MINING

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ESTABLISHING THE INFLUENCE OF THE QUARRY DEPTH ON THE INDICATORS OF CYCLIC FLOW TECHNOLOGY DURING THE DEVELOPMENT OF NON-ORE DEPOSITS

Purpose. To determine the efficiency of the cyclic flow technology at the development of non-ore deposits depending on the location of haulage level, mobile crushing and sorting plants with variable productivity of the enterprise.

Methodology. The research implemented the following methods: analytical method — to establish the dependence of the required number of dump trucks at the enterprise on the depth of non-ore quarry development at a given annual productivity; simulation modelling — to determine the influence of the mining depth of a non-ore quarry on the haulage distance of mining mass to the surface of the quarry.

Findings. The performance indicators of the haulage system for the development of a non-ore quarry using dump trucks and conveyor transport in combination with a mobile crushing complex, as well as a mobile crushing and sorting plant on the haulage level, were determined. It was established that the use of cyclic flow technology with a mobile crushing complex on the haulage level allows reducing the haulage distance by 1.9 times at a quarry depth of 150 m.

Originality. The dependence of the dump trucks productivity and their required number on the depth and production capacity of a non-ore quarry when using the haulage mining system was established. It was determined that an increase in the quarry depth from 50 to 150 m will lead to an increase in the number of dump trucks by 2.6 to 3.6 times, depending on the quarry productivity. At the same time, the use of cyclic flow technology with a mobile crushing complex in the quarry allows increasing the productivity of dump trucks by 2.1 times from 94.1 to 197.6 thousand tons/year due to the reduction of the haulage distance of dump trucks from 2525 to 575 m.

Practical value. A methodology for determining the impact of the quarry depth on the parameters of the mining haulage complex has been developed when using the technique of cyclic and current action on non-ore raw material quarries, which takes into account the location of the mobile crushing and sorting plant, changes in the depth and annual productivity of the quarry, its area and parameters of the trenches. The indicators of the cyclical-flow mining technology, necessary for the further technical and economic assessment of the proposed solutions, have been established.

Keywords: *quarry, non-ore deposits, dump truck, cyclic flow technology, mobile crusher*

Introduction. Ukraine has a wide list of deposits of non-ore minerals, without which the effective functioning of the construction, chemical and food industries is impossible. In terms of some minerals reserves the country is among the top ten world leaders, which guarantees the availability of a raw material base not only for domestic industry, but also ensures exports, which enables the economy to develop at the expense of foreign exchange earnings [1].

The improvement of technological solutions in the development of mineral base of construction raw materials deserves the main attention, since Ukraine has rich reserves of various types of non-ore minerals. These minerals can be used in the construction industry with or without prior processing [2].

Deposits of construction materials contain marl, limestone, granites, chalk, clay, sandstones, basalts, and marble [3]. These deposits are scattered throughout Ukraine, but the main reserves are located in Zhytomyr, Rivne, Khmelnytskyi, Zaporizhzhia and Dnipropetrovsk regions, which confirms the wide geography of their location.

Currently, there are hundreds of quarries for the production of crushed stone products in active use, which face the problems of reserves depletion at small depths and the need to deepen the working horizons to 100−150 m [4]. This leads to an increase in the haulage distance of dump trucks from mining faces to the surface, which affects their productivity and requires an increase in truck quantity. Therefore, the efficiency of the development haulage system is significantly reduced, and the cost of final products is constantly increasing [5].

One of the possible ways to reduce the distance of mining mass haulage from the working horizons of the quarry to the surface is the introduction of cyclic flow technology, which allows combining automobile and conveyor modes of haulage [6]. However, such a combination can be effective only if the concentration horizon in the quarry is well-founded, which will minimize the distance of haulage by road [7].

Literature review. The application of cyclic flow technology has a lot of economic advantages when working out quarries with high productivity. Therefore, the main attention during the construction of new conveyor installations is paid to the improvement of the moving mechanism and energy regeneration due to recuperation or braking during the operation of the conveyor [8]. However, the work does not consider the impact of the location depth of crushing complexes on their productivity, which complicates the analysis of the effectiveness of the proposed solutions.

The authors of the work [9] pay the main attention to the advantages of using semi-mobile or combined crushing and haulage systems in comparison with the haulage system of development using dump trucks. The work also pays attention to determining the location of semi-mobile systems, which is determined by the parameters of the quarry. However, the work did not compare the efficiency of using cyclic and cyclic-flow technology taking into account the increase in quarry depth [10].

The process of combining dump trucks and conveyor haulage with the use of semi-mobile quarry crushing and truck systems is complex and requires an individual solution for each individual mining enterprise. In this regard, the paper [11] proposed a model of mathematical programming taking into account operational constraints. This model allows determining the optimal location and time of moving the mobile crusher. However, the research does not pay enough attention to the processes that include additional mining and quarry building works for the construction of a steep trench for the location of the conveyor [12].

