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Construction and stability of an extra-large section chamber in solid backfill mining

Ju Feng [a,*], Li Meng [b,c], Zhang Jixiong [b,c], Miao Xiexing [a], Liu Zhan [a]

[a] State Key Laboratory of Geomechanics & Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221008, China
[b] School of Mines, China University of Mining & Technology, Xuzhou 221116, China
[c] Key Laboratory of Deep Coal Resource Mining, Ministry of Education of China, China University of Mining & Technology, Xuzhou 221116, China

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ABSTRACT

In solid backfill mining without gangue removal, the gangue is separated directly underground and backfilled into goaf. This necessitates the underground construction of an extra-large section chamber for separation equipments. For the construction of an extra-large section chamber in the Tangshan mine, we proposed an active support through a combination of bolting, anchor cables, lining, and a reinforced chamber floor by inverted arch pouring. ABAQUS software was used to analyze the surrounding rock deformation and the plastic zone development of the chamber under different excavation schemes. The best excavation scheme was determined, and the effectiveness of the combined supports was verified. In practice, the engineering installation showed good overall control of the movement of the surrounding rock, with roof-to-floor and side-to-side convergences of 154.6 and 77.5 mm, respectively, which meets the requirements for underground coal gangue separation.

1. Introduction

Solid backfill mining technology can substitute solid waste for the coal resources extracted, and effectively control strata movement and surface subsidence [1–6]. It has been proved to be an effective technology for the removal of unexploited coal deposits under railways, water bodies, and buildings [7,8]. It can separate coal from solid wastes (gangue) underground, lift it to the surface, and backfill the gangue into the exhausted workings (goaf) directly, and significantly enhance efficiency [9,10]. However, gangue separation is restricted by the limited underground space, and to install large-scale separation equipment underground, the construction of an extra-large section chamber is necessary.

The excavation of an extra-large section chamber is a construction process that varies with time and place [11]. Every excavation will increase and/or decrease the stress in different parts of the rock surrounding the section chamber [12]. Different excavation sequences and support schemes could cause different deformations of the surrounding rock. Therefore, the stability of extra-large section chambers has become one of the key issues for geotechnical study, and has attracted much interest from many researchers [13–18]. The construction of chamber for separating coal gangue plays an important role in determining whether or not backfill mining can run smoothly. However, current construction processes and support designs are still under development, and more studies are needed.

In addressing the technical engineering support problems of extra-large section chamber based on the movable sieve jig chambers of the Tangshan mine, we simulated and analyzed the surrounding rock deformation and plastic zone development of chamber under different excavation schemes using the nonlinear simulation software ABAQUS. We then determined the best excavation sequence, and proposed an effective support scheme to guarantee the safety of a movable sieve jig chamber in both construction and operation.

2. Engineering situation

2.1. Geological engineering conditions

The underground coal/gangue separation process of the Tangshan mine solid backfill mining system consists of six roadways, seven chambers, one gangue storage bin, three milling coal holes, and thirteen cross points. The movable sieve jig chamber has the largest section, and its installation and operation requires a chamber of 25.8 m length, 6.2 m width and 9.27 m height, with a semi-arched rectangular shape. This extra-large section chamber is at a

* Corresponding author. Tel.: +86 13605218330.
E-mail address: juf1983@163.com (F. Ju).

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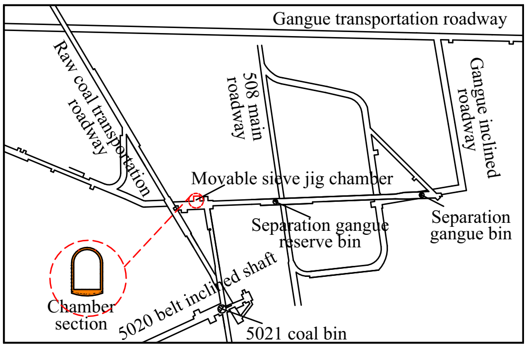

Fig. 1. Location of movable sieve jig chamber.

depth of 568 m. The surrounding rock is mainly sandstone, which is partially fractured, and has poor integrity and stability. The location of the chamber is shown in Fig. 1.

2.2. Excavation sequence and support scheme for the chamber

(1) Selection of excavation sequence

The excavation process of the chamber is a nonlinear irreversible process, which is closely related to the stress path. The selection of an appropriate construction technique can minimize the disturbance and destruction of surrounding rock [11,14]. In general, the construction of a large section chamber involves step-by-step and block-by-block excavation. Based on the actual engineering geological conditions, both upward and downward construction processes were proposed. Downward construction would be carried out from the chamber's top to the bottom, while upward construction would be the reverse. The deformation of the surrounding rock and the stability of the chamber were different in the two excavation sequences, and both needed to be studied to determine the optimal scheme.

