https://doi.org/10.31713/m1311

TECHNOLOGY OF DEEP OPEN-CAST MINES RECLAMATION

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Abstract

The subject of the study is the surface mining the mineral of deep occurrence and further reclamation of disturbed land.

The purpose of the work is the scientific and practical task of the study is to justify a new technology of flooded open-cast mines reclamation, taking into account depth of mine, its flooding level and the physical and mechanical properties of rocks.

The calculations were performed in manual and automatic search mode for the most stressed sliding surface on several calculated sliding surfaces. 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.

New technology is based on the phenomenon of when water flooding of the slope reaches the critical value at the level of 0,19 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 by increasing the influence of water retaining forces in the open pit space.

Key words: internal dump, single-tier dump, 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 [1–10]. For their construction, additional lands, which can reach 100 hectares and more, are involved in land allotments and should be located near open pits [11-20]. 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 [21-26].

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 "Novokryvyi Rih 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 the relevant task.

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

Methodology

Calculations of the stability of the slopes of the dumps were made by algebraic summation of forces using the method of slices in Rocscience Slide software. The calculation of the width of the prism of the possible landslide (a, m) and the guaranteed landslide (a_1, m) of the formed one-tier dump relates to finding the curved sliding surface.

For this, a cross-section of a one-tier dump with the necessary parameters is constructed. The location of the square is determined, in which the centers of the radii of the curved sliding surfaces are located. Next, the program finds the safety factor on curved surfaces according to all center points and radii. After that, it is necessary to determine the distance from the crest of the dump to the farthest point of intersection of the curved surface SF=1.2 and SF= 1 with the surface.

Taking into account the previous experience of similar calculations, the following physical and mechanical properties of the soil massif were taken: unit weight - 20.6 kN/m^3, cohesion - 44 kPa, internal friction angle - 21°. Rocks are dumped in a dump in the underwater part: unit weight - 20.0 kN/m^3, cohesion - 22 kPa, internal friction angle - 18°. We accept the angle of the natural slope of the massif of soil 35° (fig. 3).

For the simulation of single-tier dumps of overburden rocks, their height was taken from 100 m to 500 m with a step of 50 m, dumping height from 0 m to 40 m with a step of 50 m, the following physical and mechanical properties of the material: unit weight - 18,83 kN/m^3, cohesion - 20 kN/m^2, internal friction angle - 30 degrees (fig. 4).

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. 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).

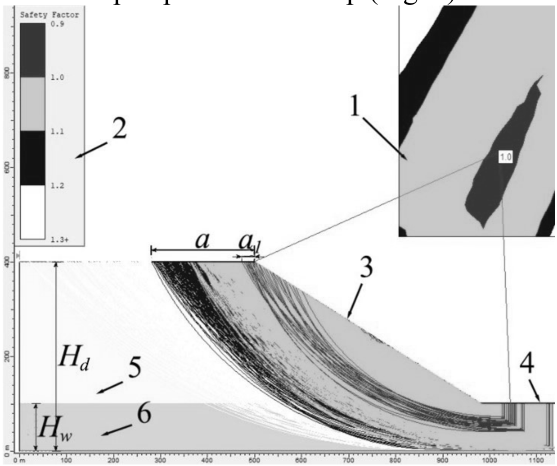

Fig. 2 Example of calculation of parameters of the prism of a possible landslide in the Slide software. *1* - square of the centers of radiuses of the curved sliding surfaces; *2* - panel with the legend of the safety factors; *3* - slope of a single-tier dump; *4* - water surface; *5* - overburden rocks, not flooded with water; *6* - overburden rocks flooded with water; *a* - the width of the prism of a possible landslide, m when *SF*=1.2; a_1 - the width of the prism of a possible landslide, m when *SF*=1.0; H_d - the height of the dump, H_w - the height of the flooded part of the dump

Calculation of stability parameter

The results of processing the parameters obtained during the calculations of the width of the prism of the possible landslide the data charts were obtained, the functions of which are mainly polynomials of the third degree, which exist only in the first coordinate angle (fig. 3-4).

