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Calculation of slope-cover height under price fluctuation in open-pit mines

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ABSTRACT

Leaving ditches between adjacent mining areas can effectively reduce re-stripping in the latter mining area and simultaneously lead to an increment in internal dumping costs in the former mining area. This paper establishes calculation models for these two marginal costs. The optimizing model for slope cover height can be determined by including marginal cost models in the objective function. The paper has two main contributions: (a) it fully considers redistribution of dumping space in the model; (b) it introduces price fluctuations and cash discounts in the model. We use the typical open-pit mine as an example to test and prove the model. We conclude that a completely covered slope is reasonable in Haerwusu open pit mine; in addition to an increasing price index, the slope cover height can be reduced; and that price changes are one of the most important influencing factors of slope cover height optimization in an open-pit mine.

1. Introduction

Almost all current Chinese large and nearly horizontal open-pit coal mines adopt an internal partition design. To optimize the level of resource recovery, such mines use no or minimal coal pillars between mining areas (as shown in Fig. 1). However, recovering resources under the coal pillar poses the problem of slope cover height. A scientific decision regarding the required slope cover height can not only improve the comprehensive benefit and production efficiency of the mine but also smoothen the transition between mining areas in terms of production, transportation, and reclamation. This is a major subject in science and technology that aims to build a green and efficient open-pit mine. Some studies of slope cover height optimization have been conducted in both Chinese and foreign contexts, but excessive simplifications and assumptions in their studies have a significant influence on the model's accuracy, which can result in an undesirable conclusion [1–6]. Some studies established a total marginal cost model that can reflect actual production more precisely by combining submodels that considers the factors of price fluctuations and cash discounts [7–12]. In this study, we solved the model by using Matlab, determined the time and height solution set of the marginal minimum cost, obtained a more reliable method to optimize slope cover height for both domestic and foreign similar open-pit mines, and provided a more reliable theoretical basis for smooth transitions and reasonable space allocations between mining areas.

2. Horizontal transportation marginal cost

2.1. Increment in working-wall transport distance

In large nearly horizontal open-pit coal mines using shovel-truck technology, the double loop transportation corridor on the complete end wall is relatively fixed and facilitates the organization of production; however, in the case of leaving ditch, the transportation corridor in the end wall changes. To facilitate discussion, the side unaffected by the leaving ditch is called side A and that containing the leaving ditch is called side B (Fig. 2). The transportation corridor on the side B end wall is cut off by a ditch that stands above the slope cover level; as spoil is transported through the entire working panel to the side A end wall, the transport distance increases dramatically. The open-pit mine working-slope transport distance on each step is related to the length of working panel, which increases with the height of the mining level. However, the calculation of working-panel length is too complex by benches; this paper presents a reasonably simplified model that hypothesizes the average working-panel length on the slope cover

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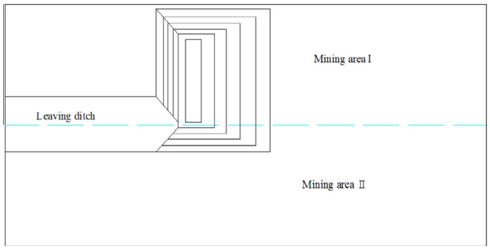

Fig. 1. Leaving ditch between mining areas.

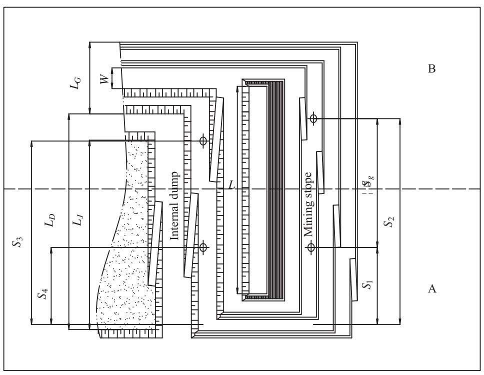

Fig. 2. Schematic of stripping transport distance in semi-covered internal dumping.

level and the highest stripping level as the average working-panel length.

$$L_1 = L + 2H\cot\alpha \quad (1)$$

$$L_2 = L + 2\Delta H\cot\alpha \quad (2)$$

$$\bar{L} = \frac{1}{2}(L_1 + L_2) \quad (3)$$

where L is the working-panel length on the slope cover level; H the mining depth of the open pit; ΔH the slope cover height; $\bar{L}$ the average working-panel length; and α the final slope angle of the open-pit end wall.

