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## CONTAINER TECHNOLOGY FOR TRANSPORTING ROCK MASSES IN QUARRIES

**Purpose.** To justify and develop the theoretical bases of the formation and operation of the container technology for moving mining mass from quarries, which ensures a reduction of economic and energy costs, as well as damage to the environment during the extraction of mineral resources.

**Methodology.** The work used complex research methods, including analysis and scientific synthesis of scientific and technical information; theoretical research; methods of mathematical and computer modeling, and design developments.

**Findings.** The analysis of existing technologies for open-pit mining and the current state of mining indicates an urgent need to develop new resource-saving technology and environmentally friendly technologies for moving rock mass for open-pit mining. A new technology for container transportation of rock mass in containers is proposed without the construction of additional transport communications in the quarry and has technological and energy-saving advantages.

**Originality.** The scientific novelty of the research consists of an integrated and systematic approach to assessing the energy efficiency and environmental safety of the proposed set of equipment for container technology for transporting rock mass.

**Practical value.** In this work, special attention is paid to the problem of the formation and effective use of a new resource-saving and environmentally friendly container technology for moving rock mass from deep quarries. These advantages are simultaneous excavation of rocks, transportation of rocks over the shortest distance, low container packing ratio, and mobility of a complex of lifting machines, which will reduce energy consumption and the cost of transporting rock mass. A transport complex has been developed to ensure the reliable operation of lifting and transport machines.

**Keywords:** *open pit mining, container technology, lifting machine, excavator-transport complex*

**Introduction.** The open-pit method for developing mineral deposits in the mining industries of many countries occupies a dominant place, as it is safer and more economical today. It accounts for up to 75 % of the total volumes of mineral extraction in the world (in the USA – 83 %, in the CIS countries – about 70 %) [1]. As the depth of quarries increases, road transport becomes the bottleneck in open-pit mining, since the increase in depth is accompanied by a complication of the profile of quarry routes. The purpose of the work is to substantiate and develop the theoretical foundations for the formation and functioning of container technology for moving rock mass from quarries, ensuring a reduction in economic, and energy costs, and also environmental damage during mining.

A large number of studies have been devoted to the interaction of single-bucket excavators with vehicles [2–6]; however, they do not have a clear universal methodology for selecting a set of equipment taking into account the most significant factors in mining operations: distances of rock mass and elevation; physical and mechanical properties of rocks (specific gravity, loosening coefficient, humidity, stickiness, etc.); characteristics of the rock mass in terms of fracturing, explosiveness, and expected yield of oversized materials; the applied development system and the parameters of its elements: height of the working ledge, width of the working platform, parameters of rock collapse after the explosion; the length and speed of advancement of the work front; water cut content of the rock mass and the method of its drainage; dumping method and dump parameters.

**Literature review.** The resulting indicator of the low efficiency of existing technological schemes in quarries is the productivity of mining and transport equipment reduced by 1.5–

2 times relative to the nameplate or theoretically possible. In this case, the main share of lost time consists of:

- for an excavator – waiting for transport;
- for transport – waiting for loading and loading time [7].

The release of excavator productivity reserves is possible due to the complete elimination of waiting for transport, transport productivity reserves - due to the complete elimination of waiting for loading and a manifold reduction in loading time [8].

The last factor – loading time – in conventional technologies is associated with the ratio of the capacity of the excavator bucket and the capacity of the dump truck body or its carrying capacity. Research using technical and economic models has established the optimal ratio of these parameters as 4–6 buckets (excavation cycles) per body. In a real quarry, it is quite difficult to maintain this ratio for several reasons due to:

- diversity in the faces of the properties of the shipped rock mass;
- variability of transportation conditions (delivery distances, lifting heights);
- various intensities of renewal of the mining and transport equipment fleet during long periods of quarry operation.