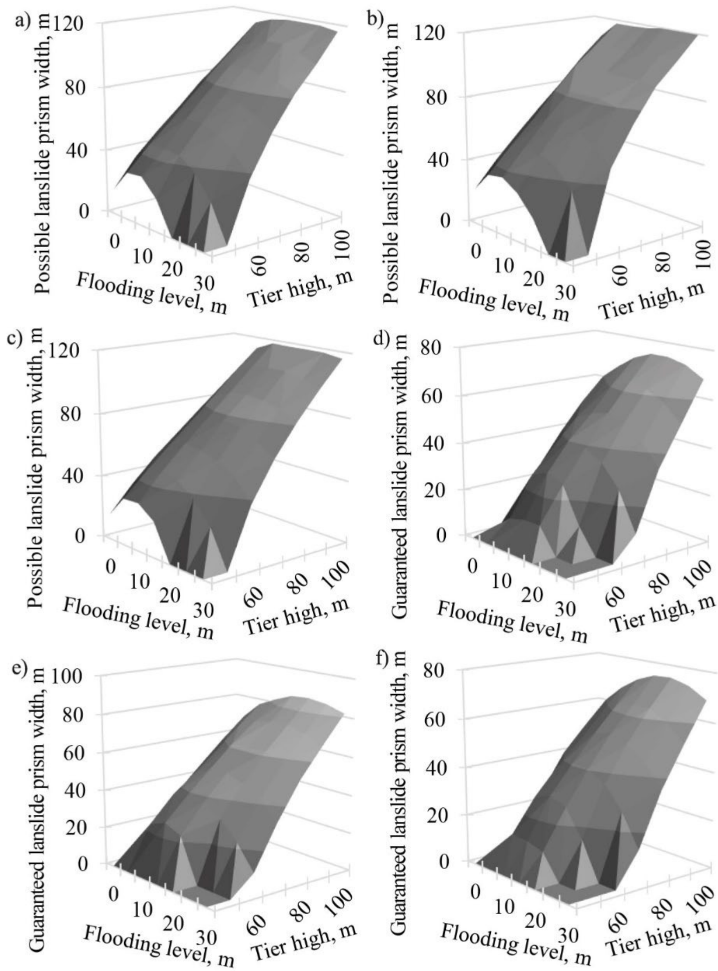

Fig. 3. Chart of the dependence of the width of the prism of a possible landslide (*SF*=1.2, *a-c*) and guaranteed (*SF*=1.0, *d-f*) on the height of dump tier and the thickness of the flooded part of the soil slope

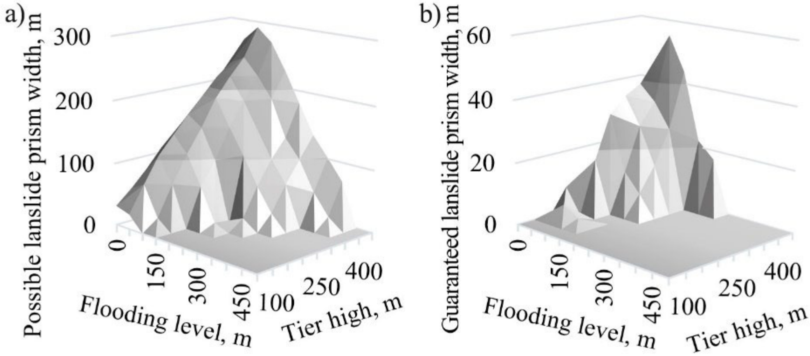

Fig. 4. Chart of the dependence of the width of the prism of a possible landslide (*SF*=1.2*, a*) and guaranteed (*SF*=1.0, b) on the height of dump tier and the thickness of the flooded part of the overburden rock slope

Analysis of fig. 3, 4 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 Kryvbass the greatest value is the distance from the upper edge to the sliding surface for the safety factor *SF*=1.2, and hence the slope in the single-tier dump has the least stable state when it is flooding to H_w=0.19H_o, 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 the fig. 4 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=0.19H_o 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.