Systems of mobile crushing and haulage of mining mass from the quarry to the surface annually cover a larger number of mining enterprises due to the increase in the efficiency of excavators with dump trucks. Therefore, in studies [13], considerable attention is paid to the minimization of operating costs for the movement of mobile complexes. A combined solution for the location of crushing complexes, taking into account their further movement in the quarry plan, is proposed. However, the performed studies did not sufficiently take into account the change in productivity of the quarry during the period of operation [14], which directly leads to an increase in the number of dump trucks for servicing the working horizons of the quarry.

Unsolved aspects of the problem. During the study on the efficiency use of semi-mobile or combined crushing and haulage systems in quarries of non-ore raw materials, it was established that insufficient attention was paid to establishing the impact of deepening the quarry on the parameters of cyclic flow technology. The question of the quarry depth impact on the number of dump trucks that haulage mining mass to a mobile crusher with variable productivity of the enterprise is gaining particular relevance [15].

To solve the identified problems, **the purpose of the research is formulated,** which consists in determining the effectiveness of the cyclic flow technology at the development of non-ore raw material quarries depending on the location of transshipment points, mobile crushing and sorting plants with variable productivity of the enterprise.

Description of the research methodology. To achieve the goal, the analytical method of research was used to establish the dependence of the required number of dump trucks at the enterprise on the depth of a non-ore quarry development at a given annual productivity. The method of simulation modelling was used to determine the influence of the quarry depth of a non-ore deposit on the distance of mining mass haulage to the surface.

During the research, the following tasks were solved: establishing the effect of increasing the quarry depth on the performance indicators of the mining haulage system when using dump trucks; determination of the influence of the mobile crushing complex location on the quantity of road trucks; sub-

stantiation of the use effectiveness of rock roll at the development of quarry deep horizons.

Presentation of the main material and obtained scientific results. The development of the methodology for determining the influence of the quarry depth on the parameters of the mining haulage complex when using cyclic and current action techniques in quarries for the development of non-ore raw materials should include the calculation of the main parameters of the mining system for the three most common technological schemes.

The most common in the development of non-ore quarries is the scheme with the use of dump trucks that haulage mining mass to the surface. The second scheme involves the haulage of mining mass to the quarry surface using cyclic flow technology. In this scheme, a mobile crusher is used on one of the working horizons of the quarry and a system of conveyors for delivering the mining mass to the surface.

The calculation of the third scheme parameters provides for its features, which consist in the location of the mobile crushing and sorting plant on the concentration horizon for obtaining marketable products. Raw materials from the concentration horizon can be delivered to the surface of the quarry by dump trucks of the company or the customer. Under certain circumstances, conveyor haulage can be used to deliver products to the quarry surface [16].

When determining the influence of the quarry depth on the parameters of the haulage system of the development, in the first technological scheme (Fig. 1), the annual productivity of the quarry, its area and the parameters of the trenches, which are used to deliver the mining mass from the quarry to the surface, should be taken into account.

The methodology for calculating the haulage quantity of dump trucks to ensure the annual productivity of the quarry, taking into account its depth, has the following sequence:

1. The volume of mining mass in the contours of the quarry, m³

$$V_{GM} = \frac{1}{3} H_K (L \cdot W + \sqrt{L \cdot W \cdot L' \cdot W'} + L' \cdot W'), \quad (1)$$

where H_K is the quarry depth, m; W is the width of the quarry bottom, m; L is the length of the quarry bottom, m; W' is the width of the upper contour of the quarry, m; L' is the length of the upper contour of the quarry, m.

2. Volume of mineral within the quarry, m³

$$V_{KK} = \frac{1}{3} h_M (L \cdot W + \sqrt{L \cdot W \cdot L'_M \cdot W'_M} + L'_M \cdot W'_M), \quad (2)$$

where h_M is the capacity of the mineral; $W'M$ is the width of the first mining horizon, m; $L'M$ is the length of the first mining horizon, m.
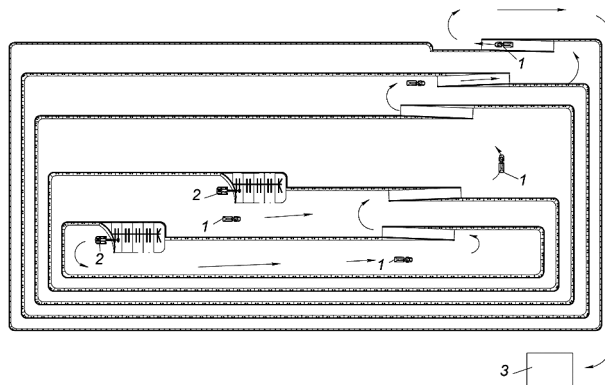

Fig. 1. Scheme for determining the parameters of the haulage system for the development of a non-ore quarry using dump trucks:

1 – dump truck; 2 – excavator; 3 – crushing and sizing plant

3. Volume of overburden within the quarry, m^3

$$V_P = V_{GM} - V_{KK}. \quad (3)$$

4. Time of quarry exploitation, years

$$T = V_{KK}/Q, \quad (4)$$

where Q is the annual productivity of the quarry, m^3/year.

