Assessment of the impact of quarry design on the production efficiency and subsequent development of man-made workings

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Abstract. The article presents the formation of man-made workings in the context of conditions of urbanization of modern society. It also studies the changes in the volume and complexity of mining operations by technological processes, depending on the shape of the designed open pit side in its ultimate position.

1. Introduction

Currently, large cities due to the annual increase in construction rate are in great need for space for building new infrastructure. At the same time, the cost of land near the agglomeration centers tends to rise over time [1, 2]. Also, the peripheral residential territories, as a rule, have a sufficiently large number of man-made mining workings (open pit and underground). With sustained planning of mining near the growing cities, these workings can be potentially used for various construction purposes [3-5]. The best world practices of using the mined space of quarries and mines show that it can be effectively used for constructing industrial workshops, shops, cultural and sports facilities, oil storages, reservoirs, warehouses, fallout shelters, storages of radioactive waste from nuclear power plants, etc. [6]

The need for 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 [7].

In this context, the use of the workings of mining enterprises located near residential areas will significantly improve the human environment, preserve the natural landscape and the architectural and historical appearance of cities, and improve the ecological situation in the regions. Mining companies have a pronounced effect on the economy, the community and the environment, which makes it important to ensure their sustainable development and corporate social responsibility for operator companies [8, 9].

2. Materials and methods

Assessment of existing man-made mine workings indicates a low degree of their suitability. Due to very specific requirements for capital construction projects, a strategic approach to the development of the subsurface resources near residential areas is advisable. This approach should consist in the planning of the mineral deposits opening technique considering both the occurrence conditions and the morphology of the ore bodies, and the subsequent use of the mined space for a specific object with given sizes. Thus,
we ensure the maximum possible compliance of man-made workings with the objects of future capital construction possibly placed inside this mined space.

As a rule, to place infrastructure objects in the working, it should have regular and close to linear shape. It is obvious that in some cases if we set the shape of workings in ultimate position, it will inevitably lead to an increase in the stripping ratio. However, it would be premature to conclude that the implementation of a mining project would be less effective. To confirm this, we carried out the studies of changes in the volume and labor intensity of mining operations by technological processes, depending on the shape of the designed open pit side in its ultimate position. The object of the study was the gold deposits "Eldorado" and "Aleksandro-Ageevskoe", located in the North-Yenisei district of the Krasnoyarsk Territory.

These deposits are characterized by the complex occurrence and spatial variability of ore bodies, and the open pit design delineation contour has a complex shape in terms of horizontal and vertical planes, as shown in Figures 1 and 2.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** Fragment of the designed position of the North-Eastern side of the open pit of the Aleksandro-Ageevskoe field.  
**Figure 2.** Fragment of the design position of the Eldorado open pit side on the northern section of the deposit.

According to the designed ultimate positions, the pit walls in some areas have cycloid or sinusoid shapes. Obviously, this position will lead to increased cost of blasting operations [10-16]. The magnitude of the linear increment of the front length due to its curvature will help to estimate this change. For cycloid, this increment will be 30%, which corresponds to an elongation ratio of 1.3. The second curve is described by an elliptic integral of the second kind, which is not expressed in elementary functions and has no analytic solution. As a result of its reduction with the given parameters, the coefficient of elongation for this type of curve is from 1.1 to 1.6. To study changes in the volume and complexity of mining operations by technological processes, depending on the shape of the designed pit side, it is advisable to take the side elongation ratio in the ultimate position equal to 1.3, as the average value, which is most relevant to practice, and the shape of the curvilinearity of the side is described by a cycloid curve [17, 18].

Quantitative assessment of changes in the volume of drilling operations is made based on a comparison of the two drilling blocks, which are characterized by the following shapes (Fig. 3), parameters and calculated indicators are given in Table 1.
Figure 3. Schemes for calculating the parameters of drilling blocks with the linear (I) and curvilinear (II) designed slope wall on the delineation contour of the pit; where 1 – slope of the linear (I) and curvilinear (II) shape - cycloidal, formed by a circle of a certain radius; 2 – additionally mined volume of rock when working with a straight front; $A_b$ – width of the drilling block, m; $L_b$ – length of the drilling block, m; $W$ – resistance line at the bottom of the bench, m; $h$ – bench height, m; $L_c$ – length of the borehole, m; $l$ – height of overdrill zone, m; $a$ – distance between the boreholes in a row, m; $b$ – distance between adjacent rows of boreholes, m; $a'$ – distance between boreholes in the contour row, m.

