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INCREMENTAL OPEN-PIT MINING OF STEEPLY DIPPING ORE DEPOSITS

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ABSTRACT

Great opportunities for improving the open-pit mining operations technology and increasing their efficiency are laid in the temporary conservation of overburden rocks and leaving a temporary basset edge within the quarry. This is due to the desire to reduce the volume of mining and stripping operations in the initial periods of quarries exploitation. To reduce costs, it is advisable to plan incremental surface mining with the establishment of pushbacks. Phased formation dynamics of the working zone of opencasts and development technologies should ensure the implementation of the projected volumes of mining and the possibility of their simultaneous intensive development within the boundaries of different stages. There are objective trends of deterioration of mining-and-engineering and mining-and-geological conditions of open-cut mining of steeply dipping deposits, in the context of dynamic markets, changes in prices, and demand for mineral raw materials. The creation of stages and pillars may be caused by the decision to reconstruct the quarry. In this case, an existing final pit boundary will serve a pushback. The process of creating a temporary basset edge was carried out when the movement of the loading faces reached the mine abandoning stage. Development of deposits in stages allows in some cases ensuring the economic feasibility of mining, and the necessary rate of return. The authors proved the necessity of forming a temporal basset edge of ore in the context of changing economic situations.

Keywords: steeply dipping ore deposits, development of deep open pits; incremental development of the deposit; open-pit development, process diagrams.

INTRODUCTION

The existing objective trends of deterioration of mining-engineering conditions for open-pit mining of steeply dipping deposits require changes in technologies and methods of subsurface use. As the depth of the quarries increases, the current stripping ratio increases. In the course of lowering mining operations, the overburden amount increases and reaches a maximum at the time when the loading face approaches the upper final pit boundary on the surface. One of the critical points in the operation of the quarry is the period when mining operations reach the designed pit limits on the surface. This period is characterized by a reduction in the width of operating platforms, a decrease in reserves by the degree of preparation for excavation, and a tendency to reduce the length of the breakthrough front, and a decrease in the productivity of the ore quarry [1-6].

The creation of stages and pillars may be caused by the decision to reconstruct the quarry. In this case, an existing final pit boundary will serve a pushback. The process of creating a temporary basset edge was carried out when the movement of the loading faces reached the mine abandoning stage.

Extending the mining operations control interval by reducing the current stripping ratio at incremental development is possible by separating differentiated parameters of the working zone, providing a set projected performance in field mining by the quarry in the volumetric circuit of the stage.

Pushback design and selection of loading equipment are the main lines of activity when planning open-pit mining. The design of the band of ore includes determining the size and shape of each band of ore and the characteristics of its operating platforms, as well as the location of transport communications [7, 8].

When performing stability calculations of the quarry band of ores, the physical and mechanical properties of the rock mass are used as input values [9-11].

METHODS

The proposed incremental method of field development assumes that one of the limit bands of ore of each subsequent stage was combined with the corresponding limit band of ore of the previous stage. With the use of transport communications, ore and rock reserves of the corresponding stage are worked out with the simultaneous formation of a combined limit band of ore of the next stage, to which transport communications are transferred after its formation, and then operations are repeated.

Transport communications are placed on the combined limit band of ore, i.e. on the band of ore of a quarry with a slope angle equal or close to the stable slope.

The horizons of such band of ore, after transferring communications from it to the next position, can only be worked out sequentially from top to bottom with an increase in the amount of overburden rocks extracted per unit of time from zero to a certain maximum value, i.e. with a high unevenness of stripping operations. The uneven mode of stripping operations leads to the need to increase the number of mining equipment in certain operation periods, as well as to additional development of the enterprise's infrastructure for its maintenance that causes a rise in the cost of mining.

Transport communications, mounted on a combined band of ore, will exist in one place for the entire

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period of the next stage development. Consequently, the combined band of ore will be stopped for the entire period. However, the height of the combined limit band of the ore increases at the cost of the lower horizons due to the ongoing deepening of the quarry.

Thus, by the end of the processing period of the next stage, the height of the combined limit band of ore will be increased compared to that at the beginning of the concerned period. After the dismantling of transport communications, the excavation of the combined limit band of ore will be made from top to bottom, starting from the upper horizons, while continuing to increase its height from below, due to the deepening of the quarry. As a result of this process, the combined limit band of ore may come down into the ore zone that will lead to a reduction in the exposed ore area and a loss of efficiency in ore production up to the complete cessation of mining operations. For an operating enterprise, reducing the mineral extraction volume is always associated with significant material damage.

