INCREASING PIT ROAD INCLINATIONS AT HIGH LATITUDE DEPOSITS OF SOLID MINERALS

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ABSTRACT

The issue of opencast flank separation caused by necessity to locate open mining is important for excavation of deep pits. It has been proved by actual mining operations that increase or decrease in outputs of additional flank separation according to optimum stability increases or decreases amount of transported rocks by tens of millions cubic meters. One of the approaches to decrease output of excavated rocks is increase in pit road inclinations and slope angle of mining flanks according to modification of junctions. In this regard the article discusses the issues of increase in pit road inclinations. Previous studies have been analyzed. Vehicle speeds as a function of road inclinations have been predicted. Positive and negative aspects have been analyzed upon variation of pit road inclination.

Keywords: open pits, deposits, road inclinations, road pavement, road adherence, slope inclination, haul truck load capacity.

INTRODUCTION

More than 270 commercial deposits are registered in arctic zone of Arkhangelsk oblast, 30 types of minerals have been detected, about one hundred occurrences of various solid minerals have been discovered without commercial interest due to their remote location and severe climate. The most important cases are as follows:

- Manganese mineralization with P_2 forecast reserves of manganese carbonate ores in Rogachevo-Tainitskaya area, Novaya Zemlya (Yuzhny Island) of 31 billion tons, and of manganese oxide ores of 1.7 billion tons;
- Forecast reserves of copper (including native copper) only at one site of southern end of Novaya Zemlya are estimated as 3 million tons. In fact, the reserves are significantly higher;
- Pavlovskoe deposit of lead zinc silver containing ores was discovered at Bezymyannaya river basin of Yuzhny Island, Novaya Zemlya in 2002. In terms of amount and content of metals, this deposit is classified as major field, only open mining is considered.

At present three kimberlite pipes are developed by open method in Arkhangelsk diamond province. Arkhangelskaya and Karpinsky-1 pipes are developed by PAO Severalmaz, AC Alrosa, and Grib pipe is developed by AO AGD Diamonds. The depths of the first two pipes from ground level are 205 m and 160 m of daylight surface, respectively, the depth of the third pipe is 230 m. According to design regulations, the final depth of open mining is 400 m and above. It should be mentioned that several kimberlite pipes were explored in the region suitable for further diamond mining. The developed and potentially suitable for development diamond deposits in terms of climatic conditions are referred to artic zone of European area of Russia; in terms of mining, the deposits are referred to deep mines with similar technology of development, flank separation and their stability.

Grib diamond deposit is located in Mezensky district, Arkhangelsk oblast, 155 km north-eastward from Arkhangelsk. The temperature of the coldest five days is below -35°C and from time to time the temperature can be as low as -50°C. Predicted height of snow cover with 5% exceedance probability is 80 cm. The regular depth of seasonal earth freezing exceeds two meters.

Earthwork of pit roads is designed according to SNiP 2.05.07-91* Industrial transport (Construction rules and regulations SNiP 2.05.07-91*), SP 37.13330.2012 Industrial transport (Updated version of SNiP 2.05.07-91*) (Code specifications SP 37.13330.2012 Industrial transport).

All roads are generally designed on earth fills. Moderate cavities are formed in the junctions to process sites for coordination of planning concepts.

The transversal inclinations of earthwork surface are 20%, those of road-bed shoulders - 40%. The slope inclination of earthwork with the height up to 6 m is assumed to be 1:1.5. The slope inclination at the heights from 6 to 12 mm is 1:1.75 at earthwork bottom (0-6 m) and 1:1.5 at earthwork top (6-12 m). In all cases a guiding bank is arranged on pit roads. On process roads intended for traffic of haul trucks with the load capacity of 130 t, the bank height is 1.5 m. The earthworks are made using fine sands from Chernoye Deposit. In order to reinforce earthwork in the case of karsts on the designed roads, the specifications stipulate filling of cavities with clay or clay loam at the distance of 10 m to the road. The earthwork is protected against washing with surface waters by means of

ARPN Journal of Engineering and Applied Sciences

drain trenches diverting waters to lower spots and to pipes. Road pavement is made of crushed stones and sand gravel mixture (Federal law of Russian Federation No 116-FZ dated July 21, 1997; Giproruda. Construction of mining and processing plant of Grib diamond deposit, 2011).

Nowadays it is attempted to substantiate increase in inclinations of pit roads with regard to the existing specification since this increase is obviously positive (Mariev *et al*., 2011; Prosandeev, 2012; Sakantsev, 2005; Yakovlev *et al*., 2012).

METHODS

Technological road on opencast mine leads to flank flattening with regard to the angle providing its stability. The flank flattening in its turn leads to increase in output of open mining, which deteriorates economic efficiency of deposit development. Increase in inclination of junctions connecting transportation levels promotes decrease in open mining activities. This is especially important for round-shaped pits of limited dimensions on surface and bottom where automobile transport is used. This is the case of Grib deposit.