Technology of deep open-cast mines reclamation

During the development of mineral deposits, especially in the open method, overburden rock dumps are formed. Since the stockpiled material is loose, the dump is deformed during its construction due to compaction. The compaction of the dump occurs most intensively in the massif of the freshly poured backfill due to the filling of air cavities under the influence of the weight of the deposited rocks. Therefore, the formation of a dump is carried out with the installation of mining equipment outside the prism of possible displacement, the width of which depends on the physical and mechanical properties of the overburden rocks deposited in the dump, its height and level of flooding. The worst conditions are observed when the slope is flooded by 20–30% of its height [27]. A further increase in the level of inundation of the slope by means of natural water inflow will help to increase its stability due to the effect of the weight of water on the slope of the dump.

There is a known method of forming internal dumps in the produced space of spent deep quarries, which includes the transportation of overburden rocks from the mine to the place of formation of the dump in the produced space from the day surface of the quarry in one tier to its full depth. This method simplifies the organization of dump operations and ensures minimum costs for the transportation of overburden rocks [28].

The disadvantage of this method is that the possibility of its application is limited by the depth of the mine and the properties of the overburden rocks deposited in the intra-quarry space. If the stable height of the dump layer is equal to the depth of the mine, then it can be filled with one ledge, if it is less – not.

The closest to the proposed method is the method of internal dump formation with the formation of supporting prisms in the bottom of the dump, which includes the formation of an internal dump and the formation of an overburden by bulldozers from rocks delivered by motor vehicles, ahead of the development of the dump layer. This method makes it possible to slightly increase the stability of the backfill massif [29].

The disadvantage of this method is the need to transport overburden rocks from the day surface to the bottom of the pit by dump trucks to form a supporting prism, which increases the costs of overburden transportation and necessitates the need to drain water from the internal pit space. In addition, the formation of a waste layer on the side of the spent quarry can partially block the transport berms, which significantly limits the application of the method.

The basis of the invention is the task of improving the method of reclamation of deep quarries, in which, by introducing new technological operations, the possibility of full use of the original conditions of the intra-pit space of spent quarries, regardless of their depth, is achieved in full in conditions of constant water inflow with the provision of a rational distance transportation of overburden rocks under stable and safe parameters of the internal dump in the continuous process of its formation and, due to this, increasing the efficiency of the technology while simplifying and reducing costs.

The task is solved by the fact that in the known method of reclamation of deep pits, which includes the formation of a waste layer by a dragline excavator in the produced space of a deep pit with natural water inflow to fill the internal pit space with overburden rocks and water when the dragline excavator is installed outside prisms of possible displacement, according to the invention, pre-determine the height of the layer of the internal dump of overburden rocks based on their physical and mechanical properties, the value of the width of the prism of possible displacement and the specified water level, form the dump layer with a dragline excavator, and when the water level of the specified mark is reached, form the next tier, adjusting the height of the dump while maintaining the specified width of the prism of a possible shift [30].

Fig. 5 shows the reclamation scheme of deep open-cast mines. In fig. *a* shows the mine in its finished contours; in fig. *b* – the beginning of the formation of the pioneer dump; in fig. *c* – the beginning of dragline operation on the formed pioneer dump; in fig. *d* – formation of the next dump tier by a dragline; in fig. *e* – the combination of two tiers with the formation of the next one; in fig. *f* – work of the dragline on the next tier; in fig. *g* – creating the possibility of forming a dump tier from the day surface; fig. *h* – the formation of a dump tier from the day surface.

The method of reclamation of deep open-cast mines is implemented as follows. The height of the layer of the internal dump of overburden rocks is pre-set based on their physical and mechanical properties, the value of the width of the prism of possible displacement and the given water level (see fig. 3, 4).

