Road longitudinal slope influence on the efficiency of excavator-automobile complexes usage

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Abstract. At present, the country's coal industry pays special attention to the open-pit mining, because of its higher efficiency and profitability. According to various surveys, currently the share of open-pit mining is 50 - 65%, and it will increase to 80 - 85% in the future. The development of an open-pit mining is accompanied by production scale increase, open pits depth increases and complexity of mining conditions of main technological equipment operation increases. With the increase of open pits depth, technological road transport becomes the most problematic issue in mining, since open-pit depth enlargement increases the distance of transportation and roads longitudinal slopes and these factors reduce the efficiency of excavator-automobile complexes.

Introduction

The share of transport costs in labour and energy consumption of mining reaches 55 -60% when mining is done from 100 -150 m depth, and when mining is done from 200-250 m depth costs in labour and energy consumption are 65 -70%. Road transport corresponds to more than 50% of them. In this regard, efficiency of the excavator-automobile complexes usage increases and reduction of transport costs becomes an urgent task [1, 2, 3, 4].

There is a need to apply a single design route scheme because the routes geometry of dump trucks movement is characterized by great variety. Depending on the geometry there are simple, loop, helix and combination tracks, which are a set of tracks. If we assume that the longitudinal slopes of the route segments change insignificantly, then any route can be represented as a simple one, when the length of transportation is related to the road longitudinal slope by an inversely proportional relationship [5, 6, 7].

Results and discussion

The road longitudinal slope has a complex effect on the performance of excavator-automobile complexes [8, 9, 10]. Let us consider a simple excavator and truck complex consisting of one excavator and one dump truck. On the one hand, if we take the technical speed of a dump

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truck unchanged, the productivity of the EAC (excavator-automobile complex) will increase with the increase in a slope due to the decrease in the transportation distance. On the other hand, the increase in the slope leads to the decrease in technical speed, which increases the transportation time, and, consequently, decreases productivity [11, 12]. Consequently, the real dependence of hourly efficiency of the road longitudinal slope is parabolic (Figure 1).
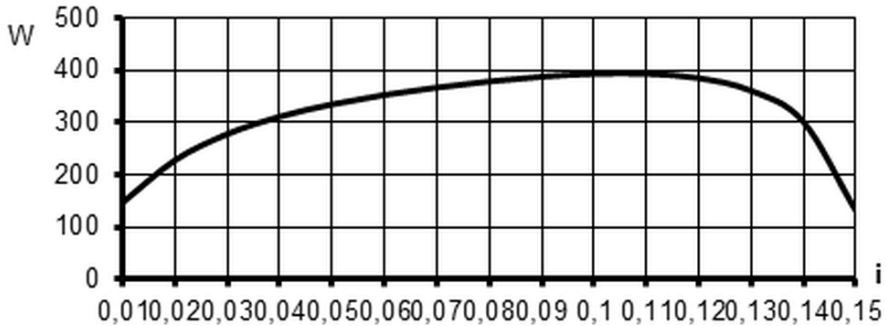
Fig. 1. The dependence of productivity W of a BelAZ-75131 dump truck on the longitudinal slope of the road i

Considering more complex excavator and automobile complexes, we find that the decrease in value of the longitudinal slope leads not only to increase in the transportation distance, but also to increase in the EAC movement factor. Thus, reduction of the longitudinal slope magnitude allows to use a larger number of dump trucks in automobile excavator-complex, increasing the performance and stability of EAC (Figure 2, 3).
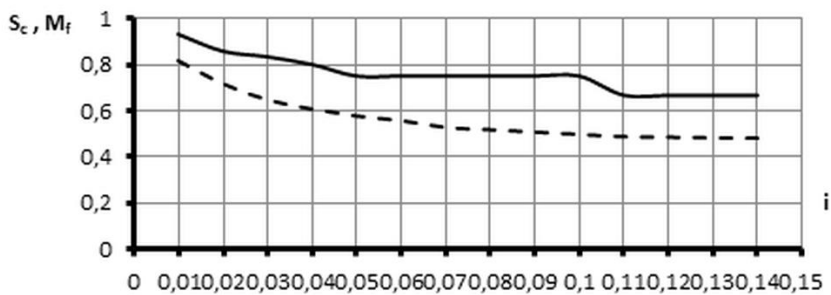
Fig. 2. The dependence of the stability coefficient (Sc) and the movement factor (Mf) on the road longitudinal slope i (dotted line - movement factor; solid line - stability coefficient)

