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Substantiation of the depth of the open pit employing the in-pit crushing and conveying technology as a determinant of the pit development at the subsequent stage of mining

Abstract. The constant increase in the depth of open pits employing the in-pit crushing and conveying technology applied to mining steeply dipping deposits causes an increase in the height of the ore lifting and transportation distance, and results in an increase in the cost of ore transportation to the surface. This, in turn, affects the depth of the subsequent stage of reconstruction of the pit transportation system. The present research aimed to substantiate the depth of the subsequent stage of iron ore pit mining applying the in-pit crushing and conveying technology using a generalising estimation figure for various consecutive time intervals during the stage-by-stage mining, which should improve the quality of design operations. The article employed methods of statistical-logical, causal and comparative analysis and the method of system-structural approach to determine the generalising figure for estimating the subsequent stage of mining by the in-pit crushing and conveying technology. When substantiating the depth of the subsequent stage of open pit reconstruction, the dependency was proposed to determine the maximum operating stripping ratio. The dependency takes into account the increase in transportation costs caused by the increased lifting height and the extension of the distance of transporting ore to crushing and reloading points of conveyor lifts located in the pit as a result of its deepening. In addition, the dependency of the position of the mined ore mass centre on the open pit depth was used in calculations. Considering the fact that in modern deep open pits, the volume of ore mined and transported by the truck-conveyor complex can reach 30 Mt annually, the search for ways to improve cargo flows of the pit transport complexes becomes one of the important designer tasks. In this connection, an estimated figure was proposed to determine the depth of the subsequent stage of mining the open pit employing the in-pit crushing and conveying technology complex, which takes into account the increased cost of ore transportation, the cost of marketable mineral products, and the current stripping ratio. At the same time, the increase in costs caused by the increased height of ore lifting due to mining deepening is taken into account to consider the increase in transport costs when designing further development of the in-pit crushing and conveying technology complex. In

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the open pit, the depth of which is determined according to the proposed methodology, the value of the current stripping ratio will not exceed the maximum operational one at the subsequent stage. This approach allows quick estimation of the depth of an iron ore open pit that mines steep deposits when designing the subsequent stage of reconstruction to provide its breakeven finalisation

Keywords: open pit working; maximum operational stripping ratio; open pit deepening; mining step

Introduction

When developing modern iron ore open pits, large volumes of rock mass are excavated, this often amounting to more than 50 Mt annually. At that, a significant proportion of the mass is transported from deep horizons. The final depth of many iron ore open pits reaches 500-700 m. It should be noted that mining inclined and steep deposits by deep open pits is characterised by a number of features that influence the development of the open pit and transport complex. The main problem affecting open pit operations consists in the fact that working conditions of open pits are continuously complicated during the entire period of deposit development due to the increase in the operation depth, the height of the working zone and the current stripping ratio value. This results in a significant increase in the height of the mining lift by transport complexes and, as a consequence, an increase in a lifting cost share in ore extraction costs. The solution to the transportation problem in a difficult situation is most often found in the wide application of complexes of the in-pit crushing and conveying technology (ICCT).

According to A. Adamchuk (2021), the traditional ICCT scheme is as follows: the rock mass is transported by a truck from the face to the concentration level where a conveyor hopper with a primary crusher is installed. The costs of transporting the rock mass by dump trucks are higher than by an inclined conveyor, so to use combined truck and conveyor transport effectively, the reloading point should be relocated every 90-105 m deepwards over time. When mining operations go deeper, further deepening of the ICCT complex is provided to reduce the distance of ore transportation from lower levels to crushing and reloading points and the in-pit journey of vehicles usually at the subsequent stage of open pit development.

N. Sarybayev *et al.* (2021b) draw attention to the current trend in ICCT development that, when deepening mining operations, extraction of ore from deep horizons requires making adjustments in the design of the open pit transport system. Yu. Hryhoriev *et al.* (2021a) noted that in the past, application of the ICCT required consideration, but now mining-technical and technical-economic conditions require search for and substantiation of the choice of the most rational parameters and the dimension-type of extraction and loading equipment of road and conveyor transport. Thus, the present work focused on technological parameters of the in-pit crushing and conveying technology at iron ore open pits, neglecting the conditions of forming cargo flows to the ICCT reloading points.