The open mining output can be determined as follows (Yakovlev *et al*., 2012):

$$V_{om}=\frac{0.5H_{pit}^{2}B_{tr}K_{rd}}{i_{lg}} \quad (1)$$

where H_{pit} is the pit depth (opening) according to the project, H_{pit} = 460 m; B_{tr} is the width of transport ramp (junction), B_{tr} = 32 m (Giproruda. Construction of mining and processing plant of Grib diamond deposit, 2011); K_{rd} is the coefficient of route development, K_{rd} = 1.5 (junction of horizontal site) (Giproruda. Construction of mining and processing plant of Grib diamond deposit, 2011); i_{lg} is the inclination limiting gradient, fractions.

The output of internal open mining V_{om}^{80} at the inclination of 80% is:

$$V_{om}^{80}=\frac{0.5\cdot 460^{2}\cdot 32\cdot 1.5}{0.08}=63{,}480{,}000\ \text{m}^3 \quad (2)$$

The output of internal open mining V_{om}^{130} at the inclination of 130% is:

$$V_{om}^{130}=\frac{0.5\cdot 460^{2}\cdot 32\cdot 1.5}{0.13}=39{,}064{,}615\ \text{m}^3 \quad (3)$$

Reduction of outputs of internal open mining ΔV_{om} upon conversion from 80% to 130% inclination is:

$$\Delta V_{om}=V_{om}^{80}-V_{om}^{130}=63{,}480{,}000-39{,}064{,}615=24{,}415{,}385\ \text{m}^3 \quad (4)$$

Reduction of outputs of internal open mining $\Delta V_{om}{}^{\%}$ upon conversion from 80% to 130% inclination in percent is:

$$\Delta V_{om}{}^{\%}=\frac{\Delta V_{om}}{V_{om}^{80}}\cdot 100=38.5\% \quad (5)$$

Let us determine such inclination of pit roads where it would be possible to run efficiently and safely the existing vehicle fleet. The predictions are based on provisions in (Yakovlev *et al*., 2012). The analysis is based on the statement that useful transportation work performed by haul truck upon upward movement is the vertical movement of load. In order to estimate the ratio of the actual road speed V_{road} and the vertical speed V_{ver} with variation of pit road inclinations, let us predict these speeds for the inclinations from 60% to 200% and plot respective curves.

The specific power of truck engine N_{sp} (Gorshkov and Tarasov, 2008) is:

$$N_{sp}=\frac{N_{eng}}{G_{tr}}=\frac{1{,}194}{237.1}=5\ \frac{kW}{t} \quad (6)$$

where G_{tr} is the weight of truck with load, t, G_{tr} = 237.1; N_{eng} is the engine power, kW, N_{eng} = 1,194.

The actual road speed V_{road} is:

$$V_{road}=\frac{0.0742\cdot N_{sp}}{f\cdot cos\propto+sin\propto} \quad (7)$$

where $\propto$ is the angle of longitudinal road profile, $\propto$ - 80% = 4.57° (Mariev *et al*., 2011); f is the coefficient of rolling resistance. Let us assume f = 0.025 (crushed stone pavement) (Burmistrov *et al*., 2016; Kozlov *et al*., 2016; Kozlov, 2017; Prosandeev, 2012; Skrypnikov *et al*., 2016a, 2016b, 2017a, 2017b, 2019);

$$V_{road}=\frac{0.0742\cdot 5}{0.025\cdot cos4.57+sin4.57}=3.54\ \text{m/s}.$$

The vertical speed V_{ver} is:

$$V_{ver}=\frac{0.742N_{sp}sin\propto}{f cos\propto+\sin\propto}=\frac{0.0742\cdot 5\cdot\sin 4.57}{0.025\cdot\cos 4.57+\sin 4.57}=0.28\ \text{m/s} \quad (8)$$

RESULTS AND DISCUSSIONS

Actual road speed and vertical speed are summarized in Table-1.

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ARPN Journal of Engineering and Applied Sciences

Table-1. Predictions of speeds.