5. Length of mining mass haulage by dump trucks through inclined mining workings, m

$$L_{IT} = \frac{1{,}000 \cdot H_K}{i}, \quad (5)$$

where i is the slope of the trench, ‰.

6. Weighted average distance of haulage by horizontal platforms in the quarry, m

$$L_{HT} = 0.5(L + W - 2(H_K \operatorname{ctg}\beta - 0.5 \cdot H_K \cdot W_B/H_y)), \quad (6)$$

where β is the angle of the quarry slope, degrees; W_B is the width of safety berms, m; N_y is the height of the bench, m.

7. Weighted average distance of mining mass haulage in the quarry, m

$$L_{CH} = L_{IT} + L_{HT}. \quad (7)$$

8. Average race time of a dump truck from mining faces to the surface, min

$$T_R = 120 \cdot \left(\frac{L_{IT}}{1{,}000 \cdot V_{IG}} + \frac{L_{CH}}{1{,}000 \cdot V_{CG}} \right) + t_M, \quad (8)$$

where V_{IG} is the speed of the dump truck when driving in an empty and loaded state, km/h; V_{CG} is the speed of the dump truck on horizontal platforms, km/h; t_M is time for loading, unloading and manoeuvres, min.

9. Productivity of the dump truck, m^3/year

$$P_{AM} = \frac{60 T_S V_T k_N}{T_R k_P k_G} N_S N_D, \quad (9)$$

where T_S is the shift time, hours; V_T — load capacity of the dump truck, t; k_N — bucket filling factor; k_P — coefficient of rock loosening; k_G — dump truck readiness factor; N_S is the number of shifts per day; N_D is the number of working days in a year.

10. The number of dump trucks to ensure the operation of a non-ore quarry during the development haulage system, units

$$N_T = \frac{Q}{P_{AM}}. \quad (10)$$

During the research, the following initial data were taken: quarry depth 50–150 m; the width of the quarry bottom is 600 m; the length of the quarry bottom is 600 m; overburden capacity – 10 m; the angle of the quarry slope is 50°; bench height – 10 m; width of safety berms – 10 m; angle of the trench inclination – 80 ‰; truck speed on the slopes – 22 km/h; truck speed on horizontal platforms – 40 km/h; time for loading, unloading and manoeuvres – 4 minutes; load capacity of the dump truck – 30 t; the number of work shifts – 1; the number of working days in a year – 305; shift duration – 12 hours; bucket filling factor – 0.85; coefficient of loosening of the rock – 1.2; the readiness ratio of the dump truck – 0.85.

The results of main indicators calculations of the haulage system development of non-ore mineral deposits are presented in Table 1.

According to the obtained research results (Table 1), it is proven that the increase in the quarry depth has an extremely negative effect on the indicators of the haulage system developed using dump trucks. First of all, the productivity of dump trucks decreases, which leads to an increase in their required number and an increase in the cost of production, as well as an increase in the negative impact on the environment due to an increase in the volume of emissions of harmful substances from the operation of internal combustion engines [17]. The dependences of the length of haulage and the productivity of dump trucks on the quarry depth are shown in Fig. 2.

The conducted research made it possible to establish that the problem of increasing the number of dump trucks during
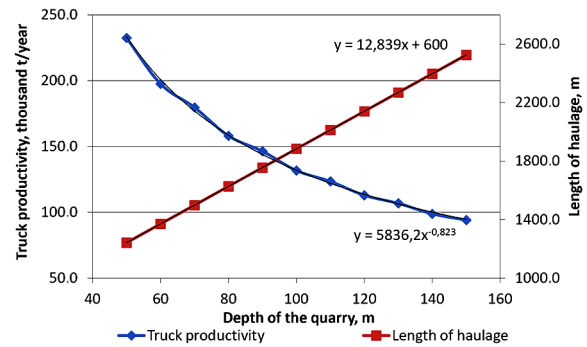

Fig. 2. The influence of the quarry depth on the length of haulage and productivity of dump trucks during the haulage system development

