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Logistics and environmental aspects of the formation of mining and transport systems of dump formation in deep pits using container technology

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Abstract

Improving the energy efficiency and environmental friendliness of waste disposal processes during open-pit mining of mineral deposits involves substantiating and developing a new mining and transport technology. Literary analysis combined with computer modeling based on the finite element method has made it possible to automate the work in designing container technology equipment at the design preparation stages. A new mining and transport system for waste disposal in deep quarries has been developed, which involves the use of container technology for moving rock mass in quarries, allowing for increased energy efficiency of transport systems and minimizing pollution of the quarry atmosphere. The proposed logistic scheme for transporting rock mass to dumps using container technology ensures the creation of a new energy-saving mining and transport system using quarry hoisting machines, which, in comparison with similar traditional systems, allows for a reduction in costs for lifting rock mass, a reduction in atmospheric gas pollution, and an improvement in mining modes. Container delivery of rock mass as a bulk and difficult-to-excavate material will allow for its single excavation and lifting from the quarry to the dump using quarry hoisting machines with a minimum tare coefficient.

Keywords: Container, Dump, Lifting machine, Logistics scheme, Mining and transportation system of dumping, Productivity, Transport, Ecology.

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1. Introduction

The delivery of rock mass from quarries to the dump is carried out using various types of transport, with the most common being road, rail, and conveyor systems [1, 2].

The main disadvantages inherent in traditional technologies for road, rail, and combined road-rail modes of transport [3, 4]:

- High tare ratio of self-propelled vehicles.
- Low slopes of transport communications in the quarry.
- Reduced productivity of excavator–automobile and excavator–railway complexes is due to the low availability of excavators with transport, which reduces downtime of expensive vehicles.
- The need for additional energy-intensive excavation when overloading the rock mass in intra-barrier warehouses with combined transport.
- High levels of dust formation occur during the overloading of rock mass in warehouses, as well as during transportation and dumping.
- Increased height of rock lifting to external dumps and the need for additional dumping equipment (bulldozer, excavator).
- An increase in the current stripping coefficient occurs due to a deviation in the direction of deepening the quarry from the optimal placement of transport communications and transshipment warehouses on temporary targets within the working area of the quarry.
- The complexity of automating the transportation process for lifting rock mass from a quarry.

2. Background

Currently, road transport is the most widespread mode of transport in open-pit mining operations. The best qualities of motor transport are maneuverability, autonomy, and mobility. From this perspective, the optimal application of vehicles in large quarries is the transportation of rock mass along the working horizons of the quarry, in areas of frequent blasting operations, and in the cramped conditions of deep horizons.

Modern trends in the development of quarry vehicles consist of increasing the scale of dump truck usage while enhancing their load capacity and improving fuel efficiency [5, 6]. When using dump trucks with large unit capacity in the quarry, the accuracy of operational regulation of the excavator's availability of vehicles in accordance with optimal needs is compromised. With a smooth change in the distance of delivery of rock mass from the excavator, its transport availability may change abruptly. The impact of this process on the efficiency of the excavator and automobile complex requires additional research.

The performed studies allowed us to establish, that:

- With an increase in the range of transportation of rock mass, capital and operating costs increase most intensively in conveyor transport [7], somewhat less in road transport [8], and to an even lesser extent in railway transport [9].
- As the depth of open pits increases, the relative increase in costs is inversely related, although to a lesser extent. The combined consideration of technical, technological, and economic factors affecting the comparative assessment of the efficiency of various modes of transport has made it possible to identify the preferred conditions for their use in deep pits.

The above indicates that it is very difficult to achieve the optimal cost-effective condition of excavating and automobile complexes, even within the same quarry. This is another serious drawback in the use of quarry vehicles.

The second most widespread method of transporting rock mass on the surface of quarries is railway transport, which is currently used mainly in large quarries with significant cargo turnover [9]. The experience of using electrified railway transport in deep quarries demonstrates its high efficiency under appropriate mining operating conditions [4].