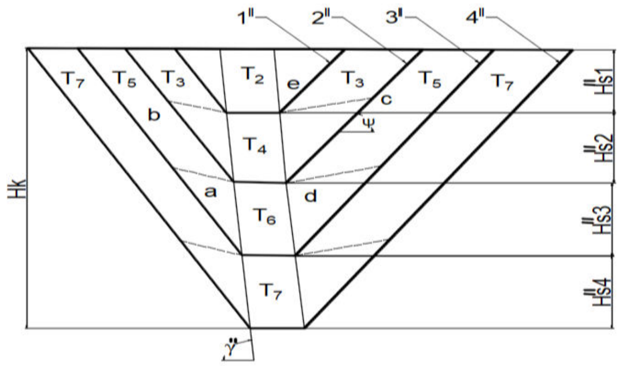
This disadvantage of the considered method is eliminated by creating a transition (reserve) zone of the designed height in the quarry mining zone, but at that the section of the temporary basset edge is represented by one pillar with the slope angle of the band of ore equal to 25-30^{o} that predetermines the insignificant value of the resulting slope angle of the resulting band of ore of the quarry [12, 13].

At an incremental quarry development, the temporary basset edge sections (pillars) are formed in the working zone of the opencast. The magnitude of the resulting slope angle of the entire loading face, presented in the form of pillars and working zones of their excavation is determined by the deepening rate of the quarry and the lowering rate of the pillar height, directional angle of deepening of the quarry, the inclination angles of the loading face in the deepening zone and pillar excavation areas, as well as the slope angle of the pillar band of ore [14-16].

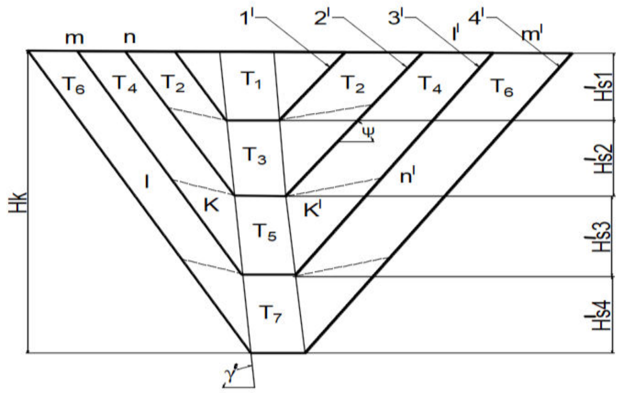
At a sufficiently high quarry deepening rate and small slope angles of the ore body, it is impossible to provide steep resulting slope angles of its loading faces.
The field of application of the mining method is a group of quarries that develop isolated ore steeply dipping deposits, or a long quarry extended along the stretch with its division into two sections.

The main idea of the proposed method of mining is the following: when each section is worked out in stages, ore extraction within the stage boundaries is performed in sequence at one of the sections, and during the mining of ore reserves of the next stage of one of the sections, the rock band of ore on another section is promoted from the boundaries of the previous stage to the boundaries of the subsequent stage of mining.

Figure-1 shows the cross-sections of quarries in sections I and II of the developed field, represented by a steeply dipping deposit.



(I)



(II)

Figure-1. Incremental mining sequence of two quarry sections.

Each section has four stages, whose lower boundaries are indicated by numbers 1', 2', 3', 4' in section I, and 1", 2", 3", 4" -– in section II. The lower limit of the last fourth stage coincides with the final pit boundary with a depth of $H'_{к}$ and $H''_{к}$. The symbols H'_{s1}, H'_{s2}, H'_{s3}, H'_{s4} and H''_{s1}, H''_{s2}, H''_{s3}, H''_{s4} indicate the depth of the stages in sections I and II, respectively, while T_1, T_2, T_3, etc. are the time periods of quarry exploitation. Ore mining is performed alternately in one of the sections.

Mining operations begin in primary section I. During the first mining period T_1, the ore reserves of the first stage in this section are fully worked out by quarry. In the next period T_2, the ore reserves of the first stage of section II are worked out. After that mining operations are transferred to section I where during the period T_3 the reserves of the second stage of this section are worked out, etc.