V. Azarian (2019) argues that it is important to develop a comprehensive efficiency estimation of the quality management technology of a generalised complex of ore flows of a mining and concentration plant (GZK in Ukrainian) that links the actual volume of ore sent for concentration, the concentrate yielded from it and the cost of processing. But GZK profits are secured by not only the quality of the iron-bearing material of the flows, but also the functioning of the transport complex that forms ore flows to concentration plants, parameters of which depend on an open pit size. In this respect, V. Monastyrskyi & A. Smirnov (2021) studied ore flows in Kryvyi Rih open pits at M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine. However, the mentioned work considered heavy-duty trucks and belt conveyors of the ICCT, leaving the complex of the Inhulets Mining and Concentration Plant, one of the largest in Kryvyi Rih Basin, unaddressed.

O. Shustov *et al.* (2021) emphasised that the increase in mining costs caused by the growing depth of development affected the cost of transporting the rock mass and recommended that the cost of transporting the rock mass should be taken into account with the increasing value depending on the depth of mining. However, the transportation cost also depends on distribution of the transported rock mass relative to the working zone of the open pit, which also should be taken into account. Generally, the growing depth of mining operations in iron ore open pits leads to the increase in the transport distance; the share of ore mass transportation costs in the cost structure also increases steadily, adding to an inevitable increase in the ore cost and raising the question of practicability of further pit deepening.

Yu. Hryhoriev *et al.* (2021b) analysed the basic computational principles and techniques for determining the final boundaries of the open pit and identified the methods of Lerch-Grossman, the floating cone, Seymour, dynamic programming methods, special neural networks, graph theories, network flows and other approaches. Based on these methods, K-Mine, SurpacN-PVSheduler, Four-X, MineShed software packages, as well as integrated three-dimensional CAD systems (Gemcom, MineScape, Data-Vulcan, MineSight, etc.) are widely used. The shortcomings of the mentioned techniques include complexity of implementation, a large amount of input data, and lack of reliable means of method evaluation. From the above, it can be concluded that the mentioned approaches to solving the problem require further development taking into account the current trends.

V. Slobodianiuk & I. Maksymov (2021) propose using the economic effect, equal to the difference of total costs for transporting the rock mass to the main conveyor at one crushing and reloading point and during development at their optimal quantity, as a criterion of the truck-conveyor transport optimisation. The analytical dependency is established to determine the optimal number of reloading points at their uniform deployment throughout the height of the working zone of the open pit. However, this work considers parameters that directly characterise the operation of the ICCT complex only when choosing an effective strategy for ICCT development. At the same time, the economic result of GZK activities, i.e. the cost of marketable products (concentrate, pellets), is also influenced by the amount of overburden per unit of mined minerals.

Therefore, to choose the strategy of the ICCT development, it is more correct to take into account the current stripping ratio and economic indicators of the GZK marketable product value in the estimation figure, as the open pit and the concentration plant are a single technological complex. In this regard, to design subsequent stages of open pit mining, a new estimation figure should include expenses for GZK marketable products, and along with that increased costs for transporting ore by the ICCT collecting transport at each stage of deposit development should be predicted. The present work aimed to improve the method of substantiating the depth of the open pit with the ICCT that develops steep deposits at the subsequent stage of its mining by means of an estimation figure for various consecutive periods of the open pit mining duration.

Materials and Methods

To achieve the goal set in the work, a systemic approach is applied considering the previous experience in mining science. Depth is one of the defining parameters in developing an open pit and its working zone. At that, calculations and selection of equipment for the ICCT schemes are performed taking into account their development by open pit methods until the end of life of mine. However, when designing, the final depth of large open pits is often and repeatedly reconsidered and adjusted. As a result, there is uncertainty when determining other parameters of other open pits with ICCT complexes as well.

Specialists and designers reconsidered initial projects and changed operational (design) stripping ratios to align the parameters of the development system with the design (Kovalchuk *et al.*, 2015). This results in the necessity of finding a method of pre-design substantiation of the depth when mining the open pit by stages on the breakeven principle. Theoretically, the basic principle of substantiating the open pit depth is based on the comparison of one of the stripping ratios with the marginal (economically expedient) one. For open pits developing inclined and steep deposits, boundaries are set by the contour stripping ratio numerically equal to the boundary one. But the bench-based analysis of mined mass volumes and stripping ratios is inconvenient due to the fact that when initial conditions change while designing, there emerges a need to recalculate the volumes.