Despite being very capital-intensive, railway transport has significantly lower operating costs compared to other types of quarry transport. With the existing infrastructure of the enterprise, increasing its input to the underlying horizons does not require a substantial increase in the rolling stock fleet or capital investments. Studies have shown that the cost of transporting rock mass by rail is 4 to 5 times lower, and the specific annual productivity per ton of load capacity is 1.4 to 1.7 times lower than that of motor transport.

The disadvantages also include two to three-fold excavation of rock mass (in stopes, at transshipment warehouses, and dumps) and its lifting from the quarry and onto dumps by main transport with a tare coefficient of 0.80 to 0.82, which increases energy consumption of production.

The loss of the excavator's working time due to waiting is also significant when the railway tracks are relocated to a new position after the excavator's approach has been completed or in connection with the railway track entering the area of blasting operations.

To increase the productivity and efficiency of using mining equipment, combined transport schemes have been introduced at many quarries [10-12], in which, in addition to railway transport, an assembly transport link has been established: dump trucks with transshipment of rock mass into railway wagons at special intra-barrier transshipment points—warehouses with a railway track.

The negative factors of using a combined rock mass delivery scheme are [13]:

- The need to perform an additional number of stripping operations to create one or more sites for transshipment warehouses in the quarry.
- Diversion of loading mining equipment to operate in reloading warehouses.
- Violation of the optimal mode (direction) of mining operations due to the temporary cessation of activities in the areas where transshipment warehouses are located.

- Limit the production capacity of the quarry by an additional condition: the possible number of transshipment warehouses in the quarry.

Of the alternative transport systems, the most popular is the conveyor delivery of rock mass [14-16]. High productivity and the possibility of automation are the main advantages of conveyor hoists. Conveyor transport systems are widely used at powerful mining enterprises in conjunction with continuous mining equipment, such as rotary and chain excavators. Mobile or stationary crushers are utilized as part of the equipment chains. On the dumps, dumpers and transport-dump bridges are employed.

Advantages of conveyor transport include high productivity, the ability to deliver rock mass at speeds of 5–10 m/s over long distances without overloading, and minimal radii for rounding conveyor routes in the quarry [17]. The volume of mining and capital works in conveyor transport is significantly less than in other types of quarry transport. The transportation distance for conveyor transport is reduced by 5–7 times compared to road transport.

In addition, conveyor transport is characterized by high energy efficiency, which can be explained by the large elevation angles of conveyor routes [18, 19].

The main disadvantages of mining technology with conveyor transport in a quarry are [20-22]:

- Difficulties in carrying out blasting operations in areas where conveyor lines are located [23].
- The need for energy-intensive crushing of waste rock before loading onto conveyor transport.
- Downtime of mining equipment during reconstruction, maintenance, and repairs of conveyor lines and crushing equipment [24, 25].
- An increase in the current overburden rate is due to a deviation in the direction of deepening the quarry from the optimal path when placing crushing plants and conveyor lines on temporary pillars in the working area of the quarry [26].
- Intensive dust release occurs during the crushing of rock in the quarry and its transfer from dump trucks to the crusher hopper [27].
- The need for the construction and insulation of conveyor galleries for operation in winter.

The considered modes of transport have significant disadvantages, and their use leads to an increase in the cost of mining and a deterioration of the environmental situation in the mining area. To solve these problems, a container technology for transporting rock mass is proposed, which will enhance the performance of open-pit mining operations, save energy resources, and elevate environmental preservation to a qualitatively new level [28].

3. Materials and Methods

With the new technology, the rock mass extracted from the faces is loaded into containers and delivered by container ships to the area of operation of the lifting machine. In container technology, the lifting of containers is carried out by a special lifting machine, which is able to move around the quarry if necessary, for example, to carry out blasting operations or when the direction of mining operations changes. At the same time, the lifting machine, like the skip lift, lifts the rock mass in the lightest possible container vessels, which is the key to the energy efficiency of container technology.

The lifting machine has a load-grabbing device that allows it to quickly grab the container and quickly unhook it at the final destination. The electric drive of the lifting machine provides higher efficiency than the internal combustion engine of a dump truck. The route for lifting the rock mass is the shortest.

