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OPTIMIZATION OF POSITION OF THE CYCLICAL-AND-CONTINUOUS METHOD COMPLEXES WHEN CLEANING-UP THE DEEP IRON ORE QUARRIES

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ABSTRACT

Purpose. An algorithm development for calculating the optimum depth for cyclical-and-continuous method schemes introduction when cleaning-up the deep iron ore quarries.

Methods. When developing an algorithm for calculating the optimum depth for cyclical-and-continuous method schemes introduction under the conditions of the Kacharsky mine, abstraction and analytical techniques were used to distinguish the parameters that most significantly influence on the depth value of the cyclical-and-continuous method schemes introduction. The developed algorithm has been applied when constructing a mathematical model based on mining-engineering parameters for cleaning-up the Kacharsky Iron Ore Mine.

Findings. An algorithm is presented for calculating the optimum depth to put into operation the railway transport and a conveyor hoister in the cyclical-and-continuous method schemes, taking into account the mining-engineering and economic parameters for cleaning-up the deep quarries in surface mining. It has been substantiated that the transition from a combined automobile-railway to a combined automobile-conveyor-railway mode of transport is economically viable and will expand the limits of the effective use of surface mining of iron ore deposits. It is recommended to restrict the depth of commissioning the railway transport to 149 m, and the conveyor hoister – to 344 m into the cyclical-and-continuous method schemes using automobile-conveyor and automobile-railway modes of transport.

Originality. Based on the constructed mathematical model, the dependences have been obtained of the prime costs for transporting the total volume of rocks mined on the depth of the cyclical-and-continuous method schemes introduction under the conditions of the Kacharsky Iron Ore Mine.

Practical implications. For the conditions of cleaning-up the Kacharsky Iron Ore Mine, the optimum parameters have been set for the mining-transport scheme of the cyclical-and-continuous method, which ensure the minimum prime costs of the rock mass transportation.

Keywords: *cyclical-and-continuous method, automobile transport, conveyor hoister, railway transport, mathematical model, calculation algorithm*

1. INTRODUCTION

The combined automobile-railway mode of transport has come into common use in many iron ore quarries of Eurasia (Drizhenko, Kozenko, & Rykus, 2009; Chetverik, Peregudov, & Romanenko, 2012). In far abroad countries, the automobile transport is mainly used in mountaintop mining (McKelvey et al., 2002). In terms of the flat terrain, the expediency of transition to the automobile-conveyor mode of transport using steeply inclined conveyors has been substantiated (Kuruppu & Golosinski, 2000; Kuruppu, 2003; Grujić, & Erdeljan, 2014). Recently, a number of foreign design organizations, motivated by quite good indicators of using the automobile transport in mountaintop mining, offer to use it in deep quarries (Mitchell & Albertson, 1985; Santos & Stanisic, 1987; Golosinski, Kuruppu, & Zhao, 1999). The good technical and economic indicators achieved, at the same time have been substantiated by the use of especially heavy-duty dumping trucks (Mevissen, Siminerio, & Santos, 1981; Santos & Frizzell 1983; Santos, 1984). However, many iron ore mines have a total depth of over 600 m, thus, they belong to the category of ultra-deep (Mitchell, 1984; Santos, 1986).

It is known from theory that in the zone of cleaning-up the deep quarries, in order to reduce the spacing of their sides, it is expedient to switch to the use of relatively low-duty dumping trucks (Rakishev, Mukhamedzhanov, Samenov, & Kuttybaev, 2012). In addition, on a flat terrain, when calculating the dumping truck lifting, the height of lifting at the external dumps should be taken into account as well as water conditions in study area (Chui, Moshynskyi, Martyniuk, & Stepanchenko, 2018; Kuzlo, Moshynskyi, Martyniuk, 2018).

It should also be noted that the technical and economic indicators of development for each specific field can vary considerably (Kalybekov, Rysbekov, & Zhakypbek, 2015; Aitkazinova et al., 2016; Kuttykadamov, Rysbekov, Milev, Ystykul, & Bektur, 2016). Therefore, the studies on the optimization of the area of various transport modes application in deep and ultra-deep quarries are particularly relevant at the present time. The economic feasibility of investment in the transition of mining operations to deep horizons depends on this.

2. TARGET OF RESEARCH

At the moment, the upper zone of soft rocks of the deepest Severnyiy area of the Kacharsky Iron Ore Mine is developed with the use of the railway transport, and the parent hard rocks of overburden and ore are developed by the combined automobile-railway mode of transport. Under the project, the total depth will be 760 m. Mining operations have already reached a depth of 375 m.

When preparing working drawings on approbation of the intensive development of the working area along a steep side below the border of railway transport application, it was set that one of the constraining factors of the rock overburden excavation and ore mining is the problem of supporting with cargo vehicle link between the faces of the quarry and points of transloading. On some horizons, there are difficulties arise in constructing the automobile downhills for the applied heavy-duty dumping trucks. The value of the transport berms width of less than 20 m reduces the speed of dumping trucks and complicates the oncoming traffic of empty and loaded dumping trucks.

Conditioned by the exceedance by 2 – 3 times in the rational height of lifting and transportation distance of dumping trucks in order to fulfil the planned volumes of mining operations, their amount should be increased. This also complicates the organization of their movement in the cramped conditions of deep horizons and further pollutes the atmosphere with dust and toxic components of the exhaust gases. Transition to the use of more heavy-duty dumping trucks with a capacity of 220 tons or more in the zone of cleaning-up the reserves of the Kacharsky Iron Ore Mine will require revising its final boundary along the daylight surface in the direction of increasing.

The low performance of excavating machinery is also caused by the cramped conditions of mining operations – work in narrow faces complicates the dump trucks manoeuvring before loading, and the lack of wide sites does not allow them to organize two-way loading.

It has been previously set that the transportation problem can be solved by significantly reducing the height of lifting and a distance of transportation by dumping trucks when switching to a cyclical-and-continuous method (CCM) using a combined automobile-conveyor-railway mode of transport.