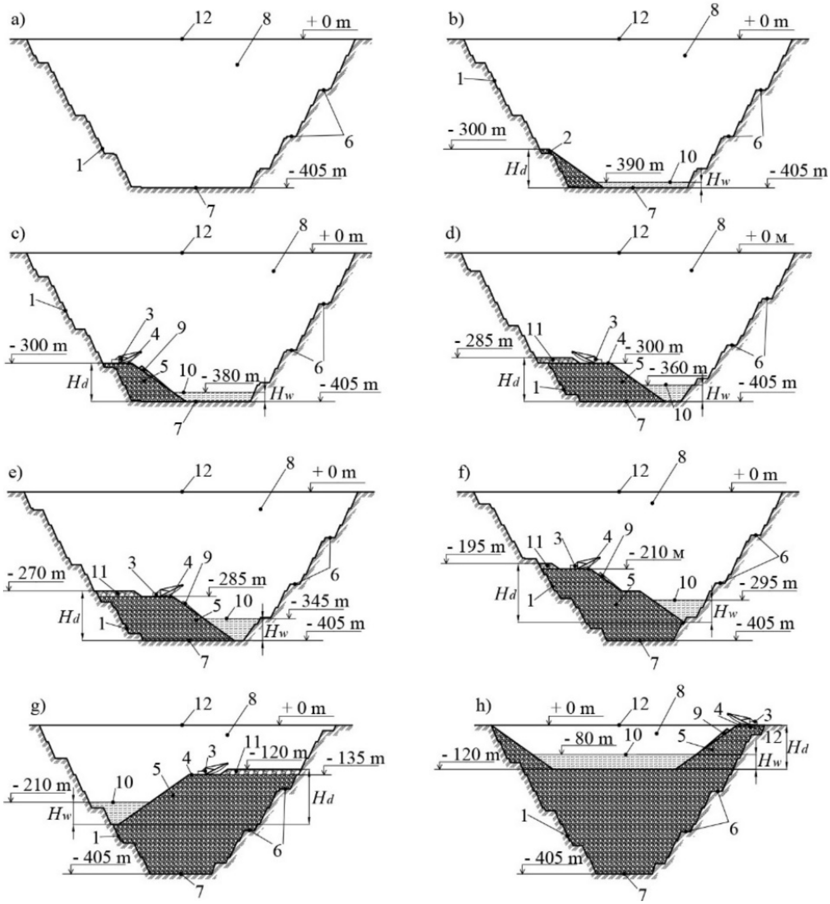

Fig. 5. Deep open-cast mine reclamation scheme: *1* - side of the quarry; *2* - pioneer dump; *3* - dragline excavator; *4*- prism of possible landslide; *5* - dump tier; *6* - transport berms; *7* - the bottom of the pit; *8* - developed intra-quarry; *9* - fallow back; *10* - height mark of the water level in the intra-quarry space; *11* - the next tier; *12* -surface

The value of the width of the prism of possible displacement (a, m) must meet the condition

$$a<R-(s+z), \tag{1}$$

where R - the unloading radius of the excavator-dragline, m; s - width of the safety embankment, m; z - is the distance from the axis of movement of the dragline excavator to the safety embankment, m.

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 from 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 is 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.

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 a ditch of sufficient width by the dragline excavator (fig. 6).

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 author’s formula

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

where 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; s - the width of the safety embankment, m.

The width of the prism of possible landslide depends on the height of the internal dump, the level of its flooding (see fig. 3, 4), the overburden rocks that make it up, in particular, their physical and mechanical properties such as the angle of internal friction, specific gravity and adhesion, and is controlled the total height of the internal dump.

