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Substantiation and development of innovative container technology for rock mass lifting from deep open pits

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Abstract

Purpose. The research purpose is to substantiate the rational parameters of innovative container technology for transporting mine rocks in open pits with account of technological advantages.

Methods. The winding machine normal operation was determined by calculation performed. The container metal structure was designed in the environment of the Compass-3D software complex. The structural elements were tested for normal operation using computer modeling methods in the APM WinMachine 9.7 program, which gives the possibility to obtain the strength calculation values.

Findings. The results of modeling the stresses on the wall of the container and the frame, as well as the yield strength are presented. The test calculation confirms the technical feasibility for operating the dragline-based mine winding machines. The influence of the container capacity on the performance of the winding machine has been determined and the dependence of the economic efficiency of the container technology introduction at the open pit depth has been revealed.

Originality. For the first time, on the basis of computer modeling, the parameters of stress distribution on the container wall have been substantiated when performing a strength calculation. It has been determined that the maximum stress in the container wall is 117.52 N/mm^2; the principal stress value is 83.85 N/mm^2. The safety factor for yield strength is 1.8. The maximum load acting on the structure is 957.5 kgf, which does not exceed the calculated value

Practical implications. The practical importance is to improve mining efficiency, reduce the cost of transporting rocks and ensure automatic container unloading. The use of replaceable containers in open pits can significantly change the formation principles of shovels and transport complexes, increase their performance and the efficiency of shovels in the main processes.

Keywords: *deep open pit, open-pit mining operations, mining practice, rocks*

1. Introduction

The problems of mining deep open pits in Kazakhstan and other countries of the world at the present stage are most often characterized by various geotechnological problems of conducting mining operations [1]-[3]. First of all, they are associated with the growing worldwide trend of transition from open-pit to underground mining, where the rock mass stress-strain state within the open space of open pits and, at the same time, the underground mining factor are mainly studied [4]-[6]. It is extremally important to develop all trends in open pit mining as mineral resources like are very important nowadays, especially technology must be safe for the environment and human health [7]-[10].

Kazakhstan is one of the leading countries in the world in terms of reserves and production of various types of mineral raw materials [11]-[15]. Therefore, in solving the problem of a significant increase in the volume of the gross domestic product, the mining industry of Kazakhstan is given the leading role. However, given the current economy state, the construction of new mining and processing enterprises is not expected in the coming years [16], [17]. Therefore, the main task is to find reserves for increasing the open-pit mining efficiency at existing enterprises. This is necessitates the intensification of mining production, that is, the implementation of an integrated process of accelerated increase in the quantity and quality of output (or work performed) per a unit of time with a simultaneous reduction in all types of resources involved in technological production [18]. Without detracting from the importance of modern geotechnological problems, when conducting mining operations at ore deposits, the need for effective modernization of technological issues and technical means, especially transport systems, in the direction of improving their parameters and organization of their operation is also an important urgent task [19]-[21].

Abroad, in deep open pits, two transport modes, road and rail, are widely used together for transporting rock mass [22],

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[23]. Practice shows that the highest technical and economic indicators are typical for electrified railway transport using traction units [24]-[27]. However, small ascents, significant curve radii, the complexity of train exchange do not allow railway transport to be used independently at depths of more than 300-350 m, even in large open pits. Dump trucks are highly mobile, do not require the construction of capital roads in the open pit, are able to overcome significant ascents and work in limited areas of the lower open-pit horizons. Their load-carrying capacity is relatively small, and the cost of transporting the rock mass is 8-10 times higher than that of railway transport. As a result, the expedient scope of their application in deep open pits is limited to a depth of 120-150 m [28], [29]. Therefore, when mining deep horizons, a combined mode of transport is usually used for transporting rock mass. The different combinations of its constituent links are conditioned by the desire to maximize the advantages of both rail and road transport, eliminating, if possible, their shortcomings. The effectiveness of using one or another open-pit transport scheme depends on the level of technical and economic indicators both directly during the rock mass transportation and during related cargo operations. In this case, the organization of transshipment operations with the simultaneous use of dump trucks and road trains in one direction of rock transportation is of great importance [30]-[32].