Road inclination,% (deg)	Haul truck speed	
	V_{road}, m/s (km/h)	V_{ver}, m/s (km/h)
60 (3.43)	4.38 (15.75)	0.26 (0.94)
70 (4.00)	3.92 (14.10)	0.27 (0.98)
80 (4.57)	3.55 (12.77)	0.28 (1.02)
90 (5.14)	3.24 (11.67)	0.29 (1.05)
100 (5.71)	2.98 (10.74)	0.30 (1.07)
110 (6.27)	2.77 (9.96)	0.30 (1.09)
120 (6.84)	2.58 (9.28)	0.31 (1.11)
130 (7.41)	2.41 (8.69)	0.30 (1.12)
140 (7.97)	2.27 (8.17)	0.31 (1.13)
150 (8.53)	2.14 (7.72)	0.32 (1.14)
160 (9.09)	2.03 (7.31)	0.32 (1.16)
170 (9.64)	1.93 (6.95)	0.32 (1.16)
180 (10.20)	1.84 (6.62)	0.33 (1.17)
190 (10.76)	1.76 (6.32)	0.33 (1.18)
200 (11.31)	1.68 (6.05)	0.33 (1.19)

The curves in Figure-1 are plotted on the basis of data in Table-1.

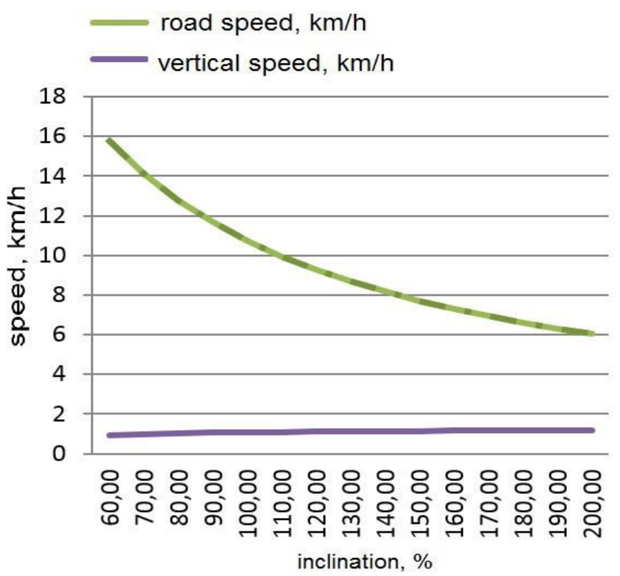

Figure-1. Actual road and vertical speed of loaded haul truck as a function of longitudinal profile of pit road.

It can be seen that the vertical speed increases the most intensively up to 160%. Therefore, the most reasonable road inclination is 160% ± 10%.

Upon travelling along roads with high inclination, the properties of cross-country ability, braking, and steering of haul trucks depend mainly on wheel to road friction. Let us determine the maximum longitudinal inclination i_{max} passed by a haul truck without wheel slippage:

$$i_{max} = (\varphi D_{fr} - f)100 \qquad (9)$$

where D_{fr} is the dynamic factor of wheel to road friction, D_{fr} = 0.65 (for haul trucks with 4×2 wheel configuration);

φ is the coefficient of wheel to road friction, φ = 0.8 (under maximum friction conditions); i_{max} = (0.8·0.65 - 0.025)100 = 49.5%.

According to the conditions of safe traffic, the friction coefficient should not be lower than 0.4. Accounting for this coefficient, let us define the safe allowable inclinations i_{all} for haul truck:

$$i_{all} = (0.4 \cdot 0.65 – 0.25)100 = 23.5\% \qquad (10)$$

On pit roads, the friction coefficient can be lower than 0.4 (wet and dirty asphalt concrete and crushed stone as well as snowed and ice sheeted road pavement). In addition, the traffic is cyclic and assumes multiple passing of inclinations during working shift. In this regard, it would be reasonable to limit the maximum inclination by 200% for haul trucks with 4×2 wheel configuration with the aim of safety.

Simultaneously it should be considered that the most hazardous site is a steep junction. In this regard, it is necessary to limit maximum allowable inclination in comparison with gradient. The northern regions are characterized by multiple atmospheric precipitations in the form of rain and snow. On wet dirty asphalt concrete or crushed stone pavement as well as on snowed or ice sheeted pavement, the coefficients vary as follows: f = 0.03; φ =0.25. In order to consider for this factor, let us determine the maximum allowable inclination i_{lim} on road pavement which is deteriorated due to weather factors:

$$i_{lim} = (0.25 \cdot 0.65 – 0.\ 03)100 = 13.2\%. \qquad (11)$$

According to the predictions and aiming at safety for stable movement of haul truck with 4×2 wheel configuration in pit (without wheel slippage), the maximum pit road inclination should be assumed to be 130%.

Efficient braking of haul truck is observed at the inclinations of 200…300% (working brakes) and 100…330 % (spare and parking brakes).

Increase in pit road inclinations has significant impact on truck tire loads. Therefore, for BelAZ-75131 with load it is allowed to move downwards along the inclination up to 80% and up to 150% upon upward motion. The allowable loads decrease with increase in load capacity. Thus, the BelAZ-75473 tires can bear the loads at high inclinations: downwards up to 110%, and upwards up to 280%.

