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DETERMINING HEIGHT OF BENCHES IN OPEN MINING OF STEEPLY-DIPPING DEPOSITS WITH CONSIDERATION OF ORE LOSSES AND DILUTION

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ABSTRACT

At present stage of the development of the mineral resource complex, a trend is seen to deterioration of geological and engineering conditions of mining ore deposits, which entails increase of losses and dilution of mineral, causing increase of the cost price of mineral production and processing. With consideration of the specified limiting conditions, the maximal net present value of deposit mining will be achieved with minimal economic loss resulted from mineral losses and dilution.

For the conditions of steeply-sloping ore pits, analysis was conducted of the impact of the bench height on the value of mineral losses and dilution, and necessary calculations were made to identify the degree of influence of the pit bench height and the height of the triangle of inmixed waster rocks on the values of losses and dilution by three possible modes of preparing a new horizon (in mining from the hanging wall to the bottom wall, in preparation across the ore body).

According to the results of the research, conclusions were made that the economic loss related to the losses and dilution, increase in direct proportion to the increase of bench heights; the mode of horizon preparation significantly influences the value of losses and dilution and the economic losses related to them; the value of losses and dilution increases with increase of bench height, and the current stripping ratio reduces. For this reason, for determining the optimal bench height, joint consideration of the losses and dilution with the current stripping ratio, is required. The conducted technical and economic calculations result in recommending the bench height in ore zone, equal to 5 m. with maintaining the rock bench height of 20 meters

Keywords: deposit, mineral dilution, economic loss, bench height, pit, stripping ratio

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1. INTRODUCTION

Losses and dilution of mineral result in reduction of the output of product and the volumes produced and processed ore, which, in turn, results in the increase of the current stripping ratio and the share of depreciation allocations [1]. Ultimately, these factors contribute to the cost price increase of mineral production and processing and decrease the profit.

Considering the abovementioned limiting conditions, the maximal value of the net present value of a deposit mining (holding all other conditions equal), will be obtained at the minimal economic loss from loss and dilution.

Knowing the values of ΔP and ΔV, it is possible to identify the economic loss caused by mineral losses and dilution. When mineral losses and dilution do not affect extraction of useful components and the quality of concentrates, the economic loss (L) is

$$L = \left(l_k \cdot \varepsilon_T \cdot \mathrm{Pr}_u - a_w + s - d - a_M - d_M - r_0\right)\Delta P \cdot \gamma_0 + \\ + \Delta V \cdot \gamma_w \left(a_w + d + a_M + d_M + r_0 - s - l_u \cdot \varepsilon_T \cdot \mathrm{Pr}_u\right), \qquad (1)$$

where ΔP is the volume of ore lost at the contact, m^3; ΔV is the volume of diluent mass, m^3; γ_0 is the volume mass of geological ore, t/m^3; l_k is the content of useful component of ore body contact; l_u is the useful component in the diluent rock; ε_T is extraction of useful component into concentrate from commodity ore; Pr_u is the price of the useful component in lost ore, roubles/t; a_w is the cost price of ore excavation without consideration of post-stripping reclamation, roubles/t; s are costs for lost ore excavation and removal from the pit, roubles/t; d is the cost price of ore processing at the dressing plant, roubles/t; a_M are specific depreciation allocations per ton of ore balance reserves; d_M are specific depreciation allocations per ton of processed ore when the dressing plant operates with full load; r_0 are unit costs for prospecting of 1 ton of ore balance reserves; γ_w is the volume weight of the diluent rock, t/m^3 [2].

Calculated values are adopted by the data of counterpart deposits and pits.

Function L = $f(\Delta P, \Delta V)$ has minimum region, and for this reason, it is possible to find such a ratio between ΔP and ΔV, at which a company will make a maximum possible profit under the following conditions [3].

Equation (1) implies that the minimum of L value can be achieved in two ways:

1) Reduction of mineral losses ΔP and admixture of waste rocks ΔV;

2) Identifying the optimal ratio of ΔP and ΔV.

2. METHODS

Analysis of the schemes shown in figure 1 and equation (1) indicates that the first condition is fulfilled via reduction of bench height *h*, and the second condition is fulfilled via determining the height of the triangle of admixed waste rocks *a*, in which, the optimal ratio is ensured between the volumes of lost ore and admixed waste rock (at fixed bench height).

To determine the minimum economic loss, we find derivative $\frac{dL}{da}$ of equation 1, equate it to zero and calculate a_{opt} which is the optimal value of the triangle of admixed waste rocks *a*.

