UDC 622.271

https://doi.org/10.33271/nvngu/2020-6/005

Ye. K. Babets[1],
orcid.org/0000-0002-5613-9779,
A. A. Adamchuk[2],
orcid.org/0000-0002-8143-3697,
O. O. Shustov[2],
orcid.org/0000-0002-2738-9891,
O. O. Anisimov[2],
orcid.org/0000-0001-8266-4481,
O. O. Dmytruk[2],
orcid.org/0000-0001-6311-6252

1 – Scientific-research Mining Institute of the "Kryvyi Rih National University", Kryvyi Rih, Ukraine, e-mail: ebabets@gmail.com

2 – Dnipro University of Technology, Dnipro, Ukraine, e-mail: Adamchuk.A.A@nmu.one

DETERMINING CONDITIONS OF USING DRAGLINES IN SINGLE-TIER INTERNAL DUMP FORMATION

Purpose. The scientific and practical task of the study is to establish the dependences of the safe distance of dragline excavators on the height of a single-tier internal dump of the overburden rocks and the level of its flooding, taking into account the physical and mechanical properties of rocks.

Methodology. To achieve these goals, the following research methods were used: computer modelling using "Slide" software to build the most stressful sliding surfaces of the dumped rock mass. The calculations were performed in manual and automatic search modes for the most stressed (weak) sliding surface on several calculated sliding surfaces. The obtained data of calculations of the width of the prism of a possible landslide were analyzed and their dependence on the height of the single-tier dump and the water level in the open pit space was established by the method of least squares. The formula for calculating the value of the distance from the safety embankment to the axis of movement of the excavator is obtained using the cosine theorem and a number of trigonometric identities.

Findings. Using the "Slide" software complex the parameters of the width of the prism of a possible landslide at safety factors 1.2 and 1.0 were calculated and their dependences on the height of the dump and the level of its flooding with water were established, which allowed establishing effective models of dragline excavators for different conditions. The formula for calculating the distance from the axis of movement of the excavator to the safety embankment taking into account the parameters of the dragline excavator and the width of the pit for unloading haul trucks is proposed.

Originality. It is established that when the slope of the dumped rock mass is flooded with water, the physical and mechanical properties of the tier sole change, and the stability of the slope begins to decrease, and the width of the prism of a possible landslide increases. After water flooding of the slope reaches the critical value at the level of 1/5.2 from the total height of the tier slope, there is an increase in stability and a decrease in the width of the prism of a possible landslide due to increasing the influence of water retaining forces in the open pit space. The slope acquires the greatest stability at its maximum flooding by water.

Practical value. The established dependences allowed determining the safe distance for installation of mining equipment, and also allowed making a choice of an appropriate model of the excavator for carrying out works on formation of a single-tier dump. The recommended height of the tier of the overburden rock when forming it with a dragline excavator is not more than 100-150 m, or higher only in case of flooding of the slope with water. It was found that dragline excavators EK 6.5-45, EK 14-50 and EK 10-50 are effective for a tier height of 100 m regardless of the level of flooding. For the formation of a dump tier with a height of 150 m, the effective use of excavators EK 11-70 and EK 20/90 is possible when at least 70 and 50 m of a slope, respectively, is flooded with water. For slopes of single-tier dumps of the overburden rocks with the height of more than 150–200 m dragline excavators EK 6.5-45, EK 14-50 and EK 10-50 are effective when the thickness of non-flooded part of a slope is 70–75 m, the dragline excavator EK 11-70 – 90–95 m, dragline excavator EC 20/90 – 100–110 m.

Keywords: *internal dump, single-tier dump, deep flooded open pit, stability of the open pit sides, physical and mechanical properties of rocks, dragline excavator, safety factor*

Introduction. Currently, one of the most important problems of the iron ore surface mining with an increasing depth of an open pit more than 500 m, due to the depletion of the capacity of existing dumps of the overburden rocks, is the formation of new external dumps. For their construction, additional lands, which can reach 100 hectares and more, are involved in land allotments and should be located near open pits. In the direct proximity of other mining companies and residential buildings, it is virtually impossible to obtain a permit to place a dump near an open pit that is being operated.

In the Open Pit No. 2-bis of the PJSC "ArcelorMittal Kryvyi Rih" this problem was solved by storing the overburden rocks in the open pit space of the Open Pit No. 1 belonging to the former mining and processing plant "Novokryvorizkyi GOK" by forming a single-tier internal dump with the excavator installed on the ground surface near the upper edge of the open pit side.

However, with the development of dumping works during the installation of the excavator on the dumped massif deformation processes began: the upper platform of the dump – the formation of cracks and fissures (Fig. 1) and there was a threat of landslide of rock mass into the mined-out space. Thus, determining the safe distance for installation of mining equipment from the upper edge of the formed single-tier dump is a relevant task.

Literature review. The main technological solutions for the formation of the dump are related to determining the stability of the sides of a flooded open pit, which is filled with rocks for the possibility of their further placement in the mined-out space and safe operation of the dump equipment.

A number of research works have been performed and published to date to substantiate the conditions for safe storage of overburden rocks in the developed open pit space. The studies on the influence of restoration of the underground water level of depression funnel on stability conditions of unloading platforms of a dump are carried out, the methods for estimating stability of flooded slopes of the open pit sides are given, the analysis of instrumental observations over the deformations of reloading platforms is executed and the variants of safety reloading of the overburden rocks into the flooded open pit are substantiated [1, 2].

It is established that the stability of the flooded dump when moving the front of the dump works in the worked out open pit is primarily affected by the "hydrostatic load" of rocks below the water level. In this case, the prism of a possible landslide is formed by loading the flooded part of the dump with the prism located above from the rocks located above the water level. Empirically determined width of the landslide prism of the reloading platform with a safety factor 1.2 is in the range of 14.5–40.0 m depending on the characteristics of flooding and the proximity of the open pit contours to the sliding surface of the prism of possible dump landslide [3, 4].

The possibility of further landslide of the dump formation front in the direction of the formed overburden cracks appears after the site stabilization, which can be from one to six months.

It is recommended to use equipment with an unloading radius of at least 100 m as dump equipment for safe mining operations, which will allow the placement of overburden rocks in the internal dump from a safe distance for excavation and loading equipment. The regulations of mining works on internal dump formation in the flooded open pit are offered, providing three stages of development of mining works at which the width of prisms of possible landslide of a part of reloading platforms changes [5]:

- within the influence of the contours of the open pit sides at a distance of 5 to 15 m;
- beyond the contours of the open pit sides at a distance of more than 50 m;
- within the transition period between stages at a distance of 15–50 m.

For the conditions of Open Pit No. 1 of the former Novokryvorizkyi GOK, it is inexpedient to use the EK 6.5/45 excavator due to the distance of the dump formation front from the rock contours of the open pit. Further safe storage of overburden rocks in the worked out open pit is expedient with the use of a stepping excavator EK 20/90 around the entire open pit perimeter. With an annual capacity of the excavator of 2–4 million m^3 and volumes of overburden rocks of Open Pits No. 2-bis and No. 3 of 40 million m^3, it can safely store about 2 million m^3 of overburden rocks annually for 20 years.

According to the research results, the analysis of the formation of a single-tier flooded dump of the north-eastern side of Open Pit No. 1 was performed; the deformations of the surface workings by the stepping excavator EK 6.5/45 and the stability of the north-eastern side of Open Pit No. 1 are analyzed; the recommendations for ensuring the conditions of safe storage of overburden rocks in worked out Open Pit No. 1 are developed [6].

According to the research results, the analysis of the formation of a one-handed flooded dump of the north-eastern side of Open Pit No. 1 was performed; the deformations of the surface workings by the excavator EK 6.5/45 and the stability of the north-eastern side of Open Pit No. 1 were analyzed; the recommendations for ensuring the conditions of safe storage of overburden rocks in the reported Open Pit No. 1 [6] were developed.