Table 1

Indicators of the haulage system development when using dump trucks

Quarry depth, m	Volume of minerals, million tons	Length of haulage on inclined sections, m	Average haulage distance on working horizons, m	Haulage distance, m	Dump truck race time, min	Productivity of the dump truck, thousand t/year	The number of dump trucks at quarry productivity, thousand t/year			
							400	800	1,200	1,600
50	16.07	625	616.95	1,241.95	16.66	232.5	2	4	6	7
60	20.63	750	620.35	1,370.35	19.20	197.6	3	5	7	9
70	25.43	875	623.74	1,498.74	21.73	179.7	3	5	7	9
80	30.46	1,000	627.13	1,627.13	24.26	158.1	3	6	8	11
90	35.72	1,125	630.52	1,755.52	26.79	146.4	3	6	9	11
100	41.24	1,250	633.91	1,883.91	29.33	131.8	4	7	10	13
110	47.01	1,375	637.30	2,012.30	31.86	123.5	4	7	10	13
120	53.03	1,500	640.69	2,140.69	34.39	112.9	4	8	11	15
130	59.32	1,625	644.08	2,269.08	36.92	106.8	4	8	12	15
140	65.88	1,750	647.47	2,397.47	39.46	98.8	5	9	13	17
150	72.71	1,875	650.86	2,525.86	41.99	94.1	5	9	13	18

the deepening of mining operations on non-ore deposits intensifies with an increase in the annual productivity of quarries.

In Fig. 3, graphs of dependences are given, which allow establishing the influence of the quarry depth on the required number of dump trucks, taking into account the increase in productivity of the quarry from 400 to 1,600 thousand tons/year.

According to the established dependencies (Fig. 3), a 3-fold increase in quarry depth from 50 to 150 m will lead to an increase in the number of dump trucks by 2.5−2.6 times, while a 4-fold increase in quarry productivity from 400 to 1,600 thousand t/year will lead to an increase in the haulage units by 3.5−3.6 times.

The established results of the research will allow further determination of the technical and economic indicators at the application of the haulage system of the mining with dump trucks in order to determine the effective area of the cyclic flow technology application during the development of non-ore mineral deposits.

According to the established dependencies, it can be stated that with an increase in the depth of the quarry, the productivity of dump trucks significantly decreases (Fig. 2), which is associated with an increase in the distance of the mining mass from the quarries to the day surface. The main reason for such an increase is the significant distance of haulage along the sloping sections of the quarry, on which, according to the design norms, the control rise cannot exceed 80 ‰.

In order to reduce the total distance of mining mass haulage by dump trucks in deep quarries, the use of trucks and conveyor haulage combination, which is located on the quarry slope in a steep trench, or on the surface of sliding slopes, has become widespread (Fig. 4).

The main advantage of the specified technological scheme of development is the reduction of haulage distances by dump trucks within the working horizons and a significant reduction of distances through external trenches, due to the arrangement of mobile crushers at transshipment points with the use of conveyor for lifting mining mass on inclined sections [18].

This technological scheme additionally provides for the use of ore waste from the upper horizons to the concentration horizon, on which the mobile crusher is located. This will make it possible to reduce the distance of haulage of mining mass on inclined sections, but will lead to the need to involve an additional loader. Its main function will be to move the mining mass from the ore pile to the mobile crusher.

Additional costs for the introduction of cyclic flow technology will also be associated with the installation of a mobile crusher, a belt conveyor and the construction of a steep trench for the installation of a belt conveyor.

Determination of the main parameters of the technological scheme for the development of a non-ore quarry using cyclic-flow equipment with a mobile crusher on the working horizon is carried out in the following sequence:
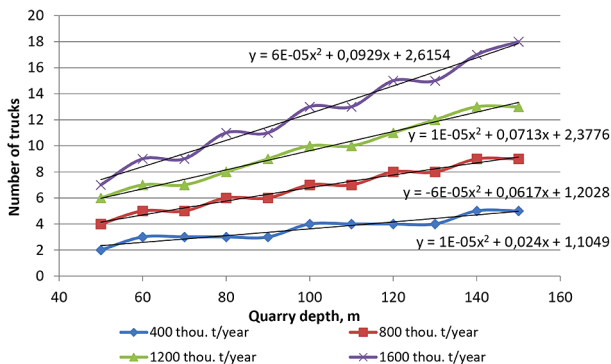

Fig. 3. The influence of the quarry depth on the number of dump trucks at a given annual productivity of the enterprise
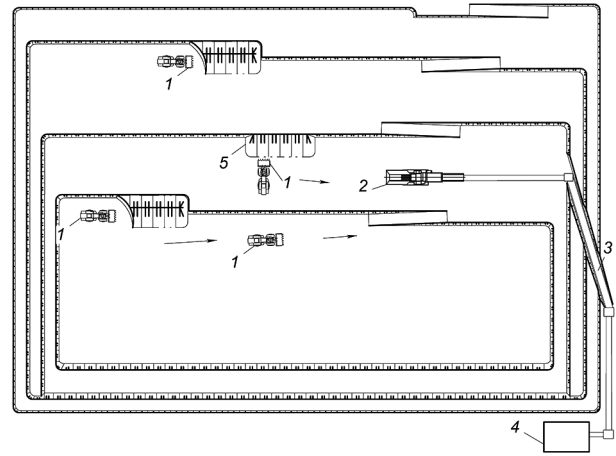