In real conditions of open-pit mining, it is necessary to take into account the energy interrelation of technological processes. The required degree of crushing by explosion depends on the choice of technological scheme for transporting rock mass in large quarries, the need for additional crushing in the quarry by mechanical means, the frequency of energy-intensive re-excavation at transfer points and at the dump, the type, length and complexity of servicing transport communications, etc. A comprehensive assessment of the energy efficiency of rock mass transportation is impossible without a comprehensive accounting of energy costs in related technological processes [9].

When moving rock mass from quarries to external dumps, a number of contradictions accumulate that cannot be resolved using existing technologies. An increase in the depth of quarries leads to an increase in the haulage arm, which necessitates the transition to dump trucks with a higher load capacity. Increasing the load capacity of dump trucks violates the optimal ratio of the capacity of the bucket of a downhole excavator and the capacity of the body. To reduce downtime of expensive dump trucks, it is recommended to increase the capacity of the excavator bucket [2].

In the operation of road transport, as the quarry deepens, a redistribution of functions occurs; it is used less and less as an assembly vehicle and increasingly performs the work of lifting rock mass along the side of the quarry [10]. When a loaded dump truck moves uphill, fuel consumption increases significantly, which leads to an increase in the cost of road transportation and at the same time the volume of pollutant emissions into the atmosphere from the engine of a working dump truck increases [11], which leads to unplanned downtime of the entire complex of mining operations due to poor ventilation.

Current trends in the development of traditional transportation technology lead to a reduction in mined ore reserves, an increase in the unit cost of 1 ton-km of road transportation, an increase in air pollution and a reduction in the production capacity of the quarry [12]. In order to reduce transportation costs, much attention has recently been paid to the introduction of cyclic flow technology (CFT) in quarries. The experience of using CFT shows that the main reasons for the low efficiency of the technology are: the bulkiness of the equipment, long periods and the high cost of constructing stationary transfer points [13]. In addition, the disadvantages of the CFT include the increase in the height of the working area of the quarry and the length of transportation by road during the construction of transfer points on the new concentration horizon, the high cost of construction and operation of conveyor lifts, and the negative impact on the mining regime of the conserved sections of the quarry walls with CFT objects.

The most economical compared to motor transport is a skip lift, which provides a minimum tare coefficient and uses a cheaper type of energy [14]. The main disadvantages of this technology include high capital costs, stationarity and the difficulty of increasing the lifting depth without replacing the entire lifting machine complex. When using this type of transport, the pit side is preserved, and significant ore reserves located under the lift have to be left for excavation at a later period.

To solve all the identified problems, it is proposed to use container technology when transporting rocks. The main element of the technology is a mobile lifting machine, without the need to build roads or railways [15] on a permanent quarry side.

Ore delivered from the quarry is loaded into containers, which are transported directly to the unloading site by lifting machines. The containers are equipped with the ability to self-unload, as a result of which the rock mass is poured directly into the place of placement on the dump [16].

When using container technology, the cost of transportation is reduced due to a decrease in the time of unloading vehicles [17], therefore, the productivity of the entire complex of rock mass lifting equipment increases.

The effectiveness of using a container ship in container technology for open-pit mining lies in reducing economic losses from vehicle downtime during loading and increasing the productivity of the excavator. The operating cycle of a container ship does not include downtime during loading, unlike dump trucks and railway trains [18].

**Methods.** The lifting machine is located on the platform of the upper ledge outside the prism of a possible collapse. The container is located on the lower platform of the ledge and the lifting machine moves it to the platform of the upper ledge, from where, through an exchange point, it is fed under the next lifting machine [19].

To implement the above, a number of schemes have been developed that differ in terms of application by methods for loading or installing containers, by types and methods for moving platforms. This work used complex research methods, including analysis and scientific synthesis of scientific and technical information; theoretical research; methods of mathematical and computer modeling, and design developments.

An empty container can be filled with rock mass directly on the platform from the overpass by unloading it from the body of a dump truck (in accordance with Fig. 1). At the same time, the presence of a mobile platform will ensure the independence and safety of the operation of the dump truck and lifting machine.