During the mining of ore reserves at the next stage of one of the sections, the rock band of ore on another section is promoted from the boundaries of the previously worked stage to the boundaries of the next stage of mining. When moving temporary basset edge to the following position to the boundaries of downstream stage, the section of a loading face with operating platforms at each horizon (in Figure-1 these areas are shown by the dashed line) are formed in the mining area that provides conditions for unhindered mining of ore reserves of the downstream stage.

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The excavation of the temporary basset edge of the next stage is carried out after working out its reserves, i.e. after completion of all mining operations of the proposed quarry section. Therefore, the slope angle of the temporary basset edge can reach the slope angle of the quarry band of ore in the final position.

Thus, by the end of working out the ore reserves at each stage, a quarry contour will be formed in the corresponding section with a depth equal to the sum of the depths of the above-located stages, including the one under consideration.

By the beginning of the excavation of temporary basset edge, all technological and auxiliary equipment will be removed from the upper horizons of the quarry section, and the access of staff will be restricted that provides high technological safety of mining operations.

The development of two sections of the field according to the technology under consideration ensures the achievement of the set goal, i.e. postponing the maximum volumes of overburden rock removal to later periods of exploitation. For example, by the beginning of the development of the third stage in section I, the rock band of ore can be formed at a slope angle equal to the slope angle of the structural band of ore in the final position.

The band of ore formed at the end of this stage will have the same slope angle, while the ore reserves of the third stage have been worked out with the slope angle of the loading face equal to the slope angle of the quarry band of ore in the final position.

The proposed method of mining the deposit allows ensuring postponing the maximum possible volumes of overburden rock removal to the subsequent periods of exploitation in comparison with other currently known technological methods of mining operations.

The considered method of working out is characterized by a high degree of stationarity of the mine opening systems. When excavating temporary basset edge of the first stage in section I, the upper horizons move intensively to the limit of the second stage along the line K'l', where they form a system of opening workings, whose lifetime in one position will be practically equal to the lifetime of two periods T_2 and T_3 of quarry operation.

When developing two sections of the field in stages, it is necessary to observe a certain ratio between the number of the stages in sections I and II. Figure 1 shows the working out option of each section in four stages. During the enterprise's operation period T_7, all ore reserves of the last fourth stage in section I are processed, and rocks are removed in the overburden zone in section II, in order to prepare for the production of the fourth stage of this section. The period T_8 is the mining operations damping time.

If the number of stages in each of the sections is equal, no technological complications in the development of mining operations may occur. Consider the following relationship: the priority section I is worked out in three stages, while section II - in four stages. In this case, during the period T_5, all ore reserves of the last third stage of section I are processed, and the rock is removed in the stripping zone of the third stage in section II.

During the period T_5, mining operations are carried out within the boundaries of the third stage in the second section. After working out the reserves of this section, a break in mining operations is inevitable, since mining operations within the fourth stage are possible only after the removal of rock in the overburden zone of this stage in section II. Therefore, the number of stages in the priority section I should not be less than the number of stages in section II. Implementation of the method involving working out two sections in stages is possible if the number of stages in the priority section I is equal or one stage more than that in section II

$n'' + 1 \geq n' \geq n''$,

where n' and n'' are the numbers of stages in sections I and II, respectively.

The relationship of main parameters and indicators of the incremental method of quarry development is established based on the proposed idea, which is as follows: during mining of the ore reserves at the stage of one of the sections, the rock band of ore at the other section is advanced from the boundaries of the previous stage to the boundaries of the subsequent stage of the mining. The duration of working out of each i-th stage is determined by the depth of the stage and the quarry deepening rate when extracting ore within the boundaries of the corresponding stage

$$T_1 = \frac{H_{S1}^{I}}{h_{D1}^{I}};\ T_2 = \frac{H_{S1}^{II}}{h_{D1}^{II}}$$
$$T_3 = \frac{H_{S2}^{I}}{h_{D2}^{I}};\ T_4 = \frac{H_{S2}^{II}}{h_{D2}^{II}}$$
$$T_5 = \frac{H_{S3}^{I}}{h_{D3}^{I}};\ T_6 = \frac{H_{S3}^{II}}{h_{D3}^{II}}$$
$$T_7 = \frac{H_{S4}^{I}}{h_{D4}^{I}};\ T_8 = \frac{H_{S4}^{II}}{h_{D4}^{II}} \quad (1)$$

where h'_{D1}, h'_{D2} ,... and h''_{D1}, h''_{D2} ,... are the deepening rates of the quarry within the boundaries of the first, second, etc. stages, respectively, in sections I and II, m/year.

