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IMPROVING THE RELIABILITY OF OPENCAST SYSTEM FOR COMPLEX STRUCTURE ORE DEPOSITS

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ABSTRACT

Regulation of stripped and ready for excavating reserves on the benches and the size of a reserve strip of operating platforms allow carrying out the optimal formation of the opencast working zone corresponding to the established opencast performance overburden ratio, as well as improving the reliability of mining opencast systems. Enhancement of the opencast operation reliability can be achieved by reducing the number of parts in a series connection (between the preparation of rock mass to withdrawal by excavation, transportation, track works, piling and between overburden removals and mining operations), increasing the operation reliability of each part of the opencast, ensuring equipment redundancy, creating mineral reserves, and outstripping of overburden removals.

Key words: Opencast Mining, Reliability Level, Reserve Supply Capacity, Reserves-to-Production Ratio

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1. INTRODUCTION

Modern mine engineering conditions for the development of deep open casts are characterized by the unprejudiced worsening of mine engineering as well as mining and geological conditions of development. The formation of the opencast operating zone in space and time is carried out by changing the width of operating platforms and carrying out pushback of opencast loading face in the course of mining operations. To maintain reliable operation of the opencast, it is necessary to have a reserve strip of operating platform, concentrating ready-to-excavation reserves. Regulation of ready-to-excavation reserves on the benches, subject to the regularities of the opencast space formation, allow creating the certain shape of opencast loading face corresponding to the maximal performance reliability of the mine engineering opencast system [1, 2].

Availability of ready-to-excavation ore reserves in the opencast is a factor affecting the opencast performance. Insufficient amount of these reserves leads to a reduction in the excavation front and increase ore dilution, reduces the quality and increases the cost of production. The excess of the optimal amount of ready-to-excavation reserves leads to the losses associated with the preservation of significant working capital, increased costs for the maintenance and repair of mining, an increase in ore losses [3].

The outstripping of the benches is characterized by the width of the reserve strip of the operating platform and ready-to-excavation reserves, which determine the degree of interdependency in operations of the benches. The creation of a reserve between the individual parts of the opencast (benches, technological processes) characterizes the connection pattern of these parts, which is different from the parallel connection because the failure of any part does not interrupt at the same time the operation of other parts, they can function certain time at the expense of the reserve.

2. RESEARCH OBJECTIVE

The research objective of the present article is to determine the optimal distribution of ready-to-excavation reserves in the course of opencast development of steeply dipping complex structure ore deposits in order to ensure a high level of opencast system reliability.

3. METHODS

The development of complex structure ore deposits by means of open casts composed of ore-bearing benches is characterized by the variability of the volume of ready-to-excavation reserves both in plan and in depth. The volume of ready-to-excavation reserves concentrated in the reserves trip of the operating platforms depends on a certain mine engineering specifics as well as mining and geological factors.

There are characteristics of endogenous complex-structure deposits of all genetic types, the distribution of endogenous deposits over deep levels of dislocation metamorphism, classification of complex formations and signs of complex-structure ore deposits, plots containing blocks, allowing qualitatively assess the degree of complexity of producing block [4-6].

To quantify the producing blocks, we proposed the general complexity index of the geological and morphological structure for opencast mining and mining and technological conditions of ore mining in the producing block [7, 8].

The complexity index depends on the structural type of the deposit, the nature of the contacts between ore locus and sterile grounds, the metal distribution in the ore, as well as the mining and technological conditions of ore mining in producing a block.

The higher the complexity index, the heavier mining conditions of the deposit, the higher the risk of design, and the greater the operating costs. The losses and dilution during extraction will be also higher. These circumstances will reduce the reliability of the opencast as an engineering system.

The ore-bearing ratio of the reserve strip of the operating platform defines the proportion of ore bodies contained in the reserves trip of the operating platform of the ore-bearing benches of the opencast, processing complex structure ore deposits.

The ore-bearing ratio of the reserve strip of the operating platform of the i-th bench ($K_{i\ ORE}$) can be written as

$$K_{i\,ORE} = \frac{\sum_{i=1}^{n} S_{ij\,ORE}}{S_{i\,REZ}}, \quad (1)$$

where $S_{i\,REZ}$ is the average area of the reserve strip of the operating platform of the i-th bench, m^2;

$$S_{i\,REZ} = \frac{S_{iK} + S_{i\,SOIL}}{2}, \quad (2)$$

where S_{iK} is the roof area of the reserve strip of the operating platform of the i-th bench, m^2; S_{iSOIL} is the soil area of the reserve strip of the operating platform of the i-th bench, m^2; $S_{ij\,ORE}$ is the average area of the j-th ore body within the reserve strip at the operating platform of the i-th bench, m^2;

$$S_{ijORE} = \frac{S_{ijK} + S_{ij\,SOIL}}{2}, \quad (3)$$

Where S_{ijK} is the area of the j-th ore body within the roof of the reserve strip of the operating platform of the i-th bench, m^2; $S_{ij\,SOIL}$ is the area of the j-th ore body within the soil reserve strip of the operating platform of the i-th bench, m^2.