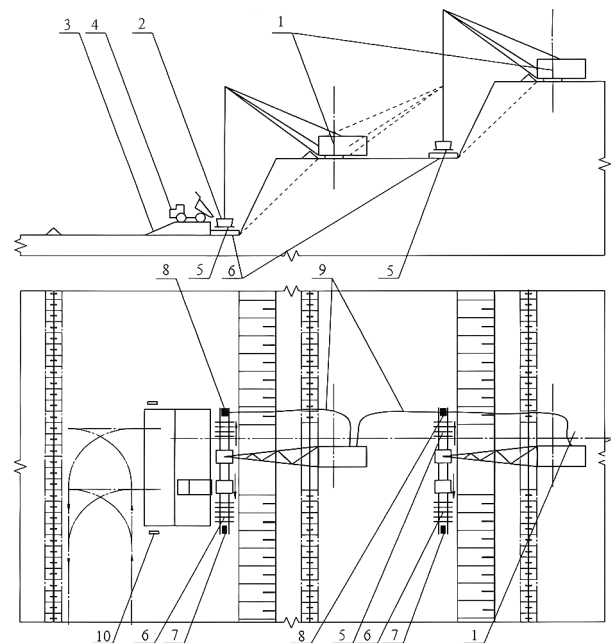
A similar scheme can be used when delivering loaded containers by container ships (in accordance with Fig. 2). In this case, the mobile platform allows the exchange of containers between the container ship and the lifting machine to be carried out safely.

The platforms are self-propelled, with electric motors and current collectors; the movement of the platforms at each container installation site is controlled by lifting machines using an electrical voltage regulator with an extended lever.

The mobile platform can ensure the safe operation of adjacent lifting machines. With a high intensity of work, it is possible to use several mobile platforms for one lifting machine. Ring feeding of platforms can be organized. There may be several installation points for loaded containers.

In the simplest version of a mobile platform, its movement can be carried out using a reversible traction winch. The winch can be controlled by the operator of the mining hoist.

When there are more than two platforms in one complex, it is advisable to use self-propelled platforms. In this case, there may be two options for driving platforms. The traditional option is to supply energy via a contact line to an electric motor installed on the platform. The second option is a linear electric motor installed on a railway track; the platform moves due to an alternating electromagnetic field, similar to the well-known conveyor trains with an electromagnetic drive.



*Fig. 1. Scheme with reciprocating movement of platforms on a railway track using a cable-controlled winch from the operator's cabin of the hoisting machine:*

- 1 – lifting machine; 2 – container; 3 – overpass; 4 – dump truck;*
- 5 – mobile platform on a railway track; 6 – railway track; 7 – winch; 8 – winch return rope block; 9 – winch control cable; 10 – remote control unit for platform movement*

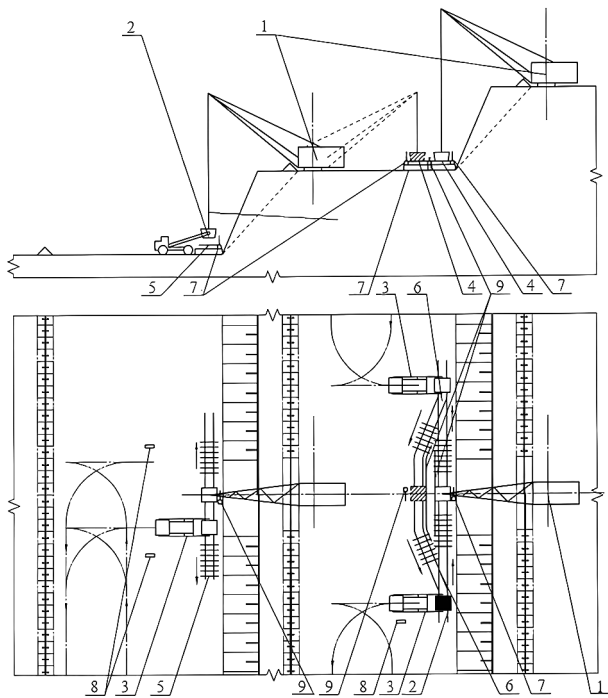


Fig. 2. Scheme with reciprocating movement of platforms on the lower horizon and the circular movement of platforms at the site for the exchange of containers with dead ends and switches on the flank sections of the railway route:

1 – lifting machine; 2 – container; 3 – container loader (boom, reach stacker); 4 – mobile platform on a railway track; 5 – railway track; 6 – turnout; 7 – block section of the contact line; 8 – regulator of electrical voltage or current in the contact line (with an extended lever); 9 – remote control unit for platform movement

Containers at pick-up and uncoupling points are installed on mobile platforms and the movement of platforms with containers at the re-coupling sites is controlled from a lifting machine. The platforms have a railway track. The platform with the container is moved using a winch and a traction rope or using an electric motor placed on the platform and powered through a current collector from the contact line. If the boom length of the lifting machine is short, the drive mechanism of the mobile platform is switched on and off from the control panel of the lifting machine via an electric cable. Changing the direction of movement of the platform is carried out by reversing the traction winch, which has a return rope and an additional block.

With a large (40–50 m) length of the boom of the lifting machine and a large distance (60–70 m) from it to the container transfer site, turning on and off the drive mechanism of the mobile platform is performed by pressing the load-handling device of the lifting machine on the switch lever of the drive mechanism of the platform movement mechanism. The drive switch for the platform movement mechanism is placed in the operating area of the lifting machine's load-handling device and is equipped with an extended lever. An electrical voltage or current regulator in the contact line is used as a switch for the drive of the platform movement mechanism, which reduces the electrical voltage or current to a value insufficient to drive its running electric motor to stop the platform.

To increase productivity and independence in the operation of adjacent lifting machines on board the quarry, sections of the railway tracks are laid on the container interchange site parallel to each other and connected on the flanks by turnouts with dead ends to change the direction of movement of the platforms. Dead-end points for changing the direction of movement and automatic turnouts ensure the continuous movement of platforms to the areas of installation and removal of containers by lifting machines, and the switches are

switched after the platforms reach a dead end, and the reversal of the platform electric motor is performed by changing the polarity of the electric current in the contact line. Control of the transfer of railway switches is interlocked with the movement of platforms with containers in adjacent block sections. The contact line is divided into block sections with separate voltage supply.

The electrical voltage supply line of each block section is equipped with a relay regulator, which, when an electric current passes through a given block section, automatically reduces the voltage or current in the block section preceding the platform in the direction of movement to a value insufficient to drive the platform's running electric motor. This is necessary to prevent the platforms from colliding and impacts. The fact that a platform with a container moves along a block section or is in a blocked state on a block section is determined by the fact of the passage of electric current in the power line supplying this block section. The block sections where containers are installed and removed from platforms are controlled from the operator's cabin of the lifting machine.

With a short boom length and short distance, this can be done using a cable connecting the lifting machine and the contact line power supply regulator. With the large length of the boom of the lifting machine and the large distance from it to the container transfer site, the power supply mode of the contact line can be controlled by pressing the voltage or current regulator lever in the contact line using the load handling device of a lifting machine. The regulator is placed in the operating area of the load-handling device and is equipped with an elongated lever.

In the lower zone of the quarry, it is advisable to use simplified options for moving platforms with containers. This is a short section of the railway track at the container interchange site and two or three platforms with a railway chassis installed on the railway tracks. The platforms are moved by a rope using a winch with reverse. The control panel for turning on the traction winch drive is located in the lifting machine and is connected to the winch by a cable. The second option provides for the presence of a contact line on a section of the railway track and platforms with a current collector and an electric motor. In this case, the mode of supplying electrical voltage to the contact line is controlled from the operator's cabin of the hoisting machine via cable. The movement of the platforms is controlled by changing the electrical voltage and current or by changing the polarity of the electrical current in the contact line.

