Stability analysis of new safety cleaning bank in steep slope mining

WU Ai-xiang, JIANG Li-chun, BAO Yong-feng, LI Jian-feng
(School of Resources and Safety Engineering, Central South University, Changsha 410083, China)

Abstract: Based on the study of the slope with gently granular structure in Xingqiao open mine, a new safety cleaning bank mode for steep slope mining was developed, including setting up dint cut, and forming natural retaining wall based on the character of gentle incline slope. It can effectively eliminate the impact of sliding body on the bottom working place and slope body, reduce the dilution of ore, keep rainwater from upper steps away, decrease influence of the weak intermediate layer, and cut cost of disposal waste rock. The safety and reliability of the mode were analyzed and verified from 3 aspects: static load calculation, ANSYS simulation of dynamic loading and spot experiment. The result of static loading calculation shows that the retaining wall can support accumulation and extrusion of granular body, and the glide or overturn disaster will not take place. The simulations of dynamic loading show that the retaining wall remains stable until sliding body collapses from 360 m (10 sublevels). Only one new safety cleaning bank in each 1 - 5 sublevels can fully meet the need of engineering. The new mode sustains steep slope mining, increases the angle of ultimate slope, and reduces invalid overburden amount of rock by 3% - 5%. The result of spot experiment has verified the exactness of the above calculations and simulations.

Key words: steep slope mining; safety cleaning bank; retaining wall; stability; ANSYS

CLC number: TD 854.6

Document code: A

1 INTRODUCTION

The slope body of open mining is a complicated dynamic open engineering system[1]. The dynamic stability is one of the most important factors related to mining security, economic benefit and continuous extraction. Measurement and data analysis suggest that a medium-scale open mine[2], 1.0 × 10^7 m^3 overburden amount of rock will be cut down if the ultimate slope angle is increased by 1°, and consequently expenditure of 1.0 × 10^9 RMB can be saved. There is still a potentiality to increase the ultimate slope angle at some slope in domestic strip mines[2-4]. Steep slope mining is an effective way to achieve this target. The increase of ultimate slope angle may bring about some new engineering problems, such as the stability maintenance of slope system, construction of safety cleaning bank, and disposal of damning and draining water. Research on this aspect was seldom carried out by scholars[4-6]. In this paper, a new safety cleaning bank mode was developed based on the static load calculation on soil mechanics, the ANSYS program simulation and the spot experiment.

2 GENERAL ENGINEERING SITUATION AND CURRENT PROBLEMS IN STEEP SLOPE MINING

Tongling Xingqiao stripe mine is a large-scale chemical mine in the period of the China National Ninth Five-year Plan. Yearly extraction capacity of ore is 9.0 × 10^3 t, and an exploitable year is about 22. The obliquity of slope is 40° - 60° in bottom slope (from +325 to -180 m, 4-31 line). Present operation is carried out at -48 m level. The mine is a rare high-steep slope in China. And the main layers of slope include efflorescent Zhaishan group and Gaolishan group diorite, Wutong formation gritstone, the Quaternary Period surface soil (QP) and residual deposit. Some layers have the characteristics of typical granular structure slope. According to the history records, there are 12 times large-scale landslides and collapses in total, the largest one is about 1.5 × 10^5 m^3. The safety of slope is essential to sustain development of the mine.

The designed slope angles are 39° and 42° above and below 36 m level, respectively. And the ultimate angle is about 41°. The angles of bank slope at open-pit floor are as follows: +36 m level above is 50°, and +36 m level below is 55°. The width of safety bank at open-pit bottom is 12 - 15 m, the width of cleaning bank is 12 - 15 m, and gradient of transportation is less than 8%.

In order to effectively decrease overburden rock amount in bottom wall slope, the following researches were done: 1) combining 3 steps into 1
1) sublevel; 2) keeping the angle of step unchanged; 3) cancelling safety bank situated at each step; and 4) centralizing safety cleaning bank in each sublevel instead. The disadvantages of these measurements are summarized as follows: 1) smooth safety bank cannot effectively hold up the collapsed rock upside; 2) bottom workings surface is easily impacted by slide rock; 3) waste rock accumulation raises dilution ratio; 4) sliding body damages slope surface; 5) too small cross section area of raceway leads to jam easily; and 6) water from upside steps in rainy season erodes interlayer of slope surface, and induces disaster of slope body.

