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EFFICIENT USING OF AUTOMOBILE TRANSPORT FOR THE DEEP OPEN-PIT MINES

Summary. In the paper the method is proposed of substantiation of the major parameters for zones of effective use of automobile transport of different load-carrying capacity by open cast development of the deep deposits. An efficient ratio is determined between the mining and transport equipment by zone-by-zone use.

ЭФФЕКТИВНОЕ ИСПОЛЬЗОВАНИЕ АВТОМОБИЛЬНОГО ТРАНСПОРТА ДЛЯ ГЛУБОКИХ КАРЬЕРОВ

Аннотация. В статье предлагается метод обоснования основных параметров для зон эффективного использования автомобильного транспорта различной грузоподъемности для открытой разработки глубоких месторождений. Эффективное соотношение определяется в зависимости от горного и транспортного оборудования горной промышленности и транспортного оборудования для каждой зоны его использования.

State of the use of vehicles on the large open-pit mines of Kazakhstan

Annual production of large mines in Kazakhstan, such as Akzhalsky, Zhayremsky, Karagaylinsky, Zhetygarinsky, Altyntausky, Sokolovsky, Sarbaisky, Kacharsky is 8 - 80 million m^3 of mining mass. Some of these deposits have reached a depth of 450 m and use mainly automobile transport. Technological complexes generally consist of downhole excavators, automobile transport inside the open pit, which transports the rock mass to the reloading station, excavators of the reloading station, automobile transport, which transports the rock mass from the reloading station to the dump of waste rock or to the mineral warehouse [1, 2].

By developing the top of the open pit heavy dump trucks were effective. At the middle area of the open pit good results are shown by the dump trucks with average load-carrying capacity. At short distances of transportation (to the reloading points), they demonstrate greater speed and better maneuverability. Reloading points are the link between the downhole and lifting facilities of transport. Their parameters are determined by the type of equipment used for reloading and its productivity. At the lower zone of open pit the dump trucks are effective with a lower load-carrying capacity, but having a short base, greater specific capacity for overcome the steep slopes [3].

Areas of the effective functioning of each type of the transport system are determined by the minimum volume of the stripping, excavated during the formation of the transport communications, the minimum dimensions of sites for reloading points and minimum current costs for transportation of the

rock mass at the open pit in whole. It is necessary to withstand the rational conditions of application of the separate components of the transport system [4-6].

Economic-mathematical model of the **automobile transport** work at the **deep open-pit mines**

Proceeding from the above requirements, the efficient parameters of the zones of effective functioning of the excavator-automobile systems are determined on the basis of economic-mathematical model, the target function of which can be written as:

$$C_{\text{у.т}} = f(C_{\text{э}}, C_{\text{п}}, C_{\text{1a}}, C_{\text{2a}}) \to \min, \tag{1}$$

where $C_{\text{у.т}}$ are the current unit costs for loading and transportation of rock mass, \$/m^3; $C_{\text{э}}, C_{\text{п}}$ - the current unit costs for the extracting-loading and reloading works, \$/m^3; C_{1a}, C_{2a} - the current unit costs for transportation of rock mass to the reloading points and from the reloading point to destination place correspondingly, \$/m^3.

The quantitative indicators for the ore, the stripping and the mineral average content at the ore serve as restrictions, which can be represented as:

$$\sum_{i=1}^{I} Q_{p.i} \geq Q_{p.пл}, \qquad \sum_{j=1}^{J} V_{вск.j} \geq V_{вск.пл}, \qquad \frac{\sum_{k}^{K} Q_{ik} a_{1ik}}{\sum_{k}^{K} Q_{ik}} - a_{2i} \leq \Delta a_i, \tag{2}$$

where $Q_{p.i}, Q_{p.iё}$ is an ore amount of the *i*-th excavator and the *j*-th complex correspondingly, m^3; $V_{вск.j}, V_{вск.пл}$ is the same for the stripping, m^3 ; Δa_i is an allowed deviation of content of the *i*-th component in ore; a_{1ik} - an average content of the useful component of the *i*-th type at the *j*-th face; Q_{ik} - amount of the excavated ore of the *i*-th type at the *k*-th face.

