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Numerical simulation study on the relationship between mining heights and shield resistance in longwall panel

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ABSTRACT

A numerical model based on a Continuum-based Distinct Element Method (CDEM) was used to carry out a dynamic simulation of the interaction between shield and rock strata movement in longwall mining. In Northern China, the Ordos coal field geological conditions and operational characteristics were used as a case example. The CDEM was constructed on Ordos coal field shield's operation characteristics and geological conditions. Numerical modelling was carried out to investigate the effects of different mining heights on the caving process, movement characteristics, equilibrium and stability conditions of overburden as the interaction between shield and surrounding rocks. With the numerical model, the internal factors for changes in shield resistance under different mining heights was found. The quantitative relationship between mining heights and shield resistance was also obtained by the numerical simulation.

1. Introduction

Currently, most numerical simulation studies of overlying strata in longwall mining focus on the mining-induced stresses, displacement fields and its variation from macro structure. They usually ignore the role of shields or over-simplify its effect. Therefore, their simulation results would not be appropriate for shield selection. Shields are the only equipment used to regulate pressure control for longwall panels [1]. Thus, shields are key to controlling the surrounding rock mass.

Research on dynamic numerical simulation of the interaction between the shield and the surrounding rock mass is the key solution for the control of the rock mass and shield selection. This paper examines the longwall panel 31401 of a coal mine in the Ordos coal field. A numerical simulation of a shield selection and the control of the surrounding rocks at the face are presented under the same geological conditions. The changes in shield resistance regarding the mining heights, as well as the overlying strata structure, are also presented, considering the same geological conditions.

2. Shield model

A dynamic numerical model is presented to simulate the actual working characteristics of a shield based on the CDEM software. The ANSYS software was used to establish the two-dimensional model of the rock strata and the shield. The shield leg model was plotted in CDEM software, achieving a two-dimensional numerical simulation of the dynamic interaction between shield and surrounding rocks.

Based on the actual working characteristics of shields [2,3], the constitutive relation of the shields' working resistance was built in CDEM and is represented by:

$$P = P_0 + K\Delta u \quad (1)$$

where P = Shield resistance, Pa; P_0 = Setting load, Pa; K = Stiffness of shield leg, Pa/m; and Δu = Incremental displacement, m (see Fig. 1).

The mechanical loading process of the shield model is:

(1) At the initial stage of simulation, the shield is given a setting load P_0.
(2) When the roof pressure is less than the setting load P_0, the shield will rise rapidly toward the roof (as shown in Fig. 2A-b). At this time, the shield enters the K_0 segment. When shield, resistance reaches the setting load, its leg will stop rising, and the shield enters the K_1 segment.

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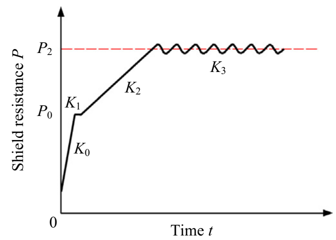

Fig. 1. Constitutive model for shield in CDEM software.

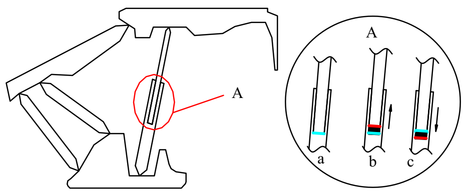

Fig. 2. Shield model used in the simulation.

(3) When the roof pressure is greater than the setting load P_0 but less than the yielding load P_2, the leg piston's extension will be reduced continuously and gradually under the action of roof loading (as shown in Fig. 2A-c). Finally, shield resistance enters the K_2 segment.
(4) When the roof pressure is greater than the yielding load P_2, the leg working model enters the K_3 segment. The leg will contract and extend repeatedly as the yielding valve opens and closes automatically, maintaining a dynamic balance between the leg resistance and the roof pressure.
(5) After the shield moves, the leg pressure goes through the cycle from (1), (2), (3) to (4) again for the next mining cycle.