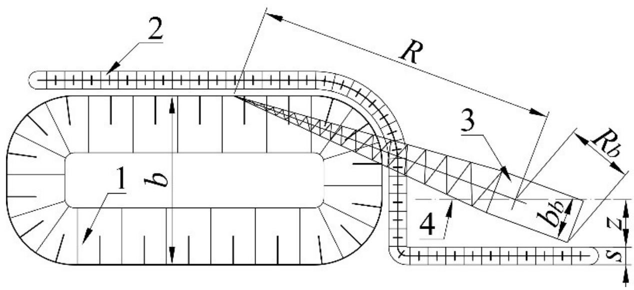

Fig. 6. Diagram for determining the distance from the safety embankment to the axis of movement of the excavator (z, m): *1* - the ditch for unloading haul trucks; *2* - safety embankment; *3* - dragline excavator; *4* - axis of movement of the dragline excavator. R - the digging radius of the excavator, 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

Next, the dump tier is formed by a dragline excavator by gradually increasing the height of the internal dump following the rise of the water level in the internal pit space in such a way that, based on the specified indicators, the height of the non-flooded part of the dump slope does not exceed approximately 70-110 m, according to studies [2], depending on the model of the dragline excavator and the physical and mechanical properties of the overburden rocks, and consists of the following technological operations.

First, a pioneer dump is formed on one of the sides of the mine to form a horizontal platform for setting up a dragline on it outside the prism of a possible shift with the possibility of dumping the tailing layer. The pioneer embankment is formed from overburden rocks, which are delivered to the quarry by dump trucks by transport berms and placed along them by bulldozers. The horizontal platform is separated from the prism of possible displacement by a safety embankment built outside of it. The difference between the marks of the formed site and the bottom should be equal to the height of the dump layer, at which it is possible to safely form it with the installation of a dragline outside the prism of possible displacement. The value of the width of which must meet the condition:

After the formation of the pioneer embankment, on the formed horizontal section on a firm, level base, the dragline excavator begins to form a pit for unloading dump trucks. The pit is formed outside the prism of a possible landslide with the unloading of rocks into the intra-quarry space. The rock is dumped until the dump pit is filled to the unloading radius of the dragline excavator at the level of its installation.

The width of the pit should provide at least one unloading place for the dump truck and the possibility for its maneuvers when feeding for unloading. The pit should be formed along the edge of the prism of possible displacement, and on the opposite side of it, along the pit, there should be an economic road. A safety embankment must be built between the utility road and the pit. It is forbidden to be in the area of action of its bucket during the operation of the dragline excavator.

After filling the backfill, it is necessary to move the excavator-dragline to a new position for further dumping of overburden rocks into the created space. The development of the front of dump works on one horizon of the installation of the dragline excavator is possible both parallel and fan depending on the height of the formed internal dump, the parameters of the spent pit and controlling the level of its flooding. It is prohibited to install a dragline excavator within the prism of possible displacement.

When the level of the specified mark of submergence is reached with a dragline excavator, the next tier is formed by adjusting the height of a single dump while maintaining the specified width of the prism of possible landslide in a continuous technological process.

When the front of the dump operations moves forward and with an increase in the level of submergence of the dump tier, the dragline excavator forms the next dump tier at the level of its installation on the opposite side of the slope of the first dump tier. For this, the excavator is installed outside the prism of possible displacement at a distance from the axis of movement of the dragline excavator to the safety embankment not less than

$$z = R_b + 1, \text{ м}. \qquad (3)$$

Between the descent to the horizon of the installation of the dragline excavator and the next tier of the dump, space must be left for the passage of dump trucks. The height of the next layer is taken taking into account the maximum unloading height of the selected model of excavator-dragline 4, but in total with the unflooded part of the first dump layer no more than approximately 70-110 m. In addition, between the slope of the next dump layer and the safety embankment of the pit a utility road must be provided. The surface of the next tier is planned by a bulldozer with the formation of a horizontal platform for further work on it by a dragline excavator.

After reaching the difference between the water level marks in the intra-quarry space and the horizontal platform of the next dumping tier, approximately 70-110 m, and also provided that it is of sufficient size for the operation of the dragline excavator. The latter is moved to the horizontal platform of the next dump tier. At the same time, the space between the slope of the next dump layer and the slope is filled in the same way as when forming the pioneer embankment, ensuring the possibility of access for dump trucks to the new horizon of the installation of the dragline excavator.

