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Design of a New Technology for Stockpile of Open Pit Dumps During Integrated Development of Man-Made Waste

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***Abstract* – In case of open-pit mineral resources mining development on the earth's surface, there is an accumulation of overburden rocks, the volume of which is comparable to the size of the open pit being developed. This is especially relevant when developing large and medium-sized deposits using high-performance equipment, since these deposits typically have high stripping ratios. At the same time, overburden rocks are stored in waste rock dumps without regard for their further use and are practically not used for the production of finished products, with the exception of some quarries of building materials. The waste rock dumps from mining enterprises contain many useful components that can subsequently be extracted and used to produce new products. One of the ways to create waste rock dumps complex is to use container technology for waste rock dump formation at the open pit. The rock delivered from the open pit will be loaded into containers and lifted to the unloading site using a special lifting machine. Based on the theoretical research carried out, container technology was developed for separate storage of rock mass on dumps for subsequent use and the developed working equipment was tested using computer modelling methods. Increasing the boom length will allow the rock to be lifted to a significant height, which will reduce the area occupied by waste rock dumps and ensure the separate placement of rocks with different physical and mechanical properties for their comprehensive processing. Conducted studies have shown that transporting rock to a waste rock dump using containers reduces energy consumption and the cost of the process. Another advantage of the new method of storing rock mass is the reduction of dust emission during the operation of mining equipment on dumps.**

***Keywords* – Container technology; environmental impact; external waste rock dumps; integrated use; lifting machine; mining waste storage; overburden; transportation and storage costs.**

1. INTRODUCTION

Pollution of the natural environment by industrial waste is one of the biggest modern problems [1]. The mining industry is one of the leaders in this area. During the production of any type of mining product, it is necessary to extract a significant amount of unused mineral

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mass. Moreover, due to a number of natural causes, the conditions for mining are constantly deteriorating, which leads to an inevitable increase in waste rock formation.

During open-pit mining, it is possible to use not only the mineral, but also the overburden, which contains rocks such as chalk, limestone, sand, clay, loam, and rock. Most overburden can be used in a variety of ways: quaternary loams can be used as a material for creating an impermeable screen; sand can be used in factories producing bricks, wall blocks, and other building structures; and coarse sand can also be used in foundries; chalk is suitable as a component in the production of lime, cement, and paints and varnishes. After processing at a chalk plant, it can be used in the chemical, paper, perfume, and other industries. Rocks are ideal for the production of crushed stone for the needs of the construction industry [2]. This allows to reduce waste accumulation while generating additional profit from product sales.

The main advantages the idea of using mining waste to update the mineral resource base are:

- mining and geological conditions for the development of most mineral deposits are decreasing in quality composition, so the introduction of mining waste into circulation will become economically feasible;
- the extracted mine rock laid in temporary dumps is already separated from the empty rock mass and only needs to be transported to the processing plant; in this case, there is no need to carry out expensive mine operations;
- the environmental situation in the mine area is improving; mining waste is being disposed of and the problems of reclamation of the developed territories are being solved [3]–[8].

World practice in the extraction of minerals in open and underground ways shows that many scientists dealt with the issues of the possibility of using mining waste [5], [8], while proposing new technologies for the production of building materials, progressive methods for extracting secondary mineral resources, processing waste from processing plants, burying waste of hazardous classes and their use as stowing material in underground mining. The use of solid waste from the mining industry, as well as tailings obtained after processing rare–earth ores, will sufficiently reduce the cost of construction products and materials [3], [6]–[8].

To reduce costs during subsequent processing of waste and reduce losses of useful components, it is necessary to separate storage of overburden rocks. At the moment, this technology has not yet been developed, so we will analyse the existing methods of storing rock in dumps.

The technology of placing waste rock in an external dump is closely related to the method of its transportation. Automobile, railway, conveyor transport led to the creation and development of bulldozer, excavator and conveyor methods of dumping. The main operation in these methods is the lifting of the rock by dump trucks, trains or conveyor to the upper platform of the dump tier and unloading directly downhill or into the pit of the dump excavator, which lays the rock in the dump. Therefore, the efficiency of dumping is mainly determined by the cost of lifting the rock [9].