In a_{opt}, the optimal ratio is achieved between the value of losses and dilution, ensuring minimum economic loss, if the ore body contacts are regular,

$$a_0 = \frac{h \cdot \gamma_0 \cdot \left(l_k \cdot \varepsilon_T \cdot \mathrm{Pr}_u - a + \mathrm{s} - d - a_M - d_M - r_0\right)}{\gamma_0\left(l_k \cdot \varepsilon_T \cdot \mathrm{Pr}_u - a + \mathrm{s} - d - a_M - d_M - r_0\right) + \gamma_w\left(a + d + a_M + d_M + r_0 - \mathrm{s} - l_\Pi \cdot \varepsilon_T \cdot \mathrm{Pr}_u\right)}, \quad (2)$$

For ore pit conditions, necessary calculations were performed in accordance with the abovementioned methods with the purpose of studying the impacts of the bench height on the loss values and dilution. The calculation results are given in figures 1 and 2.

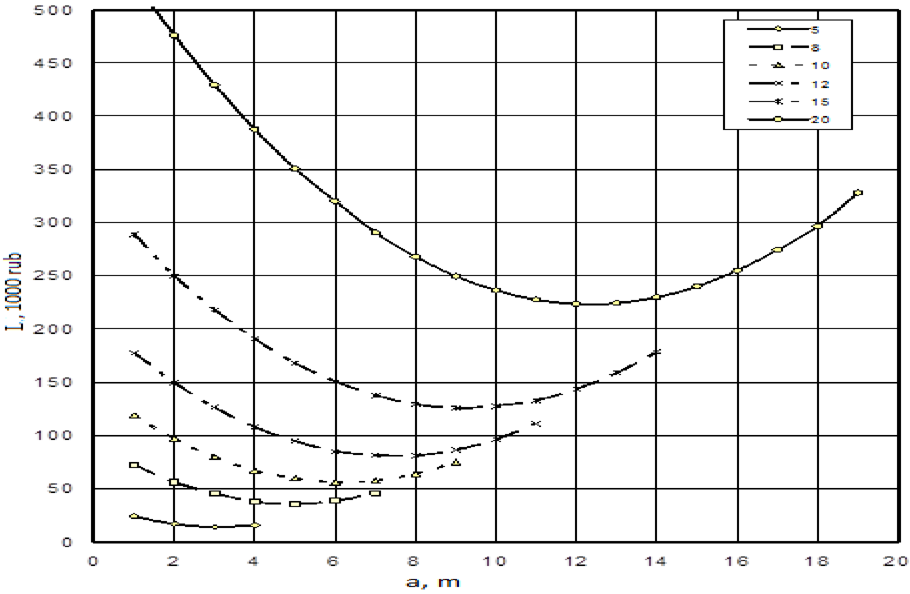

Figure 1 Graph L = *f*(a) for different values of h – bench height, with operation from hanging wall to bottom wall

When considering mineral losses and dilution, it is expedient to consider the values of bench heights, most common in pits [4], of 5, 8, 10, 12, 15, 20 m.

Value *a* which reflects the ratio between the volumes of lost ore and admixed rock, can be assumed as divisible by 1 m, which ensures enough accuracy of the results.

