining area are usually driven along the coal seam floor. Taking the crossheading of working face 3302 as an example, it is a typical deep roadway with about 5 m thick top coal. It is pretty arduous to ensure the stability of this roadway given the complex field geological conditions and about 1000 m burial depth. By analyzing the deformation characteristics of deep roadways with thick top coal and existing problems about the anchor beam support system, Li et al. (2012) and Wang et al. (2012a) developed the pressure relief anchor box beam support system, designed different support schemes, and conducted numerical tests, field tests and theoretical analysis on the preceding crossheading. The results show that the pressure relief anchor box beam support system can better support such roadways and is an ideal structure form for supporting deep roadways with thick top coal. In this context and on the basis of preceding researches, this paper focuses on the research of surrounding rock stress and displacement evolution laws through large-scale geomechanical model tests and with the pressure relief anchor box beam support system, and compares the research results with field test results to finally obtain surrounding rock deformation and failure characteristics and mechanisms of deep roadways with thick top coal. This paper can be used as a reference for theory and support parameters of deep roadways with thick top coal.

2. Background

Located in the southwest of Shandong province, Juye coal field is an oversize coal field in eastern China. As an integrated coal mine with the largest reserves in eastern China, it has a total of 5.57 billion tons of ascertained geological reserves. The coal beds are buried in depths from 800 m to 1300 m with the average thickness of coal in main mineable coal seam 3# about 8 m. 7 pairs of mines, Longgu Coal Mine, Zhaolou Coal Mine, Guotun Coal Mine, Yuncheng Coal Mine, Wanfu Coal Mine, Pengzhuang Coal Mine and Liangbaosi Coal Mine, are planned to be built in this mining area, as shown in Fig. 1.

Zhaolou coal mine is in the central part of Juye coal field, about 22 km away from Yuncheng county to the north and 13 km away from Juye county to the east. Vertical shaft is adopted to exploit coal, and the designed production capacity of the coal mine is 3.0 Mt per year. The strata in the mining area presents a north–south trend and east dip monoclinal structure in general, with subset structure of wide and gentle folds and a certain number of faults. The coal field is in the totally concealed northern China Carboniferous-Permian coal mines, with basement strata of Cambrian-Ordovician. The stratum, from top to bottom in order, is Quaternary, Neogene, Permian, Permian System Lower Shihezi Formation, Shanxi Formation, Taiyuan Formation, Benxi Formation of Carboniferous, and Middle and Lower Ordovicians, and the main coal-bearing stratum is Shanxi and Taiyuan Formation of Permian.

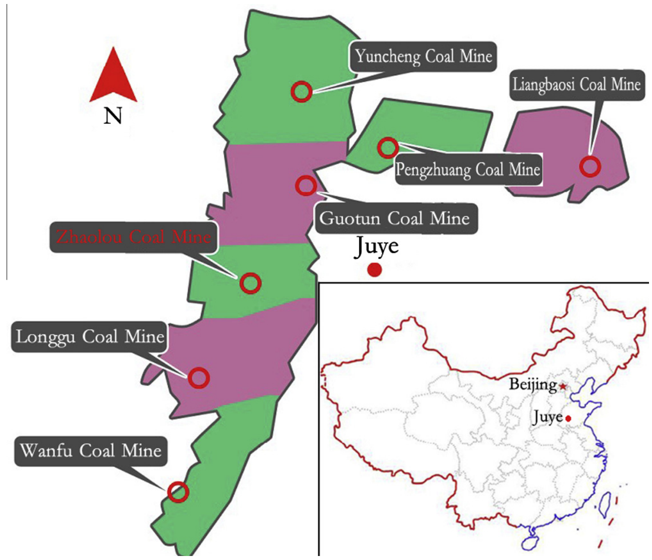

Fig. 1. Locations of coal mines.

Working face No. 3302 of Zhaolou coal mine is in 3# coal bed whose thickness ranges from 5 m to 8.5 m with the mean thickness of 7.8 m, the dip angle ranging from 0° to 13°, and the coal Protodyakonov coefficient ranging from 0.8 to 2.3 with the mean value of 1.6. The crossheadings of working face No. 3302 are entitative coal roadways. The excavating construction started from June 2010 and ended in December 2011. The transport crossheading on working face No. 3302 has the largest horizontal stress of 34.6 MPa while the principal stress in the other direction is 18.6 MPa with the vertical stress of 25.7 MPa. The immediate roof of the roadway top coal is siltstones with the average thickness of 2.8 m while the main roof is medium sandstone with the average thickness of 8.0 m. In particular, the top coal in areas with poor geological conditions has 2–4 m thick sandy mudstone and mudstone interbed above it; its immediate roof is fine sandstone with the average thickness of 11.5 m; its main floor is siltstones with the average

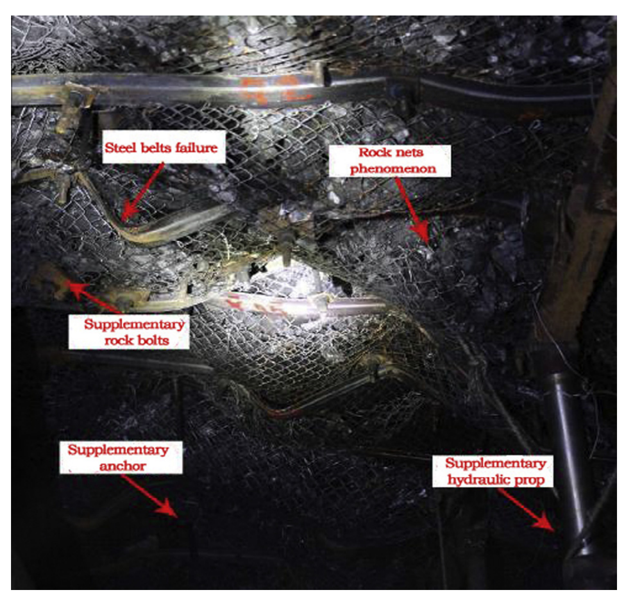

Fig. 2. Failure of roof surrounding rock.