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RESEARCH ON THE RATIONAL PROFILE OF EXIT TRAILS OF AUTO TRANSPORT IN DEEP OPEN MINES

Purpose. Technical and economical justification of the parameters of the profile of exit trails without horizontal sections in the operation of road transport in deep open mines.

Methodology. To solve the objectives, the following methods were used: analytical, graphic methods, mathematical modeling, comparison of options, and analogies. These research methods are used when studying and justifying of a rational profile of exit trails of auto transport in the open mine, as well as defining the width of the working platforms of the excavator, and doing technical-economical calculations of the proposed solutions.

Findings. Based on the performed analysis of parameters determining the distance of transportation of rock mass, it was found that when using the exit trails without horizontal sections, the transportation distance is 300 m, and with horizontal sections – 531.3 m, which exceeds the former by 1.77 times. The trip time when using the transportation scheme without horizontal sections is 7.44 min, and when using it with horizontal sections, it is 8.42 min. It is proved that the use of exit trails without horizontal sections in the open mine of Poltava Mining and Processing Plant reduces the cost of diesel fuel by 42.57 % and capital costs by 40.5 %.

Originality. A comparison of the actual distance of transportation, and time of dump truck trip by component operations is carried out, and expenses for maintenance of open mine roads when using trails with horizontal sections and without them are calculated. The scheme of exit trails without horizontal sections has been offered for the first time, which allows a reduction in the distance of transportation of rock mass by dump trucks with a reduction of rock volume for carrying out conventions by 57 %.

Practical value. The developed scheme of the route profile without horizontal sections can be applied to overburdening operations, and the development and deepening of open mines for the extraction of different types of minerals, such as iron ore and hard coal. The expected economic effect from the introduction of trails without horizontal sections is determined by the reduction of diesel fuel costs by 52.9 UAH/t.km, and accordingly 1.68 million UAH for the conduction of conventions.

Keywords: *iron ore, deep open mine, dump truck, horizontal sections, technical and economic indicators*

Introduction. The development of the surface mining method is accompanied by an increase in the concentration of production, an increase in the depth of mine workings, and, as a result, the complication of transportation of rock mass.

With the increase in the open mine depth, the share of costs for transportation of rock mass in the structure of the cost of finished products tends to increase. One of the main technical solutions to reduce the cost of finished products can be the commissioning of modern heavy dump trucks, which requires the improvement of the transportation system of the open mine [1].

Recently, the use of new heavy dump trucks with high-performance characteristics in the development of mineral deposits by surface mining methods has significantly expanded. In Ukraine, about 80 % of the total volume of rock mass extracted by the surface method is transported with dump trucks; in the USA, Canada, and South America this share makes 85 %, in Australia – almost 100 %, and in South Africa – more than 90 %. The determining parameters of a dump truck carrying capacity are reliability and quality of their assembly [2].

As a criterion for optimizing the operation of a heavy mining dump truck, its maximum productivity is taken. The effectiveness of the use of heavy dump trucks for open mines is determined by a combination of dump trucks and transport schemes of open mines, subject to full compliance with safety rules [3].

For example, the mode of movement, the technical speed of a heavy dump truck, steering, braking, etc. are determined by the passport data of the manufacturer. At the same time, transport schemes of the open mine are determined by the technical project of the development of a mineral deposit [4]. At the same time, the design parameters of the roads (for example, slopes, horizontal platforms for stopping dump trucks, etc.) are taken in accordance with the requirements of regulatory legal acts on labor protection [5].

Literature review. The main scientific provisions on the technology of surface mining with the use of road transport are set out in the works of [6, 7].

Subsequently, theoretical and experimental studies, as well as practical data of domestic and foreign experience in the use of motor tracks in deep open mines were generalized and systematized, scientific bases for the design and operation of motor tracks in open mines were created, methods of traction and operational calculations were proposed, areas of effective use of transport means were substantiated and proposals for their constructive improvement were developed [8].

The methodology of calculations of operational parameters of open mine tracks and roads, the duration of the trip and the number of dump trucks, movement speeds, cost of transportation, and flow capacity of roads in open mines are developed [9].