The traction winch or the supply of voltage to the contact line can be controlled through a special switch located in the range of the lifting machine's load-handling device and equipped with an extended lever. The winch is turned on or voltage is supplied to the contact line by pressing the load-handling device on the switch lever. Dead-end points for changing the direction of movement of platforms can be used to fill containers with rock mass or to replace empty containers with loaded ones. To do this, overpasses or platforms for forklifts are installed on the flanks of the route. At each point of filling containers or replacing empty containers with loaded ones, the movement of platforms is controlled remotely from a remote control from the driver's cab of a dump truck or loading mechanism operator.

**Results.** At intermediate sites, containers at pick-up and uncoupling points are installed on mobile platforms and at the re-coupling sites they are controlled from a lifting machine. The platforms have a railway track.

For propulsion, it is planned to use wheel sets of freight cars with possible modification of the design. The number of pairs depends on the static load on the axle. The weight of the frame is structurally assumed to be 1,000 kg. The mass of the installed drive is approximately assumed to be 4,000 kg. The weight of the loaded container is 45,000 kg. This total weight of a loaded container was selected based on the maximum carrying capacity of currently existing semi-trailers that are used

for transporting containers. Obviously, a trailer or semi-trailer with a larger load capacity could be developed.

The static load,  $P_{st}$ , per the axis is determined by the dependence

$$P_{st} = \frac{m_t \cdot g}{n}, \quad (1)$$

where total mass of self-propelled trolley on a railway track

$$m_t = m_f + m_d + m_c + n \cdot m_w,$$

where  $m_f$  is frame mass,  $m_f = 1,000$  kg;  $m_d$  – drive mass,  $m_d = 4,000$  kg;  $m_c$  – mass of the loaded container;  $m_c = 61,000$  kg;  $n$  – the number of wheelsets, assumed to be 4;  $g$  – acceleration of gravity.

In terms of static load, the RUIISH-957-G wheel pair for mainline 1,520 mm gauge railways with the following parameters is accepted: static axle load – 235 kN; mass of the wheelset with axle units with cylindrical roller bearings  $m_w = 1,379$  kg.

Due to the fact that when installing a connector on a platform it is difficult to determine which wheel pair will be loaded more, formula (1) gives the average axle load.

$$m_t = 1,000 + 4,000 + 45,000 + 4 \cdot 1,379 = 55,516;$$

$$P_{st} = \frac{55,516 \cdot 9.81}{4} = 136.$$

In order for the self-propelled trolley drive to ensure its movement along the rails, it is necessary that the power of the electric motors be sufficient to overcome the total resistance to movement.

Delivery of containers from the quarry face to the transfer sites is carried out by container truck cars. Next, the container is reloaded onto the self-propelled trolley.

For further calculations, we use well-known formulas [20], supplemented by selecting parameters from publicly available standards. Machine engine power  $N_e$ , kW, is determined by the formula

$$N_e = \frac{F_t v}{10^3 \cdot \eta_{tr}}, \quad (2)$$

where  $F_t$  is total resistance force [N];  $v$  – speed of self-propelled trolley,  $v = 1.6$  [m/s];  $\eta_{tr}$  – mechanical efficiency of the transmission;  $\eta_{tr} = 0.85$ .

The total resistance to movement,  $F_t$ , is determined by the formula

$$F_t = F_f + F_s + F_w, \quad (3)$$

where  $F_f$  is friction resistance in the chassis, which takes into account both friction in the axle boxes and resistance to wheel rolling;  $F_s$  – force to overcome resistance when moving uphill. This force is explained by the fact that in real conditions it will not be possible to lay a perfectly horizontal rail bed; most likely there will be a slight slope;  $F_w$  – wind load resistance, which will be maximum if the wind blows along the rail bed.