Expediency of application of the excavator-automobile complexes (EAC) of various capacities with zone-by-zone using of the dump trucks of the different load-carrying capacity is determined from the condition:

$$\sum_{n=1}^{m} Z_{общ} \geq \sum_{n=1}^{m} Z_{общк}, \tag{3}$$

where $Z_{общ}$ is the total cost for mining-transportation operations with application of one-type automobile transport, \$; $Z_{общк}$ - the total cost for mining-transportation operations with zone-by-zone using of the dump trucks of the different load-carrying capacity, \$.

For the given EAC the open pit's efficient zone will be the zone, where the total cost for mining-transportation operations will be minimal.

The problem is solved with using the simulation method in the following sequence. At first the pre-border of the EAC application without using of the inside-open pit reloading point is determined. Then the pre-border of a combination of EAC with the reloading points is determined. Next, the effectiveness of the EAC operation with the different capacities is evaluated depending on the height of lifting, and the areas are determined for their efficient use. By the problem's implementation the combination of EAC was considered, adduced at the table 1.

Technical and economic indices of the searched options by application of the considered types of EAC were determined for the model open pit, developing the mineral deposit with capacity of 80 m, length of up to 3.0 km, the pitch angle of 85^0 and depth of 600 m. Rocks (ore) of the open pit are strong (f>12), dry and stable.

Table 1

Combination of the excavator-automobile complexes

№	Model of the excavator			Model of the dump truck (load-carrying capacity, t)
1	EKG-5A	EKG-8I	EKG-10	BelAZ-7547 (l/c 45 t)
2	EKG-5A	EKG-8I	EKG-10	BelAZ-7555 (l/c 55 t)
3	EKG-8I	EKG-10	EKG-12	BelAZ-7557 (l/c 90 t)
4	EKG-10	EKG-12	EKG-15	BelAZ-7512 (l/c 120 t)
5	EKG-12	EKG-15	EKG-20	BelAZ-7517 (l/c 160 t)
6	EKG-15	EKG-20	EKG-30	BelAZ-75202 (l/c 200 t)
7	EKG-20	EKG-30	EKG-32	BelAZ-75501 (l/c 280 t)
8	EKG-20	EKG-30	EKG-32	BelAZ-75600 (l/c 320 t)

Computer simulation of the EAC operation and its analysis

Search of the possible options of EAC was carried out by the iterations of the mining-transportation equipment of Russian and Belarusian origin [7, 8]. In order to identify an effective combination of excavators and dump trucks, the work has been simulated of EAC, presented at the table 1. The simulation results for the complex of the ECG-12-BelAZ-7512 are presented at the tables 2 - 4.

Table 2

Magnitudes of the current unit costs for mining-transportation operation by application of EKG-12-BelAZ-7512 depending on the open pit's depth and amount of the dump trucks, $/m^3

	Depth of the open pit, m									
K	**60**	**120**	**180**	**240**	**300**	**360**	**420**	**480**	**540**	**600**
2	1,23	1,59	2,04	2,48	2,95	3,43	3,93	4,28	4,62	5,49
6	1,03	1,34	1,72	2,07	2,35	2,82	3,17	3,59	4,03	4,67
10	0,99	1,26	1,62	1,97	2,23	2,63	2,99	3,37	3,79	4,36
14	0,96	1,26	1,60	1,90	2,22	2,60	2,95	3,26	3,67	4,22
18	0,95	1,24	1,59	1,90	2,21	2,59	2,91	3,21	3,61	4,11
22	**0,93**	1,24	1,56	1,90	2,20	2,57	2,88	3,19	3,57	4,03
26	0,96	**1,22**	1,55	1,88	2,19	2,55	2,84	3,15	3,53	3,94
30	1,00	1,26	**1,54**	1,86	2,19	2,52	2,83	3,14	3,49	3,89
34	1,02	1,30	1,56	**1,85**	2,18	2,50	2,82	3,12	3,46	3,83
38	1,02	1,34	1,60	1,86	**2,16**	2,48	2,80	3,11	3,44	3,79
42	1,06	1,37	1,63	1,86	2,17	**2,46**	2,79	3,10	3,42	3,74
45	1,08	1,39	1,65	1,88	2,18	2,48	**2,77**	3,09	3,40	3,71
48	1,11	1,41	1,68	1,88	2,19	2,50	2,79	**3,07**	3,38	3,71
52	1,12	1,46	1,70	1,90	2,20	2,52	2,80	3,11	**3,38**	3,69
56	1,14	1,49	1,73	1,93	2,21	2,52	2,82	3,15	3,40	**3,68**
60	1,18	1,53	1,75	1,96	2,23	2,56	2,86	3,23	3,44	3,72