As can be seen from Table 1, the calculated indicators of drilling and blasting operations with a curved shape is worse in comparison with a straight line. Also, the relative magnitude of the change in indicators is different. In this regard, a quantitative assessment of the effect on these indicators of the coefficient of wall elongation, the results of which are shown in a relative form as graphs in Fig. 4. Relative indicators are obtained by reducing the calculated indicator obtained for the $i$-th value of $K_{elong}$ to the base value ($K_{elong} = 1$).

From the graphs (see Fig. 4) it can be seen that the dependencies obtained are non-linear; however, the intensity of these changes in terms of the rock mass yield is higher than in terms of the volume of drilling. Thus, with an increase in the coefficient of elongation from 1 to 1.5, the yield of the rock mass from 1 meter of the borehole of the marginal block is reduced by 33%, in turn, the volume of drilling works increases by 18%.
Table 1. Parameters and indicators of drilling and blasting operations by types of marginal blocks

| №  | Item                                                                 | Drilling block I | Drilling block II |
|----|----------------------------------------------------------------------|------------------|-------------------|
| 1. | Width of the drilling block, m                                       | 50               | 50                |
| 2. | Length of the drilling block, m                                      | 300              | 300               |
| 3. | Bench height, m                                                      | 15               | 15                |
| 4. | Bench angle, degrees                                                 | 75               | 75                |
| 5. | Length of the borehole, m                                            | 17               | 17                |
| 6. | Bench inclination angle to the horizon, degrees                      | 75               | 75                |
| 7. | Height of overdrill zone, m                                          | 1.5              | 1.5               |
| 8. | Distance between the boreholes in a row, m                          | 6                | 6                 |
| 9. | Distance between adjacent rows of boreholes, m                       | 6                | 6                 |
| 10.| Distance between boreholes in the contour row, m                    | 1                | 1                 |
| 11.| Resistance line at the bottom of the bench, m                       | 7                | 7                 |
| 12.| Number of borehole rows (excluding the contour row), units          | 5                | 5                 |
| 13.| Designed shape of the wall                                           | linear           | cycloidal (formed circle R = 5m) |
| 14.| Volume of drilling block, m³                                          | 225000           | 213750            |
| 15.| Additionally mined volume of rock when working with a straight front, m³ | 0                | 11250             |
| 16.| Coefficient of lengthening of the front due to the curvature         | 1                | 1.3               |
| 17.| Number of boreholes of the main row, units                           | 250              | 238               |
| 18.| Number of boreholes of the contour row, units                        | 300              | 390               |
| 19.| Yield of rock mass from 1r.m. of the marginal block borehole, m³/m   | 24.1             | 20                |
| 20.| Volume of drilling operations, m                                     | 9350             | 10676             |
Figure 4. The dependence of the relative indicators of drilling and blasting operations on the coefficient of wall elongation due to its curvature.

The wall curvature impacts the work of mining and loading equipment. Thus, according to [19], in the calculation of the effective performance of excavators, the control factor considers the discrepancy between the technical passport and actual parameters of the front, as well as the qualification of the driver. When working with a relatively linear front and a pass with a constant width, the value of this coefficient for single-bucket excavators is set at 0.85. Elementary calculations show that as this coefficient decreases to 0.7, which is characteristic of a curvilinear front in terms of a large number of excavator movements, the effective performance decreases when working on the last pass of a marginal, by about 20%.

We should mention the influence of the open pit side shape in the ultimate position on the stability of the slopes. It has been established that the stability of the end sections of the benches with an elongated shape and the edges of circular or oval shapes increases significantly. Compared with straight benches there is additional resistance to the displacement collapse prism created by lateral expansion forces. Therefore, the solutions of the flat problem of the stability of slopes in these cases are corrected with the help of the VNIMI graphs constructed based on modeling by the method of equivalent materials [20]. However, areas of the pit walls, having a curve towards the goaf, concentrate excess shear forces in their bottom. In this regard, to ensure the sustainability of mine workings, the angle of wall inclination in such areas is flattened compared with straight or concave sides. At the same time, an increase in the angle of the side in the ultimate position by 1-2 degrees, in some cases, can fully compensate for the increase in overburden volumes by straightening the shape of the wall.

It should also be noted that the organization of mining operations, in terms of surveying support, the frequency of its implementation and control, as well as the coordination of actions of workers in the main production, engineering, and technical staff, is significantly complicated.
3. Conclusion
Summing up the above, it is worth noting the need for the practical implementation of a new “civilized” approach to planning the development of mineral deposits near the agglomeration centers. It should be emphasized that under these conditions it is advisable to switch to an integral indicator of the mining project implementation effectiveness, which would stimulate the subsoil user to preserve the natural landscape of large cities.

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