The method of V. Rzhevskyi (1956) is widely used in calculations to solve the main design issues and determine the final depth of the open pit. The method is based on the comparison of current (K_c) and marginal of economically expedient (K_e) stripping ratios, i.e. $K_c \leqslant K_e$. Thus, the indicator (K_e) is decisive in determining the depth of surface mining operations. However, the mentioned estimation figures are proposed directly to determine the final boundaries of the open pit, while parameters of its subsequent stage of mining are interim.

Different options for forming subsequent stages of open pit mining may differ in depth without changing the basic parameters of the design decisions. In this case, one of the main parameters that determines operation of the ICCT complex in the open pit is the ore lifting height and transportation distance. Thus, the estimation figure, with which parameters for the subsequent stages of further development of open pits are to be compared, should take into account the increase in the costs of ore lifting and transportation. This is due to the fact that at steep deposits, the depth of ore extraction is constantly increasing resulting in the growth of costs for its transportation to the surface.

To determine the depth of the subsequent stage of mining the open pit within a particular period of its development, the present work suggests the maximum operational stripping ratio considering the value of GZK marketable products as an estimated figure. As accurate prediction of parameters of the subsequent mining stage is rather difficult, it is important to perform analytical work involving elements of the theory of similarity in order to determine the required parameters of ore flows of the working zone of the open pit. The depth of the subsequent stage of open pit development is determined on the example of the Inhulets Mining and Concentration Plant ("InGZK"), where one of the largest ICCT projects in Kryvyi Rih iron ore basin was implemented.

Available statistical materials (data on horizontal distribution of annual production volumes for the past period of the open pit operation) enabled calculating the coordinates of the mass centre of the ore working zone according to the depth of the open pit over a sufficiently long period of time. This dependency was studied on the material for the period from 1974 to 2011, as the said period is most fully represented by the available statistical data due to a large amount of the research performed on the InGZK open pit within this period.

According to technological design standards, when analysing parameters of transportation schemes for open pits under reconstruction with an annual rock mass output of more than 40 Mt, the calculation period is taken equal to 7-10 years, and 5-7 years for smaller productivity. With this in view, the estimated figure was determined for 2030. For calculations on the InGZK open pit, the existing ICCT complex, where motor vehicles are used as assembly equipment, and other parameters were taken into account (Information on production..., n.d.).

Mathematical processing of statistical data through approximation (the least squares method) enabled finding the dependency of the mass centre of the ore working zone on the depth of the open pit (Tamrazov, 1987; Semerikov *et al.*, 1998). Thus, a relationship was established between the depth of the mass centre of the ore working zone and the depth of the open pit. The obtained dependency helped predict the depth of the mass centre location of the distribution of the ore production volumes at the subsequent stage of the open pit development. Substituting the obtained value of the mass centre of the ore working zone in the proposed maximum operational stripping ratio formula enabled obtaining its value for the subsequent stage of the open pit development. Next, this value was compared with the current stripping ratio, which varies depending on the depth of the open pit, and finally, the sought-for depth of the open pit is found.

Results and Discussion

Based on the generalising nature of the methodology of substantiating the depth of subsequent stages of mining iron ore open pits with the ICCT complex that develop steep deposits, it can be considered that the obtained dependencies and recommendations are acceptable for designing the subsequent stages of reconstructing iron ore open pits with the ICCT complex by relevant design and research organisations.