The safe distance for the standing point of the working dragline excavator EK 6.5/45 relative to the upper edge of the single-tier dump in the mining conditions of the north-eastern side of Open Pit No. 1 includes the actual width of the landslide prism within 16–20 m and the body rotation radius equal to 10 m.

The state of stability of the area, which is dumped near the contours of the north-eastern side of Open Pit No. 1, is influenced by: the degree of stability of the benches composed of loose rocks and loaded with overburden rocks; parameters of rock benches (with angles of slopes exceeding the angle of natural slope of dumped rocks, with the height of more than 15 m, and the width of safety berms); parameters of the flooded prism of the support and the volume of its destruction in the form of fluid ("underwater landslide"); degree of stability of previously dumped rocks with the height from 133 to 165 m.

On the basis of the performed research studies [1, 7] the mining and technical conditions of formation of an internal dump are analyzed, the width of sliding prisms and the depth of development of deformations of a dump massif on unloading platforms are defined, measures concerning safe conducting of dump formation are resulted.

It is established that the safe distance from the outer contour of the base of the excavator EK-10/70 to the upper edge of the single-tier dump is 25 m and includes the actual width of the sliding prism of 14 m and the zone of attenuation of sedimentation deformations with the width of up to 11 m. When making dumping to the maximal height of the bucket unloading (up to 27.5 m), it is advisable to provide a temporary delay in the destruction of the "cones" in the sliding prism by leaving "windows" between the cones during the stope dumping for the further excavation of the dumped mass.

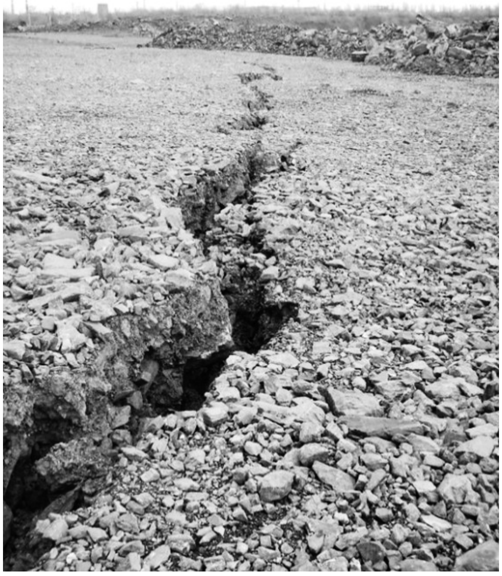

Fig. 1. Scheme of forming cracks on the northern side of the Open Pit No. 1 of the Mining and Processing Plant "Novokryvorizkyi GOK" (formation of terraces)

The analysis [5] of mining conditions and the current technology of single-tiered dump formation in Open Pit No. 1 when flooded is performed, the deformation processes of the dumps of the north-eastern side are analyzed, the stability of rocks during dump formation by EK-6/45 excavator and its productivity are calculated, recommendations are provided and measures for safe storage of overburden rocks in the worked space of Open Pit No. 1 are developed.

It is established that for accident-free movement of the dump formation front in the direction of water when placing working reloading platforms on the bulk part of the flooded dump it is necessary to perform anti-landslide measures to reduce the width of the critical deformation zone. This is achieved by increasing the width of the underwater prism protrusion by applying the technology of controlled dumping.

In order to increase the load-bearing capacity of the fresh surface working, it is advisable to increase the length of the dump formation front to 500 m and more while reducing the width of the dump to 10 m. These conditions will allow compacting the freshly dumped rock mass and stabilize the landslide of damping rates due to the increase in excavator passing time.

The geo-mechanical calculations on determining the minimal allowable safety berm for the operation of loading and mining conveyor equipment allowed establishing that at a normative safety factor of 1.15 in the conditions of dumping in a flooded open pit, the berm width is 34 m. Therewith, the acceptable pressure value at considered area is 857.5 kPa and much higher than the average pressure on the ground from the excavators EK 6/45 during operation – 58.5 kPa (when stepping – 107.8 kPa) and EK 11/70 – 97.5 kPa (when stepping – 153.9 kPa).

The following publications are devoted to the issues of ensuring the stability of the flooded open pit sides and the development of technological solutions for the further operation of the dump complex.

Thus, the work by Nikolashin Y. M., Kebal Y. V. [5] proposed a method for dump discarding in the mode of controlled deformation of rocks with a temporary support ridge in a worked out deep open pit flooded by groundwater with steep inclination angles of their sides.

Due to the developed method, the control of landslide deformations in the support ridge is provided, under the load of which the prism of the actual landslide of the dumped slope of the surface working is formed, with the establishment of stabilization of shrinkage deformation and the time of the beginning of mining operations for preparing of the excavator movement route on the dumped reloading site.

According to the results of the research [6] the analysis of the degree of influence of residual surface workings at the stage of production of mining and technical reclamation of deep open pits in conditions of restoration of the depression funnel of groundwater is performed. The problems connected with conducting mining works on internal dump formation in the flooded open pit are considered. Thus, in the conditions of residual surface workings of Open Pit No. 1 of the "ArcelorMittal Kryvyi Rih" there are deformations and landslides in the process of dump formation, which complicates the compliance with the safety requirements.

Based on the dynamics of the groundwater in the Inhulets Open Pit, the results of long-term regime observations, the patterns which must be taken into account when forecasting conditions at the pre-liquidation stage are defined. According to the results of theoretical and empirical research, the causes of dangerous deformations of fresh slope of a single-tier internal flooded dump have been determined. The analysis of research studies on internal dump formation, in residual surface workings which consider conditions of using means of open pit field drainage with the further mining and technical reclamation for economic, forest, water and other use is carried out [8, 9].

The publication by Shpakov P. S. [10] analyzes design solutions and made adjustments to the stability of internal dumps, taking into account the maximal height of the tier and the presence of a weak base. The results of calculations of the slope maximal height on a weak basis at variable angles of contact from 0 to 12° are presented. The dependences of the maximal height of the dump from the main slope angle for different angles of the base inclination which are given in the form of graphs are established.

For further dump discarding by applying the equipment used in the worked out space of Open Pit No. 1 when flooded, it is necessary to perform research to determine safe areas or develop alternative methods and technologies for storing the overburden mass in Open Pit No. 1.

Formulation of a scientific problem. Therefore, the relevant scientific and practical task is to establish the dependence of the safe distance of mining equipment location on the height of the single-tier dump, the water level in the open pit space and the physical and mechanical properties of the rocks that compose the dump rock massif. The established dependences will allow defining safe distance of placement of the mining equipment, and will allow making a choice of the expedient excavator model for conducting works on formation of a single-tier dump.

Purpose. Substantiation of the optimal parameters of schemes for uploading the overburden rocks in the mined-out space of the deep open pit at formation of a single-tier internal dump in the conditions of flooding of its slope by water.

Selection of initial data. Calculations on the stability of the dump slopes are made by the method of algebraic summation of forces taking into account the influence of the hydrostatic load side from water in the internal open pit space, changes in the density of overburden rocks, internal friction angles and engagement of "dry" and water-saturated rocks on the stability.

The following calculated characteristics were chosen as initial data:

- the average values of density of the shale and ore-free ferruginous rocks, taking into account the loosening of rock pieces segregation when rolling on the surface of a single-tier slope, including in water: in the "dry" state, and under water;
- the values of internal friction angles taking into account the normative safety factor for working tiers and sides of the dump: in the "dry" and water-saturated state;
- the values of engagement of rock pieces.

The calculation of the safe distance of installation of mining equipment from the upper edge of the formed single-tier dump is associated with the construction of a curved sliding surface [1]. To do this, it is necessary to determine the initial data: the angle of internal friction and the specific weight of rocks, the height of the dump and the water level in the internal space of the open pit.

During the calculation of the rock mass, taking into account the experience of similar calculations [3, 11], the average weighted physical and mechanical properties of the overburden rocks were adopted (Table 1).

