Influence of the parameters of the openings on the efficiency of open-pit mining

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Abstract. The article discusses the formation of workings in the conditions of rational use of subsoil resources. Studies of a quantitative assessment of the influence of the parameters of open-pit mining of mineral deposits on the volumes of overburden in the quarry field and on the area of disturbed lands are carried out. Research conducted for steeply dipping mineral deposits.

1. Introduction

In construction geotechnology, georesource is subsoil resources - components of the Earth’s crust (solid, liquid, gaseous minerals, fresh and mineral waters, internal heat of the Earth, natural and technogenic cavities) that at the current development level of productive forces are used or can be used for providing the required standard of living of the human society.

The highly competitive environment of mineral materials market, increasing consumer demands for product quality and green production technologies, and objective decrease in the quality of mineral raw materials stimulate the search for technical, economic, organizational and economic solutions to increase the competitiveness of mining companies [1], [2]. Effective solutions for mining companies can involve the development of diversification strategies based on the principles of integrated use of mineral resources managed by these companies [3], [4], [5].

Modern open-pit mining technologies entail significant anthropogenic impact on the environment (water, atmosphere, subsoil and the Earth's surface). The magnitude of the impact from the mine workings can be expressed through the stripping ratio. So, for 1 ton of mined minerals, there are up to 6-8 tons of overburden, which must be placed on the earth's surface in dumps. Studies [6], [7], [8], [9], [10] indicate that domestic mining enterprises do not provide sufficient preservation of ecotope elements, and environmental protection is not very effective. The need of lands allocation for mines exists till the moment of achievement of its final contour by the upper brows of open-cut loading faces. While outside dumping, the annual demand of lands allocation depends mainly upon the volumes of stripping soils, parameters and diagrams of dump development. Minimal rates of land disturbance are reached at the simultaneous filling of all dump layers and maximal rates are reached during the periods of filling of the first layer. It was revealed that the main indicators characterizing the labor intensiveness of the dumping process are the height of a dump, its linear plan dimensions and physical and mechanical properties of the stored rocks.

If the mine and geological conditions allow, the priority shall be given to the system of development when the stripping soils are located in the stripped area of open-cuts.
Therefore, in the current context when developing geo-resources near the agglomeration centers, the reasonable action is to find the new criteria for production efficiency, one of which is the area of land alienated for mining.

The open-pit with a limiting contour is a structure, which parameters must ensure the extraction of mineral reserves put on the balance, the stability and safety of mining operations, and the need to place transportation channels providing material haulage between the open pit production levels and the surface [11]. A lot of studies, including [12], [13], [14], established the influence of parameters of haulage benches (width and inclination) on overburden volumes in the limiting contour of the quarry.

2. Methods of research

To reach the estimated figures of production volumes and the areas of alienated lands during mathematical modeling of career space, the following parameters are additionally defined:

- quarry dimensions along the bottom and on the surface (perimeter, square area);
- the length of the opening and the number of turns of the transportation road;
- inclination angles of benches.

The simulation was performed using analytical formulas 1-5. [15], [16]. When calculating the volume of overburden rocks, the simplest geometric shapes were used. For round-shaped mineral deposits, the volume of a truncated cone is assumed. For elongated mineral deposits in the plan, the product of the cross-sectional area of the trapezoid by the strike of the deposit.

The calculation of the overburden volume in the contour of the quarry is made by subtracting the volume of mineral from the volume of the rock mass.

\[ L_n = K_y \cdot H_k / i_p \]
\[ n_b = K_y \cdot H_k / [i_p \cdot (P_a + \pi \cdot H_k \cdot ctg \alpha)] \]
\[ S_n = S_A + P_A \cdot H_k \cdot ctg \alpha + \pi \cdot H_k^2 \cdot ctg^2 \alpha \]
\[ \alpha = arctg \left( \frac{H_k}{n_b \cdot \pi \cdot \omega_p + \left(\frac{H_k^2}{H} - 1\right) \cdot \pi \cdot \omega_p + h \cdot ctg \alpha \cdot \frac{H_k}{H}} \right) \]
\[ V_r = \frac{1}{2} \cdot \pi \cdot H_k^2 \cdot ctg \alpha + \frac{\pi}{12} \cdot 2 \cdot H_k^2 \cdot ctg^2 \alpha \cdot e_p \]

Where \( L_n \) – the actual length of the opening, m; \( n_b \) – the number of turns of the spiral road, units; \( S_n \) – the surface area of the round-shaped quarry, m²; \( \alpha \) – the bench inclination angle, degree; \( V_r \) – the volume of the rock mass in one frontal bench, m³; \( K_y \) – the coefficient of road elongation; \( H_k \) – the quarry depth, m; \( i_p \) – the road limiting gradient, decimal quantity; \( P_a \) – the bottom perimeter of the round-shaped quarry, m; \( S_A \) – the round-shaped quarry bottom square area, m²; \( h \) – the bench height, m; \( \omega_p \) – the width of the haulage bench, m; \( \omega_p \) – the width of the safety bench, m; \( \omega_A \) – the width of the elongated quarry bottom, m; \( \alpha_f \) – the frontal bench inclination angle, degree; \( \alpha_{cp} \) – the average inclination angle of the foot, hanging and frontal benches, degree.

At the same time, this research carried out a quantitative assessment of the influence of the parameters of the openings both on overburden volumes of the limiting contour and on the area of land disturbed by the pit for round-shaped and elongated deposits to establish the nature and intensity of these changes. The research evaluated the impact on both indicators (overburden volume of the limiting contour – \( V_{sc} \), the area of land disturbed by the quarry pit – \( S_c \)) since they are mutually dependent.