The paper [10] focuses on the substantiation and optimization of the parameters of technological road transport of ore open mines. Based on the results of comprehensive experimental studies, the authors established the regularities of changes in the operational and technical parameters of motor tracks on different routes; developed a methodology for modeling the transport cycle of dump trucks with hydromechanical and electromechanical transmission, and selecting the optimal excavator-automobile complexes for specific operating conditions; substantiated technical and economic requirements for the creation of dump trucks with a carrying capacity of 120, 190, 230, 280 and 320 tons. However, the studies did not properly reflect the issues of operation of dump trucks at different

slopes of roads, assessment of technical limits of the use of dump trucks with different types of drive in deep open mines, etc. The developed method for modeling the modes of dump trucks is characterized by complexity and high requirements for the quality of the initial information, which limits the scope of its application.

The paper [11] is devoted to methods for calculating the parameters of the sustainable operation of motor trucks in deep open mines. Here, sustainable operation means the operation of technological motor transport of deep open mines with maintaining operational indicators at a relatively constant (stable) level. Ensuring sustainable operation involves reducing or compensating for the negative impact of the growth of the open mine depth on the operational and technical and economic performance of motor transport. The method of energy assessment of various types of transport is of particular importance, on the basis of which the method for optimization of road slopes according to the criterion of energy consumption for lifting rock mass is proposed [12].

The scientific work until the present time has been devoted to the research on conditions and peculiarities of technological auto transport operation in open mines, as well as optimization of slopes of open mine roads [13].

The influence of the longitudinal slope of roads and the depth of the open mine on the productivity, diesel fuel consumption, maintenance, and repair of dump trucks was studied by scientists in the study [14]. However, since then, there have been significant design changes in the operational and technical characteristics of dump trucks and the results of this work should be clarified.

Based on the experimental studies, the influence of the slope of roads on the volumes of spreading of open mine edges when using dump trucks of large carrying capacity was established [15]. However, the relationship between the parameters of open mine development systems and the operational and technical characteristics of different types of pit dumping trucks has not been studied sufficiently.

In numerous scientific and technical publications devoted to the study on the conditions of effective operation of heavy auto transport in open mines, considerable attention is paid to the technical justification of slopes of open mine roads and the influence of mining conditions on the productivity of the open mine equipment [16].

The weighted average slope of permanent open mine roads in conditions of shallow open mines is 70–80 ‰, and the length of sections with slopes of 100–180 ‰ is 30–35 % of the total length of roads [17]. However, the presence of such slopes and the need to adhere to them hinders the development of the working area of open mines and contributes to the extraction of additional volume of overburdened rock mass, which, in general, negatively affects the cost of mineral extraction.

It is worth noting that the increase in the slopes of open mine roads allows the development of minerals within the established contours without additional spreading of the edges due to the reduction of transport communications. This, in turn, leads to an increase in the economic performance of the surface mining method [18].

The problem of additional spreading of the open mine edges for the placement of worked-out overburden mass is one of the most urgent for the development of mineral deposits by the surface method. The volumes of additional spreading of the open mine edges make tens of millions of cubic meters of overburdened rocks. Appropriate placement of the overburden workings leads to further spreading of the open mine edges in comparison with their stable values. This is especially typical for open mines with a small length of the bottom, in which the reduction of the length of the ledges with further deepening is most intense [19].

The proposed methods should be noted for calculating the additional spread of the open mine edges with increasing road slopes. The most acceptable of the proposed methods for calculating the additional spread of the edges is the method that takes into account the curvature of the open mine edge [20]. However, this analytical method, although universal, is characterized by high labor intensity and low accuracy. The efficiency of the transition to higher slopes is largely determined by the transition scheme, which is not reflected in modern conditions of development in deep open mines.

Unsolved aspects of the problem. When using modern heavy dump trucks in open mine conditions, manufacturers recommend using only roads with constant slopes without horizontal sections. Thus, with the operation of mechanical dump trucks on roads with 50-meter inserts every 600 m with a maximum slope of more than 60 ‰, there is a risk of reducing the service life of transmissions due to an increase in the number of gear changes. Therefore, during the operation of dump trucks on roads with a constant slope, a higher average speed is achieved, rock spillage and fuel consumption are reduced, and there is a more uniform constant deceleration during the descent.