Fig. 4. Scheme for determining the parameters of the haulage system at the quarry development using cyclic flow technology with a mobile crusher:

1 − wheel loader; 2 − mobile crusher; 3 − conveyor in steep trench; 4 − crushing and sizing plant; 5 − rock roll

1. The calculation of items 1−4 is performed according to formulas (1−4), which were used to determine the parameters of the development haulage system with dump trucks.

2. The length of haulage of mining mass by dump trucks along inclined sections to the concentration horizon, which is located on the upper platform of the second bench from the bottom of the quarry, m

$$L'_{IT} = \frac{2,000 \cdot Hy}{i}. \quad (11)$$

3. Weighted average distance of mining mass haulage on horizontal platforms by dump trucks in the quarry to the mobile crusher, m

$$L'_{HT} = 0.25(L + W - 2(H_K \operatorname{ctg} \beta - 0.5 \cdot H_K \cdot W_B/Hy)). \quad (12)$$

4. Weighted average distance of mining mass haulage by dump trucks in the quarry, m

$$L'_{CH} = L'_{IT} + L'_{HT}. \quad (13)$$

Determining the duration of the journey of dump trucks and their required number is performed in accordance with expressions (8−10).

5. The length of the conveyor system, provided that the concentration horizon is located on the upper platform of the second bench, m

$$L_{CT} = 0.5W + 2 \cdot Hy \cdot \operatorname{ctg} \beta + (H_K - 2Hy) \cdot \operatorname{ctg} \gamma, \quad (14)$$

where γ is the angle of steep trench inclination, degrees.

6. Mining and construction volume of the internal steep trench, m³

$$V_{TP} = H_K^2 (\operatorname{ctg} \gamma - \operatorname{ctg} \beta) \left[\frac{b}{2} + \frac{H_K}{3} (\operatorname{ctg} \gamma - \operatorname{ctg} \beta) \frac{\operatorname{ctg} \alpha_{\grave{O}}}{\operatorname{ctg} \gamma} \right], \quad (15)$$

where b is the width of the steep trench at the bottom, m; α_T is slope angle of the trench slopes, degrees.

During the research, the ranges of quarry depth and productivity were adopted, similar to the previous calculations of the parameters of the haulage system when dump trucks using at the quarry mining. Additional parameters used for calculations: angle of steep trench inclination is 17°; the width of the steep trench at the bottom is 20 m; the slope angle of the trench is 45°.

The established results of the cyclic-flow technology parameters calculations at the development of non-ore raw materials quarries using dump trucks and conveyor haulage with the location of a mobile crusher on the working horizon in the quarry are shown in Table 2.

Table 2

Indicators of cyclic flow technology of development using truck and conveyor haulage

Quarry depth, m	Conveyor length, m	Volume of steep trench, million, m³	The length of haulage by dump trucks on inclined sections, m	The average distance of haulage by dump trucks on working horizons, m	Distance of haulage by dump trucks, m	Productivity of the dump truck, thousand t/year	The number of dump trucks at quarry productivity, thousand t/year			
							400	800	1,200	1,600
50	414.91	0.14		308.48	558.48	395.3	2	3	4	5
60	447.62	0.22		310.17	560.17	359.3	2	3	4	5
70	480.32	0.33		311.87	561.87	329.4	2	3	4	5
80	513.03	0.46		313.56	563.56	304.1	2	3	4	6
90	545.74	0.64		315.26	565.26	282.3	2	3	5	6
100	578.45	0.85	250	316.95	566.95	263.5	2	4	5	7
110	611.16	1.10		318.65	568.65	247.1	2	4	5	7
120	643.87	1.39		320.35	570.35	232.5	2	4	6	7
130	676.58	1.73		322.04	572.04	219.6	2	4	6	8
140	709.28	2.13		323.74	573.74	208.0	2	4	6	8
150	741.99	2.58		325.43	575.43	197.6	3	5	7	9

The obtained research results (Table 2) confirm that the introduction of the cyclic flow technology for the quarries when non-ore deposits development with mobile crusher on the working horizon makes it possible to significantly reduce the distances of mining mass haulage by dump trucks (Fig. 5).

According to the obtained results (Fig. 5), it was established that the greatest efficiency of this scheme is achieved with a quarry depth of 150 m and an increase in the productivity of the enterprise to 1.6 million tons/year. Under such parameters, the productivity of the dump truck increases by 2.1 times from 94.1 to 197.6 thousand tons/year in comparison with the first technological scheme, where on the quarry used only dump trucks.