During the period T_2, it is necessary to excavate a temporary basset edge in section I with a height of H'_{S1}, and a vertical rate of lowering mining operations equal to h'_{V2}.

During the period T_4, one will need to excavate a temporary basset edge with height ($H'_{S1} + H'_{S2}$) at the rate of h'_{V3} (the index n"3" indicates that the mentioned rate refers to temporary basset edge of the third stage).

For the period T_6, a temporary basset edge with a height of ($H'_{S1} + H'_{S2} + H'_{S3}$) should be excavated at a rate of h'_{V4}. Similarly, temporary basset edges are excavated in section II at the rate of h''_{V2}, h''_{V3}, and h''_{V4}. The relationship was established between the depth of the stages, quarry deepening rate, and the vertical rate of lowering mining operations during the excavation of temporary basset edges in the sections.

In section I:

$$H_{Si}^{I} \geq \frac{h_{Di}^{I}}{h_{Vi}^{II}} \sum H_{Si}^{II}, \quad (2)$$

where i is the sequence number of the mining stage, starting from the stage first from the surface.

The depth of the stages in section II is determined similarly.

The inequality sign in the formula (2) characterizes the fact that the duration of mining of ore reserves within the boundaries of the next stage in one of the sections should be equal to or greater than the duration of the excavation of the temporary basset edge in another section of the quarry that eliminates the interruption of the ore mining process.

The excavation rate of temporary basset edges at a known depth of stages is

$$h_{Vi}^{II} \geq \frac{h_{Di}^{I}}{H_{Si}^{I}} \sum_{1}^{i-1} H_{Si}^{II}, \quad (3)$$

At fixed values of quarry deepening rate and the vertical rate of excavation of temporary basset edges, the minimum allowable depth of each subsequent stage must exceed the depth of the previous stage that allows for continuous mining of ore in the quarry.

The proposed method of conducting mining operations when developing two sections of the field in stages allows working out stages with steep slope angles of the loading faces, up to the slope angle of the quarry band of ore in the final position that allows postponing the maximum volumes of overburden rock excavation to later periods of exploitation, and thus ensuring profitability and expediency of open field development in the context of high volatility of prices and demand on the mineral raw material markets.

The considered method of mining the deposit creates safe mining operation conditions when excavating temporary basset edge of the quarry, and provides a high degree of stationarity of the mine opening systems.

To ensure the continuity of the mining process, when developing field sections by stages, a number of stages in the priority section of the deposit must be equal to or one stage greater than that in the second section, while the minimum permissible depth of each successive stage must exceed the depth of the previous stage.

The minimum permissible depth of a stage in one section is directly proportional to the quarry deepening rate at this stage and inversely proportional to the vertical rate of excavation of temporary basset edge in the other section.

Performance graphs with respect to stripping operations at a fixed quarry performance are constructed using the method of creating calendar plans for the mining operations development by operation year and periods based on the designed parameters and indicators of the adopted technological method of mining [17-20].

RESULTS AND DISCUSSIONS

In order to obtain unbiased results of comparison of different options of the stripping operations, each of them must be formed in compliance with a number of requirements for the stripping operations development schedule, the mains of which are the following:

a) Mining operations should be performed alternatively in each of the sections within the boundaries of the corresponding stage, and therefore the extraction of ore at each subsequent stage must be performed in compliance with the current stripping ratio equal to or greater than that at the previous stage.

b) The current stripping ratio should be constant year-by-year of working out of each of the stages. The main distinguishing feature of the considered mining method is that at each time point the mining performance zone is located in one section, while the stripping zone is located in another section. During the ore extraction period in the "a b c d" zone of the second stage mining operations in section II, it is necessary to remove the rock in the stripping operation zone "k l m n " and "k' l' m' n'" of the third stage in section I.

The annual amount of worked out rock V in the stripping operation zone of each stage from the hanging side, per unit length of the band of ore, is

$$V = h_V B_S, \text{ m}^2/\text{year} \quad (3)$$

where h_V is the vertical rate of lowering mining operations when excavating temporary basset edge, m/year; B_S is the horizontal advance of the temporary basset edge when lowering mining operations from the upper border of the stage to its lower border, m.

$$B_S = H_S (\text{ctg}\phi \pm \text{ctg}\,\gamma), \quad (4)$$

where H_S is the depth of the stage, m; ϕ is the slope angle of the temporary basset edge, deg.; γ is the slope angle of the ore body, deg.