The indicator reflecting the breakeven operation of the open pit-concentration plant complex, provided that the profit from the sale of marketable products is spent on stripping, is the maximum operational stripping ratio. The mentioned ratio $K_{o.m}$ was determined as the sum of the current stripping ratio and its increase due to the difference between the price and the cost of marketable products, which is taken as an indicator to substantiate the depth of the subsequent stage of the open pit development and calculated according to the formula, m^3/t:

$$K_{\mathrm{o.m}} = \frac{(P_{\mathrm{c}} \cdot P_{\mathrm{s}} - C_{\mathrm{c}} \cdot P_{\mathrm{p}}) \cdot (1-i) \cdot \gamma - \Delta I_{\mathrm{tr}} \cdot P_{\mathrm{p}}}{C_{\mathrm{o}} \cdot P_{\mathrm{p}}} + K_{\mathrm{C}}, \quad (1)$$

where P_c, C_c – the price (excluding VAT) and the cost of marketable products (e.g. concentrate) of the GZK, UAH/t; P_s, P_p – the volume of sold and produced marketable products for the calculation period, t; γ – the concentrate yield from ore, unit fr.; C_o – the cost of a unit of overburden, UAH/m^3; K_c – the current stripping ratio for the recent period of the open pit operation, m^3/t; ΔI_{tr} – the increase of costs for transporting ore when deepening the open pit at the stage under consideration, UAH/t; i – the income tax, unit fr.

Comparison of the value of the current stripping ratio K_c with the maximum operational one $K_{o.m}$ calculated for the subsequent stage of the open pit development indicates the degree of approximation of the current open pit parameters, in particular its depth to the value of the depth at the subsequent stage of its development. Thus, while designing the stage-by-stage mining of the open pit, it is expedient to apply the principle when the current open pit depth is gradually increased until the current stripping ratio K_c reaches the value of the maximum operational stripping ratio $K_{o.m}$ and, accordingly, the current position of the open pit bottom reaches the depth of the subsequent stage of mining.

When input data for determining the value of the increase in the cost of ore transportation and lifting (ΔI_{tr}) during the deepening of the open pit at the stage is not available, this value can be found applying the methods of the similarity theory (Serdiuk, 2005) and approximation (Semerikov *et al.*, 1998). It is expedient to predict ore production distribution parameters on the basis of statistical data and technical and economic indicators achieved at the time of designing. At that, the process of designing an open pit within a steep deposit will be simplified if the parameter influencing significantly the operation of the ICCT complex in the open pit – the height of ore lifting at the subsequent stages of its development – is determined in advance. The intensive open pit deepening contributes to the continuous increase of this value: from the current depth ($h_{c.i}$) to the depth of the open pit at the subsequent stage of its development ($h_{s.s}$). The height of ore lifting in the open pit is functionally related to the depth of the open pit itself, the parameters of the ore working zone and the nature of distribution of horizon production volumes along the depth of the open pit.

According to B. Isakov & M. Chetveryk (2021), when designing the transition to stripping the next horizon using the in-pit crushing and conveying mining technology, a certain amount of time passes from the beginning of designing to commissioning, and the depth of the open pit can be significantly increased compared with the one at which it should have been commissioned according to the project. As this expands the transportation distance for trucks that should be maintained in the proper working condition (Savin & Sokolenko, 2024), and also reduces the economic efficiency of the designed scheme, this factor should be taken into account in the calculations.

In accordance with the Standard of the Organisation of Ukraine No. 73.020-078-1:2007 (2007), parameters of transportation schemes (weighted average lifting height, weighted average transportation distances) are analysed for the open pits to be reconstructed. Based on the input data, the amount of increase in ore transportation costs (ΔI_{tr}) at the subsequent stage of open pit deepening compared with its current state is determined. The calculation value ΔI_{tr} is determined from expression (2) (UAH/t):

$$\Delta I_{tr} = C_v \cdot \Delta L_t = C_v \cdot h_p \cdot k_{r.d} / i_t, \quad (2)$$

where C_v – the cost of 1 t·km for technological vehicles, UAH/t·km; ΔL_t – the increase in the distance of ore transportation by trucks to the ICCT reloading points due to lowering the mass centre of the ore working zone and deepening the open pit, km; h_p – the increase in the ore lifting height which is defined as the difference between the depth of the weighted average position of the mass centre of distribution of horizon production volumes in the current year and the same parameter at the subsequent stage of mining, m; $k_{r.d}$ – the road development index for open pits, unitless value; i_t – the inclination of technological roads in the open pit, %.

The study of the influence of the pit depth on the depth of the weighted average centre of mass of horizon volumes of ore extraction allows (Table 1) a dependency of changes in one factor when the other changes.