(2) Support scheme design

Based on the geological conditions of the Tangshan mine, we proposed an active support system through a combination of bolting, anchor cables, and lining to overcome the poor surrounding rock conditions. Firstly, bolts and anchor cables were to be used to reinforce the surrounding rock, improve the rock integrity, and unload some of the stress. Then, a lining would be used to increase the support stiffness, prevent further deformation, and control the stability of the surrounding rock. Finally, an inverted arch pouring would be conducted to reduce the magnitude of floor heave, thus providing a solid foundation for the installation of large equipment.

The support scheme details were as follows: A right-handed screw thread steel-resin bolt (22 mm × 2000 mm) without longitudinal reinforcement was used for bolting, with an inter-row spacing of 800 mm × 800 mm. Each bolt used a roll of CK 2860 resin anchoring agent, and fixed a steel plate of dimensions 150 mm × 150 mm × 10 mm (length × width × height). A metal mesh (1.2 m × 1.7 m) was constructed from welded steel bar with a diameter of 6.5 mm. The overlap between meshes was no less than 100 mm, and the mesh was fastened with a pair of #16 lead wires, and the distance between two fastening wires was no more than 300 mm. The bolts and meshes were arranged simultaneously. The cable material was a steel strand (17.8 mm × 6500 mm) with an inter-row spacing of 2500 mm. One cable was attached to the middle of the roof, and the two-sided cable was set at 2.5 m above the bottom of the roadway. After the excavation of the floor, an inverted pouring with a thickness of 1.0 m and a lining with a thickness of 0.5 m was constructed. A section of the support of the movable sieve jig chamber is shown in Fig. 2.

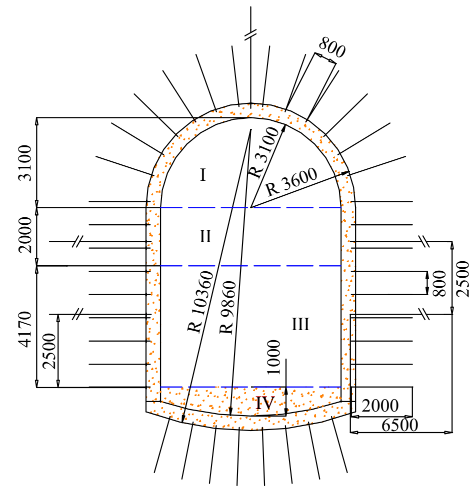

Fig. 2. Section of the support of the movable sieve jig chamber (mm).

3. Numerical simulation analysis

3.1. Models and parameters

Because of its suitability for simulating the excavation of an extra-large section chamber and its ability to solve nonlinear problems, the finite element software ABAQUS was used [19,20]. The dimensions of the section were 6.1 m × 9.27 m (width × height). An 100 m × 100 m plane strain model was built, and the chamber arch was set at the center of the model. The horizontal displacements on both the sides and on the bottom were fixed. An acceleration due to gravity of 9.81 m/s^2 was applied to the entire model. In line with the actual chamber depth, a vertical pressure of 12.5 MPa was applied on the model top for the overburden loading. For the rock surrounding the chamber, the plane strain element CPE4R was used to divide the network close to the chamber. The total number of elements was 15,205. The numerical calculation model is shown in Fig. 3.

The CPE4R element, beam element B21, and truss element T2D2 were used to simulate the lining and inverted arch pouring, bolts, and anchor cable, respectively. The division of structural support elements based on the support scheme is shown in Fig. 4.

The surrounding rock and lining used a Mohr–Coulomb model, and the mechanical parameters of the connections between the support structure, the surrounding rock, and the lining are

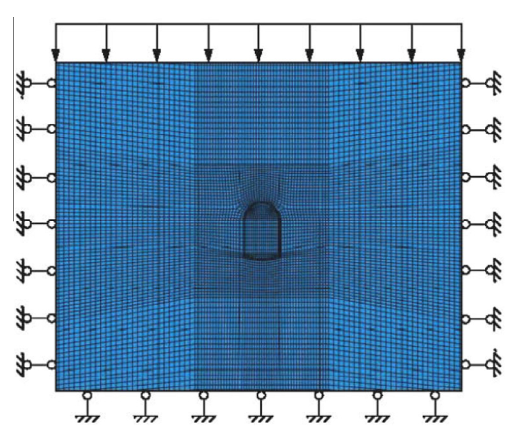

Fig. 3. Numerical calculation model.