The transport distance of the working slope is one-fourth the average working-panel length in double loop internal dumping; then, the transport distance of the working slope is three-fourth of the average working-panel length in single loop internal dumping, which results from the remaining ditch cut off at the spiral line in the end wall of side B, making the overburden to be transported around the end wall of side A. The calculation equations are as follows:

$$S_1 = \frac{1}{4}\bar{L} = \frac{1}{4}[L + (H + \Delta H)\cot\alpha] \quad (4)$$

$$S_2 = \frac{3}{4}\bar{L} = \frac{3}{4}[L + (H + \Delta H)\cot\alpha] \quad (5)$$

$$\Delta S_g = S_2 - S_1 = \frac{1}{2}[L + (H + \Delta H)\cot\alpha] \quad (6)$$

where S_1 is the average working-wall transport distance of side B when the slope is covered completely; S_2 the average working-wall transport distance of side B when the slope is semi-covered; and ΔS_g the increasing working-wall transport distance of side B compared with that when the slope is completely covered.

2.2. Increment of dumping distance

As shown in Fig. 2, leaving ditch on the end wall causes both the double loop internal dumping haul road blockade and the transport distance of internal dumping in side B to increase, while the haul road in side A is unchanged. Therefore, the distance increment occurs in transporting from the end wall of side A to side B. As the leaving ditch in side B shortens the average dumping line by an average ditch width, the average dumping distance in side B, S_3, is the sum of the average dumping distance in side A and the distance from the center line to the gravity of the side B dump. This can be calculated as follows:

$$S_3 = \frac{3}{4}\bar{L} - \frac{1}{4}(W + L_G) \quad (7)$$

$$S_4 = \frac{1}{4}[L + (H + \Delta H)\cot\alpha] \quad (8)$$

$$\Delta S_p = S_3 - S_4 = \frac{1}{4}[2L + 2(H + \Delta H)\cot\alpha - (W + L_G)] \quad (9)$$

where

$$W = \Delta H \times (\cot\alpha + \cot\beta) \quad (10)$$

$$L_G = H(\cot\alpha + \cot\beta) \quad (11)$$

where W is the width of the channel bottom; L_G the width of the channel top; β the stable slope angle of the inner-dump; S_3 the average dumping distance in side B with the ditch remaining; S_4 the average dumping distance in side B without the ditch remaining; and ΔS_p the increment in the average dumping distance in side B.

2.3. Increment in horizontal transportation costs

The horizontal transportation cost increment is calculated by the quantity affected by the ditch remaining and the horizontal transportation distance using our horizontal distance increment calculation model. Bounded by the center line of the mining area, the quantity unaffected by the leaving ditch is half of the stripping quantity per year above the slope cover height; therefore, the quantity affected by the leaving ditch is calculated by subtracting the increase in internal dumping height from half of the annual stripping quantity:

$$Q = [L + (H + \Delta H)\cot\alpha] \times (H - \Delta H) \times v \quad (12)$$

$$V_G = \frac{1}{2}v(W + L_G)(H - \Delta H) = \frac{1}{2}(H^2 - \Delta H^2)(\cot\alpha + \cot\beta)v \quad (13)$$

$$Q_b = \frac{V_G}{\mu} \quad (14)$$

$$Q_y = \frac{1}{2}Q - Q_b \quad (15)$$

$$Y_1 = Q_y(\Delta S_g + \Delta S_p)C_y \quad (16)$$

where Q is the annual stripping quantity above the slope cover height; v the average advancing speed of the open pit; V_G the increment in ditch space; μ the loose coefficient of overburden, generally 1.1–1.2; Q_b the increase in internal dumping height; Q_y the quantity affected by the leaving ditch; C_y the horizontal transportation unit cost; and Y_1 the horizontal transportation cost increment.