The total volume of the excavation ready reserves, m^3

$$\Delta P = \sum_{j=1}^{m}\sum_{i=1}^{n} S_{ij\,REZ}\, h_i, \quad (4)$$

Where m is the number of ore bodies within the reserve strip of the operating platforms of the opencast; n is the number of operating benches in the opencast.

The average area of the j-th ore body within the operating platform of the i-th bench, m^2;

$$S_{ijOPORE} = \frac{S_{ij\,ROOFAREA} + S_{ij\,SOILAREA}}{2}, \quad (5)$$

Where $S_{ij\,ROOF\,AREA}$ is the area of the j-th ore body within the roof of the operating platform of the i-th bench, m^2; $S_{ij\,SOIL\,AREA}$ is the area of the j-th ore body within the soil of the operating platform of the i-th bench, m^2.

The volume of visible opencast reserves, m^3

$$V_{US} = \sum_{j=1}^{M}\sum_{i=1}^{n} S_{ij\,REZ}\, h_i, \quad (6)$$

Where M is the number of ore bodies within the operating platforms of the opencast.

Reliability is understood as the property of the system to perform specified functions, keeping its performance indicators within the specified limits for the required period of time or the required output [9].

Mining equipment redundancy and creating a reserve in outstripping of benches allows reaching considerable performance reliability of the opencast. Outstripping of the benches is characterized by the width of the reserve strip of the operating platform and volume of excavation ready reserves, which determine the degree of the interdependency of the benches operation.

The creation of a reserve between the individual parts of the opencast (benches, and technological processes) characterizes the connection pattern of these parts different from the parallel one because the failure of any part does not simultaneously interrupt the operation of other parts which can operate during a certain time at the cost of reserves.

Enhancing the reliability of opencast operation can be achieved by reducing the number of parts in series connection increasing the reliability in operation of each part of the opencast, ensuring equipment redundancy, creating mineral reserves, and outstripping overburden removals.

For parts of the opencast, such as adjacent benches, as well as overburden removals and mining operations, equipment redundancy is impossible because of their large number. Redundant equipment is effective when improving the reliability of production processes. The real opportunity of increasing reliability of opencast mining systems is the creation of ready-to-excavation reserves of minerals and outstripping of overburden removals. The technological system means a set of elements and objects united by regular interaction or certain interdependence, and ensuring the implementation of certain functions [11].

The opencast mining system consists of subsystems of overburden removals and mining operations having independent goals and objectives aimed at implementing a single function, i.e. mining operations. The ready-to-excavation reserves in each level allow conducting mining operations regardless of the overlying formation within a certain time period. The availability factor of the processing chain [11] is defined as:

$$k_{Gi} = \frac{\sum_{i=1}^{n} t_{oi}}{\sum_{i=1}^{n} t_{oi} + \sum_{i=1}^{n} t_{foi}}, \qquad (7)$$

Where t_{oi} is the time of correct operation of the manufacturing chain of the i-th bench; t_{foi} is the forced outage hours in the manufacturing chain of the i-th bench; n is the number of forced outage hours of the manufacturing chain of the i-th bench for the considered period of time.

The availability factor of the processing chain corresponds to the reliability of operation of the top level, while for other levels the reliability of their operation will depend not only on the availability factor of the benches but on the stock among them. The availability factor characterizes the probability of the working efficiency of the mine engineering system such as opencast at a randomly selected point in time, determines the readiness of this system to work, and allows assessing the service performance of the system.

The availability factor of the i-th bench of the opencast (k_i) is associated with the forced outage rate (k_{ni}) by the following relationship [11]:

$$k_i = 1 - k_{ni}. \qquad (8)$$

The forced outage rate characterizes the probability of system failure on a randomly chosen point in time. Thus, the creation of a reserve in an operating level of the opencast improves the reliability as long as its magnitude exceeds the number of forced outage hours of the overlying formation.

$$\mu_i \le 1 - k_{ni}, \qquad (9)$$

Where μ_i is the provision of producing level with reserves for the selected period of time, years.