From this point of view, road and rail transport are not optimal as lifting devices due to the high container ratio (up to 0.8–0.9). These are trunk modes of transport. In other words, a dump truck weighing 80 tons and a payload capacity of 85–87 tons raises 62–63 tons of ballast per trip compared to a skip lift with a skip tare ratio of 0.2 [10].

A serious disadvantage of using wheeled vehicles on dumps is the difficulty of operating roads and railways due to the low bearing capacity of the dump surface.

Reception of rock at railway dumps is carried out with additional energy–intensive excavation of the rock, at bulldozer dumps – with additional movement of the rock by a bulldozer. In addition, the operation of transport and dump equipment near the prism of a possible collapse reduces the safety of work.

Environmental problems in the use of open pit vehicles have several directions [11]–[17]:

- air pollution of open pits at emission of exhaust gases by diesel engines;
- dust release during blowing from the surface of the rock mass in the body and from the interaction of the wheels of cars with the surface of roads;
- dust release from the surface of external dumps of empty rocks;
- increased land areas for placement of external dumps and withdrawal of these areas from agricultural turnover for long periods.

The purpose of this study is to create an energy-efficient, environmentally friendly and economical technology for storing rock in dumps in order to be able to reuse it to obtain new products.

2. METHODS AND METHODOLOGY

Existing technologies [6], [7] allow for the separate storage and subsequent processing of no more than 20 % of mining waste [8], so there is a pressing need to develop a new technology for placing rock in waste dumps that ensures the separate storage and subsequent use of the rock mass.

It is proposed to use the existing edge of the external waste dump to create a storage area, with a contour of clayey overburden built up next to it. This prevents water from getting inside. The resulting space will be used to store hazardous overburden, the dump layout for which is shown in Fig. 1. The boom's long length will also allow for separate storage for subsequent use.

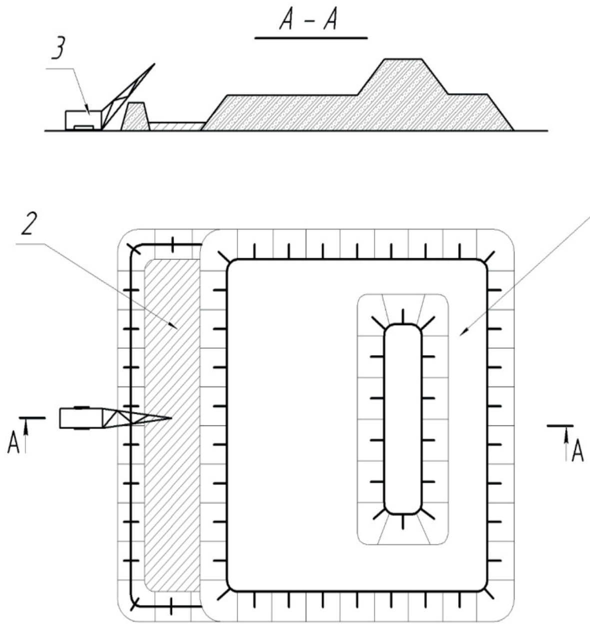

Fig. 1. Scheme of waste rockdumps (1 – overburden dump, 2 – filled rock, 3 – lifting machine).

To create an embankment, place rocks, and ensure their separate storage, it is proposed to use container technology. The key element of the technology is a mobile lifting machine, which eliminates the need to build roads or railways on board and on the surface of the dump.

The technological scheme for creating waste dumps of man–made rocks is sufficiently reliable and flexible [3], [18]. This allows for a gradual increase in lifting height, the distribution of lifting equipment throughout the dump, and the distribution of rock into different types, which will allow for its future use [19]–[23].

Thanks to the use of a new set of equipment, the height of the blade can be increased, which will lead to a reduction in its area. This will yield significant environmental and economic benefits [9].

Container technology will change the order of work, while simultaneously reducing the height of the rock mass due to its layer–by–layer horizontal stacking [24], [25]. The large dimensions of the boom of the lifting machine will allow for an increase in the volume of rock mass placed within the dump area. The safety of mining operations will be achieved due to the absence of transport communications on the surface of the dump [26]–[28].

The walking excavator, which is widely used in mining operations, best meets the proposed requirements of container technology. The design of the lifting machine is shown in Fig. 2.