The operation of deep open pits is the most difficult problem in creating cost-effective conditions, since with the deepening of mining operations, the automobile haulage length increases and, accordingly, dump trucks with a greater load-carrying capacity are required [33]. An increase in the load-carrying capacity of dump trucks violates the optimal ratio of the face shovel bucket capacity to the body capacity. In order to reduce the downtime of expensive dump trucks, it is necessary to increase the bucket capacity and standard size of the shovel. The increased dimensions of dump trucks require the expansion of roads, areas for maneuvering, etc., which significantly reduces the volumes of recovered ore. This is also facilitated by an increase in the number of in-pit transshipment warehouses used in combined transportation [34], [35].

In the road transport operation, with the deepening of the open pit, there is a redistribution of functions. With the decline in mining activity and its increasing depth, road transport is less and less used as an assembly vehicle and more and more performs the work of lifting the rock mass along the open-pit wall. Taking into account the two-threefold increase in the specific fuel consumption during the dump truck movement to the ascent, the specific cost of rock mass road transportation during the completion of open pits is steadily increasing. The volumes of polluting emissions of harmful gases into the open pit atmosphere are increasing proportionally. With an increase in the standard size and cost of dump trucks, their economically optimal number decreases per one face shovel.

Thus, the main problem of deep open pits is transportation. Modern trends in the development of traditional transportation technology lead to a reduction in the mined ore reserves, an increase in the unit value of 1 ton-km of road transportation, an increase in atmospheric pollution and a reduction in the open-pit production capacity [36]-[38].

In real conditions of open-pit mining, it is necessary to take into account the energy interdependence of technological processes. The required degree of the rock mass crushing by blasting, the need for additional mechanical crushing in an open pit, the frequency of energy-intensive re-excavation at transshipment points and at a dump, as well as the type, length and complexity of maintaining transport communications, etc., depend on the choice of a technological scheme for transporting rock mass in large open pits. An integrated assessment of the energy efficiency of rock mass transportation is impossible without a comprehensive accounting of energy consumption in related technological processes [39]-[42]. The container technology for transporting rock mass in open pits most fully meets the requirements for improving the efficiency of open-pit mining in order to save energy resources and preserve the environment.

In the technological chain of lifting containers along the open-pit wall and delivering them to the points of the rock mass unloading, there are areas where containers move over short distances along horizontal routes (Fig. 1). They arise from the safety conditions of adjacent winding machines operating in a chain, the distance between which should be more than twice the turning radius of their booms. To meet this condition, when transferring containers from one machine to another, it is proposed to move them (containers) between the grabbing and detach points on mobile platforms.

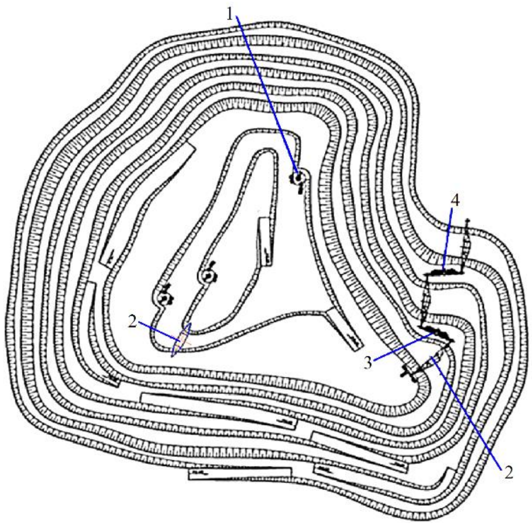

Figure 1. Scheme of opening deep horizons of an open pit using container technology: 1 – face shovels; 2 – winding machines; 3 – vehicle-mounted platform; 4 – rail-mounted platform

According to the main technological scheme, mine winding machines are installed on the sites of the open-pit wall to lift containers from the lower benches to the upper ones (Fig. 2). At intermediate sites, there is a change of loaded and empty containers. Lifting of loaded containers and unloading of rock into the dump is also performed by winding machines.

The efficiency of using a container truck in the container technology of open-pit mining is to reduce economic losses from vehicle downtime while loading and to increase the shovel performance. The container truck working cycle does not include downtime while loading, unlike dump trucks and railway trains [43]. The technological scheme with the use of mine winding machines is sufficiently reliable, flexible and versatile. It makes it possible to gradually increase the lifting height, disperse the complexes of winding machines along the open-pit walls, distribute or combine cargo traffic by types of rock mass [44], [45].