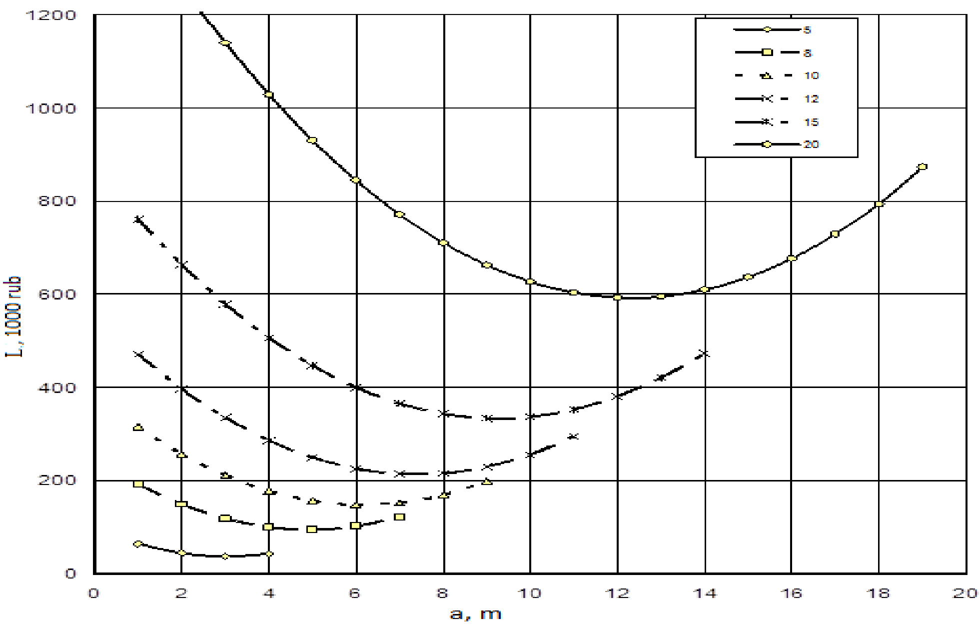

Figure 2 Graph L = *f*(a) for different values of h – bench height, with operation from bottom wall to hanging wall

3. RESULTS

Analysis of graphs L = *f(*a), shown in fig. 1 and 2, enables to make the following conclusions:

- With increase of the bench height, volumes of lost ore and admixed waste rock increase for each bench [5];
- Value a_{opt} of minimum economic loss from losses and dilution, increasing by the absolute value with increase of the bench height, remains constant in relation to certain value *h* (irrespectively of the mining font advancing in relation to ore body occurrence).

The resulting graph for this type of studies is graph L = *f(h)* – changes of the value of the economic loss related to losses and dilutions, for the pit in general (Figure 3).

The number of benches in the pit is different at their different height. The height of the triangle of admixed waste rocks *a* is assumed in calculations as equal to a_{opt}.

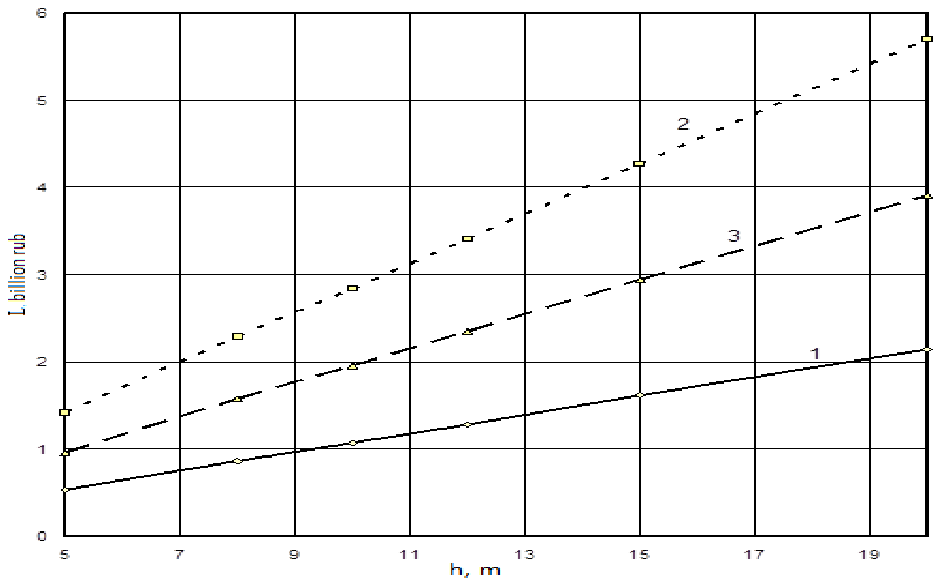

Figure 3 Graph L = *f*(h) Changes of the economic loss value related to losses and dilution, for the pit in general:

- In operation from hanging wall to bottom wall.
- In operation from bottom wall to hanging wall.
- In preparation across the ore body.

Table 1 shows value a_0 – of optimal height of triangle of waste rocks admixture at different bench value h.

Table 1 Value a_0 of optimal height of triangle of waste rocks admixture at different bench value h.

h, m	**a_0**
5	3,1
8	4,9
10	6,2
12	7,4
15	9,3
20	12,3

All the calculations are conducted by three possible modes of horizon preparation [6]. According to the results of the studies, the following conclusions can be made:

- Economic losses related to losses and dilution, increase directly proportional to increase of bench heights;
- Horizon preparation mode significantly impacts the value of losses and dilution and the economic losses related to them;
- Both for an individual horizon and for the pit in general, with increase in bench heights, the value of losses and dilution increase.