However, the reserves-to-production ratio can be calculated by [10]

$$\mu_i = \frac{\Delta B_i L_i h_i}{m_i Q_{Ei}}, \text{ years} \qquad (10)$$

Where Q_{Ei} is the operational output of the excavator at the i-th level, m^3/year; m_i is the number of excavators at the i-th level necessary for the implementation of the annual scope of work;

ΔB_i is the width of the reserve strip of the operating platform of the i-th bench, m; L_i is the work front length at the i-th level, m; h_i is the height of the bench at the i-th level, m.

In the presence of a covering stripping on steeply dipping complex structure ore deposits, the reliability of the overburden benches (subsystem overburden benches) throughout the year is determined by the formula:

$$P_{nB} = k_{nB}\left[\prod_{1}^{n-1} k_{iB} + \frac{\Delta B_{1B} L_{1B} h_{1B}}{m_{1B} Q_{E1B}} \prod_{2}^{n-1} k_{iB} + \frac{\Delta B_{2B} L_{2B} h_{2B}}{m_{2B} Q_{E2B}} \prod_{3}^{n-1} k_{iB} + \dots \right.$$
$$\left. \dots + \frac{\Delta B_{(n-2)B} L_{(n-2)B} h_{(n-2)B}}{m_{(n-2)B} Q_{E(n-2)B}} k_{(n-1)\%o} + \frac{\Delta B_{(n-1)B} L_{(n-1)B} h_{(n-1)B}}{m_{(n-1)B} Q_{E(n-1)B}} \right], \qquad (11)$$

where P_{iB} is the reliability of the i-th overburden bench (i = 1, 2, 3,..., n); m_{iB} is the number of excavators at the i-th overburden level; k_{iB} is the availability factor of the i-th overburden bench; L_{iB} is the work front length at the i-th overburden level, m; h_{iB} is the height of the i-th overburden bench, m; ΔB_{iB} is the width of the reserve strip of the operating platform of the i-th overburden bench, m; $Q_{E\,iB}$ is the operational output of the excavator at the i-th overburden bench, m^3/year.

The reliability of ore-bearing benches (mining subsystems) during the year, taking into account the reliability of the overburden removals subsystem, can be written as:

$$P_{np} = k_{np}\left[P_{nB}\prod_{1}^{n-1} k_{ip} + \frac{K_{oORE}(\Delta B_{op} L_{op} h_{op})}{m_{op} Q_{Eop}} \prod_{1}^{n-1} k_{ip} + \frac{K_{1ORE}(\Delta B_{1p} L_{1p} h_{1p})}{m_{1p} Q_{E1p}} \prod_{2}^{n-1} k_{ip} + \dots \right.$$
$$\left. \dots + \frac{K_{(n-2)ORE}(\Delta B_{(n-2)p} L_{(n-2)p} h_{(n-2)p})}{m_{(n-2)p} Q_{E(n-2)p}} k_{(n-1)p} + \frac{K_{(n-1)ORE}(\Delta B_{(n-1)p} L_{(n-1)p} h_{(n-1)p})}{m_{(n-1)p} Q_{E(n-1)p}} \right], \qquad (12)$$

Where P_{ip} is the reliability of the i-th rock-bearing ore bench, taking into account the reliability of the overburden bench operation (i = 1, 2, 3,..., n);

$\mu_o = \frac{K_{oORE}(\Delta B_{op} L_{op} h_{op})}{m_{op} Q_{Eop}}$ is the provision of the upper ore-bearing bench with reserves (characterizes the reserve between the lower overburden and the upper ore-bearing benches);

$\mu_{ip} = \frac{K_{i\,ORE}(\Delta B_{ip} L_{ip} h_{ip})}{m_{ip} Q_{Eip}}$ is the provision of the i-th ore-bearing bench with reserves; m_{ip} is the number of excavators at the i-th ore-bearing level necessary for implementation of the annual scope of works; L_{ip} is the works front length at the i-th ore-bearing level, m; ΔB_{ip} is the width of the reserve strip of the operating platform at the i-th ore-bearing bench, m; h_{ip} is the height of the i-th ore-bearing bench, m; Q_{Eip} is the operational output of the excavator at the i-th ore-bearing bench, m^3/year.

The analysis of the obtained dependencies (11 and 12) allows concluding that the reliability of the bench operation is determined by the availability factor of the processing chain on the given bench, the reliability of the overlying bench operation, as well as the reserve supply capacity (the volume of ready-to-excavation reserve sand outstripping of overburden removals) between these benches.