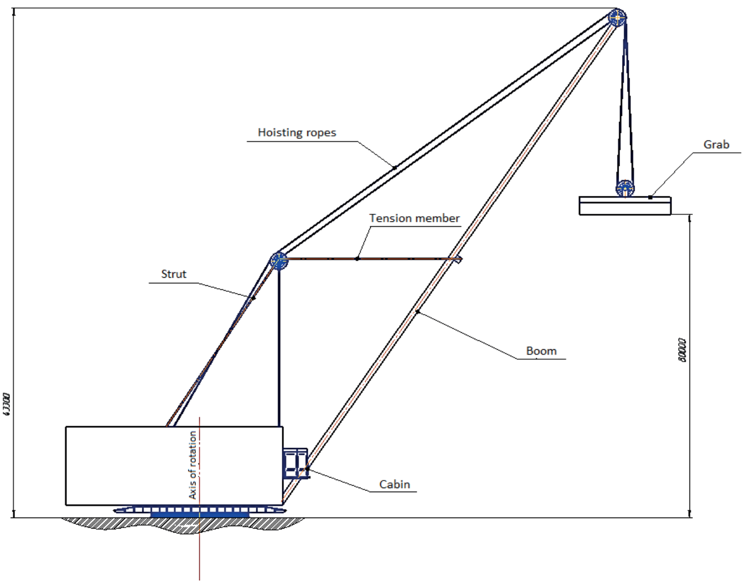

Fig. 2. Design of a lifting machine based on a walking excavator.

To determine the parameters of the dump when storing various mining waste, it is necessary to determine its height and the volume of the stope. For specific linear parameters of the lifting machine, safety conditions and properties of the stored rock, it is of interest to optimize the tilt angle of the lifting machine boom [29], [30].

The unloading radius R_u, m, is determined by the formula (1) [29]:

$$R_u = L_c \cos(\gamma) + d\,, \tag{1}$$

where

L_c is the length of the lifting machine boom, m;

γ boom tilt angle of the machine, deg.;
d is the distance from the lifting machine's axis of rotation to the heel of boom, m.

The dump height, H_{dump1}, m, by condition container unloading is determined by the formula (2):

$$H_{dump1} = L_c \cdot \sin(\beta) + h - h_k - S_2, \quad (2)$$

where
β dump slope angle, deg;
h height heel of boom axis above ground level, m;
$h_к$ container height in unloading position, m;
S_2 safe distance between container and dump during unloading, m

The height of the dump H_{dump2}, m, according to the safety condition of rotation the lifting machine is determined by the formula (3):

$$H_{dump2} = (R_u - W - S_1 - R_b)\,\mathrm{tg}(\beta), \quad (3)$$

where
S_1 safety distance between the machine body and the dump slope, m [30];
R_b machine body rotation radius, m.

A lower value is taken as the final height of the dump.
The stope width, W_s, m, is determined by the formula (4) [10]:

$$W_s = 2R_p, \quad (4)$$

Receiving capacity of stope R_c ths. m^3 between movements of the lifting machine is determined by the formula (5):

$$R_c = W_s HtS / 1000, \quad (5)$$

where
S step of movement of the lifting machine, m.

Reducing the number of technological equipment on spoil dump will reduce the cost of dumping by reducing the number of employees, reducing fuel consumption, and reducing depreciation charges. The reduction in cost price when implementing container technology for waste rock formation will be determined by the formula (6):

$$C = \left(C_{exp.base} - C_{exp.cont}\right) / A_{open\ pit}, \quad (6)$$

where
$C_{exp.\ base}$ total operating costs with the existing technology, million tenge;
$C_{exp.cont}$ total operating costs for container technology, mln. tenge;
$A_{open\ pit}$ open pit overburden capacity, million m^3.

The movement of mining equipment on the surface of the dumps and the operation of the equipment causes a large emission of dust, which worsens the environmental situation in the region. The introduction of container technology will significantly reduce the intensity of dust emission from the operation of process equipment at the dump J, mg/s, which is determined by the formula (7):

$$J = K_{un} \times K_g \times \sum\left(1 - K_{ef}\right) \times F_i \times m_i, \quad (7)$$

where

K_{un} coefficient of unaccounted sources;
K_g coefficient of the season, for the warm season;
K_{ef} efficiency factor of dust suppression by types of equipment;
F_i intensity of dust and gas emission during operation of one source;
P_i coefficient of simultaneous operation of similar mechanisms;
m_i number of similar dust emission sources.