Friction resistance in the chassis when moving along a rail track is determined by the formula

$$F_f = k_f m_t g \frac{f \cdot d + 2\mu}{D}, \quad (4)$$

where  $\mu$  is the coefficient of rolling friction of running wheels on flat head rails,  $\mu = 0.0006$ ;  $f$  – the coefficient of friction in rolling bearings of running wheels,  $f = 0.015$  m;  $D$  – wheel diameter along the rolling circle,  $D = 0.957$  m;  $d$  – trunnion diameter,  $d = 0.13$  m;  $k_f$  – the coefficient taking into account the friction resistance of the flanges of the running wheels,  $k_f = 2$ .

$$F_f = 2 \cdot 55,516 \cdot 9.81 \cdot \frac{0.015 \cdot 0.13 + 2 \cdot 0.0006}{0.957} = 3,585.$$

The resistance due to the slope of the rail bed is determined by the formula

$$F_s = m_g \cdot \sin(\alpha), \quad (5)$$

where  $\alpha$  is track slope,  $\alpha = 3^\circ$ .

$$F_s = 55,516 \cdot 9.81 \cdot \sin 3^\circ = 28,502.$$

The total wind load is determined by the formula

$$F_w = p \cdot A, \quad (6)$$

where  $p$  is distributed wind pressure, Pa;  $A$  – estimated windward area,  $m^2$ .

$$p = q \cdot k_a \cdot c \cdot n_a, \quad (7)$$

where  $q$  is dynamic wind pressure, taken  $q = 125$  Pa for wind speed 14 m/s;  $k_a$  – the coefficient taking into account the change in dynamic pressure along the height above the earth's surface is taken  $k_a = 1.0$ ;  $c$  – aerodynamic force coefficient,  $c = 1.2$ ;  $n_a$  – overload factor, for operating condition  $n_a = 1$ .

Accordingly,

$$p = 125 \cdot 1 \cdot 1.2 \cdot 1 = 150.$$

The calculated windward area consists of the side surface of the container  $6.32 m^2$  and the structural surface of the trolley frame  $0.47 m^2$ . Thus  $A = 6.32 + 0.47 = 6.79 m^2$ .

$$F_w = 150 \cdot 6.79 = 1,019.$$

We finally determine the total resistance to movement according to formula (3)

$$F_t = 3,585 + 28,502 + 1,019 = 33,106.$$

Now we can determine the required total drive power according to formula (2)

$$N_e = \frac{33,106 \cdot 1.6}{10^3 \cdot 0.85} = 62.32.$$

The designed drive of the movement mechanism provides for the installation of two identical electric motors, each of which must have the power  $N$

$$N > (0.5 \div 0.6) N_e = 31.16 \div 37.39.$$

Based on the obtained values, the equipment for the transport scheme of the container interchange point is designed.

A general view of the designed self-propelled trolley on a railway track for moving a container is shown in Fig. 3. According to the calculations performed to determine the power of the travel motor and the design of the drive, the following equipment was adopted:

- electric motor MTKN(F)511-6PND/4MTKM225M6 PND: rated power  $N_d = 37$  kW; rotation speed  $n = 930$  rpm; moment of inertia of the rotor  $I_p = 0.75$  kg ·  $m^2$ ; high-speed shaft diameter – 70 mm;

- gearbox type VKU-965M with gear ratio  $U = 25$ ;
- brake TKG-500 OST24.290.08-82: brake pulley diameter – 400 mm; braking torque – 1,500 N · m.

The selection of the cross-section of metal structures was carried out using computer modeling methods. In previous

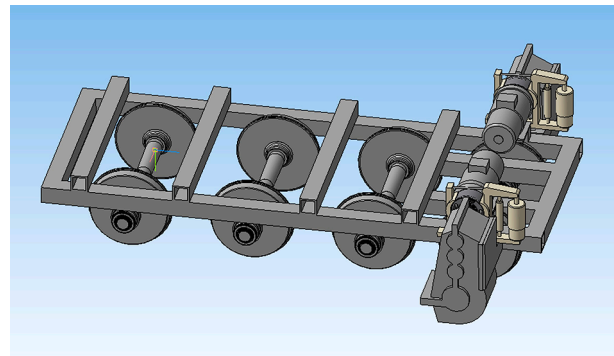


Fig. 3. General view of a self-propelled trolley on a railway track

calculations, the same load on each axle was assumed, which is a primary approximation.

