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CONTROLLING THE STABILITY OF HIGH SINGLE-TIER DUMPS IN THE UKRAINIAN RECONSTRUCTION CONTEXT

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УПРАВЛІННЯ СТІЙКІСТЮ ВИСОКИХ ОДНОЯРУСНИХ ВІДВАЛІВ В КОНТЕКСТІ ВІДБУДОВИ УКРАЇНИ

Purpose. By establishing the dependences of the safe distance of the dragline excavators on the height of the single-tier dump and the level of its flooding, to substantiate an effective method of controlling the stability of high single-tier dumps in the context of the reconstruction of Ukraine.

Methodology. The computer modeling technique was used using the "Slide" software to construct the most stressed sliding surfaces of the dumped rock massif. The obtained data for calculating the width of the prism of possible displacement were analysed and their dependence on the height of the single-tier dump and the water level in the intra-mine space was established by the least squares method.

Findings. Using the "Slide" software package, the parameters of the width of the prism of possible displacement were calculated at the coefficients of the stability margin of 1.2 and 1.0 and their dependence 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 of dump formation. It has been established that the height of the overburden layer when formed by a dragline excavator should not exceed 100–150 m, which can be increased only in the case of flooding the slope with water.

Originality. The new technology is based on the phenomenon that when the critical value of flooding the slope with water is reached at the level of 0.19 of the total height of the overburden layer, the stability increases and the width of the prism of possible displacement decreases, due to the strengthening of the influence of water-retaining forces in the open space of the mine.

Practical value. An effective method of managing the stability of high single-tier dumps has been substantiated, which consists in using the weight of water at the base of the dump to increase its stability. With the influx of water, the height of the dump gradually increases until the intra-mine space is filled with overburden rocks.

Keywords: *internal dump, single-tier dump, physical and mechanical properties of rocks, dragline excavator, safety factor.*

Introduction. The demand for steel has always been high. Iron ore mining is a highly developed and important part of the Ukrainian economy. Ukraine is one of the leaders in the export of iron ore products. Unfortunately, the Russian invasion of 2022, in particular the shelling of Kryvyi Rih and other industrial cities, seriously complicated the extraction of iron ore and the production of products from it. Ukraine will need to rebuild its destroyed infrastructure [1–4]. This will significantly increase domestic demand for construction materials, including steel [5–8]. Despite the relatively small overburden ratio, the total volume of overburden storage in external dumps is enormous. Despite the fact that the overburden ratio is an order of magnitude higher in the development of coal deposits, there is the possibility of storing rocks in the process of their extraction in the spent space of the existing mine [9–11]. When developing iron ore deposits, such storage of rocks is significantly limited. This is due to the conditions of occurrence of iron ore deposits [12–15]. Therefore, during their development, external overburden dumps are formed until they are fully exhausted. In addition, with increasing depth of iron ore deposit development, the volume of mining and storage of overburden increases. Accordingly, an increase in the volume of iron ore mining will increase the required volume of overburden storage. At the same time, even more land is disturbed, and the allocation of new area for the construction of dumps becomes more difficult [16, 17].

An effective solution for the storage of overburden is the construction of dumps in used abandoned mines. Storage is carried out using draglines. Unloading occurs directly from the earth's surface, without the arrival of transport into the mine. Due to this, minimal costs are achieved. But over time, the poured mass of a high single-tier dump begins to deform, which creates a danger to personnel and equipment. Thus, substantiation of an effective method to control the stability of high single-tier dumps is the relevant task.

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.

Calculation of stability parameters. 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. 1, 2).

Analysis of fig. 1, 2 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%.