With increase of the bench heights, in mining of steeply-dipping deposits, the current stripping ratio increases, and deposit mining becomes more economical [7].

At the same time, as it was substantiated above, with increase of the height of ore benches, economic losses caused by increasing losses and dilution [8], increase. These two contradictory factors in ore zone need to be taken into consideration.

4. DISCUSSION

Methodologically, this study can be performed as follows. In cross-sections, positions of mining works are indicated, corresponding to the marks of the pit bottom in each calendar year of deposit mining, with different values of *h* and angle of slope of the pit working flank in the ore zone, but with the same values of *h* in rock zone.

Then, the areas of extracted waste rock in each annual reduction, are measured and the current volumes of waste rock are identified in mining a deposit with different values of ore benches' height.

Then, discounted costs for removal waste rocks for the pit with various values *h* in ore zone are calculated, and then they are compared [9].

Slope angles of pit working flanks [1].

$$\varphi = \mathrm{arctg}\frac{\mathrm{h}}{\mathrm{B} + \mathrm{h}\cdot\mathrm{ctg}\alpha}, \tag{3}$$

where B is the width of the working areas, m.

Width of pit working areas [1].

$$\mathrm{B} = B_{\mathrm{res}} + \Delta B,$$

where B_{res} is the width of the reserve lane of the reserves on the horizon ready for extraction, m;

ΔB is the part of the working area, minimally necessary only for mining the underlying horizon, m.

The value of discounted costs for removal of waste rocks from the pit, and the costs of future years, are given to the first year of operation [10], [11].

$$C = \frac{V\cdot b}{(1+E)^t}, \tag{4}$$

where V are the volumes of stripped rocks removed annually in deposit mining by pit, m^3; *b* are the costs for waste rocks extraction and removal from the pit, roubles/m^3; *E* is the discount rate; *t* is the discounting time period, years.

According to the results of the studies, the optimal height of ore benches was identified (with height of rock benches of 20 m.), corresponding to the minimum costs of stripping works. The studies conducted for Ozerny pit, resulted in the following conclusions:

- Costs of extraction and removal of waste rocks are inversely proportional to ore bench height;
- Economic losses from losses and dilution are directly proportional to height of ore benches.

Obviously, for identifying h_{opt} by two main factors – costs for stripping works and economic losses from losses and dilution, it is necessary to summarize the graphs C = $f(h_{opt})$ and L = $f(h_{opt})$ [12], figure 4.

Minimum of function C + L = $f(h_{opt})$ will correspond to the optimal value of ore benches' height.

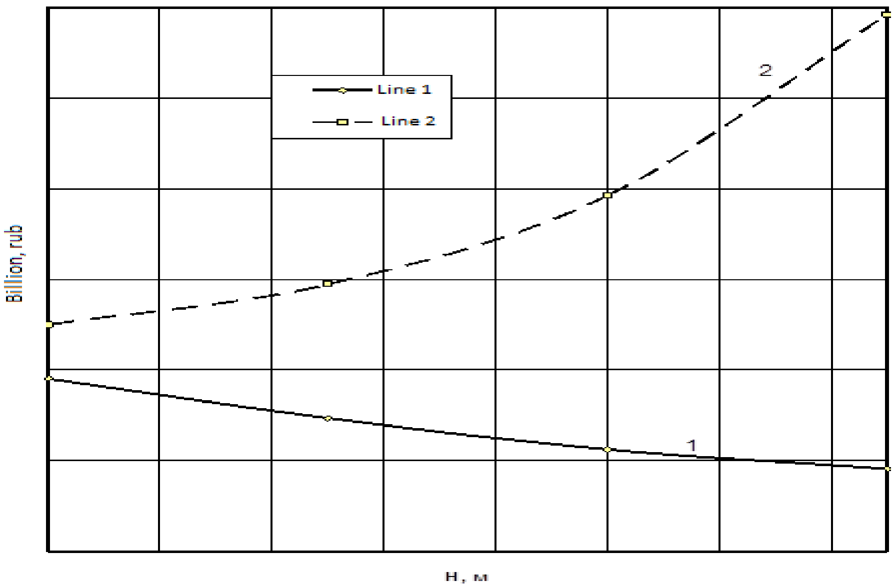

Figure 4 Graph C = *f (h)* for Ozerny pit

1 – graph of changing stripping works costs discounted in time. 2 – summary curve C + L = *f (h).*

Graphs (figure 4, curve 2) show that the minimum of function falls on the bench height in the ore zone h_{opt} = 5 m. In exiting the ore zone, 5-meter benches need to be aggregated into 20-meter benches. In this case, the loss coefficient will be η = 0.86 %, and the dilution ratio я - ρ = 2.24 %.