Due to the use of cyclic-flow technology, in addition to increasing the productivity of dump trucks by 2.1 times, it is also possible to reduce their total number by two times from 18 to 9 units with the same productivity of the enterprise and the depth of development in comparison with the haulage system, where all mining mass is delivered to the surface only by dump trucks (Fig. 6).

In addition to the significant advantages of using cyclic flow technology in a complex with dump trucks, conveyor haulage and a mobile crusher, when the depth of non-ore quarries is increased, there are significant obstacles to its implementation [19]. The main disadvantage is the increase of additional costs for mining and capital works during the construction of a steep trench on the side of the quarry for the arrangement of the conveyor [20]. Capital costs also increase due to the need to purchase a mobile crushing plant and a conveyor system.
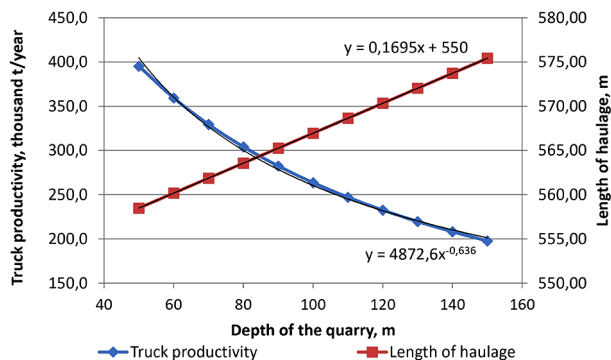
It was established that the volume of mining capital works for the construction of the trench and the length of the conveyor will increase as the depth of mining works decreases (Fig. 7). Thus, increasing the quarry depth by 3 times from 50 to 150 m will lead to an increase in the volume of the steep trench by 18.4 times, while the length of the conveyor will increase by 1.8 times from 414 to 741 m.

As mentioned earlier, for the implementation of the technological scheme using the mobile-crushing complex, the use
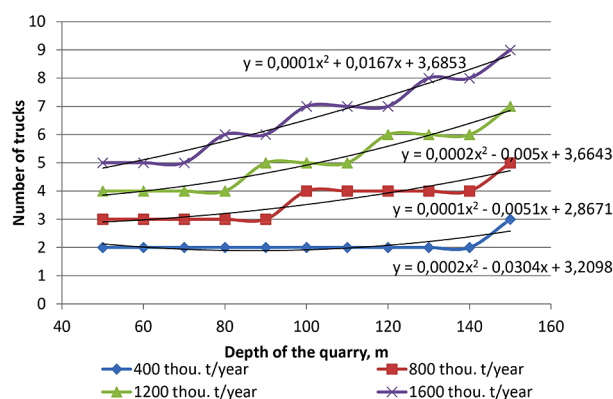

Fig. 6. Dependence of the dump trucks number on the quarry depth when developing a non-ore quarry using cyclic flow technology
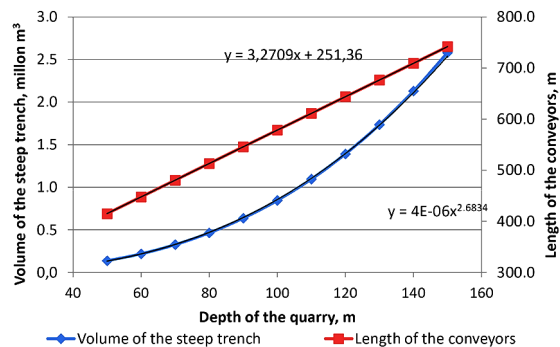

Fig. 5. The influence of the quarry depth on the productivity of dump trucks when using cyclic flow technology

Fig. 7. Dependence of the steep trench volume and the length of the conveyors on the depth of the quarry with cyclic flow technology

of an additional wheel loader is provided, which will ensure the delivery of mining mass from the ore slopes to the mobile-crushing plant. Therefore, when performing a technical and economic substantiation and comparison and efficiency of options, it is necessary to take into account additional capital costs for the extraction and loading equipment at the concentration horizon of the quarry [20].

The analysis of modern technological solutions in the field of surface mining of non-ore minerals made it possible to establish that the most promising today are the schemes with the location of a mobile crushing and sorting plant (MCSP) on the concentration horizon [21]. This scheme, unlike the previous one, in which a mobile crusher was used, makes it possible to manufacture commodity products on one of the horizons in the middle of the quarry, from where the consumer can take them to the surface with their own vehicles. In addition, this technology allows reducing the negative impact on the environment by reducing the number of working equipment in the quarry [22].

The main advantage of the MCSP is reduced overall parameters and low metal capacity compared to a stationary crushing and sorting complex on the surface of the quarry, due to which significant savings in capital costs are achieved (Fig. 8). The next factor that makes it possible to significantly reduce the cost of final products is the reduction of the distance of haulage of minerals by dump trucks from the quarry to the place of unloading.

