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O. V. Lozhnikov[*1],
orcid.org/0000-0003-1231-0295,
B. Yu. Sobko[1],
orcid.org/0000-0001-9533-5126,
A. V. Pavlychenko[1],
orcid.org/0000-0003-4652-9180,
Yu. O. Kirichek[2],
orcid.org/0000-0002-1573-0706

1 – Dnipro University of Technology, Dnipro, Ukraine
2 – Prydniprovska State Academy of Civil Engineering and Architecture, Dnipro, Ukraine
* Corresponding author e-mail: oleksii.lozhnikov@gmail.com

UTILIZATION OF THE SECONDARY RESOURCES OF TITANIUM-ZIRCONIUM PITS WHEN CONSTRUCTING HIGHWAYS

Purpose. To develop a methodology for determining the economically feasible distance of construction sand haulage, which is a secondary raw material of ore pits, to highway construction sites in comparison with the delivery of sand from mining enterprises of building materials, taking into account land conservation indicators.

Methodology. The research used a set of methods: analytical method – to establish the main technical and economic indicators that affect the cost of delivering sand from the mining enterprises to the road construction site; technical and economic analysis – to determine the influence of the building materials haulage distance on the cost of construction works.

Findings. The economically permissible haulage distance for sands form titanium-zirconium mining enterprises to highway construction objects was established in comparison with the involving of sands from deposits of building materials. It has been proven that under the conditions of using the sands of the Motronivskyi MPP, where the main raw material is titanium-zirconium ores, in addition to the economic effect of the mining waste disposal, there is an ecological effect of reducing the dumps and tailings areas. At the same time, the cost of sand rocks during the construction of the road surface will be reduced by 3 to 60 %, depending on the distance to the construction road site. All together, the area of lands saved from being disturbed by new mining operations will reach 3.3 hectares during the construction of a 2.5 km long category I-b road section.

Originality. Dependence was established of the sand cost and its delivery to the object of new highway construction on the materials haulage distance when purchasing sand at the enterprise of the main raw material and from the titanium-zirconium deposit, where it is developed as an associated raw material. The dependence of the economic efficiency indicator of the road construction on the increasing distance of sand rocks delivery from the titanium-zirconium deposit was determined, which allows justifying the rational haulage distance according to technical and economic indicators.

Practical value. The developed method for determining the effective haulage distance for sand rocks to the construction site allows one to calculate the expediency of involving associated minerals of ore pits during the reconstruction and construction of new highways, as well as to establish the effect of resource conservation due to the reduction in the area of mining facilities during the extraction of ore and building raw materials.

Keywords: *motorway, quarry, sand, haulage distance, secondary raw materials, economic efficiency*

Introduction. Ukraine has an extensive network of highways with the overall length of more than 169,000 km. A significant part of these roads is physically and morally outdated, and almost 85 % of their total length required major repairs in the pre-war period [1]. The main problem is that the condition of the road surface does not meet the modern requirements of automobile traffic, and the congestion of cars and trucks on the roads is constantly increasing. This emphasizes the topicality of intensifying the reconstruction of Ukraine's road infrastructure and the significant demand for raw materials used in building works.

The issue of road repair and reconstruction in Ukraine has become particularly acute as a result of large-scale military operations that have resulted in damage or complete destruction of highways. As of December 2022, more than 25,000 km was damaged or destroyed, of which more than 9,000 km was state roads. These roads need to be restored in the first place, because their condition influences the provision of economic activity and transport connections between settlements and enterprises [2].

The speed of the transport infrastructure restoration is primarily related to the volume of funding for the specified works, as well as sufficient volumes of construction materials. As is known from the practice of highway construction, up to 70 % of their cost is material costs, of which 40 % is haulage costs. This determines the need to reduce transport routes from quarries to road construction sites in order to optimize the company's costs [3].

In addition to providing construction facilities with local raw materials, issues of resource conservation also arise when developing quarries of building raw materials, since this process leads to the emergence of a significant number of small quarries and the violation of the natural land condition. In this regard, the importance of establishing effective parameters for the use of secondary sand and clay raw materials in the construction of roadbed for new highways, which is found in large volumes in overburden and containing rocks of titanium-zirconium pit, is increasing [4].

