Influence of depth of ore open-cut mine on parameters of mining and transport equipment complexes

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Abstract. This paper considers features of a modern state of open-cut mining. It provides a classification of deposits according to the complexity of their open-cut mining on the territory of Russia, which includes parameters of the mined rock, features of the rock bedding and adversity of climate. We provide the results of the analysis of the influence of the depth of an ore open-cut mine on the capacity of a bucket of excavators and carrying capacity of dumper trucks as basic parameters for mining and transport equipment complexes. The paper also suggests criteria for assessment and defines the areas of their optimal values.

1. Introduction
At an open-cut development of the deposits, the technological features do not limit the capacity or power-to-weight ratio of the utilized mining and transport equipment. This allows achieving a high-level performance and ensuring growing demands for solid mineral resources with a greater efficiency and at lower costs.

At the same time, an intensive development of open-cut mining is connected to the increase in depth of open-cut mines and their sizes in the plan, and moving to districts with climatic factors that complicate the technology. And the choice of optimal parameters of the equipment complexes for specific mining conditions is rather difficult. Despite the broadly developed methods in hand (from discrete programming, modelling etc., to using a subjective artificial intelligence), they still have disadvantages [1].

First of all, at present, for design and rational performing of open-cut mining, one will need to build and enhance the ties between physical and technical parameters of the mined rock, parameters of the pits and lots of parameters of the equipment in the market.

2. Analysis of relative complexity of open-cut mining
The listed circumstances define an important scientific problem of the feasibility of technological complexes for open-cut mining, as an aggregate of complexes of equipment and technological solutions jointly ensuring cost-efficient and safe extraction of mineral resources in the planned throughput. In connection to this, the authors previously performed the research [2, 3], which resulted in a classification of deposits for natural conditions of Russia with different climate (see table 1). Along with that, we found out that the complexity of the deposit development primarily depends on a compressive resistance of rock ($\sigma$, MPa), an average size of a structural block ($l$, m), bulk gravity of
rock (\(\gamma\), t/m³), a depth of the mine (\(H\), m), a distance of transporting (\(L\), km) and a toughness of climate (\(S\), point), for assessment of which we need to use the recommendations by P.I. Kokh.

### Table 1. Classification of deposits according to their relative complexity of development

| Class of a deposit according to the complexity of development | Category | Deposits parameters |
|---------------------------------------------------------------|----------|---------------------|
|                                                             |          | \(\sigma\), MPa    | \(l\), m           | \(\gamma\), t/m³ | \(H\), m | \(L\), km | \(S\), point |
| 1. Easy to develop                                           | 1-5      | ≤ 40                | ≤ 0,4              | ≤ 1,8            | ≤ 200    | ≤ 3       | ≤ 50        |
| 2. Medium to develop                                         | 6-10     | > 40                | > 0,4              | > 1,8            | > 200    | > 3       | > 50        |
| 3. Hard to develop                                           | 11-15    | ≤ 80                | ≤ 0,6              | ≤ 2,4            | ≤ 320    | ≤ 4,5     | ≤ 65        |
| 4. Very hard to develop                                      | 16-20    | > 80                | > 0,6              | > 2,4            | > 320    | > 4,5     | > 65        |
| 5. Extremely hard to develop                                 | 21-25    | ≤ 120               | ≤ 1,0              | ≤ 2,9            | ≤ 500    | ≤ 7       | ≤ 80        |
|                                                             |          | > 120               | > 1,0              | > 2,9            | > 500    | > 7       | > 95        |
|                                                             |          | ≤ 160               | ≤ 1,8              | ≤ 3,3            | ≤ 700    | ≤ 10      | ≤ 110       |
|                                                             |          | > 160               | > 1,8              | > 3,3            | > 700    | > 10      | > 110       |

### 3. Feasibility analysis of the depth of open-cut mines

This paper presents the results of the analysis of the depth of ore open-cut mines on the parameters of complexes of mining and transport equipment and shows the techniques for such analysis taking into account the suggested classification of deposits.

With that, we rely on the fact that the areas of the depth of the open-cut mines for relevant classes and categories of deposits (see table 1) are defined by labour intensity of mining operation, calculated by an energy method [4], which discards any economic calculations. Defining a rational depth of open-cut mines when designing them is, however, referred to the strategic tasks [5]. Substantiation of the mine boundary and exploitation of the ore deposit with the known mineral reserves, as well as the amount of overburden rock which will be removed, enable one to define a lifetime of the mine with the set throughput performance of this open-cut mine.

A planned ore and mineral capacity of the mine, in its turn, should be both technically and technologically achievable and economically reasonable. The mine production capacity is technically and technologically contingent on a connection between the system of development and the structure of complex mechanization. Simultaneously, the parameters and indicators of the system of development, the main ones are a cutting depth, sizes of working sites and haulage berms, length of the extraction front and time of its progress, a time of progress in depth, etc., should correspond to the parameters of the adopted mining and transport equipment. But from the economic point of view, the set production capacity of the open-cut mine should ensure the best technical and economic indicators of the development.