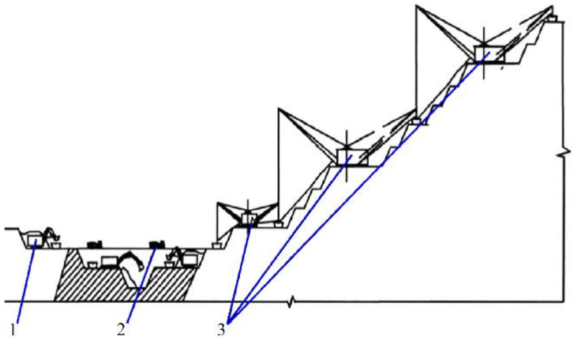

***Figure 2.** Scheme of container technology for open-pit mining operations: 1 – loading of rock mass by shovel into containers; 2 – delivery by container trucks to the place of lifting along the open-pit wall; 3 – lifting of rock mass in containers by mine winding machines*

The formulated new fundamental approaches to the open-pit mining technology make it possible to proceed to the development of a complex of new machines, mechanisms and new technological schemes. The main requirements for the design of the container complex elements are summarized below in Table 1.

***Table 1.** Requirements for the design of the container complex elements*

Name of machines and mechanisms	Basic design requirements
Container design	Low weight and metal consumption, high strength (low packing coefficient). Load-carrying capacity at bulk material density is 1.5 t/m^3 with up to 70 tons.
Design of special machines (container trucks)	High load-carrying capacity. High passing ability (off roads). Ability to grab and move a container weighing up to 70 tons.
Winding machine design	High load-carrying capacity. Possibility of quick grabbing and detach of the container (remotely, without the participation of a slinger-rigger). The possibility of automating the winding machine working cycle. Option with a container unloading mechanism into a truck or into a dump.
Load-grabbing device	High load-carrying capacity. Ability to remotely control the device. Container grabbing control system (ensuring labor safety).

Prior to the creation of specialized mine winding machines, powerful draglines, such as ESH-10/70, could be used to lift containers, equipping them with load-grabbing devices. A complex of two or three such winding machines can lift the rock mass from the open pit and onto the dump to a height of 60-90 m in one lift, depending on the wall bench parameters.

Loaders with a load-carrying capacity of up to 80 tons with automated container grabbing mechanisms, which are widely used at container terminals in maritime and rail container transportation systems, can be used to deliver containers across the open-pit sites and on the surface.

The paper proposes a new technology for container transportation of rocks in containers without construction in an open pit of transport communications, which has technological and energy-saving advantages. These advantages are: simultaneous excavation of rocks, transportation of rocks over the shortest distance, low container packing coefficient and mobility of the winding machine complex, which can reduce energy consumption and the cost of transporting rock mass.

2. Research methods

The volume of capital mining works in the construction of modern open pits, especially deep ones, reaches tens and even hundreds of millions of cubic meters. In addition to the initial front of stripping and mining operations necessary to ensure the planned mining of minerals, it is also necessary to prepare the identified reserves that ensure the functioning of the open pit for several months by the time the enterprise is put into operation.

It is proposed to consider the possibility of using the ESH-10/70 dragline as a winding machine. The winding machine performance Q_{year} thousand tons/year is determined depending on the time of its working cycle T_c by the Formula:

$$Q_{year} = \frac{3600 \cdot T_{ct} \cdot K_{eu} \cdot Q_{cont} \cdot K_{lcc}}{T_c}, \tag{1}$$

where:

T_{ct} – calendar annual fund of time, T_{ct} = 8760 hour;

K_{eu} – equipment utilization ratio with the main work, K_{eu} = 0.75;

Q_{cont} – container load-carrying capacity, tons;

K_{lcc} – load-carrying capacity utilization factor, K_{lcc} = 0.95;

T_c – time of ESH-10/70 dragline working cycle.

The initial parameter in the calculation algorithm is the bench slope angle, which determines the technical feasibility of the winding machine operation. The calculations are based on the technological parameters given in Table 2.

***Table 2.** Main technological parameters accepted for calculations*

No.	Parameter	Value
1	Distance from the container axis to the bench slope lower edge (D), m	3
2	Width of the possible sliding wedge (A), m	3
3	Shovel carrier length (B), m	8
4	Railway wagon height (H_r), m	4
5	Safe clearance between wagon and container during unloading (b), m	0.5
6	Container height when unloading (H_{cont}), m	2
7	Load-grabbing device height when unloading a container (H_{lg}), m	3
8	Height of fastening of the shovel boom tail-piece (H_b), m	2
9	Minimum height of container movement during its installation ($H_{\min}$), m	1
10	Minimum boom angle when unloading, $\beta_{\min\, un}$, deg	30
11	Minimum boom angle when lifting, $\beta_{\min\, l}$, deg	15.5

The influence of the container load-carrying capacity on the complex performance is assessed based on the passport lifting speed of a walking excavator of 2 m/s. The ascent time to a height of 60 meters is 30 seconds, so taking into account the time of container changing, the total cycle time of the winding machine is 170 seconds. The parameters of the open-pit wall, necessary for the operation of the lifting complex using container technology, are determined by the linear dimensions of the shovels and the rock mass properties (Fig. 3).