Consequently, the real dependence of the EAC efficiency on the road longitudinal slope has extremes at which the productivity will be maximum, therefore, a rational choice of the road longitudinal slope using the functional criterion makes sense when

$$i_{rat} \rightarrow Q_t = max \qquad (1)$$
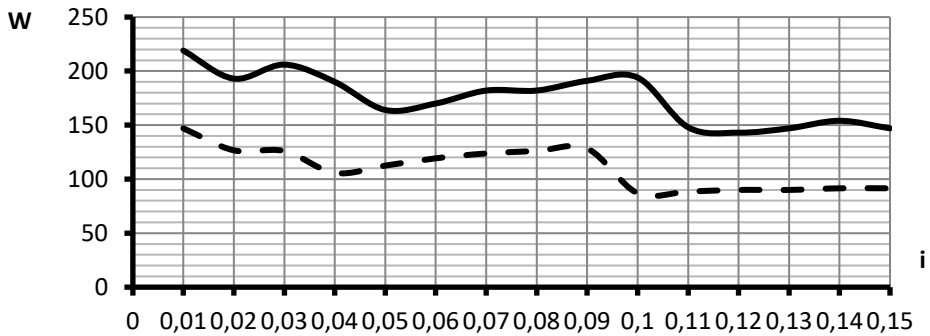
Fig. 3. The dependence of the efficiency W of the EAC on the road longitudinal slope i with different composition of the EAC

The road longitudinal slope has a complex effect on the transportation costs. On the one hand, if we take the operation costs unchanged, then with the increase in a slope, due to the increase in hourly efficiency, the transportation cost decreases and the dependence of the transportation cost on the road longitudinal slope is hyperbolic (Fig. 4).
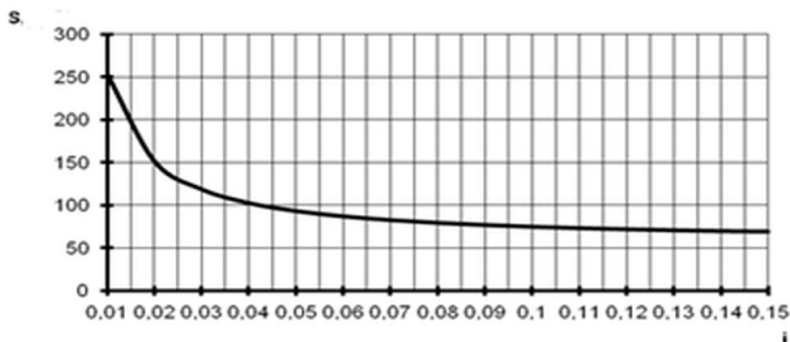
Fig. 4. The dependence of the transportation cost of price (C) of a BelAZ-75131 dump truck on the road longitudinal slope i at constant costs

On the other hand, the increase in a slope leads to the increase in fuel and lubricant consumption, leads to the resource decrease of supporting metal structures, leads to the increase in the downtime of dump trucks maintenance and repair works, leads to a faster wear of the dump trucks and, therefore, the increase in operating costs for the corresponding items. Thus, the total operating costs increase with the slope increase (Figure 5).

Consequently, the real dependence of the transportation cost on the road longitudinal slope is parabolic (Fig. 6); it means that it has an extremum at which the transportation cost is minimal.
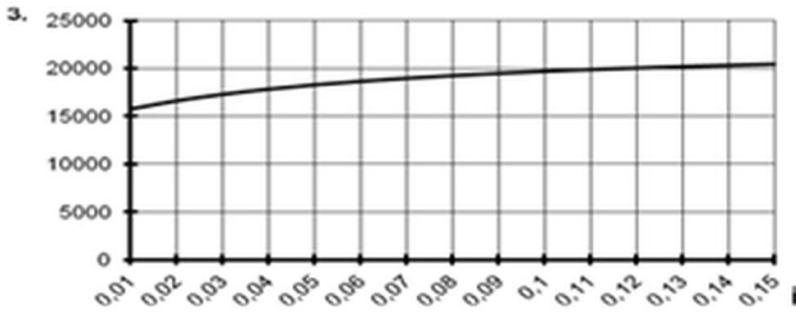
Fig. 5. The dependence of the total hourly operating costs C of BelAZ-75131 dump trucks on the road longitudinal slope i

When carrying out the transportation in open pits, two types of cargo are moved: minerals and overburden. For each type of cargo, the condition to determine the rational slope is different.