For transition to CCM, there are areas for placing conveyor hoisters in a stationary position. The practice of this method implementation at iron ore quarries shows that when using traditional inclined conveyor hoisters, it is necessary to build steep trenches for their placement. Using the steeply inclined conveyors significantly reduces the commissioning of a conveyor hoister. In this case, without additional spacing of the quarry sides, the duration of the transition to the CCM will consist of the time for manufacturing at the plant of equipment for its complexes, its delivery and assembling.

The disposition of horizons and sites for setting the steeply inclined conveyors for the separate transportation of ore and overburden rock in the Severnyiy area will reduce the weighted average height of lifting and distance of their transportation by dumping trucks. When using two KNK-180 for transportation of ore, the weighted average height of lifting during 8 years will vary from 125 to 195 m in the range of transportation distances from 2.03 to 3.17 km. Thus, this will correspond to the rational distance of transportation by dumping trucks of 2.0 – 2.5 km, which is testified in practice. When also using two KNK-180 for transportation of overburden rocks, the weighted average height of lifting of dumping trucks for 8 years will vary from 0 to 70 m in the range of transportation distances from 1.0 to 2.05 km, of which 800 m, located on the horizontal site along the berm, is on the horizon –180 m.

It has been set by calculations (Moldabaev, 2018) that the pay-back time of a complex with steeply inclined conveyors for ore transportation with a design capacity of 18 million tons will be 2.75 years, and for annual transportation of overburden rocks through the CCM in the volume of 24 million tons – 3.2 years. The specified cost savings over 8 years (with a maximum discount rate of 30%) for ore transportation will be 15.45 million USD, and for the overburden rock transportation – 9.74 million USD.

3. BACKGROUND TO THE STUDY

Based on data from a number of domestic and foreign research institutes, it is obvious that the use of cyclical-and-continuous method schemes under conditions of mining the steeply dipping deep-seated deposits, such as iron ore deposits, with an intensive rate of deepening the mining operations shows a significant positive economic effect, which is confirmed by wide experience in their operation.

To calculate the optimum position of the transloading point of the conveyor hoister in the schemes of the combined automobile-conveyor transport, a mathematical model (Zubovich & Seleznev, 2004) has been compiled in JSC VNIPIpromtekhnologii, the essence of which is that the whole quarry depth should be divided into three zones: zone of operation of automobile-conveyor transport for upward rise and the zone of automobile-conveyor transport with the automobile transport moving upward and downward.

At the same time, the constructed model does not take into account the current position of the quarry boundaries, a decrease in the rock mass volume with an increase in the depth of the quarry, the horizontal distance of transportation, as well as availability of railway transport in modern mining-transport schemes.

4. RESULTS AND DISCUSSION

The transloading point position inside the quarry space is determined in plan and by a depth. Since the conveyor hoister in the cyclical-and-continuous method schemes of deep quarries is a capital structure, it is necessary for its placement to form a section of the permanently non-mining flank. In addition, the efficiency of mineral resources development is determined by the volume of overburden rocks mined (Cherniaiev, 2017; Adamchuk & Shustov, 2018; Anisimov, Symonenko, Cherniaiev, & Shustov, 2018).

It is known that the smallest existing volumes of overburden operations with the same production capacity of the quarry are achieved by forming the ledges in one end of the quarry field at a constant design position and by means of moving the front of overburden operations at a certain angle to the longitudinal direction of the mineral deposits occurrence (Dryzhenko, Shustov, & Adamchuk, 2016; Dryzhenko, Moldabayev, Shustov, Adamchuk, & Sarybayev, 2017). Therefore, the main parameter determining the transloading point position inside the quarry space is the depth of its foundation, and in the plan it should be located on the non-mining flank of the quarry.

It should be noted that one of the most important conditions to use a conveyor hoister is that the transport unit should be provided with a rock mass for a payback time (10 – 20 years), that is, the total volume of mining for conveyor transport mode should be not less than:

$$V_C = (10...20)P_{C.O}\text{, m}^3, \quad (1)$$

where:

$P_{C.O}$ – is the operating performance of the conveyor unit, m^3/year.

The depth of constructing the transloading point (H_{conv}, m) in the cyclical-and-continuous method schemes with application of a conveyor hoister in dif-ferent variants of transport modes combination depends on total depth of the quarry (H_d, m), operating performance of the conveyor unit ($P_{C.O}$, million m^3/year), volumes of cleaning-up the rock mass within the final boundaries of the quarry (V_f, million m^3), prime costs and the distance of the rock mass transportation by railway (c_r, USD/tkm; L_r, km), by conveyor (c_c, USD/tkm; L_c, km) and by automobile mode of transport (c_a, USD/tkm; L_a, km):

$$H_c = f\left(H_d, P_{C.O}, V_f, c_r, c_c, c_a, L_r, L_c, L_a\right)\text{, m}, \quad (2)$$

where:

H_d, $P_{C.O}$, V_f – variables;

c_r, c_c, c_a – constants, and L_r, L_c, L_a should be such at which the prime costs of transporting the volumes V_f is minimum.

Let us consider the transport scheme (Fig. 1) in which the railway transport operates in the upper zone of the quarry to lift the rock mass, and automobile transport operates on the three lower ones: to lift the rock mass with transloading into railway transport, to move upward and downward with transloading into conveyor transport. Therewith, there should be the availability of a horizon of transloading from a conveyor transport to a railway one, since the railway transport is definitely the main one for delivering rock mass to the dumps and to the dressing plant in modern deep quarries.