The efficient use of associated minerals from the ore pit in the construction of large road facilities largely depends on economic indicators, which are determined by the distance of materials haulage. This indicator, in turn, directly affects the number of the road trucks, the composition of service personnel and the cost of building works. Therefore, there is an urgent task of developing a methodology for determining the economically feasible distance of construction materials haulage, which are secondary raw materials of ore raw material pits to highway construction objects in comparison with the delivery of sand from building materials quarries, which will take into account land conservation indicators.

Literature review. The world experience of using production waste from various industries in the construction of highways confirms the relevance of this research direction. The closest technical solution to the use of resource-saving technologies in the construction of highways is the utilization of ash and slag as aggregates in construction works. The use of this secondary raw material allows one to significantly reduce the cost of construction and increase the environmental friendliness at the production processes of other industries.

The experience of slag disposal confirms a 30 % reduction in the cost of road construction work. Uses of ash and slag waste are found both in the USA and in Europe, and an example of the successful implementation this experience is the construction of the Eisenhower Expressway in Chicago or the highway bridge in Denmark [5].

The research conducted by the European Business Association (EBA) in 2016 made it possible to establish that 30.4 million tons of ash and slag products were generated at EU thermal power plants, of which more than 13.5 million tons were disposed (30 % of the total volume) [6]. In the European Union, the formation of ash and slag was reduced by 43.2 % due to the reduction in the production of coal-fired power generation during 2013–2016. The lack of these raw materials led to the fact that some EU countries (for example, the Czech Republic) began to import them to be used in various construction areas and to reduce the cost of road construction [7].

Statistical data allow establishing the fact that in 2020, Ukraine exported up to 40,000 tons of ash and slag materials [8]. It is worth noting that in the country itself, the demand for this type of secondary raw material is minimal, despite the successful experience of using this raw material in the highways construction. This confirms the underestimated importance of secondary raw materials in our country, while the demand from Europe will constantly grow due to the further reduction of coal generation. It is important to note that the supplier of aggregates for construction mixes and road surface construction the should be located at an economically feasible distance from the construction site, so the use of ash and slag waste may not always be effective from the point of view of haulage costs.

There is extensive experience of the industrial waste use in road construction in the developed countries of Europe, including Poland. The difference between the waste management systems of our countries lies in the conservatism of the road construction field and the lack of experience in road construction using production waste [9]. In addition, the promotion of the industrial waste use in road construction is not enshrined in legislative documents.

The experience of the EU confirms that the use of industrial waste in the highways construction is a component of the circular economy principles, the goal of which is the maximum utilization of industrial waste [10]. It is proposed to consider waste as a secondary raw material, or a resource for various branches of construction, which corresponds to the principles of the closed cycle economy [11].

This issue is especially relevant in our country, since up to 97 % of all solid waste is generated by heavy industries [12]. The rest of the waste is solid household waste. Therefore, the issue of solid industrial waste disposal in Ukraine has the greatest potential in the implementation of the environmental protection tasks and decreasing the violation of land resources, as well as reducing costs for the construction of large infrastructure facilities. In this regard, the success of the mentioned technologies, which have been tested in foreign practices, is a confirmation the perspective of the mentioned research direction to achieve sustainable ecological, economic, and social effects [13].

In order to legalize the use of slags of metallurgical production in the construction of highways in Ukraine, DSTU 9043:2020 was developed and implemented, which regulates the production of crushed stone products from secondary raw materials. The specified standard takes into account already existing standards from "Nature Protection", "Labour Safety Standards System", as well as a significant list of building materials standards. The standard was put into effect in 2020 and made it possible to activate resource saving processes by using metallurgical slags in road construction.

In addition to slag and ash slag of thermal power plants, Ukraine has large volumes of industrial waste in the form of sand and crushed stone, which are contained in the overburden of ore quarries and can be used in the construction of highways [14]. In contrast to the use of ash and slag materials, the use of mining rocks from pits of ore or buildings raw materials can be carried out with additional evaluation and exploration of associated minerals, placing them on the government balance and including their extraction in the development project.

Compliance with this procedure will not only allow the enterprise to obtain additional profit, but also to reduce the area required for the formation of new dumps, to reduce the volume of sand and crushed stone extraction at the quarries of building materials. Under favourable conditions, this will also allow the release of land areas occupied by man-made formations with significant volumes of secondary raw materials that have been accumulated for decades [15].