The purpose of the study is a technical and economic study on the parameters of the profile of exit trails without horizontal sections during the operation of road transport in deep open mines.

Methodology for calculating the parameters of the current scheme of auto transport with horizontal sections. The position of the capital trench trail in space is characterized by its longitudinal profile (projection of the capital trench axis on the vertical plane) and plan (projection of the capital trench axis on the horizontal plane). The longitudinal profile of the trail includes horizontal and inclined sections, as well as connections between them. An important element of the longitudinal profile of the trail is the method for adjoining the inclined sections to the working horizons.

In this section, we will consider the joining on the horizontal section.

When joining on a horizontal site, the length of the trail is increased by the sum of the lengths of the horizontal adjacent sections.

The actual length of the capital trench trail is always longer than the theoretical one due to the presence of adjoining sections. The coefficient of extension of the road trail in the open mine is: at simple conventions – 1.1–1.2; at loop conventions – 1.5–1.8.

Let us consider the current scheme of exit trails of auto transport with horizontal inserts on the example of two ledges with a height of 15 meters, a slope of 80 ‰ and dump trucks of the CAT 785C model (Fig. 1).

Fig. 1 shows a diagram of the trial of vehicles with horizontal sections. To protect the dump truck engine from overheating when driving uphill over a distance l_n (m) the horizontal sections of the road with a length of l_h (l_h = 50 meters) were designed. Parameters l_n and l_h depend on the carrying capacity and traction characteristics of the applied dump trucks. The number of horizontal inserts depends on the length of transportation for lifting l (m) and the length of a unit lifting section l_n, i.e.

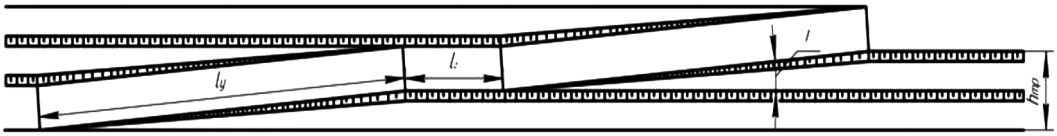

Fig. 1. Scheme of the trail of auto transport with a horizontal section

$$n = \frac{l}{l_n}.$$

The transportation distance l of the cargo will be

$$l = \frac{h_{lft}}{i},$$

where h_{lft} is load lifting height, m; i is longitudinal slope of the road, ‰.

Then the total length of rock mass transportation L_0 (m) is

$$L_0 = l + (n \cdot l_h).$$

The actual length of transportation $l_{l.1}$ (m) is greater than the theoretical (total) due to its lengthening, which is due to a decrease in the angle of inclination of the trail in curved sections and in the areas of junction of trenches to working horizons. Therefore

$$L_{l.1} = k_y \cdot L_0,$$

where k_y is the coefficient of trail elongation, for simple conventions – 1.1–1.2; for loop conventions – 1.5–1.8.

The volume of rock $V_{c.1}$ (m^3) from the convention (exit trench) is defined as a volume equal to half the volume of the parallelogram

$$V_{c.1} = l_{l,1} \cdot \left(\frac{B_c + C_o}{2} \cdot h_{lft} \right),$$

where $l_{l,1}$ is the actual length of transportation with horizontal sections, m; B_c is the width of the transport berm, m; C_o is the width of the base of the rock protection shaft, m; (C_o = 3 m)

The width of the convention depends on the technological and technical characteristics of the applied dump truck and is determined by the formula

$$B_c = z + T + K,$$

where z is the width of the prism of possible collapse, m;

$$z = hy(\text{ctg}\,\alpha_e - \text{ctg}\,\alpha_p),$$

where α_e is an angle of natural slope of the ledge, deg.; α_p is a slope angle of the working ledge, deg.; T is the width of the transport lane, m; K = 0.5–0.7 – idth of the ditch, m.

The width for a two-lane road is calculated by the formula

$$T = 2 \cdot x + c,$$

where x is the dump truck width, m; c is a safe distance between two dump trucks in oncoming movement, m (c = 1,5 m).