3. Numerical simulation model

To simplify the numerical simulation model and improve the computational speed, a numerical model was built to simulate the geological cross-section at the panel center, along the panel advance direction. The model is 230 m long by 200.2 m high. The coal seam is 4.5 m thick and 190.7 m deep. Moreover, the coal seam and the surrounding strata are horizontal. The numerical model is shown in Fig. 3. The model contains the full overburden thickness from coal seam to the surface. The vertical loading applied is the full overburden gravity load and the boundaries of the bottom, to the left and right sides of the model are fixed.

The physical and mechanical parameters of the strata were obtained by the back-calculation method. The calculation parameters were selected according to the basic principle of numerical simulation, experimental data [4–6], measured data from the surface overburden movement and shield resistance in the panel 31401.

If the simulation results in a fractured structure interval of the sub key strata are larger than the field data, the tensile strength and cohesion of the sub key strata are reduced, and vice versa. If the simulation results in shield resistance are larger than the field data, the rock strata above and adjacent to the coal seam are meshed smaller, and vice versa. This process was repeated until the simulation results was consistent with the field data. Finally, physical and mechanical parameters of the strata that represented the most the field values were obtained for the numerical simulation model.

In order to eliminate the boundary effect, the distance from the left and right boundary was set to 50 m from the caving zone. Each cut of the shearer was set to be 0.865 m deep from left to right, cut by cut. A total of 150 cuts (about 130 m) were made. In the model, the shield's setting load and yielding load were 0.94 MPa and 1.40 MPa, respectively. Measuring points were arranged in the shield leg to record the shield resistance and leg convergence. The simulation results are shown in Figs. 4–8.

As shown in Figs. 4–7, when the face has advanced to 42.385 m, the sub key strata 1 caves for the first time. The peak stress (6.51 MPa) and its corresponding peak displacement of 1.51 mm are located about 10.0 m in front of the face.

When the face has advanced of 129.75 m from the start point (Fig. 8), the sub key strata 1 has undergone five periodic weightings. The periodic weighting interval ranges from 15.57 to 19.03 m, with an average of 17.4 m. The monitored data for panel 31401 showed that the periodic weighting interval was 11–21 m at the panel center, with an average of 17 m.

As shown in Fig. 9, when the face has advanced of 40.655 m, 41.52 m, 42.385 m, 43.25 m, and 44.115 m, the shield resistances are 1.31 MPa, 1.28 MPa, 0.881 MPa, 0.925 MPa, and 1.28 MPa, respectively. The shield resistance before and after the first caving of the sub key strata 1 decreases first and then increases. During the periodic and non-periodic weightings, the maximum shield resistance was 1.31 MPa and 0.91 MPa, respectively. The field measurement of maximum shield resistance was 1.28 MPa and 0.86 MPa during the periodic and non-periodic weightings as measured in the field.

4. Numerical simulation under different mining heights

On the basis of verifying the accuracy of 4.5 m mining height in panel 31401, the coupled numerical simulation between shield and surrounding rocks under different mining heights in the same coal seam was carried out. The shield resistance and leg convergence were recorded. Based on the strength parameters for similar strata conditions in the Ordos coal field, the shield strength used in the numerical simulation were set as shown in Table 1.

Figs. 4 and 10 show that, under different mining heights, the first weighting intervals of the sub key strata 1 is about 43.0 m.

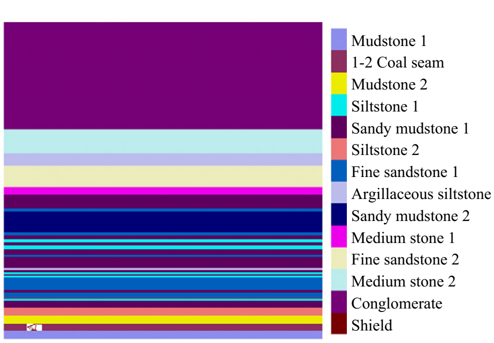

Fig. 3. Simulation model.

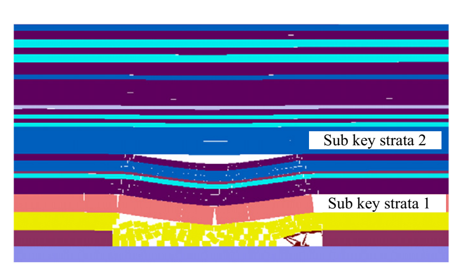

Fig. 4. First caving of sub key strata 1.