The conditional parameters of the quarries that were assessed during the research are shown in table 1.

In this research, the size of the open pit bottom was determined by the size of the ore body in the plan. The round-shaped quarry is a truncated cone with a spiral road on its side. The path of openings
in the quarry is located along the strike of the ore body on one of the sides of the pit, so the cross-section along the pit is a trapezoid. Also, to specify the overburden volumes, we considered the volumes enclosed in the frontal benches of the elongated deposit. For both types of deposits, the inclination angles of benches are determined considering their flattening by haulage benches.

When assessing the influence of the parameters of the openings on the overburden volumes and the area of disturbed lands with a given step in the working time interval, we changed the following parameters:
- the limiting gradient;
- the width of the haulage benches;
- the depth of the quarry.

So, the variation step for parameters of openings and the depth of the quarry was the following:
- for the haulage bench with a width of 5 m (from max: 35 m to min: 15 m), as well as for the case when it is absent;
- for the limiting gradient of the road of 20‰ (from max: 120‰ to min: 40‰);
- for quarry depth of 30 m (from max: 300 m to min: 30 m).

**Table 1.** Initial data used for modeling.

| S.n. | Parameter                      | Parameter value for deposits | elongated |
|------|--------------------------------|------------------------------|-----------|
| 1    | Depth of the quarry, m         | 300                          | 300       |
| 2    | Bench height, m                | 15                           | 15        |
| 3    | Bench inclination angle, degree.| 75                           | 75        |
| 4    | Width of safety bench, m       | 7                            | 7         |
| 5    | Thickness of ore body, m       | 150*                         | 150       |
| 6    | Length of ore body, m          | -                            | 2000      |
| 7    | Coefficient of road elongation  | 1.1                          | 1.1       |

* The ore body is described by the rotational surface.

### 3. Result and discussion

The results of mathematical modeling of the parameters of the mining structure (round-shaped and elongated quarries), performed taking into account the determined parameters (see table 1), are presented in graphical form in Figures 1 and 2.

Based on the analysis of graphs in Figure 1, we can conclude that an increase in the width of the haulage bench leads to an increase in the absolute values of both functions, and the intensity of their growth increases with increasing depth of the pit (the functions increase over the entire interval of values of the pit depth). At the same time, when the slope of the transport berm changes shows the inverse dynamics for both functions.

According to the graphs shown in Figure 2, a similar trend for the analyzed parameters is observed for the elongated deposits, however, the intensity of the change in the area of the land disturbed by the quarry with increasing quarry depth is almost linear, and the regression by the quadratic function allows to establish a functional connection.

At the same time, a more complete and visual representation of the influence of the parameters of the openings on the analyzed indicators ensures the classification of the latter to relative units. So, to evaluate and comparatively analyze the intensity of changes in these functions with an increase in the depth of the quarry, we alternately determined the variables (the limiting gradient of the road \(i_{rl}=80\%\)), the width of the haulage bench is 25 m), and the relative units of the analyzed functions (Figure 3) are defined as the quotient of dividing the obtained function values at the maximum and minimum values of these variables, respectively.
Figure 1. The dependency of the overburden volume of the limiting contour of the quarry ($V_{вск}$) and the area of disturbed lands ($S_{вск}$) from the quarry depth ($H_k$) and parameters of openings for round-shaped deposits.
Figure 2. The dependency of the overburden volume of the limiting contour of the quarry \( (V_{\text{wsk}}) \) and the area of disturbed lands \( (S_k) \) from the quarry depth \( (H_k) \) and parameters of openings (the width of haulage benches and the limiting gradient of the road for elongated deposits.)
V\textsubscript{вск} (decimal quantity) with changing the width of a haulage bench and ip=const
S\textsubscript{k} (decimal quantity) with changing the width of a haulage bench and ip=const
V\textsubscript{вск} (decimal quantity) with changing ip and the width of a haulage bench= const
S\textsubscript{k} (decimal quantity) with changing ip and the width of a haulage bench= const

Figure 3. The dependency of the intensity of changes in overburden volume in the limiting contour of the quarry (V\textsubscript{вск}) and the area of the disturbed land (S\textsubscript{k}) from the quarry depth (H\textsubscript{k})

The analysis of the graphs in Figure 3:
- the maximum influence of the width of the haulage bench on the overburden volumes corresponds to the smallest quarry depth value. The extremum of this function is achieved when the quarry depth is outside the working interval (H\textsubscript{k} = 333 m), the function decreases on the entire axis;
- the maximum influence of the limiting gradient of the road overburden volumes also corresponds to the smallest quarry depths. The extremum of this function is achieved when the quarry depth is H\textsubscript{k} = 250 m, the function increases on the entire axis;
- the maximum influence of the width of the haulage bench on the area of land disturbed by the quarry corresponds to the average values of the quarry depths. The extremum of this function is achieved with a pit depth of H\textsubscript{k} = 162.5 m, the function decreases in the interval from -∞ to 162.5 and increases in the interval from 162.5 to +∞;
- the maximum influence of the limiting gradient of the road on the area of land disturbed by the quarry corresponds to the average values of the quarry depths. The extremum of this function is achieved when the pit depth is H\textsubscript{k} = 200 m, the function increases along the entire axis.

4. Conclusion
In general, it can be said that both parameters of opening significantly influence the analyzed functions, however, a higher intensity of changes with increasing quarry depth is achieved with variation in the width of the haulage benches.

As for the interdependence of functions and the appropriateness of their mutual assessment, it is necessary to mention that the disturbance of the natural landscape occurs both from the mining of
workings and from the placement of production waste (overburden) in areas which dimensions, as a rule, exceed the sizes of workings.

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