According to the indicated scheme shown in Fig. 8, finished commercial products with a given fractionation can be delivered to the consumer in several options with the direct removal of crushed stone by the customer's trucks from the concentration horizon of the quarry, or by arranging an inclined conveyor on board the quarry to feed the finished products to the surface. In the second case, haulage costs will be included in the cost of crushed stone products, which reduces the profitability of the proposed solution.

Expressions (1−4, 8−13) are used when calculating the parameters of the technological scheme with a mobile crushing and sorting plant.

Determination of the distance of finished products haulage to consumer by dump trucks from the concentration horizon of the quarry to the surface is performed according to the expression, m

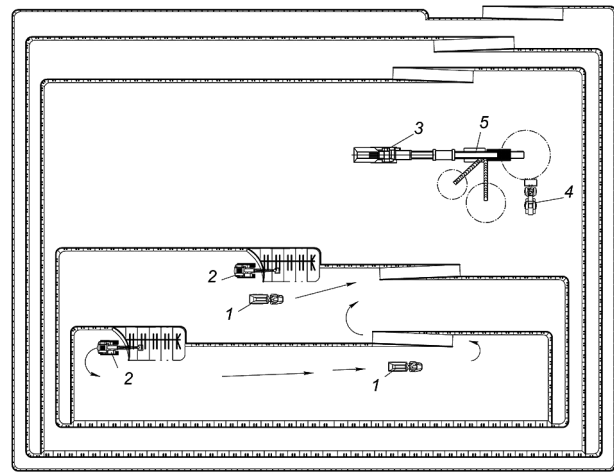$$L_{HS} = 0.5W + \frac{1,000 \cdot (H_K - 2Hy)}{i}. \qquad (16)$$

Fig. 8. Technological scheme for the development of a non-ore quarry with mining mass processing at the concentration horizon:

1 − dump truck; 2 − excavator; 3 − mobile crusher; 4 − loader; 5 − mobile crushing and sorting plant

When comparing the second and third technological schemes, it was found that a significant part of the parameters will be identical, since the same initial data were used during the calculations. In addition, the mobile crusher on the concentration horizon of the quarry is installed in the same place as the mobile crushing and sorting plant, which leads to the need to increase the quantity of haulage equipment for the delivery of commercial products to the surface. The calculations of the parameters of the road haulage during the delivery of mining mass to the MCSP and from it to the surface of the quarry are shown in Table 3.

According to the established indicators of the haulage system of the development using road trucks and MCSP, it was determined that under the condition of the delivery of commodity products from the concentration horizon to the surface of the quarry by dump trucks of the enterprise, their total fleet will be equal in number to the first technological scheme, in which the crushing of the mining mass takes place on the surface of the quarry.

A comparison of the three considered technological schemes according to the indicator of the average distance of

Table 3

Indicators of cyclic flow technology with the use of truck haulage and MCSP on the concentration horizon

Quarry depth, m	The distance of haulage by dump trucks to MCSP, m	Productivity of the dump truck on the section from the potholes to the MCSP, thousand tons/year	The number of dump trucks for the delivery of mining mass to MCSP, thousand tons				Distance from MCSP to the surface of the quarry, m	Productivity of the dump truck on the section from the MCSP to the surface of the quarry, thousand t/year	The number of dump trucks for the delivery of mining mass from the MCSP to the surface at the productivity of the quarry, thousand t/year			
			400	800	1,200	1,600			400	800	1,200	1,600
50	558.48	395.3	2	3	4	5	675.0	359.3	2	3	4	5
60	560.17	359.3	2	3	4	5	800.0	304.1	2	3	4	6
70	561.87	329.4	2	3	4	5	925.0	282.3	2	3	5	6
80	563.56	304.1	2	3	4	6	1,050.0	247.1	2	4	5	7
90	565.26	282.3	2	3	5	6	1,175.0	232.5	2	4	6	7
100	566.95	263.5	2	4	5	7	1,300.0	208.0	2	4	6	8
110	568.65	247.1	2	4	5	7	1,425.0	188.2	3	5	7	9
120	570.35	232.5	2	4	6	7	1,550.0	179.7	3	5	7	9
130	572.04	219.6	2	4	6	8	1,675.0	164.7	3	5	8	10
140	573.74	208.0	2	4	6	8	1,800.0	158.1	3	6	8	11
150	575.43	197.6	3	5	7	9	1,925.0	146.4	3	6	9	11