Table 1. *Changes in open pit depths and ore mass centres of the ore working zone by years of InGZK open pit operation*

Year	Open pit depth, m	Depth of mass centre of ore working zone, m
1974	170	127
1975	185	127
1976	185	134
1977	185	139
1978	200	153
1979	215	157
1980	215	162
1981	215	162
1982	215	176
1983	215	182
1984	230	184
1985	230	194
1986	245	194
1987	260	182
1988	260	188
1990	275	191
1991	290	203
1992	290	201
1993	305	203
1994	305	220
1996	320	228
1997	320	236
1998	335	236
1999	350	242
2000	350	235
2001	350	227
2002	365	242
2003	365	248
2004	365	252
2005	365	265
2006	380	284
2007	380	290
2008	395	292
2011	440	307

Notes: *surface marking accepted +50 m*
Source: *developed on the basis of the data collected personally by the authors*

The dependency describing the effect of the depth of the InGZK open pit on the depth of its ore working zone mass centre is obtained by approximation. Linear regression is as follows, m:

$$x_{mc.} = a \cdot h_{s.s} + b = a(h_{c.i} + \Delta h \cdot t) + b = 0.6421 \cdot h_{s.s} + 23.3, \quad (3)$$

where $x_{mc.}$ – the depth of the mass centre of the ore working zone, m; a, b – the empirical coefficients of the linear equation, unit; $h_{s.s}$ – the depth of the open pit at the subsequent stage of reconstruction, m; $h_{c.i}$ – the current depth of the open pit, m; Δh – the average annual rate of open pit deepening (for the InGZK open pit $\Delta h \approx 7$ m/year, but up to 1980 it was $\Delta h \approx 9$ m/year); t – the duration of the period from the current year to the subsequent stage of the open pit development, years.

It is proposed to assume that the preliminary depth of the open pit at the subsequent stage of its development is equal to $h_{s.s} = h_{c.i} + \Delta h \cdot t$, m. Approximation quality indicators ($r_{xy} = 0.9706$, $R^2 = 0.9421$, $A = 4.646\%$) of the obtained equation (3) allow asserting that it is adequate to mining and engineering factors being investigated, and as a simple model it can be used to solve some mining problems. With the help of the obtained dependency (3), it is possible to predict the depth ($x_{mc.}$) of the centre of mass distribution of ore production at the subsequent stage of the open pit development. If the value of this parameter for the current year is written as $x_{c.i}$, then $h_p = x_{mc.} - x_{c.i}$, m. The increase in ore transportation costs according to the formula (2) is as follows, UAH:

$$\Delta I_{tr} = C_v \cdot k_{r.d} \cdot (a \cdot h_{s.s} + b - x_{c.i})/i_t = C_v \cdot k_{r.d} \cdot (a \cdot [h_{c.i} + \Delta h \cdot t] + b - x_{c.i})/i_t. \quad (4)$$

By substituting the value of ΔI_{tr} (4) in the formula (1) and considering the case when $P_s = P_p$, the dependency is obtained that determines the value of the maximum operational stripping ratio for the subsequence stage of the open pit development, t/m³:

$$K_{\text{o.m}} = \frac{(P_{\text{c}} - C_{\text{c}}) \cdot (1-i) \cdot \gamma - C_{\text{v}} \cdot k_{\text{r.d}} \cdot (a \cdot [h_{\text{c.i}} + \Delta h \cdot t] + b - x_{\text{c.i}})/i_{\text{t}}}{C_{\text{o}}} + K_{\text{c}}. \quad (5)$$

Due to the continuous deepening of the open pit developing a steep deposit from the current depth ($h_{c.i}$) to the depth ($h_{s.s}$) of the subsequent stage of its development, the current stripping ratio (K_c) is increased to a value equal to the maximum operational stripping ratio $K_c = K_{o.m}$ at the subsequent stage of the open pit development determined by formulae (1) or (5). The design process also determines the open pit depth $h^1_{s.s}$, which is adequate to the maximum operational stripping ratio $K_{o.m}$.

It is possible that the previously accepted depth $h_{s.s}$ at the next stage of the open pit development will be greater than the depth $h^1_{s.s}$, i.e. $h_{s.s} \geqslant h^1_{s.s}$. In this case, the maximum operational stripping ratio is determined by formulae (1) and (5), but taking into account the depth $h^1_{s.s}$ and the corrected maximum operational stripping ratio $K^1_{o.m}$ adequate to the open pit depth $h^1_{s.s}$ at the subsequent mining stage.