The mentioned problem is exacerbated by the fact that in Ukraine, metallurgical slags (up to 50 %), ash slag materials (up to 30 %), and the use of sand and crushed stone from ore quarries do not exceed a few percent of the total volume [16]. This is connected both with the complex procedure of placing production waste on the balance sheet for their further selling, and with a certain lack of experience in the use of such raw materials in construction works.

According to the estimates of the European Business Association, replacing a third of crushed stone with slag materials would save up to UAH 420 million according to the volumes of road construction in 2020. In the case of using the same volumes of ash and slag, the potential saving of budget funds could amount up to UAH 500 million [17]. The ecological and social effect during the calculations was not considered, but in accordance with the reduction of land areas affected by industrial waste, these indicators would be significant.

The world experience of using certain industrial waste in building when constructing highways, bridges and transport communications confirms that the use of secondary raw materials is a key to reducing the negative impact on the country's ecological condition [18]. Therefore, the disposal of industrial waste is an urgent task, the solution of which will allow increasing the indicators of land and resource conservation, in accordance with the European trend of circular economy [19].

The analysis of the existing scientific and research works made it possible to establish that increasing the efficiency of resource conservation at the surface mining during the highways construction is possible by using the following technological solutions:

- reorientation of the basic minerals consumption from building materials quarries to similar minerals from industrial waste, including overburden rocks;
- reduction of mineral raw materials losses during mining, processing and beneficiation;
- recycling of waste and contained rocks in the building industry;
- reducing the area of disturbed land for the placement of external dumps and tailings by involving them in the construction industry;
- reducing the negative impact on the environment.

Therefore, the use of overburden rocks from ore quarries in the highways construction results in the issue of economic feasibility, since the haulage distance can reach up to 70–90 km, which significantly increases the construction cost and can exceed the cost on sand extracted from building material quarries.

It should be taken into account that the determination of the sand rocks utilization efficiency from the ore pits will also have additional environmental and economic effects. They will be obtained at the expense of slowing down the growth of the tailings storage area of the ore pits, as well as reducing the area of disturbed land during the surface mining of sand in the building raw materials quarry.

The purpose of paper is to develop a methodology for determining the economically feasible haulage distance for construction sand, which is a secondary raw material of ore pits, to highway construction objects in comparison with the deliv-

ery of sand from mining enterprises of building raw materials, taking into account land conservation indicators.

Methods. To achieve the purpose, the analytical method of research was used to establish the main technical and economic indicators that affect the cost of delivering sand rocks to the construction site, taking into account delivery cost, as well as the method of technical and economic analysis to determine the economically feasible range of sand rocks haulage at the cost of construction work taking into account the indicators of reducing the land disturbance areas during the development of ore pits and building materials quarries.

Results. The development of the methodology for determining the economically feasible haulage distance for sand rocks from titanium-zirconium pits to the road construction site is based on establishing the dependence of the haulage distance for sand rocks on the output of road dump trucks. To determine the influence of the haulage distance of mining rocks on the productivity and number of dump trucks at the road construction site, the range of distances from 10 to 160 km was considered. The volume of raw materials that must be transported by road trucks from the pits and quarries to the construction site is 500,000 tons.

During the research, the most common brands of Ford dump trucks were used with a haulage capacity of 21–26 tons; they are used in the construction of highways in Ukraine. The results of studies on the impact of haulage distance on the annual output of Ford 4142 D and Ford 3542 D dump trucks with a carrying haulage capacity of 21 and 26 tons, respectively, are shown in Table 1.

According to the obtained research results (Table 1), the haulage distance for sand rocks is an extremely important indicator that affects the cost of building raw materials at the construction site.

It was established that when the haulage distance increases by 16 times from 10 to 160 km, the productivity of dump road trucks will reduce by 8.6 times from 203.1 to 23.5 thousand t/year for the Ford 4142 D dump truck, and from 251.5 to 29.1 thousand t/year for the Ford 3542 D. This reduction in productivity will lead to the need to increase the number of vehicles by 7.3 to 9.0 times for Ford 4142 D and Ford 3542 D dump trucks, respectively.

As a result, at the delivering of the same volume of sand from pits located at different distances from the road construction site, it is necessary to involve a different number of service trucks. When the haulage distance of construction materials increases, the productivity of dump trucks will decrease, which will lead to an increase in their number, an increase in the price of mineral raw materials and the total cost of construction works.