Maximum grabbing radius R_{gr}, m, of the winding machine container is determined by the Formula:

$$R_{gr} = L_b \cdot \cos\beta + A_b, \tag{2}$$

where:

L_b – boom length, m;

β – boom angle to the horizon, deg;

A_b – distance from the shovel axis to the boom tail-piece, m.

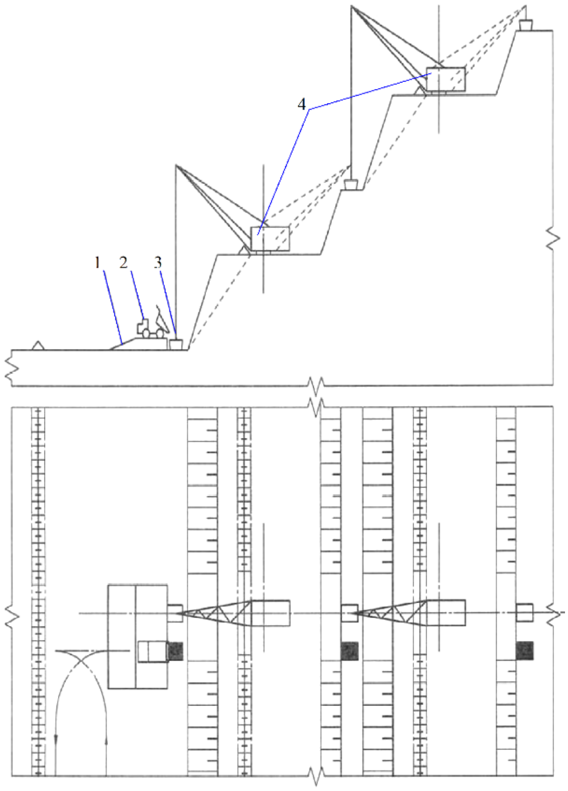

Figure 3. Technological scheme of the lifting complex operation: 1 – overpass; 2 – dump truck; 3 – containers; 4 – winding machine

Required container grabbing radius R_{req}, m, of the winding machine is determined by the Formula:

$$R_{req} = D + H_b \cdot ctg\,\alpha + A + \frac{B}{2}, \tag{3}$$

where:

D – distance from the container axis to the bench slope lower edge, m;

H_b – bench height, m;

α – bench slope angle, deg;

A – width of the possible sliding wedge, m;

B – shovel carrier length, m.

The width of the site for the mine winding machine S_{mwm} is determined by the Formula:

$$S_{mwm} = A + \frac{B}{2} + R_{gr} + D. \tag{4}$$

The condition for the possibility of the winding machine operation according to linear parameters:

$$R_{gr} \geq R_{req} \text{ or } L_b \cdot \cos\beta + A_b \geq D + H_b \cdot ctg\alpha + A + \frac{B}{2}.$$

Minimum boom angle β_{min}, deg, according to the conditions of unloading the container into the vehicle is determined by the Formula:

$$\beta_{min} = \arcsin\left(\frac{H_v + b + H_{cont} + H_{lg} - H_b}{L_b}\right), \tag{5}$$

where:

H_v – vehicle height, m;

b – safe clearance between vehicle and container during unloading, m;

H_{cont} – container height when unloading, m;

H_{lg} – load-grabbing device height when unloading a container, m;

H_b – height of fastening of the boom tail-piece, m;

L_b – boom length, m.

Minimum boom angle when working only for lifting the containers $\beta_{min\,l}$, deg, is determined by the Formula:

$$\beta_{min\,l} = \arcsin\left(\frac{c + H_{cont} + H_{lg} - H_b}{L_b}\right), \tag{6}$$

where:

c – minimum height of container movement during its installation.