The resulting angle of the dump inclination is taken as 32° for the above-water part, and 30° – for the underwater part. The height of the internal single-tier dump is taken in the range from 100 to 500 m, and the water level from 0 to 400 m, provided that the water level is less than the height of the internal dump.

Table 1

Physical and mechanical properties of the overburden rocks placed in the internal dump

Indicators	Overburden rocks	
	not flooded by water	flooded by water
Specific weight, kN/m^3	18.83	17.16
Friction, kN/m^2	20	10
Internal friction angle, degree	30	24

According to the “Regulations on the design of internal dumping and storage of industrial wastes in iron ore and flux open pits” the safety factor (K_y) when calculating the safe distance of installation of mining equipment from the upper edge and when building a curved sliding surface should be taken as 1.2.

To issue recommendations on the choice of the suitable equipment for construction of an internal single-tier dump, it is necessary to calculate the width of a section with the most intensive landslide processes. To determine it, it is necessary to set the distance between the upper edge of the dump and the point of intersection of the curved sliding surface with the horizontal surface of the dumped massif, and the safety factor should be taken as 1.0.

Performance of calculations. The section of the design side of the open pit and the current or design slope of the internal dump is constructed in the required scale and the resulting angle of its slope α_p (degrees) is graphically determined.

The “Slide” software complex was used to compare the indicators of rock stability. The essence of the Slide software is that it builds the section of the calculated array, determines the location of the square in which the centers of radiuses of curved sliding surfaces are placed, then the program finds coefficients by the curved surfaces according to all points of centers and radiuses and points to the smallest indicator. Therefore, to determine the stability near the equipment, the operator must manually determine the coefficient there [12, 13]. The horizontal scale (X) corresponds to the distances between the points of slopes and sites on the respective horizons. The vertical scale (Y) corresponds to the height position of respective horizons and surfaces of the open pit and the dump (Fig. 2).

Variants of dump formation schemes. The formation of a single-tier dump in the mined-out open pit space flooded with water consists of the following processes: transportation of the overburden rocks by haul trucks to the unloading site, unloading of the overburden rocks in heaps, selection of oversized pieces of rock from heaps and moving them outside the unloading of overburden rocks with bulldozer, planning of the dumped heaps into the ditch by the bulldozer, formation of the ditch by the dragline excavator, dumping of the overburden rocks planned in the ditch into the mined-out open pit space by the dragline excavator, movement of the dragline excavator.

The ditch for unloading of the overburden rocks is formed by the dragline excavator outside the prism of possible landslide with the unloading of rocks into the internal open pit space. The ditch width (b, m) must provide at least one place for unloading of the haul truck and the possibility for its maneuvers when directing for unloading. The ditch should be formed along the boundary of the prism of a possible landslide, and a utility road with a width of at least 5 m, or a technological road for passing haul trucks should be provided from the opposite site of the prism.

Overburden rocks are transported from the open pit to the site of unloading by haul trucks. The width of the unloading site must take into account the width of the roadway, the area for maneuvers and the length of the unloading points. Upon reaching the unloading site, the rock-loaded haul truck reduces the speed to 10 km/h and, provided there is a free unloading place, begins maneuvering shunting operations with a speed of not more than 5 km/h, so as to move reverse under unloading beyond the prism of a possible landslide perpendicular to the upper edge of the ditch at a distance of at least 5 m from it to the wheel of the haul truck.

To ensure this, it is necessary to provide a safety embankment along the upper edge of the ditch having a height of at least a half of the diameter of the haul truck wheel. If there are no free places for unloading, the haul truck enters the unloading site in such a way as not to block the exit from the site to empty haul trucks. Subsequent haul trucks are outside the unloading site at a distance of 5 m from each other. The distance between the haul trucks under loading must be at least 5 m.

Oversized pieces of the overburden rocks should not fall into the ditch, so they are selected by bulldozer and transported to the curb outside the unloading section. Selection and transportation of oversized pieces of the overburden rocks are allowed only outside the prism of possible landslide along the safety embankment.

The overburden rocks unloaded in heaps by haul trucks are transported by bulldozer to a ditch formed by a dragline excavator. The movement of the bulldozer is perpendicular to the upper edge of the dump towards the ditch. When planning the rock unloading site, the allowable distance from the upper edge of the ditch to the edge of the chains should be not less than 2 m. The surface of the rock unloading site is planned to be bulldozed at an angle of at least 3° from the upper edge of the ditch perpendicular to it at a distance of 10 m.

The dragline excavator must be installed on a solid level surface. The overburden rock is reloaded by the dragline excavator from the formed ditch into the mined-out space of the open pit. It is forbidden to stay in its bucket area during the operation of the dragline excavator. It is forbidden to carry the bucket over the roadway. The safe distance between mining equipment and the slopes of benches should be at least 1 m. Rock is dumped until the filling of the slope with unloading radius of the dragline excavator at its installation level (Fig. 3).

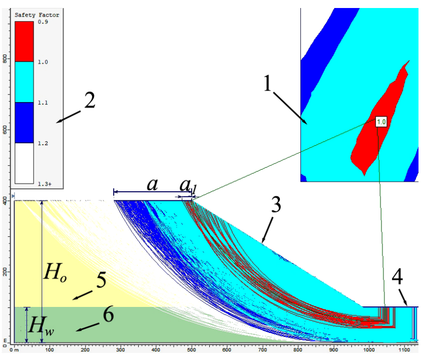

Fig. 2. Example of calculation of parameters of the prism of a possible landslide in the Slide software:

1 – square of the centers of radiuses of the curved sliding surfaces (red – for K_y < 1.0, blue and light blue – for K_y < 1.2); 2 – panel with the legend of the safety factors; 3 – slope of a single-tier dump; 4 – water surface; 5 – overburden rocks, not flooded with water; 6 – overburden rocks flooded with water; a – the width of the prism of a possible landslide (m) when K_y = 1.2; a_1 – the width of the prism of a possible landslide (m) when K_y = 1.0; H_o – the height of the dump; H_w – the height of the flooded part of the dump

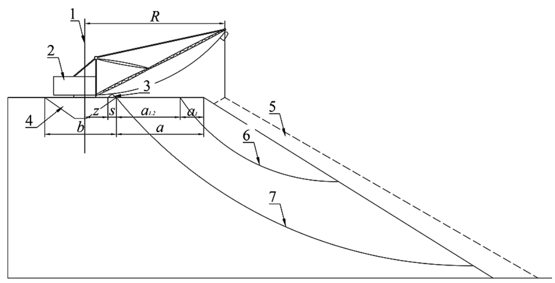

Fig. 3. The scheme of calculation of the parameters of the prism of a possible landslide:

1 – axis of movement of the excavator; 2 – excavator; 3 – safety embankment; 4 – ditch for unloading haul trucks; 5 – surface working which is dumped by an excavator; 6 – curved sliding surface for the safety factor of 1.0; 7 – curved sliding surface for the safety factor of 1.2; R – the unloading radius of the excavator, m; b – the width of the ditch for upper unloading haul trucks, m; z – the distance from the axis of movement of the excavator to the safety embankment, m; s – the width of the safety embankment, m; γ – the slope angle of the dumped massif, degrees; a – the width of the prism of a possible landslide (m) when K_y = 1.2; a_1 – the width of the prism of a possible landslide (m) when K_y = 1.0; $a_{1,2} = a - a_1$

Then the dragline excavator moves along the boundary of the prism of possible landslide, the boom herewith is installed in the direction opposite to the excavator movement, and the operations are repeated until the whole front of the slope is filled. In the event there is a threat of rock mass slide, dumping works should be stopped immediately, and the mining equipment should be moved to a safe area. To do this, a free exit for mining equipment must be provided.