One of the main advantages of container technology for lifting rock mass, in comparison with conventional road transport delivery, is the reduction of harmful emissions of exhaust gases into the atmosphere of the quarry. The volume of these emissions, as well as the specific consumption of diesel fuel, increases dramatically when a loaded dump truck is moving uphill.

After delivering containers with rock mass to the dump of empty rocks, part of the containers with rock mass delivered to the dump on mobile platforms is lifted by a lifting machine standing on the dump of the first tier. The first tier of the dump is formed by unloading containers into the body of the first tier of the dump, filling the leading dump, while the second part of the containers is installed by a lifting machine of the first tier. The first tier of the dump is uncoupled, and further lifting of these containers is performed by a lifting machine of the second tier installed on the dump of the second tier, which is formed similarly to the first tier Figure 1.

When creating high dumps with a height of 100 meters, mobile platforms on pneumatic wheels are used. At container transfer sites, a non-self-propelled autoplatfrom can be moved reciprocally by a winch controlled from the driver's cabin of the lifting machine using a switch with an extended lever.

Delivery of loaded containers from the quarry to the waste rock dump or processing plant bunker on the surface can be performed according to the scheme shown in Figure 2.

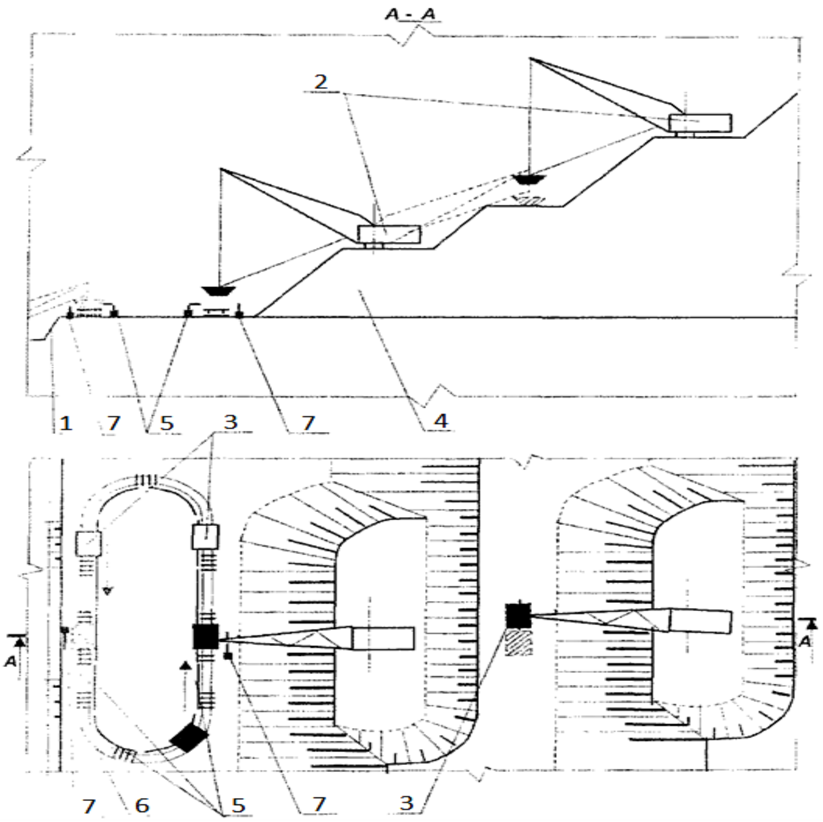

Figure 1.
Diagram with automated container delivery along the ring railway track and one–stage lifting to the dump by lifting machines: 1 – side of the quarry, 2 – lifting machine, 3 – trolleys for container transportation, 4 – overburden dump, 5 – block sections of the contact line, 6 – railway track, 7 – regulator of electric voltage or current in the contact line (with extended lever).