From the condition for the possibility of the winding machine operation, the required shovel boom angle P to the horizon is determined based on the linear parameters by the Formula:

$$P = \arccos\left(\frac{D + H_b \cdot ctg\alpha + A + \frac{B}{2} - A_b}{L_b}\right). \tag{7}$$

The container metal structure is designed in the environment of the Compass-3D software package. After construction, the part, broken into a finite element mesh, is imported into the Structure 3D program. The required material is selected for the part and the calculation is made.

The metal structures of the developed elements are tested for efficiency by methods of computer modeling. Strength calculations of all container parts are made using the APM WinMachine 9.7 program, which makes it possible to obtain the results of strength calculations in the form of graphic charts. The main modeling parameters are stress, displacement, load, fatigue safety factor, principal stresses, deformation.

3. Results and discussion

The technological equipment complete set for deep open pits is the most difficult issue in the technology of existing open pits. This shows that they contain a number of contradictions requiring new solutions. As mining deepens in open pits, the road transportation distance increases, which requires the use of dump trucks with a higher load-carrying capacity. An increase in the load-carrying capacity of dump trucks violates the optimal ratio of the face shovel bucket capacity to the dump truck body capacity. To reduce the downtime of expensive dump trucks, it is necessary to increase the bucket capacity and standard size of the shovel. The increased dimensions of dump trucks require the expansion of roads, areas for maneuvering, etc., which can significantly reduce the volumes of recovered ore. This is also facilitated by an increase in the number of in-pit transshipment warehouses used in combined transportation.

Based on the analysis of existing containers that are used in the industry for transportation of goods, it has been found that none of the container design options is suitable. In general, containers are used for transportation of bulk fine cargoes, and for the transportation of large-sized abrasive rock, a patent search has not yielded positive results. Existing designs have a number of imperfections, namely: the inability to transport bulky cargo, the complexity of manufacturing in production environment. None of the existing types of industrial containers are suitable as a container prototype for the implemented technology of rock mass transshipment.

A unique container has been designed for rock transportation in open pits. The container design, protected by the patent of the Republic of Kazakhstan, is aimed at reducing the cost of the rock mass transportation, the environmental impact on the open-pit atmosphere, while ensuring accurate rock mass unloading into a vehicle and dump. The design of the developed container is shown in Figure 4a.

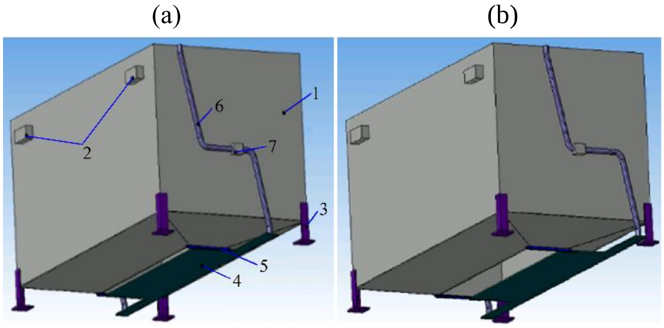

Figure 4. View of the developed container: (a) with closed bottom; (b) with open bottom; 1 – container frame; 2 – fittings for grabbing; 3 – supports; 4 – bottom; 5 – guiding device; 6 – power lever; 7 – arresting device

The container is a welded box-section structure *1* on the sides of which there are fittings *2* for grabbing. When loading, it is placed on supports *3*. Its gate-type bottom is movable *4*, and moves along the guiding devices *5*, using two power levers *6*.

The container at the time of unloading is shown in Figure 4b. When opening the container during unloading, the upper end of the levers is actuated and they move in the arresting devices *7*, forcing the container bottom to move in a horizontal plane, while the cargo is poured out due to its own weight. The bottom returns to its previous location when the power lever is actuated from the other side [46].

Figure 5 shows a diagram of the principal stresses of the container wall strength calculation.

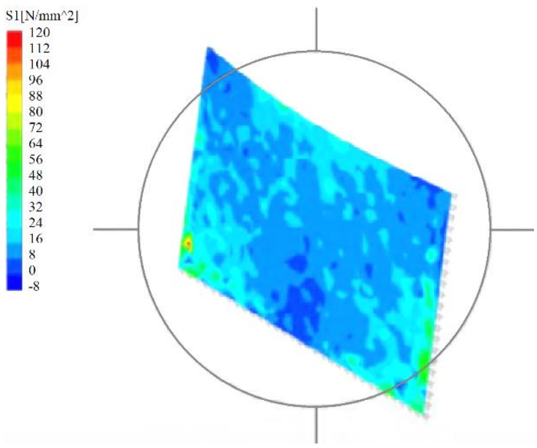

Figure 5. Diagram of the stress distribution on the container wall

The strength calculation of the container walls shows the following results:

– the maximum stress is 117.52 N/mm^2;
– the minimum safety factor for yield strength is 3.62;
– the maximum principal stresses are 83.85 N/mm^2;
– the minimum principal stresses are 6.21 N/mm^2;
– the minimum fatigue safety factor is 3;
– the maximum deformation is 0.00029 mm.