Analysis of the table 2 data shows that the current unit costs for mining-transportation operation by a fixed number of the dump trucks increase with the open pit's depth. By the fixed depth of the open pit with the increasing number of the dump trucks they are reduced to a certain magnitude (the numbers are bold), then, by a further increase in the number of dump trucks, they are rising again, i.e. the current unit costs have an optimum. These laws are general in nature, i.e. they are valid for any combination of excavator-dump truck.

Interesting results are revealed by the study of the EAC productivity, depending on the depth of lifting and the number of the serving dump trucks. As can be seen from the table 3 data, by the given number of dump trucks the EAC productivity decreases with increasing depth of the open pit. For a fixed depth of the open pit it increases with the number of dump trucks. Fairly high stable productivity of the complex is provided with a combination of the excavating-loading and transportation equipment, determined according to the table 2 data (the numbers are bold). Thus, the efficient combination of the loading and

transport equipment, determined by the criterion (a minimum of current unit costs for mining-transportation operation) provides the necessary productivity of EAC in these conditions.

Table 3

Annual productivity of EAC - EKG-12 - BelAZ-7512 depending on the open pit's depth and amount of the dump trucks, ths.m^3

	Depth of the open pit, m									
K	**60**	**120**	**180**	**240**	**300**	**360**	**420**	**480**	**540**	**600**
2	2578	2022	1581	1289	1084	938	821	762	702	644
6	7443	5801	4600	3809	3193	2813	2461	2285	2080	1934
10	12014	9640	7589	6299	5332	4688	4131	3780	3369	3135
14	16291	13069	10519	8644	7443	6447	5743	5186	4600	4248
18	**17343**	16262	13273	11106	9494	8233	7384	6593	5948	5478
22	17907	**17464**	15764	13390	11486	9962	9025	7911	7238	6593
26	18402	17871	**17450**	15441	13449	11808	10548	9377	8497	7794
30	18519	17669	17835	**17258**	15324	13566	12072	10812	9845	8996
34	18607	17815	17914	17620	**16995**	15178	13538	12219	11047	10168
38	18724	17903	17978	17669	17512	**16731**	15016	13566	12365	11340
42	18870	18049	18028	17786	17611	17495	**16439**	14856	13684	12482
45	18929	18137	18049	17874	17698	17581	17423	**15882**	14533	13421
48	19016	18196	18137	17962	17786	17669	17523	17047	**15383**	14240
52	19133	18343	18254	18079	17903	17786	17640	17493	15991	**15295**
56	19281	18460	18373	18225	18020	17932	17757	17611	17376	15597
60	19369	18577	18490	18314	18137	18049	17874	17728	17581	17258

To select the optimum ratio of the loading-transport equipment by analogy with the calculations for the complex of the ECG-12 - BelAZ-7512, the magnitudes of the minimal unit current costs are determined for various combinations of EAC. They are adduced at the table 4 depending on the depth of rock mass lifting.

Table 4

Magnitudes of the minimum unit current costs for the base options of EAC depending on the depth of lifting, $/m^3

EAC options	**Depth of the open pit, m**									
	60	**120**	**180**	**240**	**300**	**360**	**420**	**480**	**540**	**600**
EKG-5A - BelAZ-7547	0,81	1,08	1,36	1,64	1,93	2,23	2,54	2,86	3,18	3,51
EKG -8I - BelAZ-7555	0,83	1,11	1,40	1,69	1,99	2,29	2,60	2,91	3,23	3,55
EKG -10 - BelAZ-7557	0,89	1,19	1,48	1,78	2,08	2,39	2,69	3,00	3,31	3,63
EKG -12 - BelAZ-7512	0,93	1,22	1,54	1,85	2,16	2,46	2,77	3,07	3,38	3,68
EKG -15 - BelAZ-7517	0,97	1,28	1,60	1,91	2,22	2,53	2,83	3,13	3,43	3,73
EKG -20 - BelAZ-75202	1,00	1,33	1,65	1,97	2,29	2,60	2,90	3,18	3,49	3,78
EKG -30 - BelAZ-75501	1,08	1,42	1,75	2,08	2,40	2,71	3,01	3,31	3,59	3,87
EKG -32P- BelAZ-75600	1,11	1,46	1,80	2,13	2,45	2,76	3,06	3,35	3,64	3,91

As can be seen from these data, for all combinations of EAC with increasing depth of the open pit the current unit costs for mining- transportation operation increase. By the fixed depth of the open pit they increase by using of the more powerful excavator-automobile complexes. These conclusions are entirely consistent with the practical data of mining enterprises with the open-cast minerals mining.