The volume of rock from horizontal sections $V_{h.1}$ (m^3) is determined by the formula

$$V_{h.1} = h_y \cdot (B_c + C_o) \cdot l_h.$$

The total volume of rock for the convention $V_{tot.1}$ (m^3) from two horizons with a horizontal section is

$$V_{tot.1} = V_c + V_h.$$

The dump truck travel time $T_{p.1}$ (min) for trails with horizontal sections is

$$T_{p.1} = t_n + t_{dv.1} + t_{man} + t_p,$$

where t_n is duration of the loading cycle of the dump truck, min.

Depending on the carrying capacity of the vehicle Q and taking into account the time to feed the vehicle into the working area of the excavator, we will calculate by the formula

$$t_l = \frac{Q \cdot t_{ce} \cdot K_p}{\gamma \cdot q_e \cdot K_f \cdot 60 \cdot K_t},$$

where $t_{c.e.}$ is the cycle of excavator operation, 40 s; K_p is the loosening coefficient, 1,3; γ is the volume mass in a dense body, 3.3 m^3; q_e is the capacity of the excavator bucket, m^3; K_f is the bucket filling coefficient, 1,1; K_t . is the transport coefficient depending on the time of transport maneuvering and is equal to 0.9 to 0.95; t_{man} is the total time of dump truck maneuvers in the face and in the warehouse; t_l time of unloading of the dump truck, 0.52 min; $t_{dt.1}$ is the driving time of the dump truck for routes with horizontal sections, min.

$$T_{l.1} = t_l + t_{dt.1} + t_{man} + t_p,$$

where $l_{l.1}$ is the actual length of transportation for trails with mountainous sections, km; $V_{tr.s.}$ is speed of the dump truck in the load direction, 25 km/h; $V_{tr.s.}$ is speed of the dump truck in the empty direction, 30 km/h.

Development of the scheme of exit trails of vehicles without horizontal sections. To achieve a more productive use of modern road transport, it was proposed to use exit trails of auto transport without horizontal sections.

Among the main advantages of using roads with a constant slope without horizontal platforms are:

- reduction in the volume of overburden rocks, as a result – reduction in the cost of production;
- reduction of spillage of rock mass from the dump truck body, which increases the permeability of tires;
- reduction of transportation distance and, accordingly, the number of dump trucks required;
- improvement of labor safety during the operation of auto transport due to better visibility of oncoming vehicles due to the absence of "blind" zones;
- reduction of fuel consumption, reduction in CO emissions and other harmful impurities, which has a positive impact on the environment;
- reduction of the number of transmission gear shifts, which increases its service life and reduces repair costs;
- improving visibility at exits and increasing the level of occupational safety. Improvement of traffic safety due to the absence of "blind" zones into which vehicles get on exits with horizontal platforms;
- reducing fuel consumption and increasing the service life of gearboxes.

Analysis of the benefits of using roads with *a constant slope without horizontal platforms* gives grounds to conclude that making changes to the scheme of open mine road transport to improve the safe operation of dump trucks is an urgent issue.

To compare the parameters of exit trails, let us consider the proposed scheme of auto transport without horizontal sections on the example of two ledges with a height of 15 meters, a slope of 120 ‰ and dump trucks of the CAT 785C model (Fig. 2).

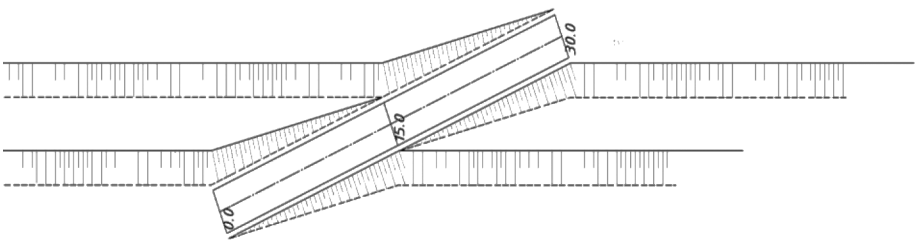

Fig. 2. Scheme of exit trails of auto transport without horizontal sections

Since there are no horizontal inserts in the scheme, the total length of the rock mass transportation is equal to the transportation distance, that is $L_0 = l_{b.h.d}$.