The container technology implementation makes the shovel operation in the face uniform and continuous. The low cost of containers allows placing two or three containers in the working area of the shovel, which are installed in the face shovel working area. Loaded containers are exchanged for empty ones by container trucks that deliver loaded containers to the container site in the area of the nearest winding machine operation. The time of filling the container with rock mass is not included in the container truck working cycle. Therefore, there is an increase in their performance, as the time spent on loading transport vessels is reduced.

The use of replaceable containers and container trucks makes it possible for the shovel to operate continuously even when it is serviced by a single container truck. This is possible with a short delivery distance and sufficiently high load-carrying container capacity, when the time of filling the container with rock mass is equal to the time of the container truck route. According to traditional technology, when servicing by a single dump truck, the shovel downtime is inevitable.

When replacing empty containers with loaded ones by placing them on the site, it is necessary to rotate the winding machine to grab the loaded container. Due to the large linear dimensions and weight of the winding machine, this operation can complicate the machine operator work. In order to eliminate the need to rotate the winding machine, it is proposed instead to move the container in each working cycle to the point of its grabbing by the winding machine lifting device.

It is proposed to use special container trucks to transport containers to the shovel work area. The most optimal and convenient option when designing a load-haul-dumper is to use a Π-shaped frame on it. The use of the latter will give the structure additional stability when lifting the container, since the load from the container will be distributed over the entire container truck frame. This design is the most convenient for the transportation of large-tonnage containers. The container truck drives up to the container in reverse, grabs the container in the upper part and lifts it to the required height, after which the support platform rises in the lower part, onto which the container is placed. The platform is raised by hydraulic cylinders and is designed for mounting (fixing) the container on the frame. After placing the container on the platform, start moving.

Using the traction calculation, the traction force necessary for the machine movement is determined. The traction force is determined taking into account the total weight force of the transport system (*G*) multiplied by the driving resistance coefficients (*f*) within 0.05-0.15. A truck tractor based on BelAZ-7420 with a load-carrying capacity of 120 tons, BelAZ engine power is 800 kW, serves as a prototype for the design of a container truck.

To fix the container during transportation, a grabbing device similar to that mounted on a winding machine is used as a holding element. Two vertical hydraulic cylinders are mounted on the trailer to lift the container. The hydraulics consists of three main parts: grabbing device compression mechanism, container lifting mechanism, and container holding mechanism. All three mechanisms work independently from each other. Initially, the container is captured, after which the hydraulic locks are activated, preventing the reversal of the hydraulic cylinders, then the container is raised to the required height, and at the end of lifting, the hydraulic locks are also activated. At the final stage, platforms are extended to fix the container.

Based on the performed strength calculations of the machine metal structure, the frame is made of Steel 35 GOST 1050-88 grade, square pipe profile of GOST 30245-2003 (300×300×12). The principal model stresses are shown in Figure 6.

Figure 6. Principal stresses in the frame model

As a result of the frame calculation, a model has been obtained that complies with the calculation standards. The safety factor for yield strength is 1.8. The maximum load acting on the structure is 957.5 kgf, which does not exceed the calculated value. The principal stress in the model is 65.79 MPa, which does not exceed the permissible stress of the material.

Vertical supports are made of Steel 10 GOST 1050-88 grade. The parameters corresponding to the calculation standards have been obtained by changing the cross-section of a standard square pipe profile. The supports are made of a standard square tube profile (140×140×3) in the amount of 8 pieces. The scheme obtained as a result of calculating the safety factor for yield strength of the model is presented in Figure 7.