**Discussion.** Delivery of containers from excavator faces to the lifting site is carried out by container truck cars. Car engine power  $N_e$ , kW, can also be calculated using the formula (2). The calculation should differ in a slightly higher speed of movement  $v = 15$  km/h (4.17 m/s) and a different mechanical efficiency of the transmission;  $\eta_{tr} = 0.8$ .

A Hilton Haulage semi-trailer with the Steeblro Sidelifter can be chosen as a possible technical solution for transporting a loaded container. This semi-trailer is shown in Fig. 4. These semi-trailers are manufactured to order from Kazakhstan. Their advantage is the possibility of lateral reloading of containers weighing up to 45 tons.

To calculate the engine power of a tractor-trailer, we will use the following parameters:

1. Approximate mass of the tractor-trailer is 52,470 kg.
2. Semi-trailer tare mass is 12,600 kg.

Then the total mass of the loaded container truck car will be equal to

$$m_c = 52,470 + 12,600 + 45,000 = 110,070.$$

Formula (3), intended to determine the total resistance to movement, can be applied again, with the only difference that the resistance to the oncoming air flow compared to other components will be so small that it can be ignored.

Instead of formula (4), a fairly simple formula can be used to determine the rolling resistance of car tires

$$F_f = f_r m_c g. \quad (8)$$

In this formula, the rolling resistance coefficient  $f_r$  (dimensionless, not to be confused with the rolling friction coefficient) depends on the condition of the road surface, car tires, and many other parameters, such as road temperature, tire pressure, degree of wear, etc. According to various literature sources, for roads in open-pit mines this coefficient can be taken equal to 0.075 (dirt road after rain). Then

$$F_f = 0.075 \cdot 110,070 \cdot 9.81 = 80,984.$$

Next, the force  $F_s$  should be determined. In this case, the maximum longitudinal slope for vehicle movement along quarry roads is assumed to be  $i = 8\%$ .

$$F_s = m_c g i = 110,070 \cdot 9.81 \cdot 0.08 = 86,383.$$

Then the total resistance to movement will be equal to

$$F_t = 80,984 + 86,383 = 167,367.$$

Finally, using formula (2), we determine the minimum engine power of the tractor

$$N_e = \frac{167,367 \cdot 4.17}{10^3 \cdot 0.8} = 872.$$



Fig. 4. Steeblro Sidelifter for transporting a loaded container [21]

As a tractor, we can choose a truck tractor based on the KOMATSU HD785-7 (Fig. 5). Various sources estimate its engine power at 1200–1300 horsepower, which when recalculated gives 883–956 kW.

In the picture shown, a coal trailer is used as a semi-trailer in this auto-train. Obviously, an adaptation of the semi-trailer with the Steeblro Sidelifter to the described vehicle will be necessary.

The technical solution described above is not exclusive. For example, container semi-trailers without a side loader can be used. In this case, special reach stackers must be used at container loading areas. These can be jib container cars widely used in container transportation – reach stackers, the maximum carrying capacity of which reaches 45–50 tons (in accordance with Fig. 6) [23].

Container technology in open-pit mining reduces the cost of transporting rock mass; therefore, when designing equipment for working at reloading sites, machines have been developed that can be manufactured at the mining enterprise itself.

Based on the results of the analysis of the performed technical and economic calculations, it was established that when replacing one dump truck with a lifting capacity of 45 tons with a container truck, the productivity of the excavator increases by 20%, and the economic effect varies depending on the distance of transportation of the rock mass. The effect is achieved due to the lower cost of a container ship compared to a dump truck and the elimination of its downtime during loading (Fig. 7).

The graph shows that the greatest efficiency is manifested at short delivery distances of a large-capacity container when the time of filling the container with rock mass is equal to the voyage time of the container ship.

The use of interchangeable containers and container carriers makes it possible for the excavator to operate non-stop even when serviced by a single container carrier. According to traditional technology, when servicing with one dump truck, excavator downtime is inevitable.