3. RESULTS

Filling containers with rock mass at quarry dumps is possible by direct transfer from dump trucks from an overpass or through an intermediate bin using a plate or belt feeder. Transferring rock mass from a dump truck into a container ensures high productivity, but is associated with high impact loads on the container and severely limits the dump truck's lifting capacity. This method is suitable for trucks with a lifting capacity equal to the containers, and for finely lumped rock.

The most universal scheme is the one shown in Fig. 3. According to this scheme, the rock mass is delivered from the faces by dump trucks of any carrying capacity and unloaded into the hopper of an apron or belt feeder, which fills the containers as they are fed by the quarry lifting machine. A disadvantage of this system is the reduced container filling rate. To eliminate this drawback, an empty container is placed on a feeder by a lifting machine and fed for loading. The hoist, on the other side of the feeder, picks up the loaded conveyor and transports it to the dump for unloading. Installing a feeder on an excavator’s crawler track will provide the necessary mobility for the complex when moving it.

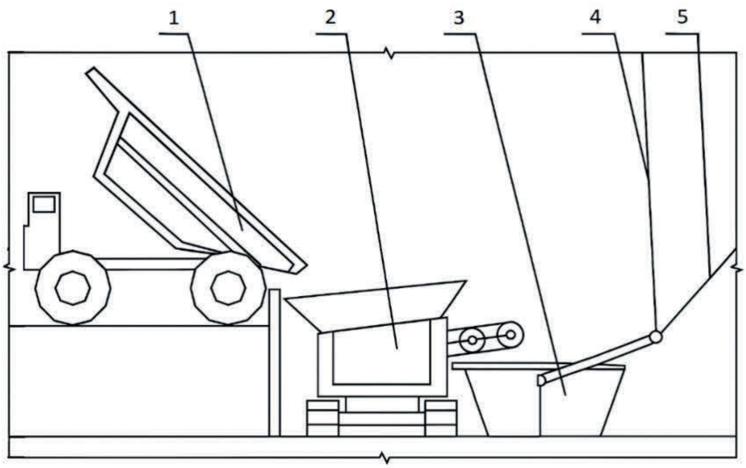

Fig. 3. Technological scheme of transferring mined rock (rock mass) from a dump truck to the hoisting machine container. (1 – dump truck, 2 – feeder with hopper, 3 – container, 4 – dragline hoist rope, 5 – lifting machine pull rope).

Based on the developed procedure for determining the dump parameters, the dependence of the receiving ability of the waste dumping on the angle of inclination of the lifting machine boom was obtained, which is given in Fig. 4.

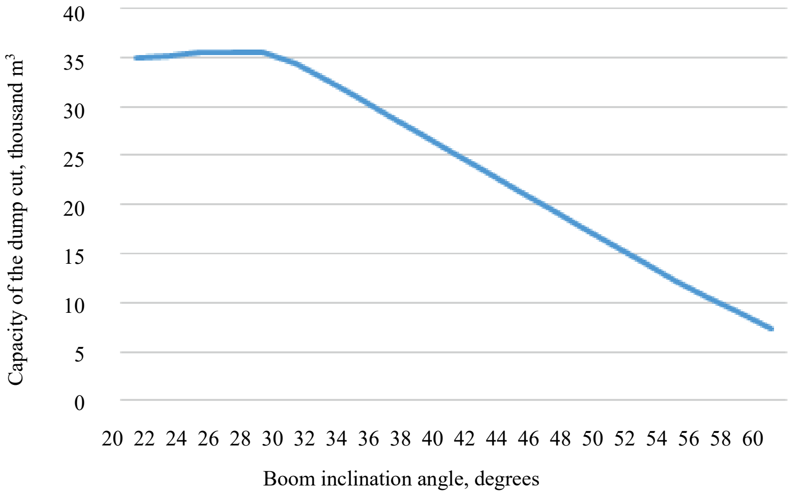

Fig. 4. Dependence of stope receiving capacity from boom inclination angle.