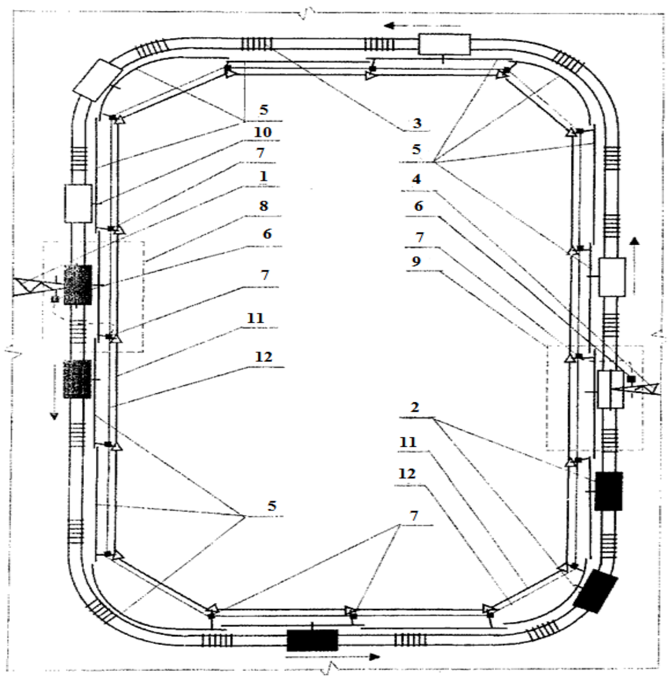

Figure 2.
Diagram of moving self–propelled platforms with containers along the ring railway track on the daytime surface from the quarry to the dump: 1 – lifting machine; 2 – container, 3 – railway track, 4 – lifting machine on the dump, 5 – block–section of the contact line, 6 – regulator of electric voltage or current in the contact line (with an extended lever), 7 – relay–regulator of electric voltage or current in the block–section of the contact line, 8 – section for replacing empty containers with loaded ones (on board the quarry), 9 – section for replacing loaded containers with empty ones (dump), 10 – current collector of a platform on a railway track, 11 – power transmission lines, 12 – communication lines of relays–regulators of electric voltage or current in adjacent block–sections of the contact line.

After lifting from the quarry, each loaded container is delivered to the dump or hopper of the processing plant on a railway platform equipped with an electric motor, a wheel drive gearbox, and a current collector. The route of the railway track has a closed contour in the plan. The contact line is divided into block sections with separate power supply, and the block section in the area of installation and removal of containers from platforms by the lifting machine is equipped with a voltage or current regulator having an extended lever or carried out on a cable to the driver's cab of the lifting machine. Each block section of the main contact line has electric current, and this block section automatically reduces the electric voltage or current on the previous one in the direction of movement of platforms. The circular shape of the railway track provides continuous movement of platforms. Reducing the electrical voltage or current on the block sections adjacent to the occupied block sections from behind in the direction of movement of platforms is necessary to prevent collisions of platforms. When the platform enters a block section with reduced voltage, it is braked, and the platform's braking mechanism is also triggered. A minimum current flow through the current collector of the stopped platform indicates that the block section is occupied, and through the relay regulator, it also reduces the voltage in the supply line of the block section adjacent to the rear in the direction of movement of the platforms. The end parts of adjacent block sections of the contact line overlap each other but have an air gap in the direction perpendicular to the line axis, so the platform current collector is constantly in contact with the contact wire.

To reduce the stress in the dump when creating a multi-tiered structure, lifting machines must be spaced at a distance of at least two unloading radii. For this purpose, when creating four-tier dumps with a height of 140 meters, a trolley mounted on a pneumatic wheel will be used to deliver containers. Its movement will be carried out with the help of a rope wound on a winch.