To ensure the safety of the internal dump-formation in the mined-out space of the open pit, the mining equipment must be outside the prism of possible landslide, so the axis of movement of the dragline excavator must be located at such a distance from the prism of possible landslide (z, m) which will provide an opportunity of formation of a safety embankment and construction of a ditch of sufficient width by the dragline excavator (Fig. 4).

Taking into account the parameters of the dragline excavator and the width of the ditch for unloading haul trucks, the distance from the axis of movement of the excavator to the safety embankment should be calculated according to the following formula of the authors'

$$z = R_b\left(\sqrt{1-\left(\frac{R_b+R\sqrt{1-\left(\frac{b_b}{2R_b}\right)^2}}{\sqrt{R^2+R_b^2+2RR_b\sqrt{1-\left(\frac{b_b}{2R_b}\right)^2}}}\right)^2}\sqrt{1-\left(\frac{b-s-1}{\sqrt{R^2+R_b^2+2RR_b\sqrt{1-\left(\frac{b_b}{2R_b}\right)^2}}}\right)^2}+\frac{(b-s-1)\left(R_b+R\sqrt{1-\left(\frac{b_b}{2R_b}\right)^2}\right)}{R^2+R_b^2+2RR_b\sqrt{1-\left(\frac{b_b}{2R_b}\right)^2}}\right)+1, \quad (1)$$

where R is the digging radius of the excavator, m; R_b is the radius of rotation of the tail part of the turntable platform, m; b is the width of the ditch for upper unloading haul trucks, m; b_b is the width of the body of the dragline excavator, m; s is the width of the safety embankment, m.

Thus, the effective use of the selected model of the excavator is determined by the inequality

$$R > z + s + a, \quad (2)$$

or

$$a < R - (z + s). \quad (3)$$

In the case where inequality (3) is not fulfilled, the above-mentioned method for dumping in the mode of controlled deformations is possible. This method differs in that the overburden rocks are dumped into the mined-out space by a dragline excavator not to the level of its installation, but to the maximal height of its unloading (H, m) (Fig. 5). Thus, the "radius" of unloading the overburden rocks into the mined-out space increases by the value $H\,\mathrm{ctg}\,\gamma$.

The idea of the method is that the zone of the most intense landslide phenomena by the dragline excavator is attracted by the embankment of overburden rocks, due to which the rock sliding in the prism of possible landslide (a_1, m) at $K_y = 1.0$ will be more intense.

The most effective method for dumping in the mode of controlled deformations will be used in conditions when the center of masses of the formed "cone" locates in the zone of the most intense landslide phenomena at $K_y = 1$. In this regard, sufficient efficiency of the selected excavator model is determined by inequality

at

$$R < z + s + a; \quad (4)$$

$$R > z + s + (a - a_1), \quad (5)$$

or

$$a - a_1 < R - (z + s). \quad (6)$$

In case of non-fulfillment of condition (6), the efficiency of application of the dump formation method in the mode of controlled deformations is less, however, under certain conditions it can be applied. Then the inefficient use of the selected model of the excavator is determined by the inequality at

$$R < z + s + (a - a_1); \quad (7)$$

$$R + H\,\mathrm{ctg}\gamma > z + s + a, \quad (8)$$

or

$$a < R + H\,\mathrm{ctg}\gamma - (z + s). \quad (9)$$

In case of non-fulfillment of condition (9) the chosen model of the excavator for dump formation of overburden rocks by a single-tier internal dump at dumping of a surface working in the mode of controlled rock deformations is inefficient because the rock mass does not get into the produced space, but only is stacked along the side of the worked out open pit.

This approach to the choice of a dragline excavator for the formation of a single-tier internal dump can be adopted in de-

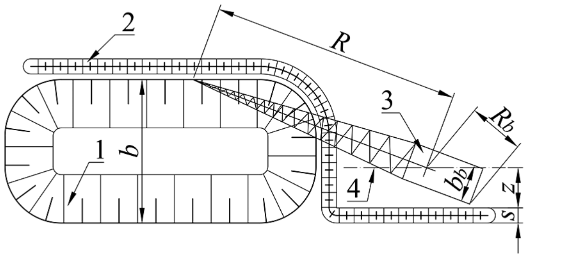

Fig. 4. Diagram for determining the distance from the safety embankment to the axis of movement of the excavator (z, m):

1 – the ditch for unloading haul trucks; 2 – safety embankment; 3 – dragline excavator; 4 – axis of movement of the dragline excavator. R – the digging radius of the excavator, m; R_b – the radius of rotation of the tail part of the turntable platform, m; b – the width of the ditch for upper unloading haul trucks, m; b_b – width of the body of the dragline excavator, m; z – the distance from the axis of movement of the excavator to the safety embankment, m; s – the width of the safety embankment, m

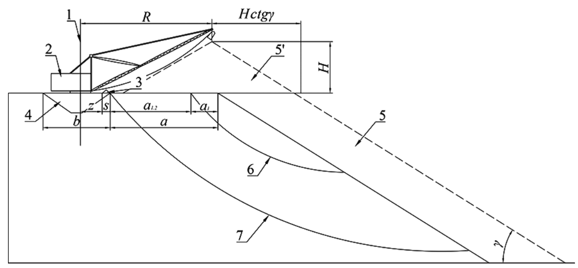

Fig. 5. The scheme for calculation of the parameters of a prism of a possible landslide at dumping of a surface working in the mode of the controlled deformations of rocks:

1 – axis of excavator movement; 2 – excavator; 3 – safety embankment; 4 – ditch for unloading haul trucks; 5 – surface working dumped by the excavator; 5′ – loading prism for controlled landslide of the dumped surface working; 6 – curved sliding surface for the safety factor 1.0; 7 – curved sliding surface for the safety factor 1.2; R – the unloading radius of the excavator, m; b – the width of the ditch for upper unloading haul trucks, m; z – the distance from the axis of the excavator movement to the safety embankment, m; s – the width of the safety embankment, m; γ – the slope angle of the dumped massif, degrees; H – the height of unloading of rock mass by dragline excavator; a – the width of the prism of possible landslide (m) when $K_y = 1.2$; a_1 – the width of the prism of possible landslide (m) when $K_y = 1.0$; $a_{1,2} = a - a_1$

sign decisions for the reconstruction of lignite open pits [14, 15], quarries for the development of ilmenite deposits [16], as well as during filling the mined-out space of open pits for mining of construction raw materials [17, 18].

Calculation of stability parameters. As a result of processing the parameters obtained during the calculations of the width of the prism of the possible landslide, data charts were obtained, the functions of which are mainly polynomials of the third degree, which exist only in the first coordinate coordinate angle (Figs. 6–8).

The horizontal distance from the upper edge to the sliding surface for the safety factor $K_y = 1.2$ for rocks with physical and mechanical properties given in Table 1 is calculated by the formulas

$$a(H_o) = f(H_w); \quad 0 \le H_w \le H_o; \tag{10}$$

$$a_{(500)} = 0.000008 H_w^3 - 0.007 H_w^2 + 1.13 H_w + 224; \tag{11}$$

$$a_{(450)} = 0.000009 H_w^3 - 0.007 H_w^2 + 1.01 H_w + 202; \tag{12}$$

$$a_{(400)} = 0.00001 H_w^3 - 0.009 H_w^2 + 1.17 H_w + 173; \tag{13}$$

$$a_{(350)} = 0.00002 H_w^3 - 0.01 H_w^2 + 1.12 H_w + 152; \tag{14}$$

$$a_{(300)} = 0.00002 H_w^3 - 0.012 H_w^2 + 1.12 H_w + 130; \tag{15}$$

$$a_{(250)} = 0.00004 H_w^3 - 0.017 H_w^2 + 1.32 H_w + 107; \tag{16}$$

$$a_{(200)} = 0.00009 H_w^3 - 0.03 H_w^2 + 1.9 H_w + 78; \tag{17}$$

$$a_{(150)} = 0.0001 H_w^3 - 0.03 H_w^2 + 1.48 H_w + 53; \tag{18}$$

$$a_{(100)} = -0.0034 H_w^2 + 0.03 H_w + 31. \tag{19}$$

Analysis of the function $a(H_o) = f(H_w)$ for the extremum showed that for rocks with physical and mechanical properties typical for the overburden rocks of dumps of the iron ore open pits of the Kryvbas the greatest value is the distance from the upper edge to the sliding surface for the safety factor $K_y = 1.2$, and hence the slope in the single-tier dump has the least stable state when it is flooding to $H_w = H_o/5.2$, with an average deviation of the calculation data of parameters of the prism of a possible landslide of 2.71 %, the maximal deviation – 7.24 %, and the minimal deviation – 0.09 %.