With known value $a_{опт}$, corresponding to the minimum economic loss from losses and dilution in any contact, it is possible to identify the places of blast holes location in the contact places of ore and rock [13], which will ensure rock mass detachment along the assigned optimal line AB (Figure 5).

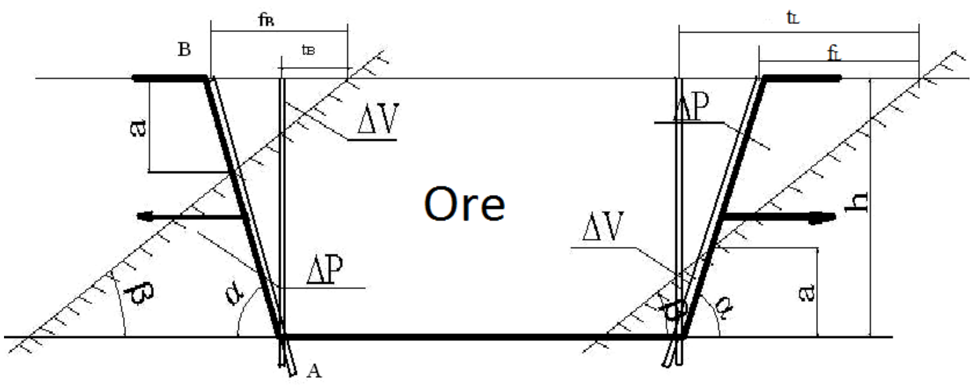

Figure 5 Scheme to the calculation of the place of blast hole location in the place of the contacts of ore and rock, ensuring rock mass detachment along the assigned optimal line AB [14].

Distance AB of inclined borehole (at bench slope angle) from the ore body contact (f) and the distance of the vertical borehole from the ore body contact (t), with operation from the middle to ore body contacts with dipping angle of ore body $\beta < \alpha$ – slope angle of working bench [15]

a). For hanging wall

$$f_B = a_O(ctg\alpha + ctg\beta_B), \text{ m} \tag{5}$$

$$t_B = (a_O - h)ctg\alpha + a_o ctg\beta_B, \text{ m} \tag{6}$$

б). For bottom wall

$$f_L = (h - a_O)\,(ctg\beta_L - ctg\alpha), \text{ m} \tag{7}$$

$$t_L = (h - a_O)\,ctg\beta_L + a_o ctg\alpha, \text{ m} \tag{8}$$

5. CONCLUSION

The following source data were used in the calculations:

Ore bench height - h = 5 m; bench slope angle - $\alpha = 70^\circ$; optimal height of triangle of admixed stripped rocks - $a_0 = 3.1$ m; weighted averages dipping angles of ore bodies (hanging wall) – $\beta_B = 39.3^o$, (bottom wall) – $\beta_L = 40.5^o$.

By formulas 4-8, calculation was performed of values f_B, f_L, t_B, t_L:

$f_B = 5.0$ m; $f_L = 2.0$ m; $t_B = 3.1$ m; $t_L = 3.8$ m.

Values f and t are calculated for weighted averages values of dipping angles of ore bodies [16]. However, some ore bodies have fairly low dipping angle – much lower than the natural slope angle of exploded rock mass, which complicates excavator loading.

Exploded ore will be placed on the bench slope and will be inaccessible to an excavator shovel. In this case, for feeding ore to the excavator, bulldozers can be used, or bench height can be reduced to some extent.

In the pit, steep-slope dipping ore bodies occur, and in exploding charges in inclined boreholes of big diameter, detachment line of rock mass can have not the assigned angles, but a lower angle. In this case, the boreholes' diameter should be reduced [17].

The performed studies enabled to make the following conclusions and recommendations:

1. Weighted averages dipping angles of ore bodies:

- From the hanging wall side – 39.3^o;
- From the bottom wall side – 40.5^o.

2. On the basis of the weighted averages of the dipping angles of ore bodies, identified in this work, the rational level of losses and dilution factor will be as follows: η = 0.86 %, ρ = 2,24 %.

3. Joint consideration of losses and dilution with the current stripping ratio and technical and economic calculations enable to recommend in the ore zone, the bench height of 5 meters with maintaining the rock benches height of 20 meters.

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