Efficient use zones of the EAC with the various capacities

Existing methods for determining the depth of transition from one type of automobile transport to another do not take into account the potential of zone-by-zone use of the excavator-automobile complexes of various capacities. To fill this gap and to identify the rational operation zones of EAC of various capacities, the work of the dump trucks was simulated with load-carrying capacity from 45 to 90 tons by transportation of rock mass to the inside-open pit reloading point and of the dump trucks with a load-carrying capacity from 120 to 320 tons for transportation from the point to the day surface. The current unit costs for mining-transportation operation were defined by the height of lifting of 480 m for the different combinations of EAC, which are shown at the table. 5. We have considered three options of rock mass transportation.

In the first option the lifting of rock mass without zoning is carried out only by the dump trucks with load-carrying capacity of 200 t. In the second case, by the two-zoned application of the auto transport the options were considered of combination of the 200-45, 200-55 and 200-90 t dump trucks. Height of lifting for the first row of machines varied from 360 to 120 m, for the second row - from 120 to 360 m. In the third option with three-zoned using of vehicles a combination was considered of the 200-90-45, 200-120-45 and 200-120-55 t dump trucks. Height of lifting for the first, second and third row of machines is adduced at the table 5 (the first column).

Table 5

Current unit costs for mining-transportation operation by the height of lifting of 480 m

Zone height, m	Combination of dump trucks load-carrying capacity, t		
1 zone	**200t**		
480m	3,17		
2 zones	**200t-45t**	**200t-55t**	**200t-90t**
360m/120m	2,80	2,81	2,87
300m/180m	2,81	2,82	2,89
240m/240m	2,83	2,84	2,90
180m/300m	2,84	2,85	2,91
120m/360m	2,85	2,86	2,92
3 zones	**200t-90t-45t**	**200t-120t-45t**	**200t-120t-55t**
240m/120m/120m	3,02	3,15	3,17
180m/180m/120m	3,03	3,16	3,16
120m/240m/120m	3,03	3,18	3,18
180m/120m/180m	3,04	3,18	3,19
120m/180m/180m	3,05	3,20	3,20
120m/120m/240m	3,05	3,22	3,23

As can be seen from the table 5 data, each of the considered options of EAC has its technological and economic benefits in certain areas of functioning. For example, by a lifting height of 480 m from the above-mentioned options when using one type of vehicles it is appropriate to use heavy dump trucks with load-carrying capacity of 200 tons, when using a two-zone it is appropriate to use combination of the dump trucks with load capacity of 200-45 tons and when using three-zone – the combination of the dump trucks with load capacity 200-90-45 t.

Among all three zones for development of the open pit with depth of 480 m the most advantageous is two-zone using of transport with application of the dump trucks with load capacity of 200 t at the upper zone with height of 360m and the dump trucks with load capacity of 45 t at the lower zone with height of 120 m.

The main technical and economic indices of the transport operation by a single-type and the zoned using of the dump trucks of various capacities with a lifting height of 480 m are adduced at the table 6.

Table 6

Technical and economic Indices of the modeling open pit

with a lifting height of rock mass at 480m

Indices	Options of EAC		
	200 t	200 t	200 t-90 t-45 t
Zones height (top / middle / lower), m	480м	360м /120м	180м/180м/120м
Open pit's dimensions on the bottom, m	300 × 80	300 × 80	300 × 80
Open pit's dimensions on the surface, m	1586×1396	1253×1034	1220×1012
Width of transport exit, m	30	30 - 22	30 - 20 - 17
Slope angle of the final board of open pit, degree	43,8	45,3	45,9
Volume of the rock mass, mln. m^3	226,12	211,74	203,91
Current unit costs, $/$m^3$	3,17	2,80	3,03
Total costs, mln.$	312,57	248,30	248,91

Based on the implemented study and the experience of the mining enterprises with application of automobile transport, by analogy with [9], it seems appropriate to divide the open-pit mines by their depth at: the shallow open-pit mines with depth of up to 240 m; the deep open-pit mines with depth of 480 m; the ultra-deep open-pit mines with depth up to 600 m (fig. 1). The latest ones consist of three zones correspondingly, where the own effective combination of the excavator-automobile complexes of different capacities are presented. Each marked area is characterized by certain operating conditions of the open pit vehicles.