The chart in Fig. 5 shows that the non-flooded tier of the open pit has a parameter of the width of the prism of a possible landslide depending on the height of the tier. Then, when it is flooded with water, the physical and mechanical properties of the tier base change, and the stability of the slope begins to decrease, and the width of the prism of a possible landslide increases. After reaching the critical point of flooding the slope with water to $H_w = Ho/5.2$ the stability increases and the width of the prism of a possible landslide decreases due to the increased influence of the retaining forces of water weight in the internal open pit space. The slope acquires the greatest stability at its maximal flooding by water

$$a_1(H_o) = f(H_w); \quad 0 \le H_w \le H_o; \tag{20}$$

$$a_{1(500)} = 0.000006 H_w^3 - 0.0038 H_w^2 + 0.5 H_w + 34; \tag{21}$$

$$a_{1(450)} = 0.000009 H_w^3 - 0.0045 H_w^2 + 0.45 H_w + 26; \tag{22}$$

$$a_{1(400)} = 0.00003 H_w^3 - 0.0106 H_w^2 + 1.07 H_w + 3; \tag{23}$$

$$a_{1(350)} = 0.00002 H_w^3 - 0.0086 H_w^2 + 0.68 H_w + 11; \tag{24}$$

$$a_{1(300)} = 0.00004 H_w^3 - 0.0096 H_w^2 + 0.54 H_w + 9.5; \tag{25}$$

$$a_{1(250)} = 0.00002 H_w^3 - 0.0053 H_w^2 + 0.22 H_w + 8; \tag{26}$$

$$a_{1(200)} = 0.0002 H_w^2 - 0.08 H_w + 8.5; \tag{27}$$

$$a_{1(150)} = -0.0009 H_w^2 + 0.09 H_w; \tag{28}$$

$$a_{1(100)} = 0. \tag{29}$$

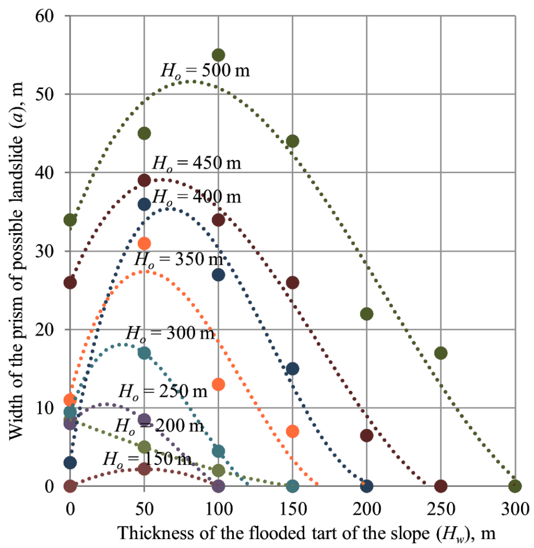

Fig. 7. Chart of the dependence of the width of the prism of a possible landslide at K_y = 1.0 (a_1, m) on the height of the single-tier dump (N_o, m) and the thickness of the flooded part of the slope (H_w, m)

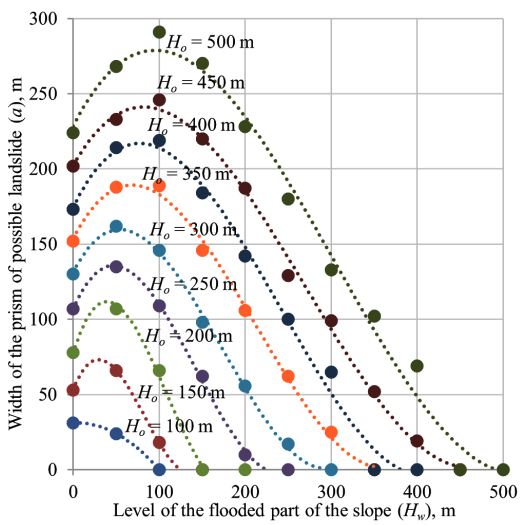

Fig. 6. Chart of dependence of the width of the prism of possible landslide when K_y = 1.2 (a, m) on the height of a single-tier dump (H_o, m) and the level of the flooded part of the slope (H_w, m)

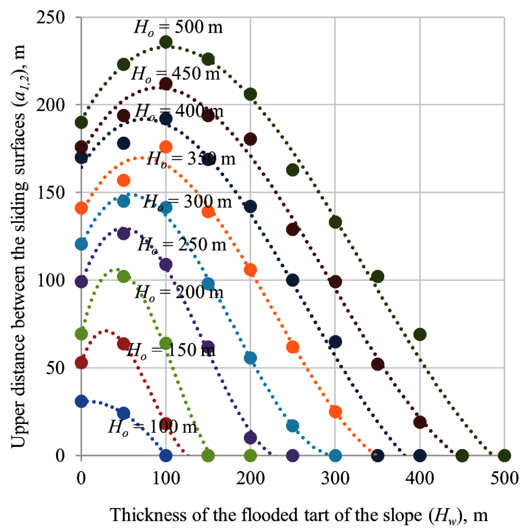

Fig. 8. Chart of the dependence of the upper distance between the sliding surfaces at the K_y = 1.0...1.2 ($a_{1,2}$, m) on the height of a single-tier dump (H_o, m) and the thickness of the flooded part of the slope (H_w, m)

$$a4_{1.2(Ho)} = f(H_w); \quad 0 \le H_w \le H_o; \tag{30}$$

$$a_{1.2(500)} = 0.000005H_w^3 - 0.005H_w^2 + 0.87H_w + 190; \tag{31}$$

$$a_{1.2(450)} = 0.000007H_w^3 - 0.006H_w^2 + 0.89H_w + 176; \tag{32}$$

$$a_{1.2(400)} = 0.000008H_w^3 - 0.006H_w^2 + 0.78H_w + 170; \tag{33}$$

$$a_{1.2(350)} = 0.00001H_w^3 - 0.008H_w^2 + 0.95H_w + 141; \tag{34}$$

$$a_{1.2(300)} = 0.00002H_w^3 - 0.011H_w^2 + 1.08H_w + 120.5; \tag{35}$$

$$a_{1.2(250)} = 0.00004H_w^3 - 0.0165H_w^2 + 1.36H_w + 99; \tag{36}$$

$$a_{1.2(200)} = 0.00009H_w^3 - 0.03H_w^2 + 1.97H_w + 69.5; \tag{37}$$

$$a_{1.2(150)} = 0.0001H_w^3 - 0.028H_w^2 + 1.34H_w + 53; \tag{38}$$

$$a_{1.2(100)} = -0.0034H_w^2 + 0.03H_w + 31. \tag{39}$$

The established dependences (10–39) are necessary at the further choice of the model of the dragline excavator by efficiency criteria given above, namely: effective – the formulas (2, 3) (Fig. 3), sufficiently effective – the formulas (3–5) (Fig. 5), not sufficiently effective – the formulas (7–9) and ineffective (Fig. 9).

An effective dragline excavator, from the point of view of forming a single-tier high dump, is one the parameters of which allow reloading the overburden rocks directly into the mined-out space at the set tier height and level of its flooding, being placed at a safe distance from the upper edge of the slope, namely beyond the prism of a possible landslide.