After that, the two formed tiers are combined and form the next one. The operations are repeated in a continuous technological process until the difference in the marks of the day surface and the next dump layer approaches the value of the height of the stable dump, the formation of which is possible with the existing dragline excavator when it is installed outside the prism of possible displacement. After that, the increase in the height of the internal dump is stopped.

After filling the pit with rocks to a mark at which its difference with the surface mark approaches the value of the height of the stable dump, the excavator-dragline is installed on the surface and a pit is formed along the perimeter of the upper edge of the slope of the side of the pit with unloading into the produced intra-pit space. At the same time, all transport berms 8 in the intra-pit space are eliminated.

During this period of dump formation, it is possible to achieve the maximum productivity of stockpiling of overburden rocks, since the operation of the dragline excavator is not limited by the parameters of the backfilled pit, and the distance of transportation of overburden rocks to the pit is minimal. In addition, at this stage, it is possible to use railway transport, which can deliver overburden from distant quarries.

The formation of the internal dump in the intra-quarry space is carried out until it is filled with overburden rocks and water to the level of the day surface.

The use of the described method of reclamation of deep quarries allows:

- To place overburden rock with a depth of more than 200-300 m in the developed space with the maximum possible completeness of filling its volume;
- To achieve optimal parameters of internal dump formation from the point of view of the safety of the dragline excavator, its productivity, the distance of transportation of overburden rocks and the completeness of their filling of the spent pit;
- To apply the force of the weight of water in the intra-quarry space to the slope of the dump layer to increase its stability, instead of spending on its drainage;
- To restore lands disturbed by mining operations for agricultural or forestry purposes;
- To create a pond, the water from which can be used as technical water for various industries;
- To prevent the violation of external dumps by the area of land, the size of which is calculated according to the formula

$$S_d = \frac{100V_K}{0{,}6\ldots0{,}7H_v} = \frac{100\cdot110}{0{,}6\ldots0{,}7\cdot100} = 157\ldots183 \text{ ha}, \qquad (4)$$

where V_K - the volume of produced intra-pit space filled with overburden rocks, million m^3; H_v - the height of the outer dump, m.

- To obtain the overall economic effect due to the preservation of land from disturbance, which is calculated according to the formula:

$$E = 0{,}0005\left(\frac{V_K}{Q}+1\right)S_d c = \qquad (5)$$
$$= 0{,}0005\left(\frac{110}{10}+1\right)\cdot(157\ldots183)\cdot(50...80) = 47{,}1\ldots87{,}8 \text{ mln UAH},$$

where Q is the annual productivity from the storage of overburden rocks in the internal dump, million m^3/year; c – annual payments for land disturbance, thousand UAH/ha·year.

When completing the reserves of the deposit with the markings of the working zone significantly above the bottom of the pit, reduce the distance of overburden rock transportation when forming an internal dump on the deep horizons of the pit according to the proposed method.

Conclusions

1. The study of 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 0,19 of its height.

2. 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.

3. The description of schemes of formation of a single-tier dump is given, their basic parameters are outlined and the author's 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.

4. 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, enough effective, not enough effective and ineffective.

5. 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 the 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 m and 50 m, respectively.

6. For slopes of single-tier dumps of the overburden rocks higher than 150-200 m the 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.

7. 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. **Adamchuk, A., & Shustov, O.** (2023). Control of dump stability lading rock on its edge. Inżynieria Mineralna, 1(1), 91–96. https://doi.org/10.29227/IM-2023-01-11

2. **Babets, Y. K., Adamchuk, A. A., Shustov, O. O., Anisimov, O. O., & Dmytruk,** O. O. (2020). Determining conditions of using draglines in single-tier internal dump formation. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 5–14. https://doi.org/10.33271/nvngu/2020-6/005

3. **Pavlychenko, A., Adamchuk, A., Shustov, O., & Anisimov, O.** (2020). Justification of dump parameters in conditions of high water saturation of soils. Technology Audit and Production Reserves, 6(3(56)), 22–26. https://doi.org/10.15587/2706-5448.2020.218139

4. **Dryzhenko, A. Yu., Adamchuk, A. A., Kozenko, H. V., & Nikiforova, N. A.** (2018). Sposib pidhotovky do rekultyvatsii vidroblenoho ta zatoplenoho vodoiu zalizorudnoho kar'ieru (Patent No. 117710).

