GPS monitoring and analysis of ground movement and deformation induced by transition from open-pit to underground mining

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Abstract: To trace the potential hazards of open-pit slope in Longshou mine, global positioning system (GPS) is applied to monitoring ground movement and deformation induced by transition from open-pit to underground mining. Through long-term monitoring from 2003 to 2008, huge amounts of data were acquired. Monitoring results show that large-scale ground movement and deformation have occurred in mining area, and the movement area is ellipse-shaped. The displacement boundary of settlement trough is 2.0 km long along the exploratory line, and 1.5 km long along the strike of ore body. GPS monitoring results basically agree with the practical deformation state of open-pit slope. It is indicated that the long-term GPS monitoring is an effective way to understand the mechanism of ground movement and deformation in mine area.

Key words: open-pit; ground movement; long-term GPS monitoring; deformation analysis

1 Introduction

Open-pit is a common and effective mining method in China. At present, above 90% of ironstones, 50% of nonferrous metal ores, 70% of chemical raw materials and almost 100% of building materials are mined with this method (Tong, 1995). However, as the reserves of shallow mineable resources decrease and open-pits deepen gradually, the mining cost and difficulty increase as well. These factors make many mines transform from open-pit to underground mining. Consequently, the problems of displacement, deformation and stability of open-pit rocks should be properly addressed; otherwise they will directly affect the production, safety and environment of underground mining. Bye and Bell (2001) studied the deformation and failure of Sandsloot open-pit, and proposed beneficial suggestions to slope assessment and design. He et al. (2008) used finite difference method to analyze the slope stability of Antaibao open-pit coal mine. Rose and Hungr (2007) used the inverse-velocity method to study the potential rock slope failure in an open-pit. Singh and Singh (1991, 1993) researched the instability of slope in an open-pit over old underground voids and underground workings. In addition, the deformation and stability of boundary pillars and steep slopes due to transition from open-pit to underground mining have been studied with different methods (Sun, 1998; Wang et al., 2000; Li et al., 2005; Song et al., 2010).

The transition from open-pit to underground mining is a complicated geomechanical process. In terms of mining sequence, slope rocks are disturbed or affected twice due to the transition of mining. With respect to spatial relationship, part of the two mining-influenced areas will be overlapped with each other; therefore, a composite dynamic system is formed (Sun, 1998; Sun et al., 1999, 2000). Thus the stress state of open-pit rocks is different from that of single-routine mining. Therefore, the mining scope, process and mechanism of ground movement and deformation are very complicated.

In the past, the geometrical and mechanical analyses, analytical analysis, numerical and physical simulations were used to study the ground movement and
deformation of open-pit (Singh and Singh, 1991, 1993; Pariseau et al., 1997; Sun et al., 2000; Wang et al., 2000, 2005; Bye and Bell, 2001; Liu et al., 2004; Rose and Hungr, 2007; He et al., 2008; Han et al., 2010). However, most of these studies lack the long-term monitoring of ground movement and deformation of open-pit after transition from open-pit to underground mining, and some results lack reliable field data. Undoubtedly, an effective monitoring system is needed for understanding the mechanism of ground movement and deformation and prediction.

In this study, a GPS monitoring network is established to record ground movement and deformation induced by underground mining in Longshou mine, Gansu Province, China. The long-term monitoring results are then analyzed to understand the characteristics of ground movement and deformation caused by transition from open-pit to underground mining.

2 Geological conditions and mining method

2.1 Strata and geological structures

Jinchuan mine is the largest nickel production base in China at present. It is located in the border area of Jinchang, Gansu Province, Northwest China. The ore deposit is about 6.5 km long, 10 to 570 m wide, and over 1 000 m deep. Due to the separation of NEE-trending faults F_8, F_16, and F_23, the ultrabasic rocks as ore-bearing native rocks are divided into four relatively independent mine fields, from west to east, which are mine fields Nos. 1–4, as shown in Fig. 1. The strata of the mine fields consist of two rock types. One is meta-hyper-metamorphic rocks in lower Proterozoic system, mainly composed of migmatite, schist, marble, gneiss, etc. The thickness of outcrops is more than 2 000 m. The other is Quaternary system with the thickness of 25–280 m from the ground.

Faults with different sizes are well developed and intersected with each other. Generally, there are three groups of faults in the mine area. The first group is NW-trending compression-shear fault, such as faults F_1 and F_16, which are the main fractures controlling the whole ore field. The second group is EW-trending compression-shear fault, such as faults F_8, F_16 and F_23. The sizes of these faults are large and the ore body is intersected with them. The third group is NE-trending tension-shear transversal fault, such as fault F_17. These small-size faults frequently cut across the ultrabasic rocks, controlling the stability of the mining stopes. Besides the fracture structures, metamorphic contact zones and alteration zones are also well developed due to the intrusion of ultrabasic rocks and frequent interpenetration of different dikes. Consequently, faults and various kinds of contact zones make rock masses fractured and instable in the mine area.