A sufficiently effective dragline excavator is the one whose parameters do not allow unloading the overburden rocks into the mined-out space directly, but allow unloading rock mass into the area of the dump tier with the most intense landslide phenomena.

A not sufficiently effective dragline excavator is the one whose parameters do not allow unloading the overburden rocks into the mined-out space directly or into the area of the dump tier with the most intense landslide phenomena, but when dumping the stack of the overburden rocks along the upper edge of the tier slope to the maximal height, the rock mass falls into the mined-out open pit space.

An inefficient dragline excavator is the one whose parameters do not allow unloading the overburden rocks into the mined-out space directly or into the area of the dump tier with the most intense landslide phenomena, as well as when dumping the stack of the overburden rocks along the upper edge of the tier slope to the maximal dragline unloading height, the rock mass does not fall into the internal open pit space.

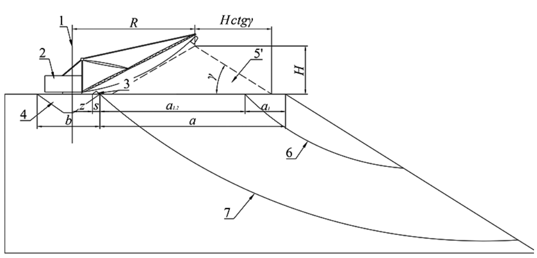

Fig. 9. Illustration of the case when the selected dragline model is ineffective for dumping the surface working in a single-tier dump:

1 – axis of movement of the excavator; 2 – excavator; 3 – safety embankment; 4 – ditch for unloading haul trucks; 5′ – surface working, which is dumped by an excavator; 6 – curved sliding surface for the safety factor of 1.0; 7 – curved sliding surface for the safety factor of 1,2; R – the unloading radius of the excavator, m; b – the width of the ditch for upper unloading haul trucks, m; z – the distance from the axis of movement of the excavator to the safety embankment, m; s – the width of the safety embankment, m; γ – the slope angle of the dumped massif, degrees; H – the height of unloading of rock mass by the dragline excavator; a – the width of the prism of a possible landslide (m) at $K_y = 1.2$; a_1 – the width of the prism of a possible landslide (m) at $K_y = 1.0$; $a_{1,2} = a - a_1$

Choosing an excavator model. The following models of dragline excavators are considered in the study: EK 6.5-45, EK 11-70, EK 14-50, EK 10-50, EK 15-80, EK 20-65, EK 20/90 (Table 2). The experience of designing single-tier dumps allows taking the width of the safety embankments (s) 4 m, the angle of inclination of the dumped massif (γ) 32°, and the width of the ditch for unloading haul trucks (b) 35–40 m.

The question of determining the efficiency of using a particular model of dragline excavator is solved by a system of equations.

For effective dragline excavators

$$\begin{cases} a = AH_w^3 - BH_w^2 + CH_w + D \\ a = R - (z + s) \end{cases}, \tag{40}$$

where A, B, C, D are coefficients of the function equation $a = f(H_o, \boldsymbol{H_w})$, in which H_o is the heigh of the dump, m; H_w is the height of the flooded part of the dump, m.

For sufficiently effective dragline excavators

$$\begin{cases} a_{1,2} = A'H_w^3 - B'H_w^2 + C'H_w + D' \\ a_{1,2} = R - (z + s) \end{cases}, \tag{41}$$

where A', B', C', D' are coefficients of the function equation $a_{1,2} = f(H_b, H_w)$, in which H_o is the heigh of the dump, m; H_w is the height of the flooded part of the dump, m.

For not sufficiently effective dragline excavators

$$\begin{cases} a = AH_w^3 - BH_w^2 + CH_w + D \\ a = R + H\,\mathrm{ctg}\gamma - (z + s) \end{cases}, \tag{42}$$

where γ is an angle of the dumped massif slope, degrees, H is the height of unloading rock mass with the dragline excavator, m.

Dragline excavators EK 6.5-45, EK 14-50 and EK 10-50 are effective when dumping overburden rocks into the internal open pit space in one tier with a height of 100 m, regardless of the level of flooding the slope with water. It is effective in 200 m dumps with flooding of not less than 125 m, in 300 m dumps with flooding of 230 m, i. e. the thickness of non-flooded part is no more than 70–75 m.

Dragline excavator EK 11-70 is effective for formation of a single-tier dump of the overburden rocks of 150 m high, not flooded with water or with flooded part of not less than 70 m. It is effective in 250 m dumps with flooded part of not less than 160, 300 m dumps of rocks with flooding of not less than 205 m, i. e. the thickness of non-flooded part is no more than 90–95 m.

Excavator-dragline EK 20/90 is effective for the formation of single-tier rock dumps with a height of 150 m, but when it is

Table 2

Parameters of schemes of operation of dragline excavators at formation of a single-tier dump

Model	Unloading radius, R, m	Width of the body, b_b	Radius of rotation of the tail part, R_b, m	Distance from the excavator movement axis to the safety embankment, z, m	Unloading height, $\boldsymbol{H}$, m
EK 6.5-45	43.5	7.6	9.7	9.0–9.5	19.5
EK 11-70	66.5	10	15	10.0–11.0	27.5
EK 14-50	46.5	10	15	11.5–12.5	20.5
EK 10-50	46.5	10	15	11.5–12.5	20.5
EK 15-80	76.5	17.2	17.5	13.0–14.0	32
EK 20-65	61	17.2	17.5	14.0–14.5	27
EK 20/90	83	14.5	19.7	12.5–13.0	38.5

flooded by 10–50 m it is sufficiently effective or not sufficiently effective. It is effective in 200 m dumps with flooding of not less than 100 m, in 300 m dumps with flooding of not less than 190 m, i.e. the thickness of non-flooded part is no more than 100–110 m.

The procedure of filling the mined-out space of an open pit with a depth of more than 150–200 m is proposed as follows. To install a dragline excavator on the rocks, on the reloading horizon of the combined internal open pit transport (for automobile-railway transport 150–200 m [19] and automobile-conveyor transport 270–350 m [20]) which is used to start formation of the internal dump. The movement of the dragline excavator to the new surface working should be carried out after reaching the level of tier flooding, which will provide the stability sufficient for effective use of the equipment. As the water level rises, to increase the height of the dump until the worked out open pit is filled with overburden rocks and water.

Conclusions.

1. Using the Slide software, the models of the dumped overburden rock mass having the slope height of 100 to 500 m with the step of 50 m and the level of flooding from 0 to 500 m with the step of 50 m were constructed. The following physical and mechanical properties were used: specific weight of the overburden rocks not flooded with water – 18.83 kN/m^3, flooded – 17.16 kN/m^3; friction of the overburden rocks not flooded with water – 20 kN/m^2, flooded – 10 kN/m^2; the angle of internal friction of the overburden rocks, not flooded with water – 30°, flooded – 24°. Based on the constructed models, the parameters of the width of the prism of a possible landslide at the safety factors 1.2 and 1.0 are calculated and their dependences on the height of the dump and the level of its flooding with water are established. The charts of the functions describing these dependences are polynomials of the third degree that exist exclusively in the first coordinate angle.

2. The study on the obtained functions to the extremum revealed that the least stable position for the dumped overburden rock massif is achieved when the slope of the dumped rocks tier is flooded by 1/5.2 of its height.

3. It is established that when the slope of the dumped overburden rock mass is flooded with water, the physical and mechanical properties of the tier base change, and the stability of the slope begins to decrease, and the width of the prism of a possible landslide increases. After reaching the critical point of flooding the slope with water, there is an increase in stability and a decrease in the width of the prism of a possible landslide due to the increased influence of the retaining forces of the water weight in the internal open pit space. The slope acquires the greatest stability when it is maximally flooded by water.