Table 1

Characteristics of the dump trucks operation during the construction of highways

Haulage distance, km	Truck driving time, min		Vehicle productivity, thousand tons/year		Number of trucks, units	
	Ford 4142 D	Ford 3542 D	Ford 4142 D	Ford 3542 D	Ford 4142 D	Ford 3542 D
10.0	29.4	251.5	203.1	251.5	3.0	2.0
25.0	51.9	142.6	115.1	142.6	5.0	4.0
40.0	74.4	99.5	80.3	99.5	7.0	6.0
55.0	96.9	76.4	61.7	76.4	9.0	7.0
70.0	119.6	61.9	50.0	61.9	10.0	9.0
85.0	142.1	52.1	42.1	52.1	12.0	10.0
100.0	164.6	45.0	36.3	45.0	14.0	12.0
115.0	186.9	39.6	32.0	39.6	16.0	13.0
130.0	209.4	35.4	28.6	35.4	18.0	15.0
145.0	231.9	31.9	25.8	31.9	20.0	16.0
160.0	254.4	29.1	23.5	29.1	22.0	18.0

The determined indicators of productivity and the required number of dump trucks to perform the given amount of work (Table 1) allow making a further calculation of technical and economic indicators for comparing the efficiency of transporting sand to the construction site from the pit of the main and associated raw materials, taking into account the of resource conservation indicators.

In most cases the use of sand from titanium-zirconium pits in the construction of roads will lead to an increase in logistics costs, which is associated with a raise in the haulage distance compared to the use of sand from quarries of building raw materials which are located at a small distance from the construction site.

To determine the economic feasibility of transporting secondary raw materials from titanium-zirconium pits to construction sites, the change in the cost of building raw materials when replacing the supplier from a local sand quarry to a pit of associated raw materials, was investigated. It should be noted that the average distance from the quarry of building materials to the construction site is assumed to be 10 km, while the distance from the titanium-zirconium pit of the Motronivskyi MPP to the section of the road under construction is 85 km.

According to the previously established indicators (Table 1), when the haulage distance increases by 8.5 times from 10 to 85 km, the productivity of the Ford Trucks 4142D dump truck will decrease by 4.8 times from 202 to 42 thousand tons per year. Thus, to haulage a given volume of sand (500,000 tons) it will be necessary to increase the number of used dump trucks by 5 times, from 3 to 15, which will lead to a significant increase in the cost of construction materials for the customer. This is due to an increase in capital and operating costs for maintaining an additional number of trucks.

On the other side, the use of sand rocks as a secondary raw material for the construction of highways roadbed will allow obtaining the following economic and environmental advantages:

- decrease in the cost of purchasing secondary raw materials in contrast to the cost of sand in a building materials quarry;
- reduction in land areas required for placement of mining waste in tailings and dumps at the titanium-zirconium pit development;
- reduction in land disturbance areas by open development in non-ore quarries where sand is mined.

That is, in addition to economic advantages, the application of the proposed technological solutions in the highways construction will have significant environmental and social effects, which are achieved due to resource conservation [20]. The first will consist in reducing the negative impact on the environment, which is related to the disposal of significant volumes of mining waste when placed into the dumps and tailings, with dusting surface for decades [21]. The second advantage will occur due to a reduce in the consumption of sand, as the main raw material of building materials quarries, which will lead to a decrease in the land disturbed by surface mining [22].

In some cases it will be possible to discard the building of a new quarry of low productivity, which will ultimately have a positive effect on the environment, ensure the improvement of living conditions for people, and also create conditions for increasing the number of new jobs related to the processing and use of secondary resources.

When evaluating the effectiveness of the involvement of secondary raw materials from titanium-zirconium pits in the highway construction, not only the indicator of the haulage distance of construction raw materials and its purchase cost, but also the economic effect of land conservation and environmental protection will be taken into account.

To solve this problem, a method for determining the economically feasible distance of transporting sand from titanium-zirconium pits to the road construction object is proposed, taking into account the purchase price of sand from building ma-

terials quarries [23], the cost of delivering mineral raw materials to the construction object and resource saving indicators.

The specified method will allow taking into account cost savings from the slowing down of the dynamics of the increase in the tailings pits area of associated raw materials and land disturbance by surface mining of building materials quarries. Calculation of indicators of the actual cost of sand for the construction site is proposed to be performed in the following sequence:

1. The total working time of dump trucks is determined according to their number

$$T_a = N_a \cdot T_{cm} \cdot N_{cm} \cdot N_{rd}, \quad (1)$$

where N_a is the number of dump trucks, units; T_{cm} is working shift time, hours; N_{cm} is the number of work shifts per day; N_{rd} is the number of working days on the site.