In order to compare all types of rubber-tired vehicles applied in mining industry, let us predict maximum allowable inclination on road pavement the properties of which were deteriorated due to weather factor for heavy-duty trucks with all driving wheels.

ARPN Journal of Engineering and Applied Sciences

$$i_{\lim} = (\varphi D_{\text{fr}} - f)100 \qquad (12)$$

where D_{fr} is the dynamic factor of wheel to road friction, $D_{\text{fr}} = 1$ (for heavy-duty trucks with all driving wheels), $i_{\lim} = (0.25 \cdot 1 - 0.03)100 = 22\%$.

It can be seen that the use of heavy-duty trucks with all driving wheels makes it possible to increase maximum allowable inclination by about 8…9%.

For the existing vehicle fleet, it is possible to apply the junction inclination up to 130%. Another important role in safety of traffic along steep junctions is played by the properties of road pavement, namely by the friction coefficient. Table-2 summarizes the friction coefficients determined experimentally at Sarbay opencast mine (Sakantsev, 2005).

Table-2. Friction coefficients as a function of type of road pavement and travelling speed.

Road conditions	Longi-tudinal Incli-nation, %	Road speed, km/h			
		10	20	30	40
Asphalt concrete	0	0.79	0.78	0.77	0.76
Asphalt concrete (wet)	0	0.59	0.58	0.57	0.55
Cement concrete	0	0.75	0.74	0.72	0.71
Cement concrete (wet)	0	0.58	0.57	0.56	0.54
Crushed stone	0	0.63	0.63	0.61	0.59
Crushed stone (wet)	0	0.48	0.48	0.46	0.37
Soil	0	0.52	0.51	0.49	0.48
Soil (wet))	0	0.39	0.38	0.37	0.34

It follows from Table-2 that the best friction coefficient, other conditions being equal, is that of asphalt concrete pavement. The friction coefficient of asphalt concrete is by 25% higher in comparison with that of crushed stone pavement and by 5% higher in comparison with that of cement concrete.

Table-3 summarizes friction coefficient of crushed stone pit roads in winter for West pit, Kachkanar GOK (BelAZ Holding; Gorshkov and Tarasov, 2008; Kozlov *et al.*, 2016; Mackerle, 1985; Skrypnikov *et al.*, 2016a, 2016b, 2017b).

Table-3. Friction coefficient of crushed stone roads in winter (West pit, Kachkanar GOK).

Road pavement state	Longi-tudinalincli nation, %	Friction coefficient at the speed, km/h			
		10	20	30	40
Regular conditions	0	0.63	0.63	0.61	0.59
Loose snow, thickness: 10 mm	0	0.45	0.43	0.39	0.38
Loose snow, thickness: 10 mm	8	0.30	0.28	0.34	0.37
Thin ice sheet (glaze frost)	0	0.30	0.32	0.34	0.37

Output predictions of open mining with various road inclinations (80…200%) are summarized in Table-4.

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Table-4. Reduction of internal mining outputs upon conversion to steeper road inclinations.

Limiting gradient,%	Amount of internal open mining, m^3	Reduction of internal open mining (in comparison with the inclination of 80%), m^3	Reduction of internal open mining (in comparison with the inclination of 80%), %
80	63,480,000	0	0
90	56,426,667	7,053,333	11
100	50,784,000	12,696,000	20
110	46,167,273	17,312,727	27
120	42,320,000	21,160,000	33
130	39,064,615	24,415,385	38
140	36,274,256	27,205,744	43
150	33,856,000	29,624,000	47
160	31,740,000	31,740,000	50
170	29,872,941	33,607,059	53
180	28,213,333	35,266,667	56
190	26,728,421	36,751,579	58
200	25,392,000	38,088,000	60

It follows from Table-4 that the effect of decrease in open mining output due to increase in the limiting gradient of pit route decreases upon conversion to steeper inclinations. Thus, upon conversion from 90% to 100% inclinations, the decreased output with regard to route construction with 80% inclination is 9%, and upon conversion from 180% to 190%, inclination is only 2%. Hence, it is possible to conclude that the highest effect of internal open mining output will be observed upon increase in inclinations from 80% to 145%.

However, increase in pit road inclinations leads to modification of operation conditions of vehicles, to decreased adherence, to increased braking length, that is, to reduced safety of vehicle operations including more frequent repairs of these vehicles.

CONCLUSIONS

Therefore, in general terms the results of increase in road inclinations are as follows: reduced distance of transportation of mined rock and increased depth of excavation without expansion of open pit surface boundaries; decrease in open mining by increase in slope gradients of mining and nonmining flanks of opencast; convex shape of flank at opencast bottom which also decreases open mining activities. Yet, it is required to perform detailed studies of controllability of haul trucks upon motion along steep pit roads, which agrees with previous opinions concerning this topic.

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