The opposite situation is possible when the assumed previous depth $h_{s.s}$ of the open pit will be less than the depth $h^1_{s.s}$, i.e. $h_{s.s} \leqslant h^1_{s.s}$. In this case, the maximum operational stripping ratio $K^1_{o.m}$ is also calculated taking into account the depth $h^1_{s.s}$. In both cases, the duration of the period t from the current date to the subsequent stage of the open pit development will be $t^1 = (h^1_{s.s} - h_{c.i})/\Delta h$, years. In the case where $h_{s.s} = h^1_{s.s}$, $K^1_{o.m}$ is not calculated.

According to formula (5) at $t = 19$ years for 2030, for the InGZK open pit where vehicles are used, the calculated maximum operational ratio is equal to $K_{o.m} = 0.66$ m³/t. In this example, it is considered that the maximum operational ratio $K_{o.m} = 0.66$ m³/t is adequate to the previously accepted depth of the open pit, i.e. $h_{s.s} = h^1_{s.s} = 573$ m.

Thus, the principle of finding a substantiated open pit depth at the subsequent stage of its development is that when deepening the open pit to the depth of the subsequent development stage ($h^1_{s.s}$), the current stripping ratio will not exceed the maximum operational ratio ($K_c \leqslant K^1_{o.m}$), which will allow the fullest use of the advantages of open pit mining. Application of the proposed estimation figure – the maximum operational stripping ratio – is appropriate for different consecutive periods of time when solving the design issues of each subsequent stage of reconstruction during the stage-by-stage open pit development.

This method of approximating the open pit depth at the subsequent stage of its development can be used to substantiate prospective design solutions. Yu. Hryhoriev *et al.* (2021a) argue that mining conditions of mineral deposits will be characterised by further increases in the open pit depth and transportation distances. This can be fully agreed with and taken into account when studying ICCT parameters at the subsequent stage in the open pit development. One of the main challenges in open pit designing is its sustainable development and minimisation of costs, and given the long development time of the deposit and variable mining and engineering conditions of open pits, correction of previously made decisions is an inevitable step to increase their efficiency. At the same time, revision of even one of the essential parameters of open pits at the subsequent stage, such as depth, can affect efficiency of the decisions made, especially at the pre-design stage. Therefore, this factor is essential for prospective decisions.

N. Sarybayev *et al.* (2021a) indicate that the area of the most economical use of the ICCT method with belt conveyors of the standard inclination (up to 16°) is provided within the range of technological parameters – the capacity of 10-25 Mt/year and the lift height of 250-600 m. At the same time, when designing a new technological transportation scheme, it is necessary to delineate the efficient area of its application, which can be done with the help of the estimation figure proposed in this work. S. Kuzmenko *et al.* (2019) believe that one of the most important conditions to use a conveyor lift is provision of the transport with the rock mass for the payback period of 10-20 years. The ICCT schemes employed at Kryvyi Rih open pits largely depend on specific mining conditions. According to N. Sarybayev *et al.* (2021b), deepening of mining operations will require adjustment of the transport system of the open pit. However, the examples show that the economic effect of this technology is always positive.

V. Slobodianiuk & I. Maksymov (2021) suggest the use of mobile crushing and reloading points. However, the authors believe that construction of a new stationary crushing and reloading point is inefficient, since it is not possible to create an area of the required size with a lifetime that justifies relevant construction costs. In this case, it is also necessary to assess the mining and engineering situation in the open pit using an estimation figure. Yu. Hryhoriev *et al.* (2021b) state that mining conditions of mineral deposit development in the coming years will be characterised by a further increase in the open pit depth and transport distances, with which one can fully agree and take into account when studying the parameters of the ICCT at the subsequent stage of the open pit development.

Thus, summarising the above, it is possible to conclude that when transiting to the subsequent stage of the open pit development, it is necessary to assess the mining and engineering situation using an estimation figure to outline the rational field of applying the technological transport complex and determine the ways of further improvement of ICCT parameters at the subsequent stage of the open pit development. In this regard, in order to perform approximate estimates of the open pit depth at the pre-design stage, the use of the maximum operational stripping ratio to substantiate the subsequent stage of the open pit development is proposed.