2. Operational costs *OPEX* for maintaining a park of dump trucks are determined

$$OPEX = \sum_{i=1}^{n} H_i C_i K_i, \quad (2)$$

where n is the number of consumables types; H_i is consumption of material of the i^{th} type, ton; C_i is the cost of material of the i^{th} type, UAH; K_i is the coefficient of haulage costs.

3. The annual costs are established for operating the material assets that are used when transporting sand from the pits to the construction site

$$A_C = \frac{Ba \cdot \left(\frac{100 + i_p}{100}\right)}{T}, \quad (3)$$

where *Ba* is the cost of the equipment, UAH; i_p is annual loan rate, %; T is the period of useful operation of the equipment, years (machines with internal combustion engines – 7 years).

4. The cost of sand haulage from the pit to the road construction site is determined

$$C_T = \frac{C_H}{Q}, \quad (4)$$

where C_H is the total cost of sand haulage, UAH; Q is the total volume of transported sand, i. e.

5. The cost of the sand including the delivery to the road construction site during truck haulage from mining enterprises is calculated for:

- building materials quarries

$$C_1 = C_{P1} + E_{T1}; \quad (5)$$

- titanium-zirconium pits

$$C_2 = C_{P2} + E_{T2}, \quad (6)$$

where C_{P1} is the market value of sand at the quarry of the main raw material, UAH/t; E_{T1} is the cost of sand delivery from the quarry of the main raw material, UAH/ton; C_{P2} is the price of sand at the pit as an associated raw material, UAH/t; E_{T2} is the cost of sand delivery from the pit as an associated raw material, UAH/ton.

When calculating the economic indicators, the previously determined number of dump trucks needed to transport a given volume of sand rocks (Q = 500 thousand tons) from sand quarry and ore raw material pit was taken (Table 1).

The results of the calculation of technical and economic indicators of the dump trucks operation and the sand rocks cost with delivery to the road construction site, established according to the proposed methodology, are shown in Table 2.

According to the obtained calculation results (Table 2), it was established that in the case of the same distance of sand haulage to the construction road site, the economic advantage is given to the pits of secondary raw materials.

The efficiency of using sand from the ore pits is related to the low purchase cost of the raw material with the same costs for haulage work. The low purchase cost of sand in ore pits is explained by the fact that, in comparison with the operation of a pit where sand is extracted as the main raw material, the capital and operating costs per unit of production will be much lower.

The sand being involved from the titanium-zirconium pits, the cost will be much lower and will be equal to the cost of overburden and loading works. This is due to the fact that clay and sand are associated minerals that must be stored in man-caused formations on additional lands. In this regard, the company is interested in finding a consumer of secondary raw materials, as this will allow reducing the costs of their storage in dumps and tailings, the formation of which also requires the search for new territories for their location.

In Fig. 1 shown the dependence of sand cost with delivery on the haulage distance when raw materials are obtained from sand and titanium-zirconium pits.

As a result of the economic indicators comparison (Fig. 1), it was established that the utilization of sand from the titanium-zirconium pit is economically feasible even when increasing the haulage distance in comparison with the location of the sand quarries. Thus, the delivery of sand from the quarry of the main raw material, located 10 km from the construction road site, is equivalent to the distance of 86 km from the quarry of the secondary raw material and reaches 180 UAH/ton. That is, in the case when the road construction object will be located at a shorter distance from the titanium-zirconium pit, the construction organization can even reduce costs in comparison with the purchase of sand from a quarry of building materials.

6. At the final stage, the economic efficiency of involving the sands from titanium-zirconium pits in the construction of a road object is determined, taking into account the effect of land conservation, which is achieved by slowing down the dynamics of increasing the area of ore pit tailings and by reducing the area of disturbed land in the sand quarries according to the following expression

$$E = (C_1 - C_2) \cdot Q + E_{N.D} + E_{N.L}, \quad (7)$$

where Q is the volume of sand required for the construction of a roadbed, million tons; $E_{N.D}$ – cost savings from reducing the area of tailings storage in the ore pit, million UAH; $E_{N.L}$ – cost savings from land disturbance by surface mining operations during the development of the sand quarry, UAH million.