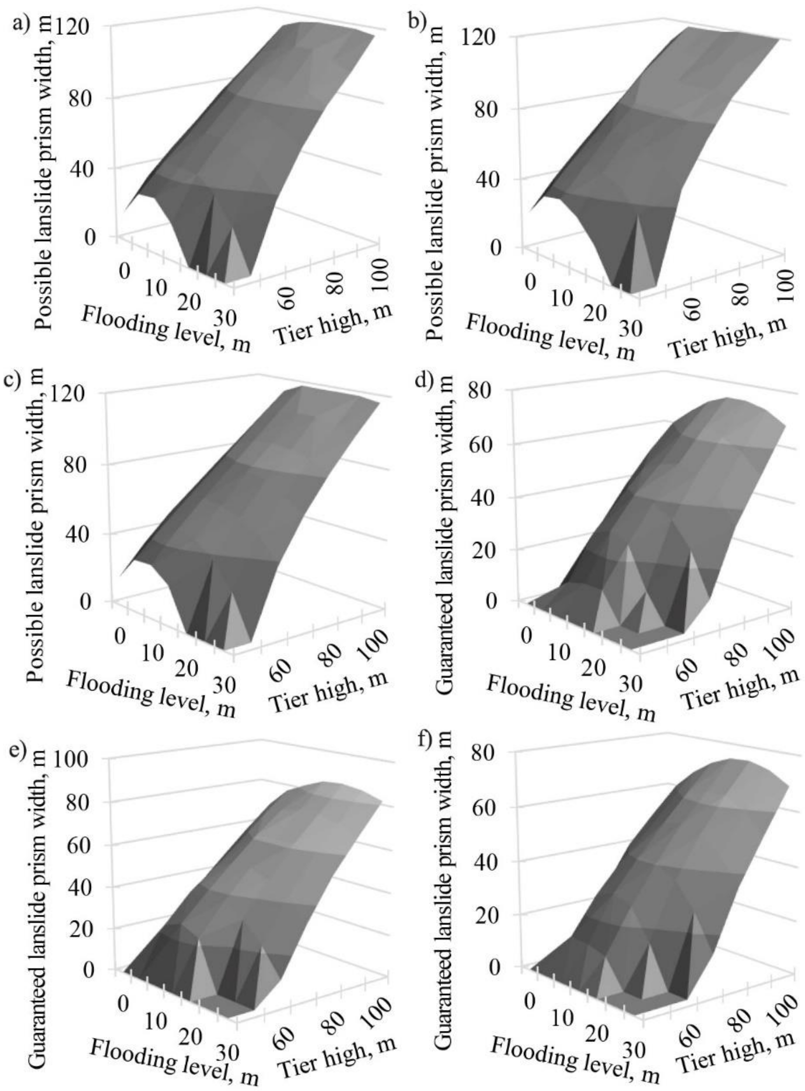

Fig. 1. Chart of the dependence of the width of the prism of a possible landslide (*SF* = 1.2, a–c) and guaranteed (*SF* = 1.0, d–f) on the height of dump tier and the thickness of the flooded part of the soil slope

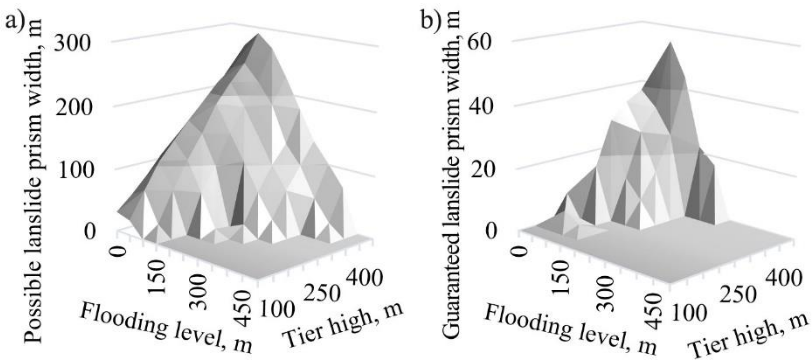

Fig. 2. Chart of the dependence of the width of the prism of a possible landslide (*SF* = 1.2, a) and guaranteed (*SF* = 1.0, b) on the height of dump tier and the thickness of the flooded part of the overburden rock slope

The chart in the fig. 2 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 controlling the stability of high single-tier dumps. The task is solved by the fact that in the known method, 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.

Fig. 3 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. 1, 2).

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.