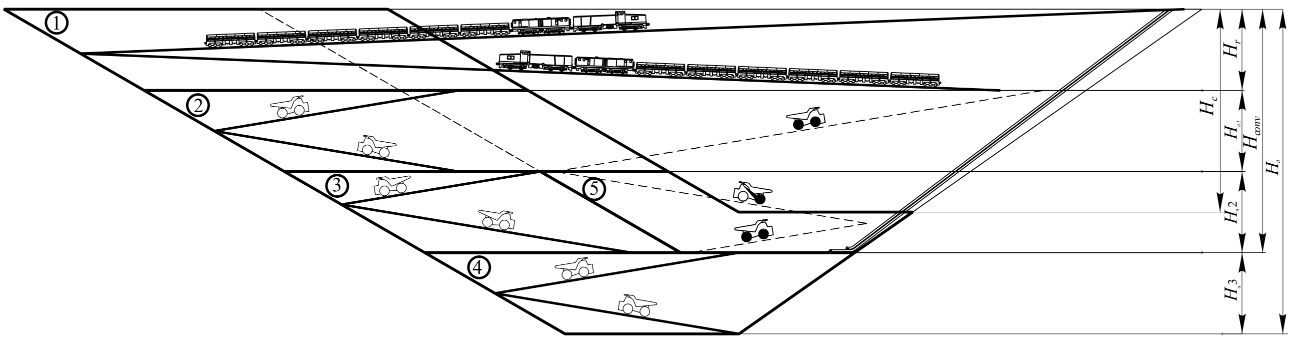

Figure 1. Scheme of the combined automobile-conveyor and automobile-railway mode of transport inside the quarry: 1 – a zone of the railway transport operation; 2 – a zone of the automobile transport operation for moving upward with transloading into railway transport; 3 – a zone of the automobile transport operation for moving downward with transloading into conveyor transport; 4 – a zone of the automobile transport operation for moving upward with transloading into conveyor transport; 5 – a zone of the automobile transport operation for moving upward with transloading into railway transport when uncovering the deep horizons for the construction of a conveyor hoister

In such a way, the total depth of the quarry will take the following form:

$$H_d = H_r + H_{a1} + H_{a2} + H_{a3} = \\ = H_{conv} + H_{a3} = H'_r + H'_c + H_{a3}, \quad (3)$$

where:

H_r – height of lifting the rock mass by railway transport, m;

H_{a1}, H_{a2}, H_{a3} – height of the rock mass transportation by dumping trucks, for moving upward with transloading into railway transport, for moving downward with transloading into conveyor transport, for moving upward with transloading into conveyor transport, respectively, m;

H_r' – height of lifting the rock mass by railway transport with unloading the conveyor transport into it, m;

H_c' – height of lifting the rock mass by a conveyor with transloading into railway transport, m.

To calculate the prime costs of transportation, the volume V_f should be divided by n of horizontal layers so that:

$$V_f = \sum_{i=1}^{n_r} V_{r.i} + \sum_{i=1}^{n_{a1}} V_{a1.i} + \sum_{i=1}^{n_{a2}} V_{a2.i} + \sum_{i=1}^{n_{a3}} V_{a3.i}\text{, m}^3; \quad (4)$$

$$n = n_r + n_{a1} + n_{a2} + n_{a3}\text{ , m,} \tag{5}$$

where:

n_r, n_{a1}, n_{a2}, n_a – amount of horizontal layers of the volume V_f with its transportation, respectively, by railway transport for lifting, by automobile transport, respectively, for lifting with transloading into railway transport, by dumping trucks moving downward and upward with transloading into the conveyor transport;

$V_{r.i}$, $V_{a1.i}$, $V_{a2.i}$, $V_{a3.i}$ – part of the volume V_f in the i-th horizontal layer with its transportation, respectively, by railway transport for lifting, by automobile transport for lifting with transloading into railway transport, by dumping trucks moving downward and upward with transloading into the conveyor transport, million m^3.

The prime costs of transporting the residual volume of the rock mass inside the quarry is calculated by the formula:

$$\begin{aligned} C_{V_f} &= c_r \sum_{i=1}^{n_r} L_{r.i} V_{r.i} + c_a \sum_{i=1}^{n_{a1}} L_{a1.i} V_{a1.i} + c_a \sum_{i=1}^{n_{a2}} L_{a2.i} V_{a2.i} + \\ &+ c_a \sum_{i=1}^{n_{a3}} L_{a3.i} V_{a3.i} + c_r L_r \sum_{i=1}^{n_r} V_{a1.i} + c_c L_c' \sum_{i=1}^{n_{a2}} V_{a2.i} + \\ &+ c_c L_c' \sum_{i=1}^{n_{a3}} V_{a3.i} + c_r L_r' \sum_{i=1}^{n_{a2}} V_{a2.i} + c_r L_r' \sum_{i=1}^{n_{a3}} V_{a3.i} \to \min, \end{aligned} \tag{6}$$

C_{Vf} – in USD; where:

L_r, L_r', L_c' – the distance of the rock mass transportation, respectively, by railway transport with unloading an automobile and conveyor transport into it and by conveyor transport with transloading into the railway transport, km.

The algorithm for calculating the depth to put the railway transport into operation (H_r, m) and constructing the transloading point of automobile and conveyor transport (H_{conv}, m) operates as follows (Fig. 2).