Analysis of the diagrams shows that the maximum receiving capacity of the stope (35.6 thousand m^3) is achieved with an inclination angle of the boom of the lifting machine of 280. The stope width is 113 meters, four times greater than with excavator dumping. The tier height will be 30 meters.

To deliver the rock mass to the dump, it is proposed to equip the lifting machine with a grapple that will transport interchangeable containers. The container with the grapple during unloading is shown in Fig. 5.

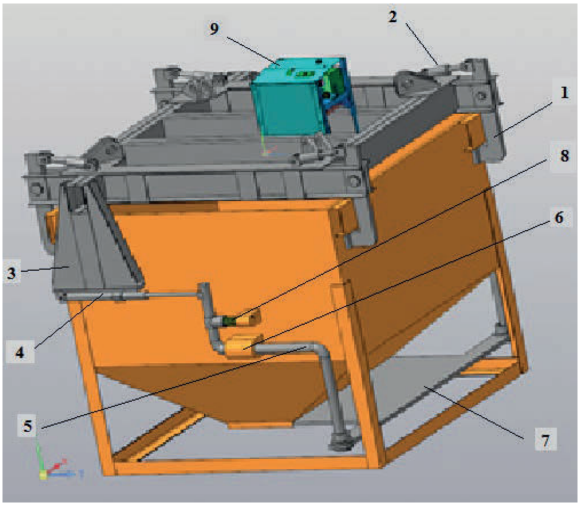

Fig. 5. Container with grip during unloading. (1 – container grippers, 2 – container gripper system control hydraulic cylinders, 3 – brackets for mounting container bottom opening hydraulic cylinders, 4 – bottom opening hydraulic cylinders, 5 – bottom opening lever system, 6 – lever guides, 7 – container bottom, 8 – container bottom closing springs, 9 – hydraulic control station for the gripper).

The container is gripped using holding levers 1, which are rotated using control hydraulic cylinders 2. Hydraulic cylinders 4 are installed in brackets 3, acting on the container lever system 5. The levers move in guides 6, causing the container bottom 7 to move in a horizontal plane, while the cargo is poured out due to its own weight. The bottom is returned to its original position by spring 8, which is attached to a stop on the vertical wall of the container. A hydraulic station 9 is installed on top of the longitudinal beams of the gripper, ensuring the operation of all hydraulic cylinders of the gripper.

A patent for an invention was granted by the Republic of Kazakhstan for the container and grapple design. The advantages of the developed equipment are its reliability, simplicity of design, the ability to transport large-sized cargo, the ability to unload from a low height, and precise placement at the required storage location. The lever system allows for complete unloading of the container and quick return to its original position. This equipment will be easily manufactured by the mining company itself.

When designing the container, computer modelling methods were widely used. Strength calculations were performed using the software suite using the Solidworks Professional software suite. The result of modelling deformations of container metal structures is shown in Fig. 6.