While considering the opencast as a system consisting of bench parts, and determining the reliability of its operation, then using the series connection of the parts is impossible, because providing the desired opencast performance results from the operation of all the benches, and not just from the lower bench.

The parallel connection of parts does not reflect the actual model of the opencast mine engineering system, because at stopping one or more benches, the operation of remaining benches, as a rule, cannot provide the necessary performance. Therefore, the opencast mine engineering system is a system with a parallel connection of the parts, the reliability of which is determined as a weighted average:

$$P_K = \frac{Q_1 k_1 (P_{nB} + \mu_o) + Q_2 k_2 (P_1 + \mu_1) + \ldots + Q_n k_n \left[P_{(n-1)} + \mu_{(n-1)} \right]}{Q_1 + Q_2 + Q_3 + \ldots + Q_n}, \quad (13)$$

Where P_i is the reliability of the i-th ore-bearing level; Q_i is the annual volume of mineral resources extraction at the i-th level, m^3.

In the development of complex deposits, where all kinds of minerals are extracted on all the operating benches, the availability factor of the processing chain characterizes the reliability of the upper bench. For the lower benches, the reliability will be determined not only by the availability factors but also by the volume of ready-to-excavation reserves of mineral resources in the benches.

At the development of complex deposits, the reliability of opencast mine engineering system during the year is expressed by the following formula:

$$P_n = k_n \left[\prod_{1}^{n-1} k_i + \sum_{f=1}^{r} \frac{\Delta G_{1f}}{m_1 Q_E} \prod_{2}^{n-1} k_i + \sum_{f=1}^{r} \frac{\Delta G_{2f}}{m_2 Q_E} \prod_{3}^{n-1} k_i + \ldots \right.$$
$$\left. \ldots + \sum_{f=1}^{r} \frac{\Delta G_{(n-2)f}}{m_{(n-2)} Q_E} k_{(n-1)} + \sum_{f=1}^{r} \frac{\Delta G_{(n-1)f}}{m_{(n-1)} Q_E} \right] \quad (14)$$

$f \in k$; $k = 1, 2, 3, \ldots, r$,

where k_i is the availability factor of the i-th opencast bench; f is the number of extracted minerals; n is the number of working benches in the opencast ($i = 1, 2, 3, \ldots, n$); ΔG_{if} is the volume of ready-to-excavation reserves of the f-th type of mineral product at the i-th opencast bench; m_i is the number of excavators at the i-th opencast bench; Q_{op} is the operational efficiency of the excavator, m^3/year.

Maintaining minimum width of operating platforms at two or more adjacent levels is undesirable since in this case, the simultaneous mining operations at the adjacent benches are impossible. Therefore, the reserve supply capacity (the volume of ready-to-excavation reserves and outstripping of overburden removals) need to be on all of the operating benches.

4. RESULTS

Improving the operation reliability of steeply dipping complex structure ore deposits is achieved in the case when the volume of ready-to-excavation reserves of the underlying ore-bearing bench is smaller than that of the upper bench.

Figure 1 shows the distribution of the volume of ready-to-excavation reserves over the height of the opencast loading face at the end of the ore-bearing levels prepared at 40, 25 and 10 m.

To ensure the opencast operation reliability of steeply dipping complex structure ore deposits, the opencast loading face profile consisting of ore-bearing benches should take a convex shape.

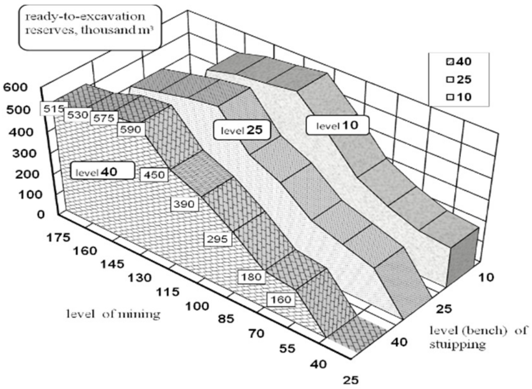

Figure 1. Distributing the volume of ready-to-excavation reserves over the height of the opencast loading face at the end of the ore-bearing levels prepared at 40, 25 and 10 m of the opencast developing steeply dipping complex structure ore deposits

5. CONCLUSION

The establishment of non-uniform rational distribution of ready-to-excavation reserves at the end of preparation of all levels in the course of the opencast development, that provides a high level of opencast system's reliability, allows for optimal planning of mining operations and the formation of opencast loading face.

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