4. The description of schemes of formation of a single-tier dump is given, their basic parameters are outlined and the authors' formula of calculation of the distance from an axis of a dragline excavator movement to the border of a safety embankment taking into account dimensions of a dragline and the required width of a ditch for unloading haul trucks is offered. Depending on the model of the excavator for a ditch with the width of 35–40 m, this distance is equal to 9.0–14.5 m.

5. The limits of efficiency of use of the dragline excavator for a certain height of a single-tier dump are substantiated. Regarding the height of formation of a single-tier dump the dragline excavator can be effective, sufficiently effective, not sufficiently effective and ineffective.

6. By comparing the obtained dependences of the width of the prism of possible landslide on the height of the dumped overburden rock mass slope and the level of their flooding with the limits of efficiency of the dragline excavator use for a certain height of a single-tier dump, it was found that dragline excavators EK 6.5-45, EK 14-50 and EK 10-50 are effective for a tier height of 100 m regardless of the level of flooding, which is confirmed by the practice of dumping in the mined-out space of Open Pit No. 1 of the "ArcelorMittal Kryvyi Rih". For the formation of a dump tier with a height of 150 m, the effective use of excavators EK 11-70 and EK 20/90 is possible when the slope is flooded with water by at least 70 and 50 m, respectively.

7. For slopes of single-tier dumps of the overburden rocks higher than 150–200 m dragline excavators EK 6.5-45, EK 14-50 and EK 10-50 are effective when the thickness of non-flooded part of a slope is 70–75 m, the dragline excavator EK 11-70 – 90–95 m, the dragline excavator EK 20/90 – 100–110 m.

8. The recommended height of the tier of the overburden rocks when forming it with a dragline excavator is not more than 100–150 m, which can be increased only in case of flooding the slope with water.

References.

1. Anisimov, O.O. (2018). Research on parameters of the working area on an internal dump for developing open pits. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (1), 27-34. https://doi.org/10.29202/nvngu/2018-1/17.

2. Lozynskyi, V., Medianyk, V., Saik, P., Rysbekov, K., & Demydov, M. (2020). Multivariance solutions for designing new levels of coal mines. *Rudarsko Geolosko Naftni Zbornik*, *35*(2), 23-31. https://doi.org/10.17794/rgn.2020.2.3.

3. Savenko, V.Ya., & Dahua, L. (2017). Definition of the most effective method of calculation of slope stability. *Automobile roads and road construction*, *101*, 116-128.

4. Sadovenko, I., Zahrytsenko, A., Podvigina, O., Dereviahina, N., & Brzeźniak, S. (2018). Methodical and applied aspects of hydrodynamic modeling of options of mining operation curtailment. In *Solid State Phenomena,* (Vol. 277, pp. 36-43). Trans Tech Publications Ltd. https://doi.org/10.4028/www.scientific.net/SSP.277.36.

5. Nikolashin, S.Yu., Nikolashin, Yu.M., & Kebal, Ya.V. (2018). Hydro-and geomechanical conditions of internal dumping in a flooded open pit mine. *Mining Informational and Analytical Bulletin*, *2018*(6), 38-44. https://doi.org/10.25018/0236-1493-2018-6-0-38-44.

6. Nikolashin, Yu.M., & Kebal, Ya.V. (2016). Ways of using areas of residual open-pit workings flooded by underground waters. *Visnyk Kryvorizkoho Natsionalnoho Universytetu*, *43*, 45-47.

7. Rysbekov, K., Toktarov, A., Kalybekov, T., Moldabayev, S., Yessezhulov, T., & Bakhmagambetova, G. (2020). Mine planning subject to prepared ore reserves rationing. *E3S Web of Conferences*. https://doi.org/10.1051/e3sconf/202016800016.

8. Nikolashin, S.Yu., Nikolashin, Yu.M., & Matsak, N.A. (2017). Ecological and legal problems of providing technogenic safety during mining-technical reclamation of areas of open-pit workings of deep open pits flooded by underground waters. *Problemy obespecheniia bezopasnosti pri likvidatsii posledstviy chrezvychainykh situatsiy*, *1*, 269-273. Retrieved from https://www.elibrary.ru/item.asp?id=37158086.

9. Kalybekov, T., Rysbekov, K., Sandibekov, M., Bi, Y.L., & Toktarov, A. (2020). Substantiation of the intensified dump reclamation in the process of field development. *Mining of Mineral Deposits*, *14*(2), 59-65. https://doi.org/10.33271/mining14.02.059.

10. Shpakov, P.S., Mirnyy, I.Ya., Dolgonosov, V.N., & Starostina, O.V. (2016). Assessment of parameters of stable internal dumps at "Bogatyr" open-cast. *Mining Informational and Analytical Bulletin*, *2*, 345-356.

11. Sotskov, V., Dereviahina, N., & Malanchuk, L. (2019). Analysis of operation parameters of partial backfilling in the context of selective coal mining. *Mining of Mineral Deposits*, *13*, 129-138. https://doi.org/10.33271/mining13.04.129.

12. Buzylo, V., Pavlychenko, A., Savelieva, T., & Borysovska, O. (2018). Ecological aspects of managing the stressed-deformed state of the mountain massif during the development of multiple coal layers. *E3S Web of Conferences*, *60.* https://doi.org/10.1051/e3sconf/20186000013.

13. Buzylo, V., Pavlychenko, A., Borysovska, O., & Saveliev, D. (2019). Investigation of processes of rocks deformation and the earth's surface subsidence during underground coal mining. *E3S Web of Conferences*, *123*. https://doi.org/10.1051/e3sconf/201912301050.
14. Shustov, O. O., Bielov, O. P., Perkova, T. I., & Adamchuk, A. A. (2018). Substantiation of the ways to use lignite concerning the integrated development of lignite deposits of Ukraine. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (3), 5-13. https://doi.org/10.29202/nvngu/2018-3/6.
15. Babets, Y. K., Bielov, O. P., Shustov, O. O., Barna, T. V., & Adamchuk, A. A. (2019). The development of technological solutions on mining and processing brown coal to improve its quality. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 36-44. https://doi.org/10.29202/nvngu/2019-6/6.
16. Sobko, B. Y., Denyschenko, O. V., Lozhnikov, O. V., & Kardash, V. A. (2018). The belt conveyor effectiveness at the rock haulage under flooded pit excavations. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 26-35. https://doi.org/10.29202/nvngu/2018-6/4.
17. Symonenko, V., Hrytsenko, L., & Cherniaiev, O. (2016). Organization of non-metallic deposits development by steep excavation layers. *Mining of Mineral Deposits*, *10*(4), 68-73. https://doi.org/10.15407/mining10.04.068.
18. Denyshchenko, O. V., Shyrin, A. L., Rastsvietaiev, V. O., & Cherniaiev, O. V. (2018). Forming the structure of automated system to control ground heavy-type ropeways. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 79-85. https://doi.org/10.29202/nvngu/2018-4/12.
19. Kuzmenko, S., Kaluzhnyi, Y., Moldabayev, S., Shustov, O., Adamchuk, A., & Toktarov, A. (2019). Optimization of position of the cyclical-and-continuous method complexes when cleaning-up the deep iron ore quarries. *Mining of Mineral Deposits*, *13*(3), 104-112. https://doi.org/10.33271/mining13.03.104.
20. Belmas, I., Kogut, P., Kolosov, D., Samusia, V., & Onyshchenko, S. (2019). Rigidity of elastic shell of rubber-cable belt during displacement of cables relatively to drum. *International Conference Essays of Mining Science and Practice, 109*, 00005. https://doi.org/10.1051/e3sconf/201910900005.