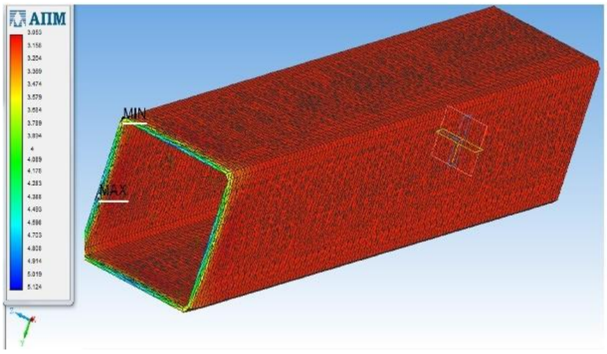

Figure 7. Safety factor for yield strength of the model

Thus, it is confirmed that the mobile platform can ensure the safe operation of winding machines. The mobile platform is moved by a traction reversible winch. Winch control can be performed by the mine winding machine operator.

The advantage of the developed equipment is its operational reliability, simple design, the possibility of transporting large-sized cargo and full automation of work. The lever system enables the container to be completely unloaded and return to its original state quickly. These containers will be easily manufactured by the mining enterprise itself.

It is proposed to use an improved container technology for transporting rock mass during open-pit mining, which will increase the open-pit mining performance in terms of saving energy resources and preserving the environment to a qualitatively new level. The energy consumption and destructive impact of open-pit mining on the environment are reduced through the use of optimal transport modes at all stages of the rock mass delivery, as well as through the performance of transshipment operations with high productivity without additional rock mass excavation. The calculations results confirm the technical feasibility for operating the dragline-based mine winding machines. The obtained wall parameters, necessary for the operation of mine winding machines, correspond to the real conditions of deep open pits.

The technological scheme with the use of mine winding machines is sufficiently reliable, flexible and versatile. It makes it possible to gradually increase the lifting height, disperse the complexes of winding machines along the open-pit wall, distribute or combine cargo traffic by types of rock mass. The influence of the container load-carrying capacity on the winding machine performance is shown in Figure 8.

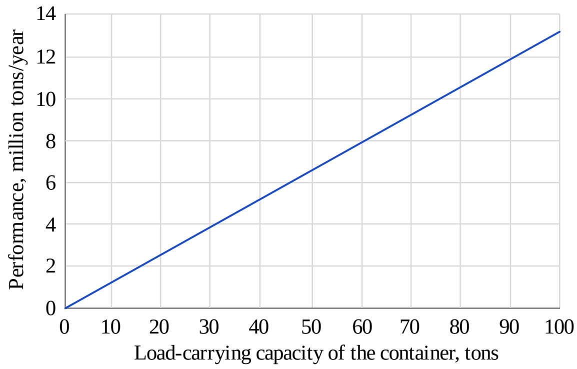

Figure 8. Influence of the container load-carrying capacity on the winding machine performance

Analyzing this graph, it can be stated that one complex of winding machines can provide a performance of about 10.0 million tons, and if greater performance is needed, the number of lifting complexes should be increased. Therefore, based on predictive calculations, Figure 9 shows the growth in the economic efficiency of container technology depending on the open-pit depth at a performance of 10.0 million tons per year.

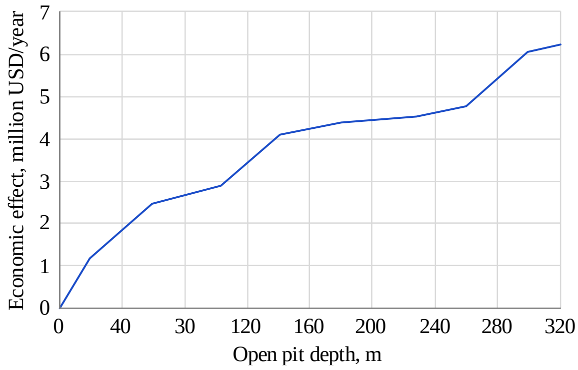

Figure 9. Dependence of the economic efficiency of the container technology implementation on the open-pit depth

Analyzing this graph, it can be concluded that the economic efficiency of implementing container lifting in an open pit increases with an increase in the mining depth. Economic efficiency is conditioned by lower operating costs, such as diesel fuel consumption, reduced equipment repair and depreciation costs.

Experience in operating the equipment shows that its further application at deep horizons will be accompanied by a significant increase in the mining cost. The growing volume of overburden mining requires additional land areas for their stockpiling, the allocation of which is problematic. The location of transport communications and transshipment units on the open-pit walls not only causes their increased spacing, but also additional disturbance of the earth's surface, as well as eliminates the possibility of stockpiling the overburden rocks in the mined-out space. Therefore, the problem of maintaining the production capacity of deep open pits and equipping them with appropriate equipment with further deepening should be solved by fundamentally new methods in the direction of optimizing technical and economic indicators based on a study of the mining-transport system parameters. This mining-transport system is a set of technological solutions for the choice of means of transport and mining-loading equipment directly related to it.