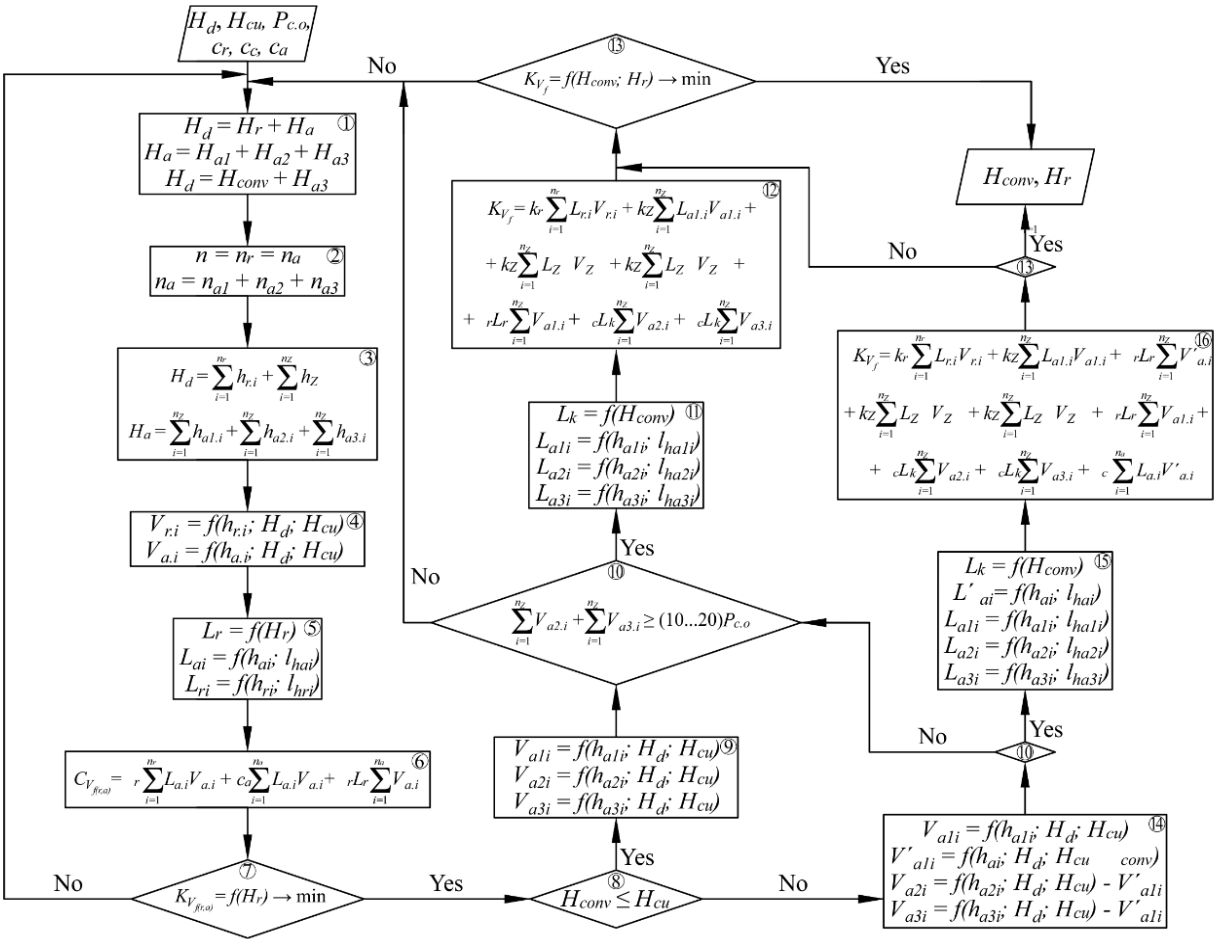

Figure 2. The algorithm for calculating the depth to put the railway transport (H_r) and conveyor hoister (H_c) into operation

There should be introduced the values of total depth of the quarry development (H_d, m), its existing depth (H_{cu}, m), operating performance of the conveyor hoister ($P_{C.O}$, million m^3/year), prime costs of the rock mass transportation by railway transport (c_r, USD/tkm), by automobile transport (c_a, USD/tkm), by conveyor transport (c_c, USD/tkm). After the source data are set, the following operations should be performed:

1. The total depth value of the quarry (H_d, m) is divided into four zones: a zone of railway transport operation for lifting (H_r, m), the zones of operation of automobile transport (H_a, m) moving upward with transloading into railway transport (H_{a1}, m), moving downward (H_{a2}, m) and upward (H_a3, m) with transloading into the conveyor hoister. Therewith, the depth to put into operation the conveyor hoister (H_{conv}, m) is equal to the sum of the three upper zones (Fig. 1).

2. The amount of horizontal layers of rock mass (n) over the entire depth of the quarry, as well as their amount in the zones of railway transport (n_r) and auto-

mobile transport (n_a) operation is determined. This value in turn is divided by the amount of horizons of its work to move upward with transloading into railway transport (n_{a1}), to move downward (n_{a2}) and to move upward (n_{a3}) with transloading into the conveyor hoister.

3. The thicknesses of the *i*-th horizontal layers in the zones of railway transport ($h_{r.i}$, m) and automobile transport ($h_{a.i}$, m) operation are calculated to move upward with transloading into railway transport ($h_{a1.i}$, m), to move downward ($h_{a2.i}$, m) and to move upward ($h_{a3.i}$, m) with transloading into the conveyor hoister. Operating experience of modern mining equipment shows that the thickness of the horizontal rock mass layer is usually 10 – 15 m.

4. Volumes are determined of *i*-th horizontal layers in the zones of railway transport ($V_{r.i}$, million m^3) and automobile transport ($V_{a.i}$, million m^3) operation. The values of volumes of the *i*-th horizontal layers are determined by their horizontal thickness ($h_{r.i}$, $h_{a.i}$, m), by position of final and existing boundaries, expressed by total (H_d, m) and existing (H_{cu}, m) depth of the quarry.

5. The distance of the rock mass transportation is determined from the face in the *i*-th horizontal layer to the surface when transporting it by railway transport to move upward ($L_{r.i}$, km), by automobile transport moving upward to the point of transloading with railway transport ($L_{a.i}$, km) and railway transport from the transloading point to the surface (L_r, km). When calculating the distance of transportation, its horizontal site (l_{hri}, l_{hai}, m) and inclined site should be considered, expressed by the depth of horizontal layer (H_r, $h_{r.i}$, $h_{a.i}$, m) location.

6. The prime costs of the rock mass transportation is calculated according to the scheme of automobile-railway combined transport within the final boundaries of the quarry $C_{V_{f(r,a)}}$, USD.