4. Results and Discussion

Delivery of loaded containers from the quarry to the dump of empty rocks or the bunker of the processing plant on the surface is carried out according to a circular scheme. After lifting from the quarry, each loaded container is delivered to the hopper of the processing plant on a railway platform equipped with an electric motor, a wheel drive gearbox, and a current collector. The route of the railway track has a closed contour in the plan. In this work, a self-propelled trolley for transporting containers on a railway track was designed. The drive consists of: МТКН(F)511–6ПНД/4МТКМ225М6 electric motor: rated power Nd=37 kW; rotation speed n = 930 rpm; ВКУ–965М gearbox with a gear ratio U = 25; МУВП type coupling: rated torque – 2000 N·m; type coupling – МЗ–13–Н160 State standard ГОСТ50895–96–96 (torque – 150000 N·m); brake ТГК–500 industry standard ОСТ24.290.08–82 (brake pulley diameter – 400 mm; brake torque – 1500 N·m). According to the static load, a wheelset РУ1Ш–957–Г is accepted for main railways of 1520 mm gauge with parameters (static load on the axle – 230.5 (23.5) kN (t); weight – 1178 kg; weight of a wheelset with axle box assemblies with cylindrical roller bearings – 1383 kg). A general view of the designed self-propelled trolley on a railway track is shown in Figure 3 [17].

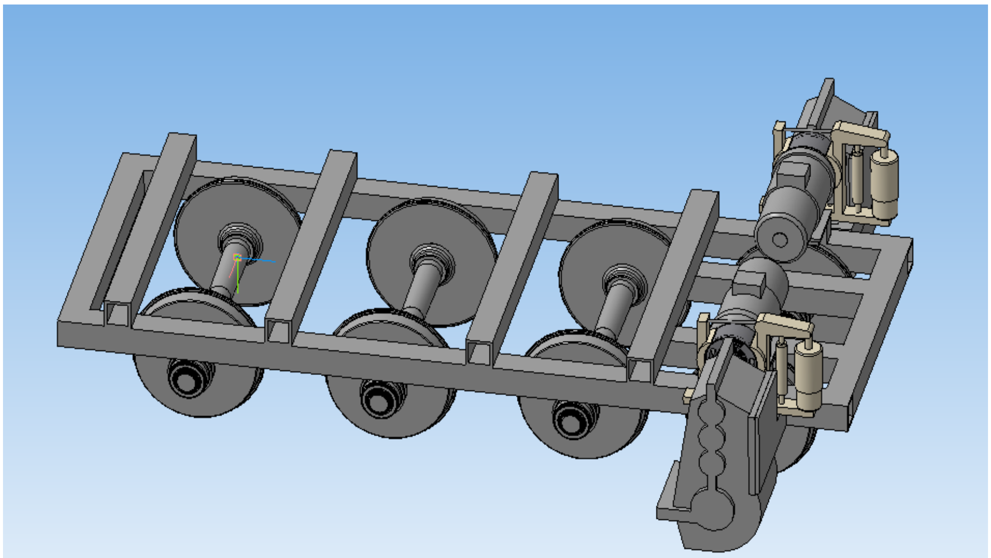

Figure 3.
General view of a self–propelled platform on a railway track.

In the technological chain of lifting containers on the upper tiers of the dump, air-wheeled trolleys will be used. A mobile platform can ensure the safe operation of adjacent lifting machines. The movement of the mobile platform is carried out by means of a traction reversible winch. The winch can be operated by the operator of a quarry lifting machine.

Based on design calculations, the power of the winch engine was determined, and the gearbox, coupling, and brake were selected. Strength calculations of the trolley frame were made based on the condition of installing a container on it. To move the trolley, it is proposed to use a traction winch. A diagram of the movement mechanism is shown in Figure 4.

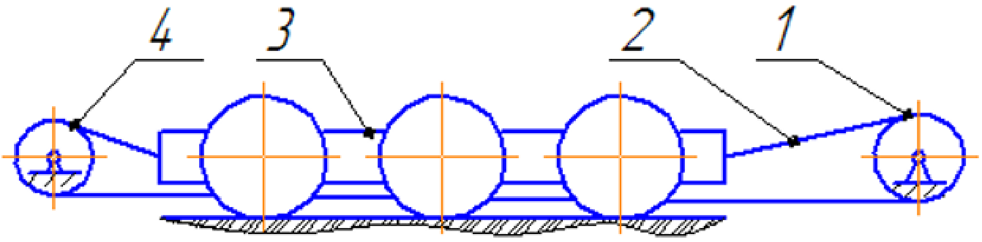

Figure 4.
Diagram of the movement mechanism.