**Conclusions.** A multidimensional analysis of literary sources revealed the absence of a relationship between the increasingly complex mining technology as the depth of quarries increases and the low efficiency of existing technologies for mining and transport complexes of quarries. Against this back-



Fig. 5. KOMATSU HD785-7 mining auto-train [22]



Fig. 6. Container loader – reach stacker Terex CS 45 KM [19]

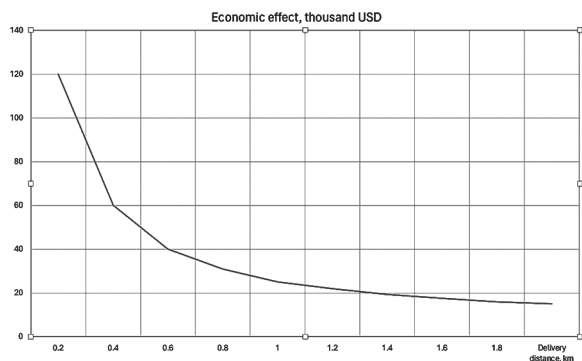


Fig. 7. Changes in economic effect when replacing one dump truck (45 t capacity) container carrier (own analysis)

ground, the development of a new resource-saving container technology for moving rock mass during open-pit mining is the main tool for increasing the efficiency of open-pit mining. To solve this problem, for the first time, the design and operational parameters of container technology for moving rock mass have been justified and developed, ensuring a reduction in environmental and energy costs when moving rock mass in deep quarries. The use of container technology reduces the cost of transportation processes by reducing vehicle downtime during loading and unloading, as well as increasing excavator productivity.

Container technology will affect the main criteria when choosing the type and size of an excavator in the excavation and transport complex, i.e. The priority may not be the time of filling the container, but the specific energy intensity of excavation, and the maximum height (depth) of scooping. It has been established that when replacing one dump truck with a container truck, the productivity of the excavator increases by 20 %, and the economic efficiency varies depending on the transportation distance (Fig. 7). This effect is achieved due to the lower cost of a container truck compared to a dump truck and the absence of downtime during loading. The research results indicate that the container technology for delivering rock mass from quarries in its parameters corresponds to the best existing domestic and foreign analogs used in transporting rock mass in quarries, and in many respects, it surpasses them.

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## Контейнерна технологія транспортування гірничої маси на кар'єрах

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**Мета.** Обґрунтувати й розвинути теоретичні основи формування та функціонування контейнерної технології переміщення гірничої маси з кар'єрів, що забезпечує зниження економічних та енергетичних витрат, а також шкоди навколишньому середовищу при видобутку корисних копалин.

**Методика.** У роботі використовувався комплекс методів дослідження, що включає: аналіз і науковий синтез науково-технічної інформації; теоретичні дослідження; методи математичного й комп'ютерного моделювання, конструкторські розробки.

**Результати.** Аналіз існуючих технологій видобутку корисних копалин відкритим способом і сучасного стану гірничого виробництва вказує на нагальну необхідність розробки нових ресурсозберігаючих технологій та екологічно чистих технологій переміщення гірської маси відкритим способом. Запропонована нова технологія контейнерного транспортування гірничої маси в контейнерах без будівництва додаткових транспортних комунікацій у кар'єрі має технологічні та енергозберігаючі переваги.

**Наукова новизна.** Наукова новизна дослідження полягає в комплексному й системному підході до оцінки енергоефективності та екологічної безпеки запропонованого комплексу обладнання контейнерної технології для транспортування гірської маси.

**Практична значимість.** У даній роботі особливу увагу приділено проблемі формування та ефективного використання нової ресурсозберігаючої та екологічно чистої контейнерної технології переміщення гірської маси з глибоких кар'єрів. Такими перевагами є одночасне збудження гірських порід, транспортування гірських порід на найкоротшу відстань, низька тароємність, мобільність комплексу підйомних машин, що зменшить енерговитрати й вартість транспортування гірської маси. Для надійної роботи підйомно-транспортних машин розроблено транспортний комплекс.

**Ключові слова:** *відкриті гірничі роботи, контейнерна технологія, підйомна машина, екскаваторно-транспортний комплекс*

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