7. It is set whether the value $C_{V_{f(r,a)}}$ is minimal under the conditions of the accepted value of the depth of railway transport (H_r, m) introduction. In the case of a negative result, the operations (1 – 6) are repeated with a different value of H_r.

8. In case of the condition (7) fulfilment, the accepted value of H_{conv} is compared with the value of H_{cu}. In case if the first is less than or equal to the second, proceed with the operation (9), if the first is higher – with the operation (14).

9. Volumes of *i*-th horizontal layers are calculated in the zones of automobile transport operation to move upward to railway transport ($V_{a1.i}$, million m^3), to move downward ($V_{a2.i}$, million m^3) and to move upward ($V_{a3.i}$, million m^3) to the transloading point of the conveyor hoister.

10. The sum of the volumes of horizontal layers in the zone of automobile transport operation in a complex with a conveyor hoister should ensure the work of the latter for at least a pay-back time of 10 – 20 years. In case of non-fulfilment of this condition, the operations (1 – 9) should be repeated with a different value of H_{conv}.

11. If the condition (10) is fulfilled, the distance is calculated of the rock mass transportation by a conveyor hoister (L_c), by automobile transport moving upward with transloading into railway transport ($L_{a1.i}$, m), to move downward ($L_{a2.i}$, m) and to move upward ($L_{a3.i}$, m) with transloading into the conveyor hoister. Therewith, the horizontal site of transportation in the *i*-th layer (l_{ha1i}, l_{ha2i}, l_{ha3i}, m) and the inclined site, which is expressed by the location depth of *i*-th horizontal layer (H_{conv}, $h_{a1.i}$, $h_{a2.i}$, $h_{a3.i}$, m), are taken into account.

12. The prime costs of the rock mass transportation is calculated according to the schemes of automobile-railway and automobile-conveyor combined transport within the final boundaries of the quarry C_{V_f}, USD).

13. It is set whether the value C_{V_f} is minimal under the conditions of the accepted value of the depth of conveyor hoister (H_{conv}, m) introduction. In the case of a negative result, the operations (1 – 12) are repeated with a different value of H_{conv}. If the result is positive, the values of H_r, H_{conv} should be determined.

14. Values of volumes are calculated of the *i*-th horizontal layers in the zones of automobile transport operation to move upward to railway transport ($V_{a1.i}$, million m^3), volumes of uncovering the deep horizons for the construction of a conveyor hoister ($V'_{a1.i}$, million m^3), and volumes of the *i*-th horizontal layers in the zone of conveyor transport ($V_{a2.i}$, $V_{a3.i}$, million m^3) operation minus the volumes of $V'_{a1.i}$, million m^3. Then the operation (10) is performed. If the condition is not fulfilled, the operations (1 – 8, 14) are performed with a different value of H_{conv}.

15. If the condition (10) is fulfilled, the distance of the rock mass transportation in the *i*-th horizontal layer is calculated by a conveyor hoister (L_c), by dumping trucks moving upward to the point of transloading into railway transport ($L_{a1.i}$, m), to move downward ($L_{a2.i}$, m) and to move upward ($L_{a3.i}$, m) with transloading on the horizon of setting the conveyor hoister. Moreover, the distance of the rock mass transportation in the *i*-th horizontal layer is calculated of the volumes extracted for the construction of a conveyor hoister and transported according to the automobile-railway transport scheme ($L'_{a1.i}$, m).

16. The prime costs of the rock mass transportation is calculated according to the schemes of automobile-railway and automobile-conveyor combined transport within the final boundaries of the quarry with account of uncovering the deep horizons of the quarry for the construction of a transloading point of cyclical-and-continuous method (C_{V_f}, USD). Then the operation (13) is performed. If the set condition is not fulfilled, the operations (1 – 8, 14) are repeated, in case of fulfilment – values of H_r, H_{conv} should be determined.

The developed algorithm was applied when calculating the effective depth of commissioning the railway transport (Fig. 3) and conveyor hoister (Figs. 4 – 7) under the conditions of the Kacharsky Iron Ore Mine operation in Kazakhstan.

The constructed model of the automobile-conveyor transport performance makes possible to present data in the form of a dependency graph of the prime costs of the rock mass transportation on the depth of commissioning the railway transport. The obtained function graph $C_{vf(r,a)} = f(H_r)$ is a convex curve approximated in shape to a parabola (Fig. 3). In the range H_r = 0…149 m, the function $C_{vf(r,a)} = f(H_r)$ decreases, in the range H_r = 150…764 m – it increases.

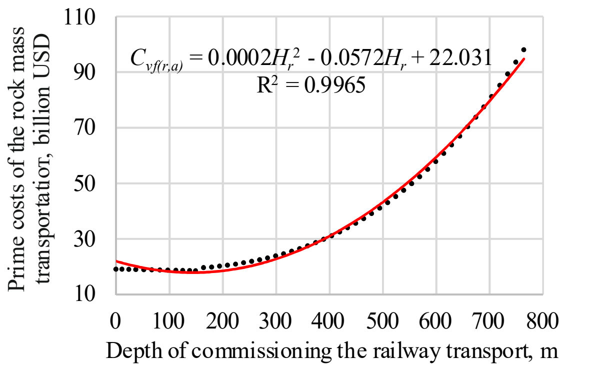

Figure 3. The dynamics of changes in the prime costs for transportation of the total volume of the rock mass ($C_{vf(r,\,a)}$) with increasing depth of commissioning the railway transport (H_r) for a combined automobile-conveyor transport under the conditions of the Kacharsky Iron Ore Mine operation

The growth of function is explained by necessity to involve additional rocks of overburden into the development to ensure the normal railway transport operation when uncovering the deep horizons of the quarry. Based on the obtained model and the graph constructed on its basis, it can be concluded that under the conditions of the Kacharsky Iron Ore Mine operation using the combined automobile-conveyor transport schemes, the optimum depth of commissioning the railway transport is 149 m, which is confirmed by current projects, international operating experience and previous studies.