When transporting overburden, enterprises do not receive income from the transportation, so they are interested in minimizing all operating costs. Consequently, the rational slope for the overburden transportation is that one at which the cost of transportation is minimal:

$$i_{rat} \rightarrow S = min \qquad (2)$$

The road longitudinal slope affects the technical speed of dump trucks, therefore, the variable items of the transportation cost of rock mass are those that are affected by the movement speed, namely the fuel, lubricants, tires, maintenance and repair works costs, as well as costs associated with the maintenance of open-pit roads.
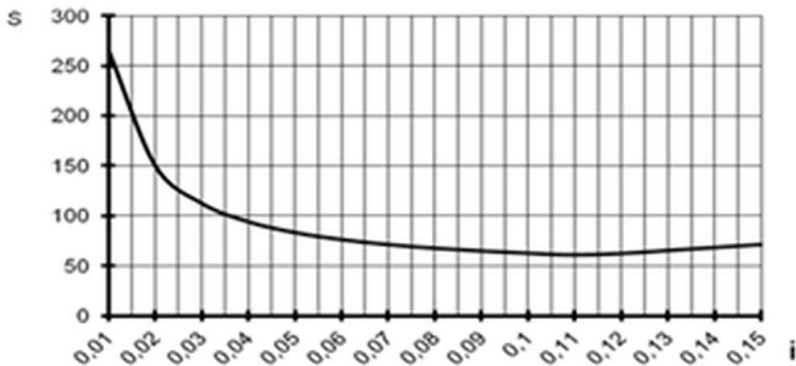
Fig. 6. The real dependence of the transportation cost of price C of BelAZ-75131 dump trucks on the road longitudinal slope i

Minerals transportation is one of the most important option to get profit by mining enterprises. The great importance is not only the amount of operating costs for transportation, but also the amount of profit received for a certain period and this is the key factor. Consequently, it is impossible to assess the rational slope of the mineral transportation, using only one transportation cost. Thus, for example, the increase in a slope when transporting a mineral, compared with a slope where the cost is minimal, will lead to the increase in operating costs; but due to the increase in efficiency of mining dump trucks, the total profit from the mineral transportation for a certain period of time increases. The dependence of the

planned profit from the mineral resource transportation on the road longitudinal slope has the form of a parabola inverse to the X-axis of the cost price parabola (Fig. 7).

However, the extremes of the cost and profit dependences of the road longitudinal slope coincide quite rarely. Thus, the condition to determine the rational slope during the mineral resource transportation will be written in the form:

$$i_{rat} \rightarrow P = P - C * Q = max \qquad (3)$$

where C is the cost of transportation, rub./t; P – profit from the sale of the mineral volume transported over a certain period, rub.; Q is the volume of minerals transported over the same period, i.e.
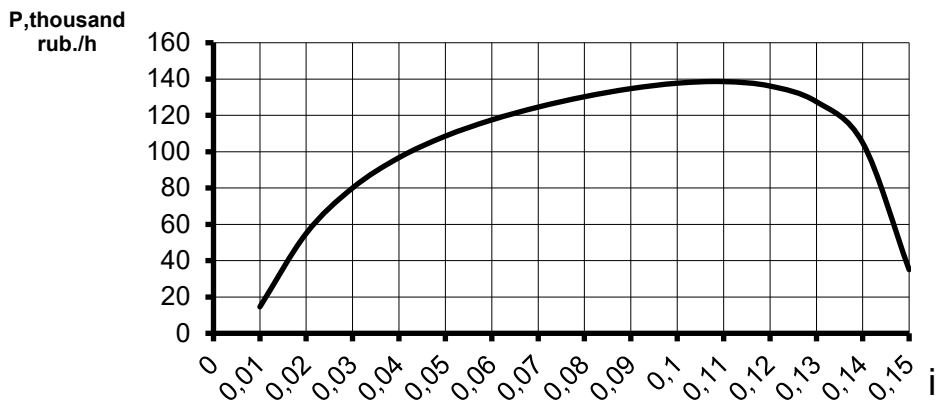
Fig. 7. The dependence of the planned profit P of BelAZ-75215 dump trucks per hour, obtained as a result of mineral transportation on the road longitudinal slope i

Conclusion

When designing and laying mountain roads, it is necessary to take into account all factors, including the ratio of the route length to its longitudinal slope. So, both of these parameters have a huge impact on the efficiency of the excavator and automobile complex, and, as a result, on the profit of the coal mining enterprise. The increased longitudinal slope increases the costs associated with the equipment operation, but when it is reduced to minimum values, it leads to the increase in the length of the route, which also affects the operating costs. The conducted researches revealed a non-linear dependence of the estimated profit of the enterprise on the longitudinal slope of a mountain road. Therefore, it is necessary to take into account the composition of the EAC and the road longitudinal slope more carefully.

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