Conclusions

In the course of solving the problem using the similarity theory, a method has been proposed that allows a more deep approach to the study and evaluation of such important parameters as the depth of the subsequent stage of developing with the ICCT complex, determination of the value of the maximum operational stripping ratio for this stage and its adequate open pit depth and substantiation of the economic expediency of the subsequent stage development of the open pit the pre-design stage. Application of dependencies determined using the similarity theory makes it possible to solve the tasks necessary for the further development of the ICCT complex and substantiate the depth parameter for the subsequent stage of the open pit development, which ultimately allows obtaining the designed technological and economic result in a given period. The methodological approach to determining the depth of the subsequent stage of mining the iron ore open pit with the ICCT complex during the stage-by-stage development can be used by design organisations and research institutes when designing reconstruction of open pits in steeply dipping deposits. The issue of how the nature of ore distribution throughout the height of the open pit working zone affects the provision of optimal operational conditions for each of the applied types of the ICCT complex still remains unaddressed, which may be the subject of further research. It is also useful to analyse the influence of open pit deepening and changes in the depth of the mass centre in distributing ore production volumes on the dynamics of stripping ratios.

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Conflict of Interest

None.

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Обґрунтування глибини кар'єру з циклічно-потоковою технологією як визначальної величини його відпрацювання в черговому етапі розробки

Анотація. Постійне збільшення глибини кар'єрів з циклічно-потоковою технологією, що розробляють круто падаючі родовища, викликає зростання висоти підйому та відстані перевезення руди, і як наслідок, збільшення витрат на її доставку на поверхню, що впливає на величину глибини чергового етапу реконструкції транспортної системи кар'єру. Метою даної роботи було обґрунтування глибини чергового етапу відпрацювання залізорудного кар'єру з комплексом циклічно-потокової технології за допомогою узагальнюючого показника оцінки для різних послідовних відрізків часу при поетапній розробці кар'єру, що має покращати якість проектних робіт. В статті використовувалися методи статистично-логічного, каузального і компаративного аналізу та метод системно-структурного підходу, щодо визначення узагальнюючого показника оцінки чергового етапу відпрацювання кар'єрів з комплексом циклічно-потокової технології. Запропоновано при обґрунтуванні глибини чергового етапу реконструкції кар'єру залежність для визначення максимального експлуатаційного коефіцієнту розкриву, в якій враховано збільшення транспортних витрат через зростання висоти підйому та подовження відстані транспортування руди на дробильно-перевантажувальні пункти конвеєрних підйомників розташованих в просторі кар'єру внаслідок його поглиблення. В розрахунках також використано залежність положення координати центру мас видобутої руди від глибини кар'єру. Враховуючи, що в сучасних глибоких кар'єрах обсяги руди, що видобувається і транспортується автомобільно-конвеєрним комплексом протягом року можуть становити 30 млн. т, одне з важливих завдань проектувальників полягає в пошуку шляхів вдосконалення вантажопотоків транспортних комплексів кар'єру. У цьому з'вязку запропоновано оціночний показник для визначення глибини чергового етапу відпрацювання кар'єрів з комплексом циклічно-потокової технології, в якому у взаємозв'язку враховано збільшення витрат на доставку руди, вартість товарної продукції гірничозбагачувального комбінату, поточний коефіцієнт розкриву. При цьому береться до уваги збільшення витрат через збільшення висоти підйому руди при пониженні гірничих робіт в кар'єрі, що дозволяє врахувати приріст транспортних витратат при проектуванні подальшого розвитку комплексу циклічно-потокової технології. У кар'єрі, глибина якого визначається по запропонованій методиці, значення поточного коефіцієнту розкриву не перевищуватиме максимального експлуатаційного коефіцієнту розкриву в черговому етапі. Даний підхід дозволяє оперативно оцінити глибину залізорудного кар'єру, що розробляє крутопадаючі поклади при проектуванні чергового етапу реконструкції за умови беззбиткового його доопрацювання

Ключові слова: відкрита гірнича виробка; максимальний експлуатаційний коефіцієнт розкриву; поглиблення кар'єру; сходинка відпрацювання