In formula (4), the "+" sign is taken when determining B_S from the hanging layer, while the " - " sign is taken to determine the bottom layer of the ore body.

In the mining zone of each stage, overburden rocks will also be removed during ore extraction, for example, from the "e c d" prism from the hanging layer side. For a fixed time period of mining ore reserves at each stage, it is necessary to remove the bulk of rocks in the mining zone as well as in the stripping zone.

At the end of the mining at the second stage of ore reserves, in section II of the overburden removal, in the mining zone, productivity will fall to almost zero. In order to stabilize the current stripping ratio for the mining period of ore reserves, it is necessary to reduce the vertical rate of lowering rocks when excavating temporary basset edge in the stripping zone at the beginning of the mining period of ore reserves of the stage, uniformly increasing it towards the end of the period.

The vertical rate of lowering mining operations h_V, when excavating temporary basset edge, is the main initial indicator that determines the values of all parameters and indicators of the considered method of mining the field.

The stabilization condition of the current stripping rate for the mining period of ore reserves of the stage is

$$h_{V_H} = h_{V\max} - h_D, \tag{5}$$

where h_{V_H} is the vertical rate of lowering mining operations when excavating the temporary basset edge in the stripping zone at the beginning of the mining period of the ore reserves of the stage, m/year; $h_{V\max}$ is the maximal value of the rate of lowering mining operations.

The mathematical condition of not exceeding the current stripping ratio of each previous operation period in relation to the subsequent one at fixed productivity of a quarry is written as:

$$\frac{h^{II}_{D(i-1)}H^{I}_{Si}}{H^{II}_{S(i-1)}}\sum_{1}^{i-1} H^{I}_{Si} \le \frac{h^{I}_{Di}H^{II}_{SI}}{H^{I}_{SI}}\sum_{1}^{i-1} H^{II}_{SI}, \tag{6}$$

where $h''_{D(i-1)}$ is the deepening rate required to ensure the accepted productivity for ore in the mining zone of the (i - 1)-th stage of section II, m/year; h'_{Di} is the deepening rate required to ensure the accepted productivity for ore in the mining zone of the i-th stage of section I, m/year.

By simplifying and converting the expression (6), we get a formula that reflects the condition of not exceeding the current stripping ratio of each previous period of quarry operation in relation to the subsequent one:

$$H^{I}_{Si} \le \frac{H^{I}_{S(i-1)}{h^{II}_{Di}}^{2}}{h^{I}_{Di}h^{I}_{D(i-1)}}. \tag{7}$$

If the deepening rate values for mining stages in each section are equal, the condition (7) is converted to the form:

$$H^{I}_{Si} \le \frac{H^{I}_{S(i-1)}{h^{II}_{Di}}^{2}}{h^{I}_{Di}h^{I}_{D(i-1)}},$$

$$H^{I}_{Si} \le \frac{H^{I}_{S(i-1)}{h^{II}_{Di}}^{2}}{{h^{I}_{Di}}^{2}}. \tag{8}$$

Thus, the depth of each subsequent stage of the first section must be equal to or be less than the depth of the previous stage, multiplied by the ratio of the squares of the deepening rates of the quarry in the sections I and II.

Stabilization of the current stripping ratio by year during the ore reserves mining period of each of the stages is achieved by a uniform increase of the vertical rate of lowering mining operations from the beginning to the end of this period when excavating the temporary basset edge in the stripping operations zone.

CONCLUSIONS

Thus, the following conclusions can be drawn:

- When working out both sections of the field with the same deepening rate, the depth of the stages in the sections should be the same. In the course of developing priority section with the lower deepening rate than that of the second section, depth of the subsequent stage in relation to the depth of the previous stage shall not exceed the ratio of the square of the deepening rate in the second section to the square of the deepening rate of the primary development section.
- When developing a priority section with the deepening rate greater than that of the second section, the depth of the subsequent stage in relation to the depth of the previous stage shall not exceed the ratio of deepening rate at the priority section to deepening rate at the second development section.
- With the increase in the intensity of incremental development of the field sections, the current stripping ratio during the mining period of ore reserves at the corresponding stage remains unchanged.
- When increasing the depth of each subsequent stage, the duration of the quarry operation periods at a constant current stripping ratio increases. At the maximum allowable depth of stages, the duration of each enterprise operation period is equal to the sum of the mining periods of ore reserves of the two stages.

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