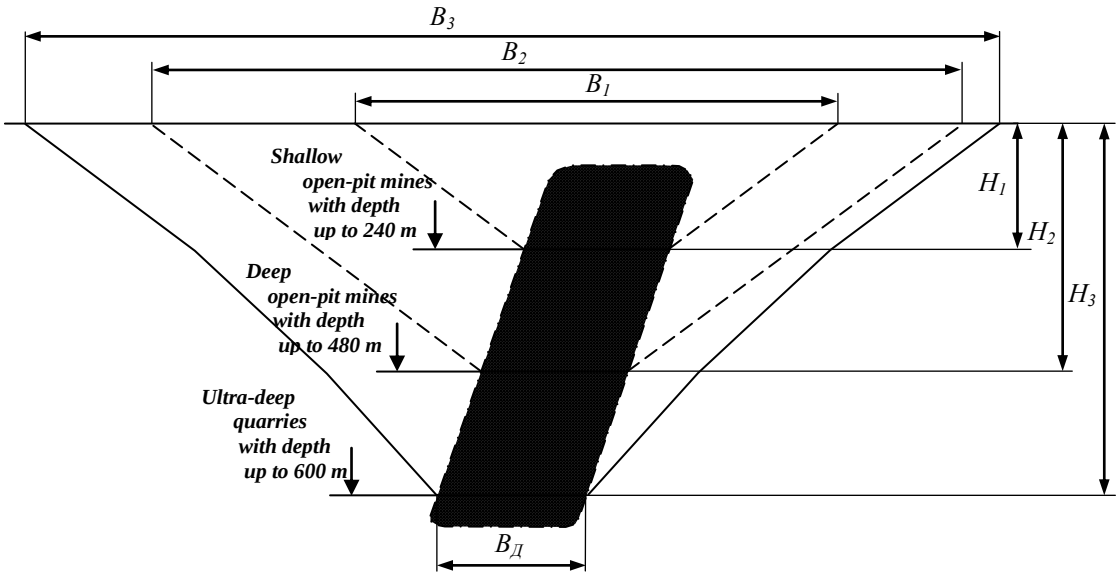

Fig. 1. Zoned distribution of the excavator-automobile complexes in the deep open-pit mines
Рис. 1. Зонное распределение экскаваторно-автомобильных комплексов в глубоких карьерах

CONCLUSION

1. At the shallow open pit with depth up to 240 m with an annual volume of transportation till 15 million tons the mining-transportation operation is appropriate to carry out without division of the open pit into zones using excavators with the bucket capacity of 3-12 m^3 and the dump trucks with load capacity of 30-120 tons, depending on the depth of lifting.

2. At the deep open-pit mines with depth up to 480 m, with an annual volume of transportation till 50 million tones the mining-transportation operation is appropriate to carry out with division of the open pit space into two zones in height. At the upper zone of 180-360 m in height the excavators with the bucket capacity of 10-20 m^3 and the dump trucks with load capacity 90-200 t should be used, at the open pit's lower zone of 60-180 m in height the excavators with the bucket capacity of 5-10 m^3 and the dump trucks of 45-90 t should be used.

3. At the ultra-deep open-pit mines with a depth up to 600 m, with an annual volume of transportation

till 80 million tones the mining-transportation operation is appropriate to carry out with division of the open pit space into three zones in height. At the upper zone of 180-360 m in height the excavators with the bucket capacity of 20-32 m^3 and the dump trucks with load capacity of 200-320 t should be used, at the middle zone of the open pit with 120-240 m in height – the excavators with the bucket capacity of 10-15 m^3 and the dump trucks with load capacity of 90-160 t, at the lower zone of 60-180 m in height the excavators with the bucket capacity of 5-10 m^3 and the dump trucks with load capacity of 45-90 t should be used.

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