5. **Dryzhenko, A.Yu., Adamchuk, A.A., Tamuia, S.A., & Telnov, V.H.** (2018). Research of inside dump parameters in worked-out area of deep opencast mines. Collection of Research Papers of the National Mining University, 53, 56–65.

6. **Dryzhenko, A., Shustov, O., & Adamchuk, A.** (2016). Prospects for future mining of steep iron-ore deposits in the context of Kryvbas. Metallurgical and Mining Industry, 10, 46–52. http://nbuv.gov.ua/UJRN/metmi_2016_10_9

7. **Moldabayev, S., Sdvyzhkova, O., Babets, D., Kovrov, O., & Adil, T. (**2021). Numerical simulation of the open pit stability based on probabilistic approach. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 29–34. https://doi.org/10.33271/nvngu/2021-6/029

8**. Kovrov, O., Babiy, K., Rakishev, B., & Kuttybayev, A.** (2016). Influence of watering filled-up rock massif on geomechanical stability of the cyclic and progressive technology line. Mining of Mineral Deposits, 10(2), 55–63. https://doi.org/10.15407/mining10.02.055

9. **Kovrov, O., Kolesnyk, V., & Buchavyi, Y.** (2020). Development of the landslide risk classification for natural and man-made slopes based on soil watering and deformation extent. Mining of Mineral Deposits, 14(4), 105–112. https://doi.org/10.33271/mining14.04.105

10. **Babets, Y., Anisimov, O., Shustov, O., Komirna, V., & Melnikova, I.** (2021). Determination of economically viable option of liquidation the consequences of external dump deformation. E3S Web of Conferences, 280, 08014. https://doi.org/10.1051/e3sconf/202128008014

11**. Pysmennyi, S., Chukharev, S., Kyelgyenbai, K., Mutambo, V., & Matsui, A**. (2022). Iron ore underground mining under the internal overburden dump at the PJSC "Northern GZK." IOP Conference Series: Earth and Environmental Science, 1049(1), 012008. https://doi.org/10.1088/1755-1315/1049/1/012008

12. **Pysmennyi, S., Fedko, M., Shvaher, N., & Chukharev, S.** (2020). Mining of rich iron ore deposits of complex structure under the conditions of rock pressure development. E3S Web of Conferences, 201, 01022. https://doi.org/10.1051/e3sconf/202020101022

13. **Dryzhenko, A., Moldabayev, S., Shustov, A., Adamchuk, A., & Sarybayev, N**. (2017). Open pit mining technology of steeply dipping mineral occurences by steeply inclined sublayers. International Multidisciplinary Scientific GeoConference: SGEM: Surveying Geology & Mining Ecology Management, 17(1.3), 599–605. https://doi.org/10.5593/sgem2017/13/S03.076

14**. Moldabayev, S. K., Sultanbekova, Z. Z., Adamchuk, A. A., Sarybaev, N. O., & Nurmanova, A. N**. (2022). Technology of an open pit refinement under limit stability of sides. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 5–10. https://doi.org/10.33271/nvngu/2022-6/005

15. **Moldabayev, S., Sultanbekova, Z., Adamchuk, A., & Sarybayev, N.** (2019). Method of optimizing cyclic and continuous technology complexes location during finalization of mining deep ore open pit mines. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 19(1.3), 407–414. https://doi.org/10.5593/sgem2019/1.3/S03.052

16. **Sdvyzhkova, O., Moldabayev, S., Bascetin, A., Babets, D., Kuldeyev, E., Sultanbekova, Z., Amankulov, M., & Issakov, B.** (2022). Probabilistic assessment of slope stability at ore mining with steep layers in deep open pits. Mining of Mineral Deposits, 16(4), 11–18. https://doi.org/10.33271/mining16.04.011