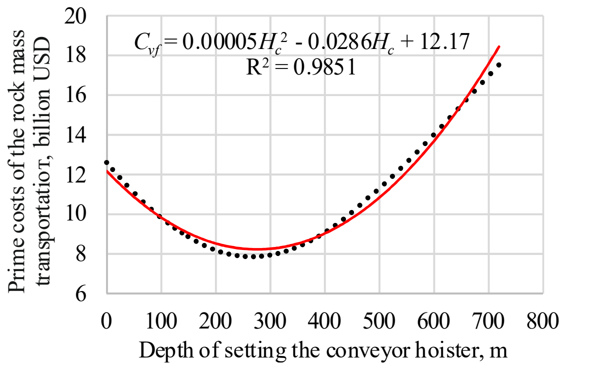

Figure 4. The dynamics of changes in the prime costs for transportation of the total volume of the rock mass (C_{vf}) with increasing depth of setting the conveyor hoister (H_c) for a combined automobile-conveyor transport under the conditions of the Kacharsky Iron Ore Mine operation

The function graph $C_{vf} = f(H_c)$ in Figure 4 is a convex curve approximated in shape to a parabola. A model, by which data the graph has been constructed, envisaged the transport scheme for using the automobile transport, regardless of the depth of setting the conveyor hoister. The function decreases in the range $H_c = 0…269$ m, and increases at $H_c = 270…719$ m. The function does not exist in the range $H_c = 720…764$ m, since the condition (1) is not fulfilled. According to the schemes of automobile-conveyor transport, the optimum depth of setting the conveyor hoister is 269 m.

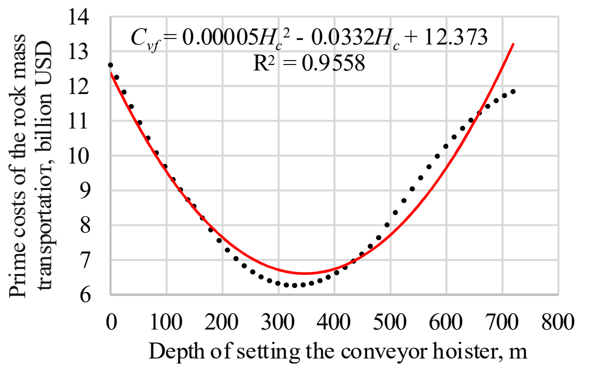

Figure 5. The dynamics of changes in the prime costs for transportation of the total volume of the rock mass (C_{vf}) with increasing depth of setting the conveyor hoister (H_c) for a combined railway and automobile-conveyor transport under the conditions of the Kacharsky Iron Ore Mine operation

The function graph $C_{vf} = f(H_c)$ in Figure 5 is a convex curve approximated in shape to a parabola, at that there is a concavity in the range $H_c = 479…719$ m. Modelling of transportation processes was conducted with account of commissioning the railway transport and its operation to a depth of 149 m. On the underlying horizons, an automobile-conveyor transport scheme is envisaged. The function decreases in the range $H_c = 0…329$ m, increases at $H_c = 330…719$ m and does not exist in the range $H_c = 720…764$ m, since the condition (1) is not fulfilled. The optimum depth value of setting the conveyor hoister is 329 m.

When modelling the transportation processes according to the schemes of combined automobile-conveyor and automobile-railway transport with the introduction of railway tracks to a depth of 149 m, the data have been obtained regarding the prime costs for the rock mass transportation, based on which the graph in Figure 6 is constructed. The graph is a convex curve approximated in shape to a parabola. The function decreases in the range $H_c = 0…344$ m, increases at $H_c = 345…719$ m and does not exist at $H_c = 720…764$ m, since the condition (1) is not fulfilled. The optimum depth value of setting the conveyor hoister is 344 m.

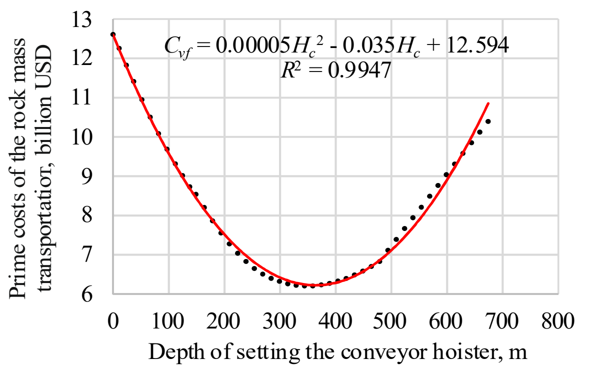

Figure 6. The dynamics of changes in the prime costs for transportation of the total volume of the rock mass (C_{vf}) with increasing depth of setting the conveyor hoister (H_c) for a combined automobile-conveyor and automobile-railway transport under the conditions of the Kacharsky Iron Ore Mine operation

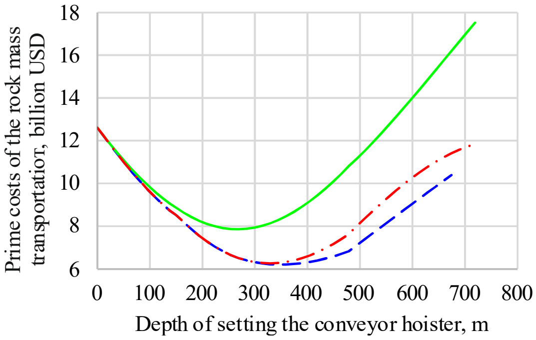

Figure 7. Compatible chart of changes in the prime costs for transportation of the total volume of the rock mass (C_{vf}) with increasing depth of setting the conveyor hoister (H_c) with various transport schemes: green – automobile-conveyor; red – railway, automobile-conveyor; blue – automobile-railway, automobile-conveyor

5. CONCLUSIONS

As can be seen from the above, an analysis of the combined transport models under the conditions of the Kacharsky Iron Ore Mine (Fig. 7) has shown that, if compared with automobile transport, the prime costs for transportation of remaining total rock mass volume when using the automobile-conveyor transport with setting the conveyor hoister at a depth of 269 m are reduced by 37.6%, railway transport (H_r = 149 m) and automobile-conveyor transport (H_c = 329 m) – by 50.3%, automobile-railway transport (H_r = 149 m) and automobile-conveyor transport (H_c = 344 m) – by 50.8%. As a result of the studies, it has been substantiated that transition from a combined automobile-railway to a combined automobile-conveyor-railway mode of transport is economically viable and will expand the limits of the effective use of surface mining of iron ore deposits.