2.2 In-situ stresses

The distribution of initial in-situ stresses is one of the predominant factors inducing the displacement of surrounding rocks in Jinchuan mine area. Field measurements of initial in-situ stresses have been performed on various kinds of rocks at different depths (Liao and Shi, 1983; Cai et al., 1999). According to the measurement results, the following distribution characteristics of initial in-situ stresses in Jinchuan mine area are obtained (Li et al., 2004):

(1) The horizontal stress is the maximum principal stress. The direction of the maximum principal stress is basically perpendicular to the strike of ore body.

(2) The dominant stress is the intermediate principal stress, which is somewhat smaller than the overburden pressure. The direction of the minor principal stress is horizontal, which is almost parallel to the strike of ore body.

Fig. 1 Geological sketch of Jinchuan mine area.
(3) As the mining depth increases, the ratio of the maximum principal stress to the minor principal stress approaches to 2.5, and the ratio of the maximum principal stress to the intermediate principal stress is close to 2. It is indicated that the stress differences in the original rocks are great. Evidently, the distribution characteristics of in-situ stresses in Jinchuan mine area are unfavorable for the stability of underground mining engineering.

2.3 Engineering geological conditions

The open-pit is 1280 m long, 670 m wide, and 200–300 m deep. It is oriented at N50°–60°W, dips in SW direction with an angle of 70°, and extends about 1,000 m. From the 1960s onward, it has been mined successively for more than 40 years. The transition of open-pit to underground mining started in July, 1990. The underhand drift cut-and-fill mining was adopted. However, because the faults and weak structural planes are well developed, the instability of rock masses makes exploitations rather difficult. During the process of the open-pit mining, slope rocks in open-pit deformed with time, which led to the failure of shafts, serious landslides and collapses for many times. Although underground filling method was employed after the completion of open-pit, large deformation and damage of slope rocks were still observed. In the east of open-pit, ground fractures were intensively developed in open-pit slopes and boundaries. Large deformation or even failure of slope rocks occurred in the hanging wall and footwall of ore body, which seriously threatened the safety and production of the mine.

2.4 Mining method

In Jinchuan mine area, the fractured ore body cannot serve as the stope roof due to the well-developed structural planes. Thus, the cemented backfill mining method is adopted in this mine, which has been developed in recent 30 years (Fall et al., 2005). It is believed that the backfill mining method can effectively control ground pressure and prevent the occurrence of ground movement and deformation (Whittaker et al., 1989; Bell et al., 2000; Yang et al., 2001; Swift and Reddish, 2002; Belaaazoua et al., 2008).

In Longshou mine, the inclined roadways and shafts are used for underground mining. Cemented undercut and fill stopping with hexagonal drifts, which are 30 m long, 5 m high and 6 m wide, are designed for exploitation.

3 GPS monitoring of ground movement

At present, GPS monitoring technology is used to monitor the movement or deformation of global plate motion, subsidence, geological hazards such as landslide, key engineering structures such as dam, and so on (Whittaker and Reddish, 1989; Bell et al., 2000; Yang et al., 2001; Swift and Reddish, 2002; Du and Teng, 2007; Psimoulis et al., 2007; Samsonov et al., 2008). Furthermore, GPS can be used to carry out three-dimensional (3D) survey, which is characterized by continual monitoring, high precision, high efficiency, high automation and low labor requirement.

The instability of open-pit slope is of great negative effects on the shafts and buildings in and outside the open-pit, the roadways in rock slope and the roof of underground mining field. In this project, 300 GPS monitoring points have been established in the open-pit since 2003. In addition, 7 stable base points, far away from the mining area, are set up to establish the reference net. The ground movement monitoring has been recorded for 12 times from December 2001 to 2008.

As for the base point, the WGS-84 coordinate system was adopted in GPS monitoring. The precision of WGS-84 coordinate system depends on the monitoring level, thus level E monitoring net should be used in consideration of the length of baseline. However, for a higher monitoring precision, level D monitoring net with a higher monitoring level was selected.

The mark for data collection was located on the top of a three-storied building in a stable area, which was relatively far away from the mine area. According to long-term monitoring, the data were very stable and credible. The whole mine area is in a circle with the center of the data mark and the radius of 3–4 km. Then, an effective and continual monitoring could be carried out.