1 – reverse traction winch; 2 – traction rope;
3 – trolley; 4 – bypass block.

The traction winch is performed according to well-known schemes that are used in lifting machines to move cargo carriages of tower cranes.

To calculate the power required to move an auto platform with a loaded container weighingой 70 tons, the maximum tension of the traction rope S_{max}, N, is determined by the formula [29].

$$S_{\max} = \frac{W + F_B}{\eta_Б^n}, \qquad (1)$$

Where
W is the resistance to movement of the auto–platform with the load, N;
F_B is the wind load on the auto–platform and the load, N;
η_B is the efficiency of the bypass block (we accept η_B = 0.96) [29];
n is the number of guide blocks (we accept n = 1) [29].
The total resistance W, H, when moving on a pneumatic wheel is determined by the formula [29]:

$$W = W_1 + W_2, \qquad (2)$$

where
W_1 is the resistance force that occurs during movement, N;
W_2 is the drag force resulting from the slope of the path, N.
The drag force that occurs when moving is determined by the formula [29]:

$$W_1 = f_0 \cdot (m_T + m_K + m_Г) \cdot g \cdot \cos\alpha, \qquad (3)$$

where
f_0 is the coefficient of resistance, depending on the condition of the working platform, for dense soil (we accept 0.035÷0.04) [29];
m_T is the mass of the autoplatform (we accept 18.27106 tons);
m_K is the mass of the container (m_K = 10 tons);
$m_Г$ is the mass of cargo in the container ($m_Г$ = 60 tons);
α is the permissible slope angle of the working platform (we accept $\alpha=2^0$).

$$W_1 = 0{,}037 \cdot (18271{,}06 + 10000 + 60000) \cdot 9{,}81 \cdot \cos 2 = 32020{,}18N$$

The drag force resulting from the slope of the path is determined by the formula [29]:

$$W_2 = (m_T + m_K + m_Г) \cdot g \cdot \sin\alpha, \qquad (4)$$

$$W_2 = (10000 + 18271{,}06 + 60000) \cdot 9{,}81 \cdot \sin 2 = 27187{,}48N,$$

$$W_2 = 32020{,}18 + 27187{,}48 = 59207{,}66N,$$

$$S_{\max} = \frac{59207{,}66}{0{,}96} = 61674{,}64N,$$

The required power of the electric motor N, kW, is determined by the formula [29]:

$$N = \frac{S_{\max} \cdot V}{1000 \cdot \eta}, \qquad (5)$$

Where
V is the speed of movement of the platform (we accept V=1.5 m/s) [29];
η is the efficiency of the drive (we accept η = 0.95) [29].

$$N = \frac{61674{,}64 \cdot 1{,}5}{1000 \cdot 0{,}95} = 97{,}381 kW.$$

The drive motor is a general industrial electric motor 4MTM280L4 (4MTH280L4, MTH613–4) [29] with the following characteristics: N=110 kilowatt at ПВ=100%; n=1500 rpm.

A steel wire rope is used as a traction element. In accordance with the requirements of the international standard ISO 4301/1, steel ropes are selected according to the breaking force [30]:

$$F_0 \geq S \cdot Z_P, \quad (6)$$

Where

F_0 is the breaking force of the rope as a whole, H (we accept it according to the certificate);

S is the maximum tension of the rope branch H (we accept it equal to S_{max});

Z_p is the minimum coefficient of rope use (the minimum coefficient of rope safety margin) (we accept Z_P=9) [30].

$$F_0 \geq 61674{,}64 \cdot 9 \geq 555071{,}76 N.$$

Accepted rope type ЛК–РО 6x36 (6x36·(1+7+7/7+14)+1 o.c.) with an organic core State standard ГОСТ7668–80–80 (rope diameter d=33 mm; breaking force – 626.5 kN).

The developed assembly drawing of a pneumatic wheeled trolley is shown in Figure 5.