The Russian design practices show that profit (\(E\), RUR/t) is often used as an economic criterion to justify the boundaries of a lossless open-cut development of ore deposits; the profit is calculated as follows:

\[
E = P \cdot G \cdot K_1 \cdot (1 - K_2) - (C_1 + C_2 \cdot K_3 + C_3 + C_4) \cdot \frac{1 - K_1}{1 - K_4},
\]

where \(P\) – the price of a mineral on the market, RUR/g; \(G\) – content of minerals in ore, g/t; \(K_1\) – recovery ratio of minerals from the ore during separation, unit fraction; \(K_2\) – ratio of ore loss during
extraction, unit fraction; \( C_1 \) – cost of ore extraction by an open-cut method, RUR/t; \( C_2 \) – cost of overburden operations, RUR/m³; \( K_3 \) – overburden ratio (ratio of volumes of overburden operations to volumes of ore extraction), m³/t; \( C_3 \) – cost of processing of 1 ton of ore, RUR/t; \( C_4 \) – general business and other expenses, RUR/t; \( K_4 \) – ratio of ore dilution when mining.

When performing a feasibility analysis, at the stage of entering of the reserves on the balance sheet, if the value calculated by formula (1) is \( E \geq 0 \), the ore reserves that are limited by the mine are classified as balance reserves, the use of which is economically viable with the existing or utilized advanced machinery and technology of extraction and processing of raw materials. If \( E < 0 \), then the ore reserves are classified as off-balance, which are not economically viable or technically and technologically feasible at present, but they can later be transferred to the balance ones [6].

4. Substantiation of the dynamics of the parameters of mining and transport equipment complexes

Transforming formula (1) into formula (2), we get an expression allowing one to define a relative level of profitability in the form of a correspondent module of ore value (\( B \)):

\[
B = \frac{P \cdot G \cdot K_1 \cdot (1 - K_2)}{(C_1 + C_2 \cdot K_3 + C_3 + C_4) \cdot \frac{1 - K_1}{1 - K_4}}. \tag{2}
\]

Thus, for formulae (1) and (2), the following conditions will be true:

– if \( E \geq 0 \), then \( B \geq 1 \);

– if \( E < 0 \), then \( B < 1 \).

With regard to the above-mentioned, we calculated costs \( C_1 \) and \( C_2 \) for all the categories of deposits according to their development complexity, variants of open-cut mines and competitive complexes of mining and transport equipment offered on the Russian market. The difference of these costs in all the variants of the technology and complex mechanization of mining operations allows determining an influence of the depth of rounded ore open-cut mines on the parameters of mining and transport equipment.

At the same time, we rely on the complex of main equipment consisting of drilling rigs, excavators, dump trucks, bulldozers. When designing, the first thing to choose is an excavator, as it is a key element of the complex. The principal kind of transport in the given conditions is automotive [2]. The number of excavator buckets loaded to a dump trucks bed varied from 3 to 7 to follow the principles of consistency according to the regulating documents. The rational depth of mining operations for each case with variable values of \( C_1 \) and \( C_2 \) is calculated at \( B = 1 \). The equipment complex which turned out to be more powerful, perfect, more productive and less costly, ensured an efficient performing of mining in greater depth.

As an example, the curves below (see figure 1) show the dynamics of average sizes of buckets of excavators (\( V, \text{m}^3 \)) with electric drive manufactured by ИЗ-КАРТЭКС, УЗТМ (IZ-KARTEX, Ural Heavy Engineering Plant, Russia) and carrying capacity (\( q, \text{t} \)) of dump trucks by Caterpillar, Komatsu, Terex, Hitachi, Liebherr (USA, Japan, Germany) depending on the depth of the mines and the complexity of the deposit development.
**Figure 1.** The influence of the depth of open-cut mines on an average capacity of a bucket of electric excavators manufactured by IZ-KARTEX, UHEP, and carrying capacity of dump trucks by Caterpillar, Komatsu, Terex, Hitachi, Liebherr when developing the deposits of different categories of complexity: a – 5; b – 10; c – 15; d – 20; e – 25.

The interrelation of rational parameters of the equipment complexes and the depth of the ore open-cut mine here may be tracked by the value of absolute deviation ($\Delta H_i$, m):

$$\Delta H_i = H_{i_{\text{max}}} - H_{i_{\text{min}}},$$

where $H_{i_{\text{max}}}$ – a maximum effective depth of the open-cut mine, correspondent to $i$-category of the deposit in terms of the development complexity and less costly complex of equipment, m; $H_{i_{\text{min}}}$ – a minimum effective depth of the open-cut mine of $i$-category of the deposit in terms of the development complexity and a more costly complex of equipment, m.
5. Conclusions

The results of the research demonstrate that such key parameters of the equipment complexes as an average capacity of an excavator bucket and carrying capacity of a dump truck are in a close correlation with economically effective depth of an open-cut mine. The growth of the unit power of the machines and the general decline of operation costs enable one to increase the profitability of the development of the deposit by an open method and the value of its ores, along with increasing of the complexity and the depth of development in a greater extent.

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