Container technology, when used in deep open pits, makes it possible to solve the whole range of problems of the main technological processes of open-pit mining. The use of replaceable containers in open pits will significantly change the principles of the formation of shovel-transport complexes, increasing their performance and the efficiency of shovels in terms of their main work. The replacement of outdated mining-transport vehicles with advanced equipment will increase transport safety, the degree of use of the mining front and the production capacities of open pits. The most important advantage of container technology is the prospect of automating a number of the transport process operations in an open pit.

4. Conclusions

The performed analysis of existing open-pit mining technologies and the current state of mining production indicates an urgent need to develop new resource-saving and environmentally friendly technologies for open-pit mining. The main peculiarity of the proposed technology is that all types of equipment for container transportation are easy to manufacture and can be created directly in the conditions of mining enterprises. For container delivery, the authors of the paper have developed a full complex of equipment.

The efficiency of using a container truck in the container technology of open-pit mining is to reduce economic losses from vehicle downtime while loading and to increase the shovel performance. The container truck working cycle does not include downtime while loading, unlike dump trucks and railway trains. Container technology, when used in deep open pits, makes it possible to solve the whole range of problems of the main technological processes of open-pit mining. The use of replaceable containers in open pits will significantly change the principles of the formation of shovel-transport complexes, increasing their performance and the efficiency of shovels in terms of their main work.

The replacement of outdated mining-transport vehicles with advanced equipment will increase transport safety, the degree of use of the mining front and the production capacities of open pits. The most important advantage of container technology is the prospect of automating a number of the transport process operations in an open pit. All container technology equipment can be easily manufactured by the mining enterprise itself.

The efficiency of container lifting in open-pit container mining technology is to reduce energy and economic losses from vehicle downtime while loading and to increase the shovel performance. The course of the container truck working cycle does not include downtime while loading, unlike dump trucks and railway trains. The technological scheme with the use of mine winding machines is sufficiently reliable, flexible and versatile. It makes it possible to gradually increase the lifting height, disperse the complexes of winding machines along the open-pit walls, distribute or combine cargo traffic by types of rock mass.

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Обґрунтування та розробка інноваційної технології контейнерного підйому гірничої маси з глибоких кар'єрів

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Мета. Обґрунтування раціональних параметрів інноваційної контейнерної технології переміщення гірських порід у кар'єрах з урахуванням технологічних переваг.

Методика. Продуктивність підйомної машини визначалася, виходячи з проведеного розрахунку. Металоконструкція контейнера проєктувалася у середовищі програмного комплексу Compass-3D. Перевірка конструктивних елементів на працездатність здійснювалася при використанні методів комп'ютерного моделювання у програмі APM WinMachine 9.7, яка дає змогу отримати значення розрахунків міцності.

Результати. Представлені результати моделювання напружень на стінці контейнера і рами, а також запасу плинності. Перевірочний розрахунок підтверджує технічну можливість роботи кар'єрних підйомних машин на базі драглайну. Визначено вплив вантажопідйомності контейнера на продуктивність підйомної машини та встановлена залежність економічної ефективності впровадження контейнерної технології від глибини кар'єру.

Наукова новизна. Вперше, на підставі комп'ютерного моделювання, обґрунтовані параметри розподілу напружень на стінці контейнера при здійсненні міцнісного розрахунку. Встановлено, що максимальне напруження у стінці контейнера становило 117.52 Н/мм^2, величина головних напружень склала 83.85 Н/мм^2. Коефіцієнт запасу за плинністю дорівнював 1.8. Максимальне навантаження, що діє на конструкцію, складає 957.5 кгс, що не перевищує розрахункове значення.

Практична значимість полягає у підвищенні ефективності гірничих робіт, зниженні собівартості транспортування гірничої маси та забезпеченні автоматичного розвантаження контейнера. Використання змінних контейнерів у кар'єрах значно змінить принципи формування екскаваторів і транспортних комплексів, підвищить їх продуктивність та ефективність роботи екскаваторів за основними процесами.

Ключові слова: *глибокий кар'єр, відкриті гірничі роботи, гірниче виробництво, породи*