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Numerical simulation of land subsidence and verification of its character for an iron mine using sublevel caving

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ABSTRACT

Combined with a digital bored photography system and in-situ statistics concerning the joints and fissures of both ore-body and surrounding rock, a 2D discrete model was constructed using UDEC. The stress field and displacement field changes of different sublevel stoping systems were also studied. Changes in the overlying rock strata settlement pattern has been analyzed and validated by in-situ monitoring data. The results show that: in the caving process, there exists an obvious delay and jump for the overlying rock strata displacement over time, and a stable arch can be formed in the process of caving, which leads to hidden goafs. Disturbed by the mining activity, a stress increase occurred in both the hanging wall and the foot wall, demonstrating a hump-shaped distribution pattern. From the comparison between simulation results and in-situ monitoring results, land subsidence shows a slow-development, sudden-failure, slow-development cycle pattern, which leads eventually to a stable state. This pattern validates the existence of balanced arch and hidden goafs.

1. Introduction

Since its introduction from Sweden in the 1960s, the sublevel caving method has been widely used for its merits as follows: simple structure, flexibility, high mechanization level and intense mining activity. Despite these advantages, the disadvantages are also obvious, such as low ore recovery rate, high dilution rate and ecological and environmental problems that are caused by ground settlement, which is a complex spatio-temporal evolution process and the form of which is usually influenced by several complex factors. At present, research into this aspect is scarce and hence a study of the rock displacement pattern arising from the caving method of mining is necessary.

Because of the high cost and long duration of the physical modeling method, numerical simulation has been widely applied as an effective method. Compared with other numerical simulation software, UDEC has an apparent superiority when applied to rock simulation with developed joint fissures. Much research has been carried out by scholars both in China and abroad, and a great deal of findings have been achieved [1–6]. Gao et al. simulated the span change problem for the longwall mining method in a coal mine by using UDEC; Liu et al. conducted a stability analysis for a rock slope using UDEC; Hamid et al. simulated the influence of blasting vibrations on the stability of a jointed rock mass slope based on UDEC; Jelena et al. conducted laboratory tests and simulations of the diagonal tension strength of cemented rock [7–12]. For studies in China: Wu et al. carried out hydro-mechanical coupling analysis for jointed rock using UDEC; Du et al. conducted a stability analysis for a high rock slope by means of coding, using 'Fish', which is an inherited programming language of UDEC [13–14]. Due to the concision of the model, fast computation, etc., UDEC has been increasingly applied to practical engineering projects, especially for mines with complex geological conditions [15–18].

In this paper, on the basis of UDEC, a numerical analysis model was built and the ground settlement process caused by mining activity was simulated. In combination with numerical analysis and in-situ monitoring data, the ground settlement pattern of a metal mine employing the caving method was revealed.

2. Engineering background

Chengchao Iron Mine is a large-scale ferrous metal underground mine in China, located in E'zhou, Hubei Province. It is 7.5 km southeast of the city of E'zhou and 20 km east of the city of Huangshi. The mining area is 2300 m long from east to west

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Fig. 1. Photograph of land subsidence on-site.

and 800 m wide from north to south. The iron ore is within a skarn-type deposit and the terrain of the mine is higher in the northeast region and lower in the southwest region. Since the introduction of the sublevel caving method for the −290 m level mining in 2002, mine production has been normal prior to the stoping of the −360 m level in 2005. In 2006, the mine experienced severe ground settlement, which lead to production cessation for over one month. After years of mining, a 4140 m^2 collapse pit has been formed in the center of the settlement. Along with the underground mining activity, the range of the settlement and the extent of damage are still increasing (as can be seen in Fig. 1). Apart from that, the road within the range is increasingly devastating, with obvious cracks in it.

At present, the major mining activity is pillar recovery on −290 m and −375 m levels. Stoping is ongoing on at −395 m and −410 m levels and the preliminary mining for −500 m level or below has not yet been completed. The deep mining is characterized by soft rock, high density of joints, various orientation of cracks and so on, hence it is difficult to meet the standards of safety and efficient mining at the same time.