The actual length of transportation l_d (m) is greater than the theoretical (total) one due to its lengthening, which is caused by the reduced angle of inclination of the trail in curved sections and in the areas of junction of trenches to the working horizons. Therefore,

$$l_{d.2} = k_y \cdot l_{b.h.d}.$$

Further, the methodology for calculating the parameters of exit trails without horizontal sections is identical to the current scheme. It was found that the travel time of the dump truck under the developed scheme is 7.44 minutes, which is almost a minute less compared to the use of horizontal sections.

Fig. 3 shows a comparison of the actual transportation distance when using trails with and without horizontal sections.

Based on this comparison, it can be noted that when using the trail scheme without horizontal sections, the actual transportation distance will be reduced by 1.77 times.

Fig. 4 shows a comparison of the dump truck travel time when using trail layouts with and without horizontal sections.

Based on Fig. 4, we can say that the flight time when using trails without horizontal sections will decrease by 11.6 %.

Economic justification of the adopted options for technical and technological solutions. Capital costs C^C (UAN) associated with the main process of rock mass transportation should be calculated as

$$C^C = C_T^C + C_{REP}^C + C_{RR}^C + C_{MW}^C,$$

where C_T^C is capital expenditures for the purchase of rolling stock of road transport, UAH; C_{REP}^C is capital expenditures on repair and technical base, UAH; C_{RR}^C is capital expenditures for construction and maintenance of roads, UAH; C_{PS}^C is capital expenditures in the sphere of public services, UAH; C_{MW}^C is capital expenditures on mining capital works and reconstruction of transport communications, UAH.

Operating costs C_O (UAN) for road transport were calculated by the formula

$$C_O = C_S + C_{FUEL} + C_{LUB} + C_{AM} + C_{OC} + C_{RR} + C_{CR},$$

where C_S is expenses for basic and additional salaries of drivers, UAH; C_{FUEL}, C_{LUB} are costs, respectively, for diesel fuel and lubricants, UAH; C_{AM} is depreciation charges for full restoration and overhaul of the dump truck, UAH; C_{OC} is operating costs for maintenance of garage facilities, UAH; C_{RR} is operating costs for maintenance and repair of roads, UAH; C_O is the main expenses in the service sector, UAH; C_{CR} is overhead costs, UAH.

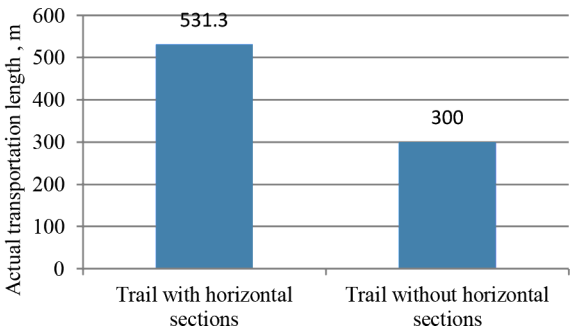

Fig. 3. Dependence of transportation distance on the use of the existing and proposed schemes

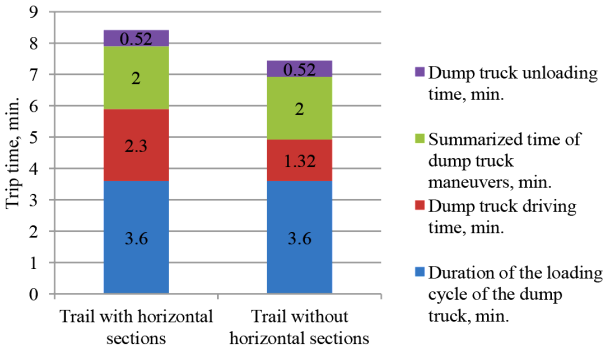

Fig. 4. Dependence of the dump truck trip time by component operations on the use of the existing and proposed schemes

According to the iron ore open mines, basic and additional wages, overheads (O&M) were assumed to be 80 % of annual costs, and lubricants – 30 % of diesel fuel costs.

To compare the proposed options, a diagram of operating costs for the maintenance and repair of open mine roads was built (Fig. 5).

Based on the above, it can be concluded that when using roads without horizontal sections, the cost of capital construction of roads will decrease by 43.53 %, the cost of conventions – 57 %, fuel consumption to overcome the segment – 42.57 %, operating costs for fuel – 42.57 %, lubricants – 34.53 % and the cost of maintenance and repair of roads – 43.53 %.

