Averaging the operating stripping ratio for sinking mining systems based on mathematical simulation

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Abstract. The article contains the research results for a rational mining mode, definitions, and averaging of the operating stripping ratio. When determining the mining mode using open-pit hydraulic excavators, the problem appears with averaging the operating stripping ratio. Averaging is usually achieved by changing the pit wall angle at the expense of the respective change in the bench width. Minimum bench width serves as a limiting factor if working benches have to be reduced during the open pit mining. Continuous mining operations in an open pit require calculation and averaging the operational stripping ratio. There is a classical approach to calculate the average operational stripping ratio, but this method is graphical and has some errors. Therefore, a mathematical simulation was carried out based on integral calculus to obtain more precise values.

1. Introduction

Currently, mining companies use software products to describe and calculate the entire production cycle from exploration and 3D modeling of solid mineral deposits to tracking the mine production, planning, and control of operational parameters of the open pit; their application significantly improved open-cut mining and provided more simple, quick and easy calculations. The most widely used planning and designing software products in the Russian Federation are Surpac and Gemcom (owned by the French company Dassault Systèmes), Micromine (Australia), Datamine (UK), and others.

Large companies have special departments using modern software products for modeling open pit mining of solid minerals [1]. However, it is not always possible to use these software products by smaller companies and during the individual study of the modern state of the open-pit mining industry. Most software products are made for specific mining companies and some of them are not used widely.

During the study, the certificate of state registration was obtained for software No. 2017617003 Bench Width Calculation during the Sinking Mining Mode [2].

Bench Width Calculation during the Sinking Mining Mode software was designed to determine the balanced bench width considering average stripping ratio. Average value is usually calculated by variations in the angle of pit wall over time by changing the bench width, which affects the amount of recovered stripping soils. Reduction of the stripping soil amount will decrease operational costs, production costs and improve cost efficiency of mining operations at the deposit.

This software can be used in universities when preparing course and graduation projects, calculations, and charts of postgraduates for research purposes.
Bench Width Calculation during the Sinking Mining Mode software (Figure 1) provides the following features:

- Calculation of the area for the zone limited by the bench, bench face, and wall of the pit;
- Calculation of bench width at different levels.

![Flowchart and Program Window](image)

**Figure 1.** Bench Width Calculation During the Sinking Mining Mode software: a – software logic; b – program window

This software takes into account area of the zone limited by the upper and lower benches, bench slope and pit wall (S).

Mining-geometrical analysis of open-pit fields remains the basic method to study open pit mining. Fundamental basics of this method were set by V.V. Rzhevsky and A.I. Arsentiev.

As equipment and technology improved, computers were used more and more widely in routine life and production. PC application for mining-geometrical analysis of open pits allows minimization of the human factor impact during calculations and obtaining more precise results.

There were the following main objectives of this study:

- to study an interconnection between the mining mode and the operating stripping ratio;
- to create a method for averaging the operating stripping ratio based on mathematical simulation.

2. Methods

The results of mining-geometrical analysis of an open pit serve the basis for choosing the mining mode. The mining mode is the sequence of stripping and mining works within the open pit field during entire or long-term operation period [3]. Rational mining mode is among the drivers of efficient operations at present-day open pits. Mining mode features production rates by the mineral extracted and operational stripping ratio [4]. These parameters determine the type and number of mining equipment operated in the open pit, production costs and sales revenues [5].

The experience gained by mining companies and design entities demonstrates that variation of the stripping ratio is the main tool to manage the mining mode at pre-set production rate of the open pit. In most cases, graphic representation of the stripping mode is a broken line. When mining steeply dipping deposits or ones located in mountainous terrain, the plot of stripping works moves upward at
the mining beginning, tips at the maximum point and moves downward towards the end of the pit operation life [6, 7].

The choice of the rational mining mode is a difficult task; many scientists studied this issue, and their papers substantiate rational options for the mining scope distribution based on certain evaluation criteria [8, 9]:

1. Stable mode of mining operations: V.V. Rzhevsky and K.N. Trubetskoy determined that the scope of stripping works is stabilized by reducing the mining scope at the time of intensive increase of the stripping work scope;

2. V.S. Khokhyakov revealed in his papers that rational mining mode during the stage-by-stage mining of large open pits is achieved by gradual increase of stripping ratio per each period. Throughout the entire operation life of the pit, its performance increases or becomes stable;

3. Shifting the peak performance to the earlier period of open pit mining: V.V. Istomin proposed to achieve averaging by the uniform distribution of the stripping work scope and to advance within the initial periods of open pit mining;

4. Shifting the peak performance of stripping works to a later mining period: A.I. Arsentiev proved that it would be more feasible to shift a part of the stripping peak performance to a later operational period to achieve a rational mining mode;

5. Changing the pit wall angle within various open-pit mining periods may provide permanent mining rates. According to G. A. Kholodnyakov, the scope of stripping works and the scope of mining ones for all types of minerals should be averaged within the specific periods when mining complex deposits.

When choosing the mining mode, adjustable parameters of the mining system are used most commonly: the mining front length, bench width, and height.

For mining steeply dipping deposits, changing the pit wall angle is one of the most efficient ways to adjust the mining mode [10, 11]. Changing the bench width allows variations in the pit wall angle; that, in turn, allows approaching the averaging method of the operational stripping ratio [12,13,14].

The dependence of the operational stripping ratio upon the bench width is deterministic and can be represented by the plot $k = f(B)$ (Figure 2).