3. Numerical analysis for land subsidence

3.1. Statistical survey of the joints

In China, the scan-line method and digital bored photography system have been widely applied to obtain statistics about joints and fissures. In this experiment, −410 m level and 46–49 routes were measured using the digital bored photography system, in which the fan-shaped boreholes were scanned in the stopes and the 2D and 3D images were obtained in Fig. 2. The isopycnic graph and rose diagram of joint surface were finally obtained, which was shown in Figs. 3 and 4.

As part of the underground geotechnical window mapping process, dip and dip direction were measured for the observed joint sets used in the rock stability assessment. Two prominent joint sets were identified, which were 244°∠55° and 47°∠53°, respectively.

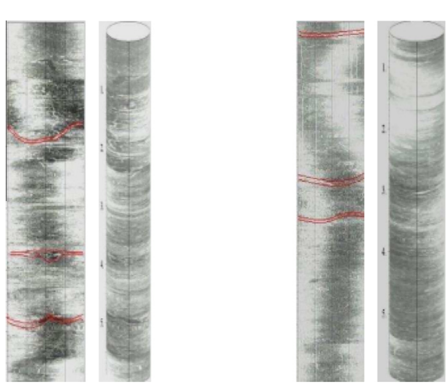

Fig. 2. Blasting hole scanning images based on digital bored photography system.

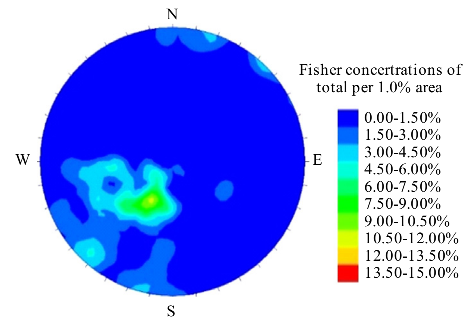

Fig. 3. Isopycnic graph of joint surface.

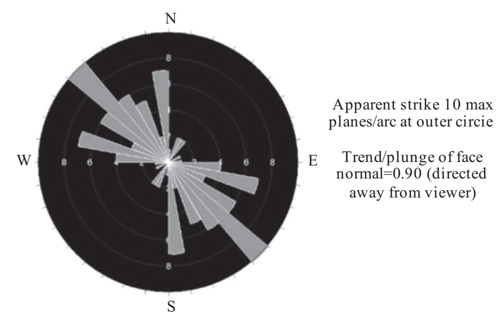

Fig. 4. Rose diagram of joint surface.

3.2. Numerical model building

Based on the practical geological conditions, 3D numerical analysis is better in reflecting the true situation of the mine, but the modeling is complex and requires a lot of computational power. Therefore, in this paper, the UDEC was used to simulate the process of ground settlement, where the starting point of the model is (587649.46, 3356927.36) and the ending point is (586179.12, 3356927.36). The vertical range of the model is from the −700 m level up to ground level and the model has a size of 1470 m in width and 790 m in height. The top of the model is wide and the foot of it is narrow, therefore for parts that are far from the stopes, the joint density was altered to increase the spacing between the joints. By doing this, the number of blocks in the model was decreased and hence the time needed for the computation was reduced. The final model is shown in Fig. 5 as shown below.

3.3. Physical and mechanical parameters

In the caving models, the most difficult task is to scale the rock mass parameters. There are different approaches for this, based on the objective of the model. Some examples can be found in some engineering books, but probably the most influential reference is the synthetic rock mass approach for jointed rock mass modeling [19]. The basic rock parameters obtained from uniaxial and triaxial tests are shown in Table 1. It is well known that in-situ rock mass mechanical parameters are much lower than those derived from laboratory strength tests. Laboratory parameters therefore need to be scaled to in-situ values [20]. While the purpose of this paper is to reveal the macroscopic laws of the ground settlement, we have also taken laboratory data into consideration. For large-scale computations, such as those required to study land subsidence, it is difficult to acquire the true parameters relating to the joints and mechanical properties. For any type of mining, the geological conditions are complex and the rock parameters are difficult to obtain from on-site or laboratory tests. Before these