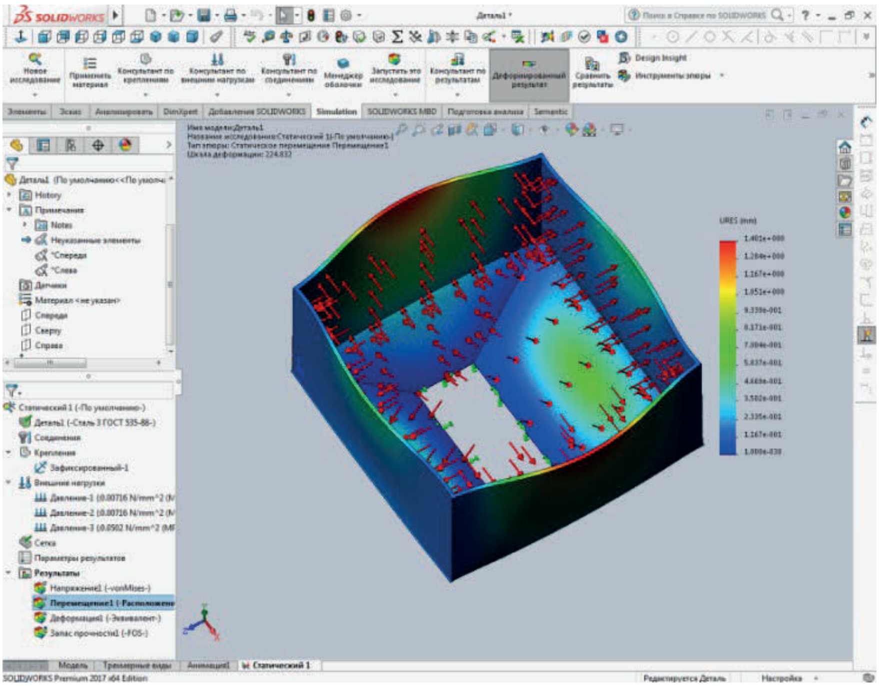

Fig. 6. Simulation of container wall deformations when it is loaded with rock.

To estimate the reduction in waste disposal costs, the equipment requirements for different waste dump construction technologies were calculated. The technology of laying rock using bulldozers was adopted as the basic one, the developed container technology is the design one. The results of calculating the amount of equipment on dumps with different technologies are given in Table 1.

TABLE 1. THE AMOUNT OF EQUIPMENT REQUIRED FOR STACKING ROCKS INTO WASTE HEAPS USING DIFFERENT STORAGE TECHNOLOGIES

Equipment	Basic version using bulldozer dump formation	Design option with containers
Dumptrucks Cat-777D	12	7
Bulldozers	1	–
Lifting machine	–	2
Overloading facility	–	2
Containers	–	6

Operating costs were calculated for various technologies for transporting and laying rock mass on external dumps, the results of which are given in Table 2.

TABLE 2. DEFINITION OF OPERATING COSTS

Cost item	Base cost option, million tenge	Project cost option, million tenge
Wages	290.8	297.5
Depreciation charges	2325.6	2131.72
Repair costs	1744.2	1598.6
Electricity costs	–	748.4
Fuel and lubricant costs	3266.5	1760.9
Operating costs	7627.1	6537.12

The introduction of the new technology will reduce the harmful impact on the ecology of the region due to a decrease in dust emissions from equipment operating at the dump, calculation results presented in Table 3.

TABLE 3. DETERMINATION OF DUST EMISSION INTENSITY WITH DIFFERENT OPTIONS FOR CREATING DUMPS

Equipment	Intensity of dust emission when using bulldozer dumping, mg/s	Dust emission rate during container technology of rock laying, mg/s
Dumpers Cat-777D	28 800	16 800
Bulldozers	1200	–
Transhipment complex	–	864
Total	30 000	17 664

4. CONCLUSION

Any mining enterprise engaged in open-pit mining should operate with minimal waste generation. It is necessary to organize storage and subsequent processing of overburden rocks at the mining enterprise, and when laying the rock in a dump, it is necessary to isolate harmful waste that requires special storage methods to create environmental safety in the region.

To solve all these issues, it is proposed to use container technology for separate laying of rocks in a dump. The main element of the technology is a mobile lifting machine, while there is no need to build roads or railways on board and on the surface of the dump.

The rock mass delivered from the quarry is loaded into containers, which are delivered by lifting machines immediately to the place of unloading. Containers are equipped with the possibility of self-unloading, as a result of which the rock is poured directly into the place of laying on the dump.

When using container technology, the cost of transportation is reduced due to a decrease in the unloading time of vehicles, therefore, the productivity of the entire complex of equipment for lifting rock mass increases.

The safety of mining operations will be achieved by the absence of transport communications on the surface of the dump. The rock will be automatically discharged at the required point on the surface of the dump, then the empty container is delivered back to the loading area by a lifting machine.

Container lifting allows you to solve some problems of rock dumping:

– rock mass lifting is carried out using hoisting machines, which reduces energy consumption compared to transportation by road;
– the long boom length of the hoisting machine allows to significantly increase the height of the dump tier and the width of the stope;
– height of rock mass lifting is reduced due to its layer-by-layer horizontal laying.

Container technology solves a wide range of issues related to improving the environmental situation in the field area. The introduction of container technology will reduce environmental dust emissions that arise from the movement of dump trucks on the surface of the dump. Due to the reduction of equipment equipped with internal combustion engines on dumps, the emission of harmful gases is significantly reduced.

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