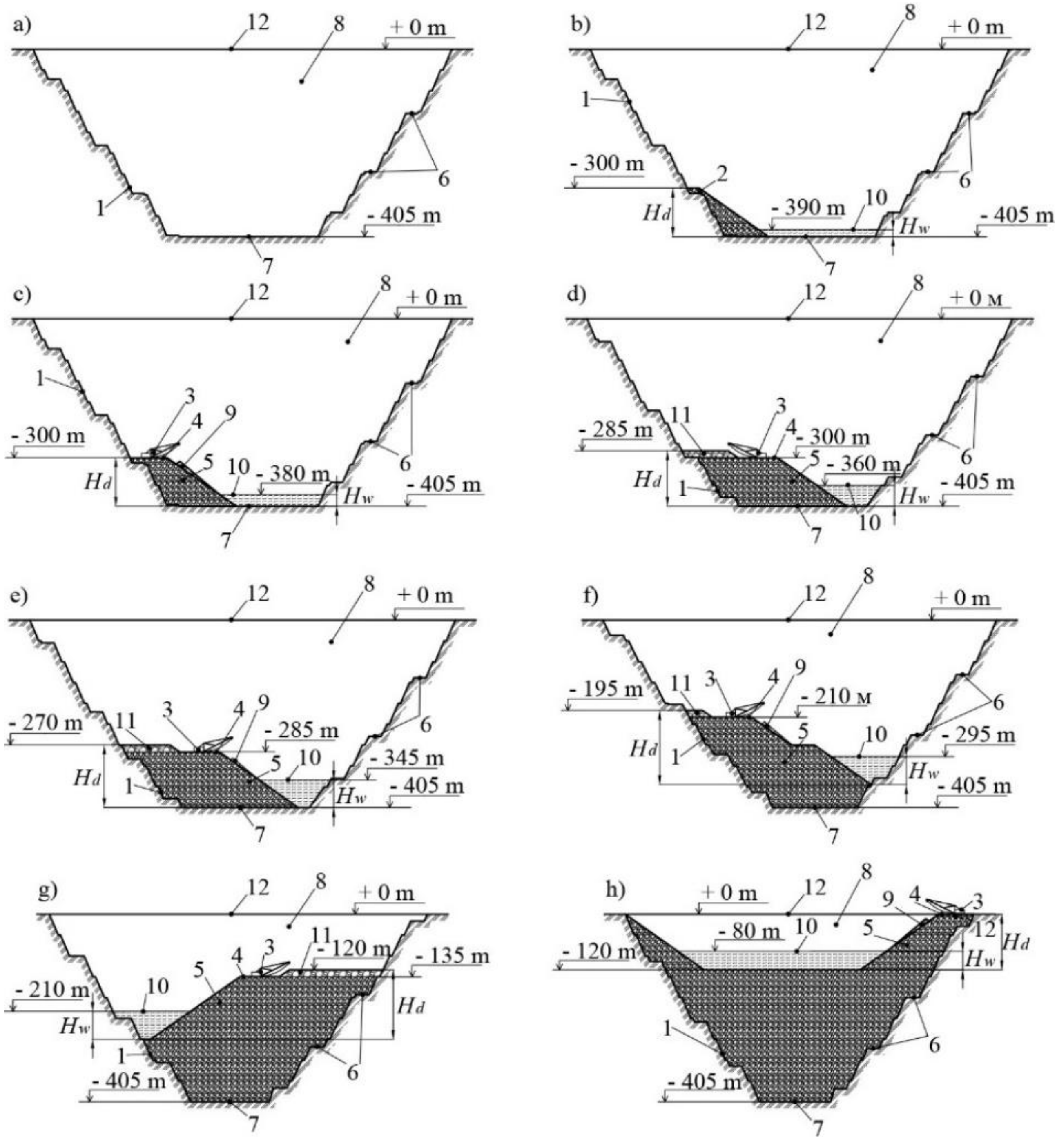

Fig. 3. Deep open-cast mine reclamation scheme: 1 – side of the mine; 2 – pioneer dump;; 3 – dragline excavator; 4 – prism of possible landslide; 5 – dump tier; 6 – transport berms; 7 – the bottom of the pit; 8 – developed intra-mine space; 9 – fallow back; 10 – height mark of the water level in the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

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.

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 mine 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-mine 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.

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-mine 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 mines.

Conclusions. The use of the described method of controlling the stability of high single-tier dumps 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-mine 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 157–183 ha

– To obtain the overall economic effect due to the preservation of land from disturbance for 47–88 mln UAH.

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.

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АНОТАЦІЯ

Мета. Шляхом встановлення залежностей безпечної відстані розташування екскаваторів-драглайнів від висоти одноярусного відвалу та рівня його підтоплення обґрунтувати ефективний спосіб управління стійкістю високих одноярусних відвалів в контексті відбудови України.

Методика. Застосовувалась методика компьютерного моделювання з використанням програмного забезпечення «Slide» для побудови найбільш напружених поверхонь ковзання відсипаного масиву гірських порід. Отримані дані розрахунків ширини призми можливого зрушення було проаналізовано і встановлено їх залежність від висоти одноярусного відвалу та рівня води у внутрішньокар'єрному просторі методом найменших квадратів.

Результати дослідження. За допомогою програмного комплексу «Slide» розраховано параметри ширини призми можливого зрушення при коефіцієн-тах запасу стійкості 1,2 та 1,0 та встановлені їх залежності від висоти відвалу та рівня його підтоплення водою, що дозволило встановити ефективні моделі екскаваторів-драглайнів для різних умов ведення відвалоутворення. Встановлено, що висота ярусу розкривних порід при формуванні його екскаватором-драглайном має бути не більше 100–150 м, яку можна збільшити лише у разі затоплення укосу водою.

Наукова новизна. Нова технологія заснована на явищі, що при досягненні критичного значення затоплення схилу водою на рівні 0,19 від загальної висоти ярусного схилу відбувається підвищення стійкості та зменшення ширини призми можливого зсуву, за рахунок посилення впливу водоутримуючих сил у відкритому просторі кар'єру.

Практичне значення. Обґрунтовано ефективний спосіб управління стійкістю високих одноярусних відвалів, що полягає у використанні сили ваги води в основі відвалу для підвищення його стійкості. Із водоприпливом відбувається поступове збільшення висоти відвалу до заповнення внутрішньокар'єрного простору породами розкриву.

Ключові слова: *внутрішній відвал, одноярусний відвал, фізико-механічні властивості гірських порід, екскаватор-драглайн, коефіцієнт запасу стійкості.*

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