For gently inclined slope, the horizontal projection reaches 13 m between the upper and the bottom edges of steps. The value is far beyond the capability of the current mining techniques and bore equipment. Blasting leads to great problem at the cleaning outer bottoms of steps, so the special methods should be necessary.

To deal with the retaining wall, the following methods are suggested: 1) increasing the meshwork density; 2) enhancing the linear density of explosive in each drill hole; 3) shifting the drilling equipment outside; and 4) carrying out the secondary blast.

The methods also have disadvantages as follows: 1) a large amount of explosive is needed and dynamic load of slope is increased; 2) slope surface is directly damaged; 3) drilling meters are increased; 4) unsafe risk is high because the gravity centre of equipment shifts outside; and 5) cost is increased due to blasting bottom rock again.

3 NEW SAFETY CLEANING BANK

As shown in Fig. 1, the new safety cleaning bank can easily overcome the above problem, and effectively make use of the character of gently slope whose resistive line is too large to explode. The retaining wall survived naturally in the process of forming ultimate steps, can effectively decrease the damage to slope body by dynamic load of blasting.

The functions of the new system are as follows,

1) 2 safety steps in each sublevel are saved, the ultimate pit slope angle is increased, and the invalid overburden amount of rock are decreased by 3% - 5%; 2) the dilution ratio of ore is reduced; 3) damage to bottom working surface is minimized by slide rock of sublevels upside, and the cost of cleaning and truckage are greatly reduced; and 4) eroding damage to slope and weak interlayer is minimized because water is withheld and drained from upside steps.

After calculation, the cost of new safety bank is not increased much. But, the new system increases the ultimate pit slope angle, cuts down the invalid overburden rocks, and ensures the normal production of mine. The economic benefits are obvious as a whole.

4 SAFETY VERIFICATION OF RETAINING WALL

Stability analysis of retaining wall can be carried out from 3 aspects: static loading, impacting load and spot verification. Because the retaining wall is formed during digging of natural slope, it is extruded by exploding strain wave and eroded by harassment of digging equipments, but the internal medium has little change. Hence, it is quite different from manual retaining wall. It is reasonable to regard the retaining wall as a uniform rigid configuration and the shear stress should be very high.

4.1 Static loading calculation

In view of maximum load, the sunken chimn is fully filled by granular body till natural angle of rest, and manual disposition is not needed. The stability verification of retaining wall is mainly based on the Mohr-Coulomb law and the other related formulas. The initiative pressure of granular to the retaining wall has close relation with the physical characteristics and borderline of accumulation.

If the accumulating height of slide rock behind wall is $h$, the initiative force $F$ is given as follows:

$$F = \int_0^H \rho dh = \int_0^H \gamma h \left(\frac{\pi}{\pi + 2\varphi_0} + 2\varphi_0\right) dh (1)$$

where $\gamma$ is the volume mass of slide rock, $\rho$ is the pressure of slide rock to retaining wall, $H$ is the retaining height, $\varphi_0$ is the equivalent friction angle of the accumulation, and $\beta$ is the incline angle of the accumulation behind wall.

If the accumulating height of slide rock behind wall is $h$, the initiative force $F$ is given as follows:

$$F = \int_0^H \rho dh = \int_0^H \gamma h \left(\frac{\pi}{\pi + 2\varphi_0} + 2\varphi_0\right) dh (1)$$

where $\gamma$ is the volume mass of slide rock, $\rho$ is the pressure of slide rock to retaining wall, $H$ is the retaining height, $\varphi_0$ is the equivalent friction angle of the accumulation, and $\beta$ is the incline angle of the accumulation behind wall.

The active moment $M_a$ of the accumulation to the bottom wall is calculated by

$$M_a = \int_0^H (H - h) \rho dh (2)$$

4.1.1 Anti-shearing stability verification

Fig. 2 shows stress distribution and dimension of retaining wall, where $\Sigma H$ is the horizontal anti-