$$y = 95.403x^{0.6483}$$

$$y = 94.955x^{0.6513}$$

$$y = 321.87x^{0.278}$$

Depth of the quarry, m

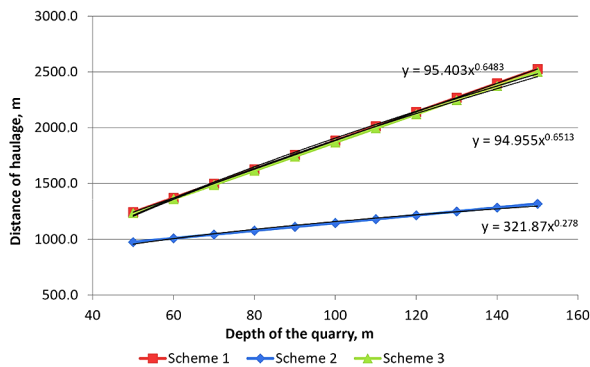■ Scheme 1　◆ Scheme 2　▲ Scheme 3

Fig. 9. Influence of the quarry depth on the distance of mining mass haulage to the surface

haulage of the mineral to the surface of the quarry when its depth changes is shown in Fig. 9.

Obtained dependencies (Fig. 9) allow determining that the most effective technological solution is the use of cyclic flow technology for working out the quarry with the location of the mobile crushing complex on the concentration horizon, which is located on the second bench from the bottom of the quarry. This solution allows reducing the total distance of haulage of mining mass to the quarry surface by 1.9 times from 2,550 to 1,350 m at a quarry depth of 150 m, due to which the number of dump trucks is reduced by 2 times from 18 to 9 units at the productivity of cars 1,600,000 tons.

Conclusions. The established indicators of cyclic and cyclic-flow technologies for the development of a non-ore quarry using various combinations of road and conveyor haulage, as well as the use of MCSP on the concentration horizon of the quarry, allow determining that the most effective in terms of the total distance of mining mass haulage to the surface of the quarry there is a second scheme using cyclic flow technology with the location of the mobile crushing complex on the concentration horizon. Due to the use of conveyor haulage in this scheme, the total distance is reduced by 1.9 times at a quarry depth of 150 m, and the number of dump trucks is reduced from 18 to 9 units when hauling an annual volume of minerals of 1.6 million tons.

The obtained results allow proceeding to the next stage of research, the purpose of which is to substantiate the effective parameters of the cyclic-flow technology in non-ore quarries according to technical and economic indicators. The performed calculations are a component of methodological recommendations for the selection of technological schemes for the development of non-ore quarries.

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Встановлення впливу глибини кар'єру на показники циклічно-потокової технології при відпрацюванні нерудних родовищ

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Мета. Визначити ефективність циклічно-потокової технології при відпрацюванні кар'єрів нерудної сировини в залежності від місця розташування перевантажувальних пунктів, мобільних дробильно-сортувальних установок при змінній продуктивності підприємства.

Методика. У роботі використано комплекс методів досліджень: аналітичний — для встановлення залежності необхідної кількості автосамоскидів на підприємстві від глибини розробки нерудного кар'єру при заданій річній продуктивності; імітаційного моделювання — для визначення впливу глибини розробки нерудного родовища на відстань транспортування гірничої маси на поверхню кар'єру.

Результати. Визначені показники роботи транспортної системи розробки нерудного кар'єру з використанням автосамоскидів і конвеєрного транспорту в поєднанні з мобільно-дробильним комплексом, а також мобільною дробильно-сортувальною установкою на концентраційному горизонті. Встановлено, що застосування циклічно-потокової технології з мобільно-дробильним комплексом на концентраційному горизонті дозволяє скоротити відстань транспортування в 1,9 разів при глибині кар'єру 150 м.

Наукова новизна. Встановлена залежність продуктивності автосамоскидів та їх необхідної кількості від глибини й виробничої потужності нерудного кар'єру при використанні транспортної системи розробки. Визначено, що зростання глибини кар'єру з 50 до 150 м призведе до зростання кількості автосамоскидів від 2,6 до 3,6 разів у залежності від продуктивності кар'єру. У той же час, застосування циклічно-потоковій технології з мобільно-дробильним комплексом у кар'єрі дозволяє підвищити продуктивність автосамоскидів у 2,1 рази з 94,1 до 197,6 тис. т/рік за рахунок зменшення відстані транспортування автосамоскидів з 2525 до 575 м.

Практична значимість. Розроблена методика визначення впливу глибини кар'єру на параметри гірничо-транспортного комплексу при використанні техніки циклічної й поточної дії на кар'єрах нерудної сировини, що враховує місце розташуванні мобільної дробильно-сортувальної установки, зміну глибини та річної продуктивності кар'єру, його площу й параметри траншей. Встановлені показники циклічно-потокової технології розробки, необхідні для подальшої техніко-економічної оцінки запропонованих рішень.

Ключові слова: *кар'єр, родовище нерудної сировини, автосамоскид, циклічно-потокова технологія, мобільна дробарка*