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REFERENCES

Adamchuk, A.A., & Shustov, O.O. (2018). Systemnyi pidkhid do vyboru novykh zasobiv transportu dlia roboty na hlybokykh karierakh. *Zbirnyk Naukovykh Prats NHU*, (54), 8-18.

Aitkazinova, S., Soltabaeva, S., Kyrgizbaeva, G., Rysbekov, K., & Nurpeisova, M. (2016). Methodology of assessment and prediction of critical condition of natural-technical systems. International *Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM* 2, 3-10. https://doi.org/10.5593/sgem2016/b22/s09.001

Anisimov, O., Symonenko, V., Cherniaiev, O., & Shustov, O. (2018). Formation of safety conditions for development of deposits by open mining. *E3S Web of Conferences*, (60), 00016. https://doi.org/10.1051/e3sconf/20186000016

Cherniaiev, O.V. (2017). Systematization of the hard rock non-metallic mineral deposits for improvement of their mining technologies. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 11-17.

Chetverik, M.S., Peregudov, V.V., & Romanenko, A.V. (2012). *Tsiklichno-potochnaya tekhnologiya na glubokikh kar'yerakh*. Perspektivy razvitiya. Krivoy Rog, Ukraina: Dionis.

Chui, Y.V., Moshynskyi, V.S., Martyniuk, P.M., & Stepanchenko, O.M. (2018). On conjugation conditions in the filtration problems upon existence of semipermeable inclusions. *JP Journal of Heat and Mass Transfer*, *15*(3), 609-619. https://doi.org/10.17654/hm015030609

Drizhenko, A.Yu., Kozenko, G.V., & Rykus, A.A. (2009). *Otkrytaya razrabotka zhelezorudnykh rud Ukrainy: sostoyanie i puti sovershenstvovaniya*. Dnepropetrovsk, Ukraina: NGU.

Dryzhenko, A., Shustov, A., & Adamchuk, A. (2016). Prospects for future mining of steep iron-ore deposits in the context of Kryvbas. *Metallurgical and Mining Industry*, (10), 46-52.

Dryzhenko, A., Moldabayev, S., Shustov, A., Adamchuk, A., & Sarybayev, N. (2017). Open pit mining technology of steeply dipping mineral occurences by steeply inclined sublayers. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management*, *17*(13), 599-606. https://doi.org/10.5593/sgem2017/13/s03.076

Golosinski, T.S., Kuruppu, M.D., & Zhao, S.N. (1999). Development of a steep angle conveyor for surface mining applications. *Mining Science and Technology*, 657-660.

Grujić, M., & Erdeljan, D. (2014). Advantages of high angle belt conveyors (Hac) in mining. *Applied Mechanics and Materials*, (683), 73-77. https://doi.org/10.4028/www.scientific.net/amm.683.73

Kalybekov, T., Rysbekov, K., & Zhakypbek, Y. (2015). Efficient land use in open-cut mining. *New Developments in Mining Engineering 2015: Theoretical and Practical Solutions of Mineral Resources Mining*, 287-291. https://doi.org/10.1201/b19901-51

Kuruppu, M.D. (2003). The steep angle conveying option for large open pit mines. *Proceedings Paper of 5th Large Open Pit Conference*, 65-69.

Kuruppu, M.D., & Golosinski, T.S. (2000). Steep angle conveying for material transportation in open cut mines. *Mine Planning and Equipment Selection 2000*, 731-734. https://doi.org/10.1201/9780203747124-137

Kuttykadamov, M.E., Rysbekov, K.B., Milev, I., Ystykul, K.A., & Bektur, B.K. (2016). Geodetic monitoring methods of high-rise constructions deformations with modern technologies application. *Journal of Theoretical and Applied In-formation Technology*, *93*(1), 24-31.

Kuzlo, M.T., Moshynskyi, V.S., Martyniuk, P.M. (2018). Mathematical modelling of soil massif's deformations under its drainage. *International Journal of Applied Mathematics*, *31*(6), 751-762. https://doi.org/10.12732/ijam.v31i6.5

McKelvey, P., Beale, G., Taylor, A., Mansell, S., Mira, B., Valdivia, C., & Hitchcock, W. (2002). Depressurization of the north wall at the Escondida Copper Mine, Chile. *Geological Society, London, Special Publications*, *198*(1), 107-119. https://doi.org/10.1144/gsl.sp.2002.198.01.08

Mevissen, E.A., Siminerio, A.C., & Santos, J.A.D. (1981) High angle conveyor study. *Dravo Corporation for Bureau of Mines, U.S. Department of the Interior under Bureau of Mines Contract No. J0295002*, (1-2).

Mitchell, J.J. (1984). High angle conveyors climb to the top. *Coal Mining*, 39-43.

Mitchell, J.J., & Albertson, D.W. (1985). High angle conveyor offers mine haulage savings. *International Materials Handling Conference*, 1-12.

Moldabaev, S.K. (2018). *Tekhniko-ekonomicheskoe obosnovanie tselesoobraznosti perekhoda na transportirovanie gornoy massy kombinirovannym avtomobil'no-konveyerno-zheleznodorozhnym vidom transporta i vybor tipa avtosamosvalov na Kacharskom kar'yere AO "SSGPO"*. Almaty, Kazakhstan: NAO "KazNITU im. K.I. Satpaeva".