Table 2

The cost of sand including delivery to the construction site

Haulage distance, km	Trucks operating time per year, thousand hours	Operating expenses *OPEX*, million UAH	Total costs for haulage works, million UAH/year	Sand haulage cost, UAH/ton	The cost of sand including delivery to the road construction site, UAH/ton	
					Delivered from building material quarries	Delivered from titanium-zirconium pits
10.0	341.0	10.3	13.84	27.69	177.7	62.1
25.0	683.5	20.5	27.69	55.38	205.4	89.8
40.0	911.3	27.3	36.92	73.85	223.8	108.2
55.0	1139.2	34.2	46.15	92.31	242.3	126.7
70.0	1367.0	41.0	55,38	110.77	260.8	145.1
85.0	1708.8	51.3	69.23	138.46	288.5	172.8
100.0	1936.6	58.1	78.46	156.92	306.9	191.3
115.0	2164.4	64.9	87.69	175.39	325.4	209.8
130.0	2506.2	75.2	101.53	203.08	353.1	237.5
145.0	2734.0	82.0	110.76	221.54	371.5	255.9
160.0	2961.9	88.9	120.00	240.00	390.0	274.4

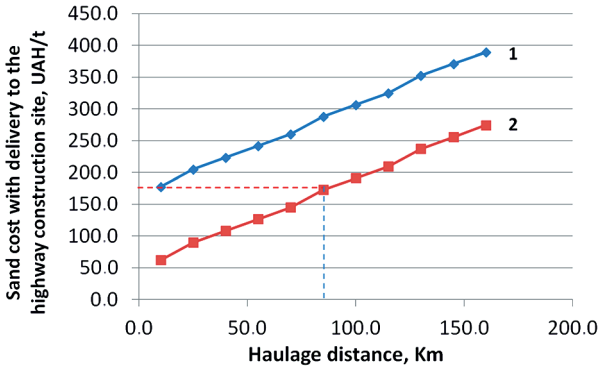

Fig. 1. Dependence of the sand cost including delivery to the highway construction site on the haulage distance when supplying sand from:

1 – sand quarry; 2 – titanium-zirconium pit

According to the proposed methodology, the dependence was established of the economic efficiency indicator at involving the sands of titanium-zirconium pits in the roads construction on the haulage distance of raw materials, taking into account the effect of land conservation on the mining enterprises of the main and accompanying raw materials (Fig. 2).

In accordance with the established dependencies (Fig. 2), the effectiveness of the proposed technological solutions regarding the application of resource-saving technologies and the waste utilization from the mining of titanium-zirconium deposits during the construction of new roadbed at a distance of 85 km from the pit of associated raw materials is determined.

When comparing the existing option of delivering sand from the main raw material quarry for a distance of 10 km and the proposed option for the disposal of sand from the titanium-zirconium pit, which is located at an average distance of 85 km from the road construction site, it was established that the cost of sand including delivery will decrease by 2.8 % from 177.7 to 172.8 UAH/t.

It has been established that the involvement of the given amount of sand necessary for the construction of the area under investigation (length 2.5 km and volume of building works 500 thousand tons) will allow obtaining an economic effect in the amount of 2.4 million UAH. This indicator also takes into account cost savings from the reduction of the tailings storage area by 1.85 ha (111.1 thousand UAH/year) and the preservation of land from violations by surface mining of sand quarry as a main raw material to 3.3 ha (200.0 thousand UAH/year).

Conclusions. The influence of the haulage distance for sand raw materials on the productivity of road dump trucks during the construction of the roadbed of highways has been established. It was determined that when the haulage distance increases by 16 times from 10 to 160 km, the productivity of dump trucks decreases by 8.6 times from 203.1 to 23.5 thousand t/year for the Ford 4142 D dump truck, and from 251.5 to 29.1 thousand t/year for Ford 3542 D. It is established that the corresponding reduction in productivity will require an increase the number of vehicles by 7.3 to 9.0 times for dump trucks, depending on their load capacity.