The apparatus, GPS receiver Z-12, is fabricated by Ashtech, USA. The static model was used in the monitoring, and data sampling rate changed from every 20 s to every 10 s to obtain more monitoring data. Every two monitoring points and a mark formed a triangle, thus simultaneous observation was carried out based on these three points. The monitoring duration varied from 1 hour to 2 hours and even longer, which depended on different observation conditions. Alignment adjusting and height measuring of the antenna were carried out on every point. The optical plummet was used to adjust alignment. The height of antenna was measured at three identical places of the edge of antenna plane before and after survey.
4 Characteristics and mechanism of ground movement and deformation

Based on the continual monitoring from 2003 to 2008, vast monitoring data were acquired. The dynamic and accumulated deformations were calculated for every monitoring point. The characteristics and mechanism of ground movement and deformation are plotted in Figs. 2–4.

In Longshou mine, large movement and deformation were induced by transition from open-pit to underground mining. Taking the main goaf as the center, the ground settlement developed continuously with increasing mining depth (Fig. 5).

The displacement boundary of settlement trough was confined by fault F1 in the north. It is about 2.0 km long along the exploratory line, and 1.5 km long along the strike of ore body (Figs. 2 and 3). In addition, there were two settlement centers located in hanging wall and footwall, separately. Whereas a heaving center at...
the bottom of open-pit was formed due to the interaction of underground mining and strong compression of open-pit slope. The settlement area in hanging wall extended greatly away from the boundary of the open-pit, while it was merely distributed within the open-pit in footwall. This indicates that the interaction of former open-pit and the present underground mining in hanging wall is larger than that in footwall.

The size of settlement area in hanging wall was 2–3 times of that in footwall. Besides, the center of footwall was obviously controlled by fault F8, and the maximum settlement reached 568.8 mm until 2008. The settlement center of hanging wall developed between exploratory lines 12 and 20, and the maximum accumulated settlement reached 440.8 mm until 2008. In addition, at the bottom of the open-pit, the largest accumulated uplift reached 458.1 mm until 2008 (Fig. 5(b)).

The horizontal and total displacements in hanging wall were larger than those in footwall. In the mining area, almost all the horizontal displacement vectors pointed toward the goaf and the displacement values changed with the distance from monitoring points to the settlement center (Fig. 2). In the open-pit, collapses in different extents appeared in many open-pit steps, and a large number of ground fissures were formed on the surface.

The largest horizontal displacements occurred in open-pit slope between the exploratory lines 16 and 28. The horizontal displacement was larger in hanging wall than that in footwall. At the end of 2008, the maximum horizontal and total displacements of hanging wall reached 853.1 and 951.7 mm, respectively. The maximum horizontal and total displacements of footwall reached 763.5 and 952.1 mm, respectively.

As shown in Fig. 5, the settlement curves are fluctuant. In Fig. 5(b), the significant heaving of the monitoring point 24-4, which is located at the bottom of open-pit, was caused by the squeezing action of the overall movement of open-pit slope. While other fluctuations were closely related to the well-developed structural planes, small faults and rock mass properties. In Jinchuan mine, the response of relatively strong and brittle rocks, such as marble, ultrabasic rock, chroismite, to the settlement is different from that of weaker and plastic strata, such as mudstone and shale. Therefore, a combination of steeply dipping ore bodies and interlayed rocks, with large variations in their geotechnical properties, may result in shear displacement along bedding planes during settlement. Thus, numerous scarps existed along the ground surface in cross-section of settlement trough.

Furthermore, the deformation of open-pit slope in east-central part was greater than those in other places. The horizontal and total displacements in the hanging wall and the uplift rate at the bottom of open-pit decreased gradually. However, the overall horizontal and total displacements increased steadily in footwall.

5 Conclusions

In Longshou mine, GPS monitoring is applied to investigating ground movement and deformation induced by transition from open-pit to underground mining. Through analyzing the long-term monitoring results, following conclusions can be drawn:

(1) Under the condition of transition from open-pit to underground mining, prominent ground movement and deformation were observed in Longshou mine. Two settlement centers developed in hanging wall and footwall, respectively. In addition, a heaving center at the bottom of open-pit occurred due to the interaction of underground mining and strong compression of open-pit slope.

(2) The displacements of monitoring points in hanging wall were larger than those in footwall. In mining area, almost all the plane displacement vectors pointed toward the goaf. The maximum plane displacement was 853.1 mm in hanging wall, while 763.5 mm in footwall.

(3) GPS monitoring results basically agree with the actual states of open-pit. Thus, GPS monitoring system is an effective way for studying and understanding the characteristics and mechanisms of ground movement and deformation of goaf under complicated mining.
conditions.

References