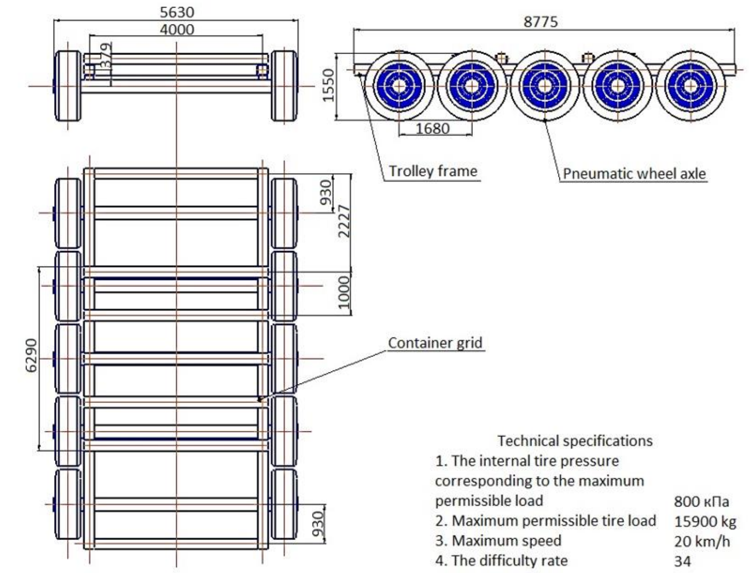

Figure 5.
Air-wheeled trolley assembly drawing.

Table 1.
Elements of the winch drive.

Name	Type and characteristics
Asynchronous electric motor with a short–circuited rotor	4MTM280L6 with characteristics: N = 110 kW at ПВ = 100%; n = 725 rpm; I_P = 4,8,8 kg·m²; maximum torque–3800 N·m, weight – 989 kg; high–speed shaft diameter – 90 mm; M_{MAX}/M_{HOM} = 3,2.
Gearbox	Ц2Н–630–40–11–К–У3: gear ratio – 40; diameter of the low–speed shaft – 220 mm; diameter of the high–speed shaft – 80 mm; torque on the low–speed shaft – 71 kN·m; rated transmitted power – 697/223 kilowatt, the maximum (minimum) efficiency of the gearbox – 0.96; weight – 3330 kg.
Coupling	For connecting the drum shaft and gearbox coupling МЗ–13–Н160 State standard ГОСТ50895–96: torque – 150000 N·m, the diameters of the connected shafts are within 100÷250 mm. For connecting the shaft of the electric motor and gearboxвтулочно, the sleeve–finger coupling Industry standard ОСТ24.848.03–79: torque – 8000 N·m, the diameters of the shafts to be connected are within 80÷95 mm; the diameter of the brake pulley – 500(600) mm; the moment of inertia of the coupling I_M – 28.6(57.8) kg·m².
Brake	ТКГ–500 Industry standard ОСТ24.290.08–82: diameter of the brake pulley – 500 mm; braking torque – 2500 N·m.
Drum	Drum diameter D = 940 mm, drum length – 5.48 m.
Rope	ЛК–РО rope 6x36·(6x36(1+7+7/7+14)+1 o.c.) with an organic core State standard ГОСТ7668–80: rope diameter d = 38 mm; breaking force – 881 kN, marking group – 1860(190) N/mm²·(kg·s/mm²).

5. Conclusion

As a result of the conducted research, a new mining and transport technology for dump formation in deep quarries during open-pit mining of mineral deposits has been developed. This technology differs from the previously existing methods by utilizing container technology for transporting rock mass to external dumps. The rock delivered from the quarry will be loaded into containers and lifted to the unloading site with the help of a special lifting machine. The advantages of container technology for dump formation in deep pits in addressing the challenges of quarrying are:

- Improving the productivity of excavation work.
- Increase in the utilization rate of transport equipment.
- Reducing the energy intensity of the process of transporting and storing rock mass in landfills.
- Significant reduction of environmentally harmful pollutants during rock mass transportation.

The mining and transport equipment designed during operation is easy to manufacture and can be created by the mining enterprise itself.

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