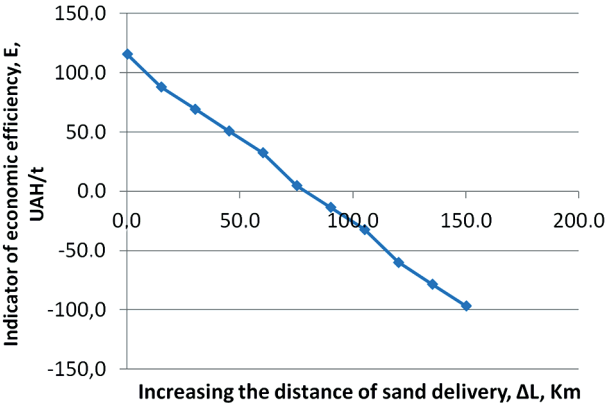

Fig. 2. Dependence of the economic efficiency indicator on the increasing distance of sand delivery from the titanium-zirconium pits to the construction road site, taking into account the effect of land conservation

The methodology has been developed for determining the economically feasible haulage distance for secondary sand raw materials from the titanium-zirconium ore pit to the road construction sites, taking into account the economic effect of land conservation. The proposed method made it possible to establish the fact that the use of sand rocks, which are the associated raw materials of titanium-zirconium pits, during the construction of a section of the roadbed located at a distance of 85 km, will allow reducing the cost of raw materials at the construction site by 2.8 %, which is 4.9 UAH/t.

The proposed technological solutions will also make it possible to increase the effectiveness of land conservation by reducing the area of tailings at the titanium-zirconium pits by 1.85 hectares and save the land from disturbance at the sand raw material quarries with a total area of 3.3 hectares.

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Використання вторинних ресурсів титан-цирконієвих кар'єрів при спорудженні автомобільних доріг

О. В. Ложніков[*1], *Б. Ю. Собко*[1], *А. В. Павличенко*[1], *Ю. О. Кірічек*[2]

1 – Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна
2 – Державний вищий навчальний заклад «Придніпровська державна академія будівництва та архітектури», м. Дніпро, Україна
[*] Автор-кореспондент e-mail: oleksii.lozhnikov@gmail.com

Мета. Розробити методику визначення економічно доцільної відстані перевезення будівельного піску, що є вторинною сировиною кар'єрів рудної сировини, до об'єктів будівництва автомобільних доріг у порівнянні з доставкою піску з гірничих підприємств нерудної сировини з урахуванням показників землезбереження.

Методика. У роботі використано комплекс методів досліджень: аналітичний – для встановлення основних техніко-економічних показників, що впливають на собівартість доставки піску з місця розробки до об'єкта спорудження дороги; техніко-економічний аналіз – для встановлення впливу дальності перевезення будівельних матеріалів на собівартість виконання будівельних робіт.

Результати. Встановлена економічно допустима відстань перевезення пісків титан-цирконієвих гірничих підприємств до об'єктів будівництва автошляхів у порівнянні із залученням пісків з родовищ нерудної сировини. Доведено, що за умов використання пісків Мотронівського ГЗК, де основною сировиною є титан-цирконієві руди, окрім економічного ефекту від утилізації відходів гірничого виробництва є також і екологічний ефект від зменшення площ відвалів і хвостосховищ. При цьому собівартість піщаних порід при спорудженні дорожнього полотна буде знижена на суму від 3 до 60 % у залежності від відстані до об'єкту будівництва. При цьому площа земель, збережених від порушення новими гірничими виробками, сягне 3,3 га при будівництві ділянки дороги категорії І-б довжиною 2,5 км.

Наукова новизна. Установлені залежності вартості піску та його доставки на об'єкт спорудження нової автомобільної дороги від відстані перевезення матеріалів при закупівлі піску на підприємстві основної сировини та з титан-цирконієвого родовища, на якому він розробляється як супутня сировина. Визначена залежність показника економічної ефективності спорудження автомобільної дороги від збільшення відстані доставки піщаних порід з титан-цирконієвого родовища, що дозволяє обґрунтувати раціональну відстань транспортування за техніко-економічними показниками.

Практична значимість. Розроблена методика визначення ефективної відстані транспортування піщаних порід до будівельного об'єкту дозволяє розрахувати доцільність залучення супутніх корисних копалин рудних кар'єрів при реконструкції та спорудженні нових автомобільних доріг, а також встановити ефект ресурсозбереження за рахунок зменшення площ гірничих об'єктів при видобутку рудної та нерудної сировини.

Ключові слова: *автомобільна дорога, кар'єр, пісок, відстань транспортування, вторинна сировина, економічна ефективність*

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