Rakishev, B.R., Mukhamedzhanov, E.B., Samenov, G.K., & Kuttybaev, A.E. (2012). Ustanovlenie granits primeneniya ekskavatorno-avtomobil'nykh kompleksov razlichnoy moshchnosti v glubokikh kar'yerakh. *Gornyy Informatsionno-Analiticheskiy Byulletel'*, (7), 90-98.

Santos, J.A.D., & Frizzell, E.M. (1983). Evolution of sandwich belt high-angle conveyors. *CIM Bulletin*, *576*(855), 51-66.

Santos, J.A.D. (1984). Sandwich belt high angle conveyors-applications in open pit mining. *Bulk Solids Handling, Trans Tech Publications D-3392 Clausthal West Germany*, *4*(1), 67-77.

Santos, J.A.D. (1986). Sandwich belt high angle conveyors – broad horizons. *CoalTrans '86 Rai Congress Centre*.

Santos, J.A.D., & Stanisic, Z. (1987). In-pit crushing and high angle conveying in Yugoslavian copper mine. *International Journal of Surface Mining, Reclamation and Environment*, *1*(2), 97-104. https://doi.org/10.1080/09208118708944108

Zubovich, P.T., & Seleznev, A.V. (2004). O tselesoobraznoy glubine vvoda konveyera pri kombinirovannom transporte. *Gornyy Informatsionno-Analiticheskiy Byulleten'*, (2), 182-185.

ОПТИМІЗАЦІЯ ПОЛОЖЕННЯ КОМПЛЕКСІВ ЦИКЛІЧНО-ПОТОКОВОЇ ТЕХНОЛОГІЇ ПРИ ДООПРАЦЮВАННІ ГЛИБОКИХ ЗАЛІЗОРУДНИХ КАР'ЄРІВ

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Мета. Розробка алгоритму розрахунку оптимальної глибини введення схем циклічно-потокової технології при доопрацюванні глибоких залізорудних кар'єрів.

Методика. При побудові алгоритму розрахунку оптимальної глибини введення схем циклічно-потокової технології для умов Качарського кар'єру були застосовані метод абстрагування та аналітичний метод для виділення параметрів, що найбільш суттєво впливають на величину глибини введення схем циклічно-потокової технології. Розроблений алгоритм був застосований при формуванні математичної моделі на основі гірничотехнічних параметрів доопрацювання Качарського залізорудного кар'єру.

Результати. Розроблено алгоритм розрахунку оптимальної глибини введення залізничного транспорту і конвеєрного підйомника у схемах циклічно-потокової технології з урахуванням гірничотехнічних та економічних параметрів доопрацювання глибоких кар'єрів відкритим способом. Доведено, що перехід з комбінованого автомобільно-залізничного на комбінований автомобільно-конвеєрно-залізничний вид транспорту економічно доцільний і дозволить розширити межі ефективного застосування відкритого способу розробки залізорудних родовищ. Рекомендовано глибину введення залізничного транспорту обмежити до 149 м, а конвеєрного підйомника – 344 м у схемах циклічно-потокової технології з автомобільно-конвеєрним й автомобільно-залізничним видами транспорту.

Наукова новизна. На підставі побудованої математичної моделі були отримані залежності собівартості транспортування сумарного обсягу виїмки гірських порід від глибини введення схем циклічно-потокової технології в умовах Качарського залізорудного кар'єру.

Практична значимість. Для умов доопрацювання Качарського кар'єру встановлені оптимальні параметри гірничо-транспортної схеми циклічно-потокової технології, що забезпечують мінімальну собівартість транспортування гірничої маси.

Ключові слова: *циклічно-потокова технологія, автомобільний транспорт, конвеєрний підйомник, залізничний транспорт, математична модель, алгоритм розрахунку*

ОПТИМИЗАЦИЯ ПОЛОЖЕНИЯ КОМПЛЕКСОВ ЦИКЛИЧНО-ПОТОЧНОЙ ТЕХНОЛОГИИ ПРИ ДОРАБОТКЕ ГЛУБОКИХ ЖЕЛЕЗОРУДНЫХ КАРЬЕРОВ

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Цель. Разработка алгоритма расчета оптимальной глубины ввода схем циклично-поточной технологии при доработке глубоких железорудных карьеров.

Методика. При построении алгоритма расчета оптимальной глубины ввода схем циклично-поточной технологии для условий Качарского карьера был применены метод абстрагирования и аналитический для выделения параметров, наиболее существенно влияющих на величину глубины ввода схем циклично-поточной технологии. Разработанный алгоритм был применен при формировании математической модели на основе горнотехнических параметров доработки Качарского железорудного карьера.

Результаты. Представлен алгоритм расчета оптимальной глубины ввода железнодорожного транспорта и конвейерного подъемника в схемах циклично-поточной технологии с учетом горнотехнических и экономических параметров доработки глубоких карьеров открытым способом. Доказано, что переход с комбинированного автомобильно-железнодорожного на комбинированный автомобильно-конвейерно-железнодорожный вид транспорта экономически целесообразен и позволит расширить границы эффективного применения открытого способа разработки железорудных месторождений. Рекомендовано глубину ввода железнодорожного транспорта ограничить до 149 м, а конвейерного подъемника – 344 м в схемах циклично-поточной технологии с автомобильно-конвейерным и автомобильно-железнодорожным видами транспорта.

Научная новизна. На основании построенной математической модели были получены зависимости себестоимости транспортирования суммарного объема выемки горных пород от глубины ввода схем циклично-поточной технологии в условиях Качарского железорудного карьера.

Практическая значимость. Для условий доработки Качарского карьера установлены оптимальные параметры горнотранспортной схемы циклично-поточной технологии, обеспечивающие минимальную себестоимость транспортирования горной массы.

Ключевые слова: *циклично-поточная технология, автомобильный транспорт, конвейерный подъемник, железнодорожный транспорт, математическая модель, алгоритм расчета*

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