![Figure 2. Plot of operational stripping ratio vs the bench width: AD – dependence of operational stripping ratio on bench width under normal conditions; $k$ – operational stripping ratio; $k_{\text{min}}$ – minimum operational stripping ratio; $k_{\text{max}}$ – maximum operational stripping ratio; $B$ – bench width; $B_{\text{min}}$ – minimum bench width; $B_{\text{max}}$ – maximum bench width.](image)
The plot type depends on mining-geological and mining-engineering conditions of the specific deposit. However, this plot form provides a general outlook of the mining work progress. As shown on the plot \( k = f(B) \), AD segment determines the dependence of the operating stripping ratio on the bench width under normal conditions. Conditions are considered as normal as long as the open pit operations are within two extreme values of the bench width. Point A is the limit for the minimum bench width at the minimum operational stripping ratio. Point D is a maximum possible bench width at a maximum operational stripping ratio.

3. Results
During the studies, the table is prepared for cumulative amounts of stripped material (V) and cumulative amounts of minerals (P) (Table 1) based on level-by-level plan views and axial sections, considering the mining direction.

| Level | \( V, \ km^3 \) | \( P, \ km^3 \) | \( V, \ km^3 \) | \( P, \ km^3 \) | \( V, \ km^3 \) | \( P, \ km^3 \) | \( V, \ km^3 \) | \( P, \ km^3 \) |
|-------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 0     | 0              | 0              | 0              | 0              | 0              | 0              | 0              | 0              |
| 1     | 600            | 106.2          | 82.8           | 87.6           | 48.6           | 67.8           | 34.8           | 52.2           |
| 2     | 1,762          | 260.1          | 427.2          | 240            | 238.8          | 219            | 147.6          | 197.4          |
| 3     | 2,814.7        | 404.2          | 1,105.8        | 387.6          | 661.8          | 363            | 432            | 335.4          |
| 4     | 3,905          | 537.6          | 2,045.4        | 519.6          | 1,335.6        | 495.6          | 902.4          | 460.2          |
| 5     | 5,151.6        | 671.4          | 3,149.4        | 660            | 2,205          | 643.8          | 1,523.4        | 623.4          |
| 6     | 6,209.9        | 804.7          | 4,405.8        | 781.8          | 3,342.5        | 782            | 2,355.8        | 766.1          |
| 7     | 7,161.3        | 981.8          | 5,646.6        | 911.4          | 4,241.1        | 898            | 3,471.9        | 956.3          |
| 8     | 7,964.7        | 1,169.6        | 7,126.4        | 1,112.2        | 5,333.3        | 1,066.9        | 4,281.7        | 1,076.4        |
| 9     | 8,395.1        | 1,299          | 7,965.3        | 1,325.6        | 6,577.5        | 1,247.5        | 5,298.6        | 1,212.6        |
| 10    | 8,625.9        | 1,385.5        | 8,426.8        | 1,500          | 7,917.3        | 1,456.5        | 6,566.8        | 1,365.8        |
| 11    | 8,752.1        | 1,441.7        | 8,646.2        | 1,600          | 8,558.5        | 1,640.2        | 7,573.2        | 1,477.5        |
| 12    | 8,869.8        | 1,716.6        | 8,869.8        | 1,716.6        | 8,869.8        | 1,716.6        | 8,869.8        | 1,716.6        |

Plot of cumulative volumes \( V = f(P) \) at each pit wall angle was made (Figure 3) based on the data shown in Table 1.

Potential cases of mining operations with constant stripping ratio may be shown within the range of two extreme values \( \phi_{\text{min}} \) and \( \phi_{\text{max}} \).

At the particular angle of pit wall, performance is stable provided the AB averaging line is intersected (drawn to \( \phi_{\text{max}} \)).
Based on the data shown in Table 1 and using software, we defined the equation that describes the maximum angle of pit wall $\phi_{\text{max}} = 20^\circ$ and filled Table 2.

**Table 2.** Equation for the pit wall angle.

| No | Equation type | Equation                                      | Determination factor |
|----|---------------|----------------------------------------------|----------------------|
| 1  | quadratic     | $0.00202982 x^2 + 1.85354 x - 166.172$        | 0.99                 |
|    |               | Straight-line equation (AB average line)     |                      |
| 2  | linear        | $5.16707 x$                                  | 0.99                 |

For pit wall angle $\phi = 20^\circ$, the system of equations from Table 2 needs to be solved (1):

$$\begin{align*}
y &= 0.00202982 x^2 + 1.85354 x - 166.172 \\
y &= 5.16707 x
\end{align*}$$

Once the system of equations is solved (1), it gives the roots that determine the volume of stripped material and volume of minerals within a specific operational period. Using this method, it is easy to find the average operating stripping ratio.

The values obtained are entered in Table 3.

**Table 3.** Average values of V and P, operating stripping ratio.

| $\phi = 20^\circ$ | V     | P     | Stripping ratio |
|-------------------|-------|-------|-----------------|
|                   | 8689.47 | 1681.12 | 5.16            |

In the classical averaging method, the values are defined visually, and they are not always correct.
4. Discussion
Mining-geometrical analysis of an open pit is the basis for defining the mining mode. Rational mining mode is one of the drivers providing efficient operation in present-day open pits and features production rates and the operating stripping ratio. These parameters determine the type and number of mining equipment operated in the open pit, production costs and revenues from sales.

The method of averaging the operating stripping ratio using mathematical simulation makes the calculations more simple and accurate for various mining-geological conditions of mineral deposits.

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