Conclusions. To improve the technical and economic performance of transportation of rock mass in deep open mines, a new scheme of exit trails of road transport without horizontal sections was proposed.

On the basis of the analysis of the parameters that determine the distance of transportation of rock mass, it was found that when using exit trails without horizontal sections, the transportation distance is 300 m, and with horizontal sections – 531.3 m, which is 1.77 times less. The trip time when using the transportation scheme without horizontal sections is 7.44 minutes, and when using with horizontal sections – 8.42 minutes.

As a result of the studies, it was found that the expected economic effect of the trails without horizontal sections is determined by the reduction of diesel fuel costs by 52.9 UAH, and the cost of holding congresses, respectively, 1,679,691 UAH.

This allows asserting that the introduction of a new scheme of exit road transport trails is economically feasible and can be used in the overburden operations, development and deepening of open mines for the extraction of various types of minerals such as iron ore and black coal.

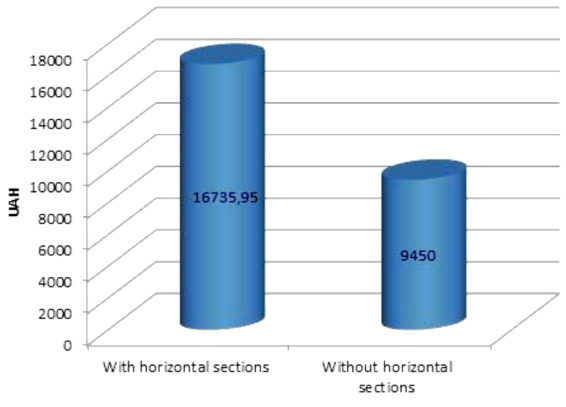

Fig. 5. Operating costs for maintenance and repair of open mine roads

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Дослідження раціонального профілю виїзних трас автотранспорту на глибоких кар'єрах

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Мета. Техніко-економічне обґрунтування параметрів профілю виїзних трас без горизонтальних ділянок при експлуатації автомобільного транспорту в умовах глибоких кар'єрів.

Методика. Для вирішення поставленої мети застосовані наступні методи: аналітичний, графічний, математичного моделювання, порівняння варіантів і аналогій. Зазначені методи досліджень використані при дослідженні та обґрунтуванні раціонального профілю виїзних трас автотранспорту в кар'єрі, визначенні ширини робочих площадок екскаватора й техніко-економічних розрахунків доцільності запропонованих рішень.

Результати. На основі проведеного аналізу параметрів, що визначають відстань транспортування гірничої маси, було встановлено, що, при використанні виїзних трас без горизонтальних ділянок, відстань транспортування становить 300 м, а з горизонтальними ділянками – 531,3 м, що в 1,77 рази більше. Час рейсу при використанні схеми транспортування без горизонтальних ділянок складає 7,44 хв, а при використанні з горизонтальними ділянками – 8,42 хв. Доведено, що використання виїзних трас без горизонтальних ділянок на кар'єрі Полтавського ГЗК знижує витрати на дизельне паливо на 42,57 %, а капітальні витрати – на 40,5 %.

Наукова новизна. Виконане порівняння дійсної відстані транспортування, часу рейсу автосамоскида за складовими операціями, розраховані витрати на утримання кар'єрних автодоріг при використанні трас з горизонтальними ділянками та без них. Уперше запропонована схема виїзних трас без горизонтальних ділянок, що дозволило скоротити відстань транспортування гірничої маси автосамоскидами зі зменшенням обсягу порід для проведення з'їздів на 57 %.

Практична значимість. Розроблена схема профілю траси без горизонтальних ділянок може застосовуватись при розкритті, відпрацюванні й поглибленні кар'єрів із видобутку різнотипових корисних копалин таких як залізна руда й кам'яне вугілля. Очікуваний економічний ефект від запровадження трас без горизонтальних ділянок визначається зменшенням витрат на дизельне паливо на 52,9 грн/т · км, а на проведення з'їздів відповідно 1,68 млн. грн.

Ключові слова: *залізна руда, глибокий кар'єр, автосамоскид, горизонтальні ділянки, техніко-економічні показники*

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