17. **Moldabayev, S., Rysbaiuly, B., Sultanbekova, Z., & Sarybayev, N.** (2019). Methodological approach to creation of the 3D model of an oval-shaped open pit mine. E3S Web of Conferences, 123, 01049. https://doi.org/10.1051/e3sconf/201912301049

18. **Moldabayev, S.K., Adamchuk, A.A., Toktarov, A.A., Aben, Y., & Shustov, O.O.** (2020). Approbation of the technology of efficient application of excavator-automobile complexes in the deep open mines. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 4, 30–38. https://doi.org/10.33271/nvngu/2020-4/030

19. **Gorova, A., Pavlychenko, A., Kulyna, S., & Shkremetko, O. (**2012). Ecological problems of post-industrial mining areas. Geomechanical Processes During

Underground Mining - Proceedings of the School of Underground Mining, 35–40. https://doi.org/10.1201/b13157-7

20. **Gorova, A., Pavlychenko, A., & Borysovs'ka, O.** (2013). The study of ecological state of waste disposal areas of energy and mining companies. Annual Scientific-Technical Colletion - Mining of Mineral Deposits 2013, 169–171.

21. **Kovalenko, A., & Pavlychenko, A.** (2013). Analysis of ecology-social consequences of mining waste dumping. Mining of Mineral Deposits, 7(4), 405–408. https://doi.org/10.15407/mining07.04.405

22. **Hapich, H., Andrieiev, V., Kovalenko, V., Hrytsan, Y., & Pavlychenko, A.** (2022). Study of fragmentation impact of small riverbeds by artificial waters on the quality of water resources. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 3, 185–189. https://doi.org/10.33271/nvngu/2022-3/185

23. **Lozhnikov, O., Sobko, B., & Pavlychenko, A.** (2023). Technological Solutions for Increasing the Efficiency of Beneficiation Processes at the Mining of Titanium-Zirconium Deposits. Inżynieria Mineralna, 1(1). https://doi.org/10.29227/IM-2023-01-07

24. **Shustov, O. O., Pavlychenko, A. V, Bielov, O. P., Adamchuk, A. A., & Borysovska, O. O**. (2021). Calculation of the overburden ratio by the method of financial and mathematical averaged costs. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5, 30–36. https://doi.org/10.33271/nvngu/2021-5/030

25. **Pavlychenko, A., Kolosov, D., Adamchuk, A., Onyshchenko, S., & Dereviahina, N.** (2023). Regarding the issue of post-war development of mining regions and restoration of destroed infrastructure facilities. In Key trends of integrated innovation-driven scientific and technological development of mining regions (pp. 612–644). UNIVERSITAS Publishing. https://doi.org/doi.org/10.31713/m1226

26. **Gorova, A., Pavlychenko, A., Borysovs'ka, O., & Krups'ka, L. (**2013). The development of methodology for assessment of environmental risk degree in mining regions. Annual Scientific-Technical Colletion – Mining of Mineral Deposits 2013, 207–209. https://doi.org/10.1201/b16354-37

27. **Dryzhenko, A. Yu.** (2014). Vidkryti hirnychi roboty: pidruchnyk. Natsionalnyi hirnychyi universytet.

28. **Dryzhenko, A. Yu., Prosandieiev, N. I., & Martynenko, V. P**. (n.d.). Sposib rekultyvatsii kar'ieru vnutrishnim vidvalnym ustupom, shcho vkliuchaie yoho vidsypku (Patent No. 825771).

29. **Arsientiev, A. I., Bukin, I. Yu., & Myronenko, V. A.** (1982). Stiikist bortiv i osushennia kar'ieriv. Nadra.

30. **Pavlychenko, A.V., Adamchuk, A.A., Anisimov, O.O., & Shustov, O.O.** (2022). Sposib rekultyvatsii hlybokykh karieriv (Patent No. 152133).