Визначення умов використання драглайнів при формуванні одноярусного внутрішнього відвалу

Є. К. Бабець[1], *А. А. Адамчук*[2], *О. О. Шустов*[2], *О. О. Анісімов*[2], *О. О. Дмитрук*[2]

1 – Державний науково-дослідний гірничорудний інститут Криворізького національного університету, м. Кривий Ріг, Україна, e-mail: ebabets@gmail.com
2 – Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна, e-mail: Adamchuk.A.A@nmu.one

Мета. Науково-практичною задачею дослідження є встановлення залежностей безпечної відстані розташування екскаваторів-драглайнів від висоти одноярусного внутрішнього відвалу скельних порід і рівня його підтоплення з урахуванням фізико-механічних властивостей скельних порід.

Методика. Для досягнення поставлених задач використовувались наступні методи дослідження: комп'ютерне моделювання з використанням програмного забезпечення «Slide» для побудови найбільш напружених поверхонь ковзання відсипаного масиву гірських порід. При цьому розрахунки виконувалися в ручному й в автоматичному режимі пошуку найбільш напруженої (слабкої) поверхні ковзання по декількох розрахункових поверхнях ковзання. Отримані дані розрахунків ширини призми можливого зрушення були проаналізовані та встановлена їх залежність від висоти одноярусного відвалу й рівня води у внутрішньокар'єрному просторі методом найменших квадратів. Формула розрахунку величини відстані від запобіжного валу до вісі руху екскаватора отримана з використанням теореми косинусів і низки тригонометричних тотожностей.

Результати. За допомогою програмного комплексу «Slide» розраховані параметри ширини призми можливого зрушення при коефіцієнтах запасу стійкості 1,2 і 1,0 та встановлені їх залежності від висоти відвалу й рівня його підтоплення водою, що дозволило встановити ефективні моделі екскаваторів-драглайнів для різних умов ведення відвалоутворення. Запропонована формула розрахунку відстані від вісі руху екскаватора до запобіжного валу з урахуванням параметрів екскаватора-драглайна й ширини приямка для розвантаження автосамоскидів.

Наукова новизна. Встановлено, що при підтопленні укосу відсипаного масиву скельних порід розкриву водою відбувається зміна фізико-механічних властивостей підошви ярусу, і стійкість укосу починає зменшуватися, а ширина призми можливого зрушення – збільшуватися. Після досягнення критичної відмітки затоплення водою укосу, величиною 1/5,2 від загальної висоти укосу ярусу, відбувається збільшення стійкості та зменшення ширини призми можливого зрушення за рахунок підвищення впливу утримуючих сил ваги води у внутрішньокар'єрному просторі. Найбільшої стійкості укіс набуває при максимальному затопленні його водою.

Практична значимість. Отримані залежності дозволили визначати безпечну відстань встановлення гірничого обладнання, а також дали змогу зробити вибір доцільної моделі екскаватора для ведення робіт з утворення одноярусного відвалу. Рекомендована висота ярусу відвалу скельних порід розкриву при формуванні його екскаватором-драглайном не більше 100–150 м, або більше лише в разі підтоплення укосу водою. Встановлено, що екскаватори-драглайни ЕК 6,5-45, ЕК 14-50 і ЕК 10-50 ефективні для висоти ярусу 100 м незалежно від рівня затоплення. Для формування відвального ярусу висотою 150 м ефективне використання екскаваторів ЕК 11-70 та ЕК 20/90 можливе при підтопленні укосу водою не менше, ніж на 70 та 50 м відповідно. Для укосів одноярусних відвалів скельних порід розкриву висотою більше 150–200 м екскаватори-драглайни ЕК 6,5-45, ЕК 14-50 і ЕК 10-50 ефективні при потужності незатопленої частини укосу 70–75 м, екскаватор-драглайн ЕК 11-70 – 90–95 м, екскаватор-драглайн ЕК 20/90 – 100–110 м.

Ключові слова: *внутрішній відвал, одноярусний відвал, затоплений глибокий кар'єр, стійкість бортів, фізико-механічні властивості гірських порід, екскаватор-драглайн, коефіцієнт запасу стійкості*

Определение условий использования драглайнов при формировании одноярусного внутреннего отвала

Е. К. Бабец[1], *А. А. Адамчук*[2], *А. А. Шустов*[2], *О. А. Анисимов*[2], *О. А. Дмитрук*[2]

1 – Государственный научно-исследовательский горнорудный институт Криворожского национального университета, г. Кривой Рог, Украина, e-mail: ebabets@gmail.com
2 – Национальный технический университет «Днепровская политехника», г. Днепр, Украина, e-mail: Adamchuk.A.A@nmu.one

Цель. Научно-практической задачей исследования является установление зависимостей безопасного расстояния расположения экскаваторов-драглайнов от вы-

соты одноярусного внутреннего отвала скальных пород и уровня его подтопления с учетом физико-механических свойств скальных пород.

Методика. Для достижения поставленных задач использовались следующие методы исследования: компьютерное моделирование с использованием программного обеспечения «Slide» для построения наиболее напряженных поверхностей скольжения отсыпанного массива горных пород. При этом расчеты выполнялись в ручном и в автоматическом режиме поиска наиболее напряженной (слабой) поверхности скольжения по нескольким расчетным поверхностям скольжения. Полученные данные расчетов ширины призмы возможного сдвига были проанализированы и установлена их зависимость от высоты одноярусного отвала и уровня воды во внутрикарьерном пространстве методом наименьших квадратов. Формула расчета величины расстояния от предохранительного вала до оси движения экскаватора получена с использованием теоремы косинусов и ряда тригонометрических тождеств.

Результаты. С помощью программного комплекса «Slide» рассчитаны параметры ширины призмы возможного обрушения при коэффициентах запаса устойчивости 1,2 и 1,0 и установлены их зависимости от высоты отвала и уровня его подтопления водой, что позволило установить эффективные модели экскаваторов-драглайнов для различных условий ведения отвалообразования. Предложена формула расчета расстояния от оси движения экскаватора до предохранительного вала с учетом параметров экскаватора-драглайна и ширины приямка для разгрузки автосамосвалов.

Научная новизна. Установлено, что при подтоплении откоса отсыпанного массива скальных пород вскрыши водой происходит изменение физико-механических свойств подошвы яруса, и устойчивость откоса начинает уменьшаться, а ширина призмы возможного обрушения – увеличиваться. После достижения критической отметки затопления водой откоса, величиной 1/5,2 от общей высоты откоса яруса, происходит увеличение устойчивости и уменьшение ширины призмы возможного обрушения за счет повышения влияния удерживающих сил веса воды во внутрикарьерном пространстве. Наибольшую устойчивость откос приобретает при максимальном затоплении его водой.

Практическая значимость. Полученные зависимости позволили определить безопасное расстояние установления горного оборудования, а также позволили сделать выбор целесообразной модели экскаватора для ведения работ по созданию одноярусного отвала. Рекомендуемая высота яруса отвала скальных пород вскрыши при формировании его экскаватором-драглайном – не более 100–150 м, или более – только в случае подтопления откоса водой. Установлено, что экскаваторы-драглайны ЭШ 6,5-45, ЭШ 14-50 и ЭШ 10-50 эффективны для высоты яруса 100 м независимо от уровня затопления. Для формирования отвального яруса высотой 150 м эффективное использование экскаваторов ЭШ 11-70 и ЭШ 20/90 возможно при подтоплении откоса водой не менее, чем на 70 и 50 м соответственно. Для откосов одноярусных отвалов скальных пород вскрыши высотой более 150–200 м экскаваторы-драглайны ЭШ 6,5-45, ЭШ 14-50 и ЭШ 10-50 эффективны при мощности незатопленной части откоса 70–75 м, экскаватор-драглайн ЭШ 11-70 – 90–95 м, экскаватор-драглайн ЭШ 20/90 – 100–110 м.

Ключевые слова: *внутренний отвал, одноярусный отвал, затопленный глубокий карьер, устойчивость бортов, физико-механические свойства горных пород, экскаватор-драглайн, коэффициент запаса устойчивости*

Recommended for publication by V. I. Symonenko, Doctor of Technical Sciences. The manuscript was submitted 16.05.20.