Control of Dump Stability Loading Rock on its Edge

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Abstract

The question of the overburden rock dump formation during the development of iron ore deposits of Ukraine was considered. An analysis of the technology of forming a high single-tier dump in an abandoned deep pit was carried out. Two technology options are considered: loading rock on the slope of high single-tier dump and on its edge. The influence of the dependence of the loading rock on the edge of high single-tier dump on its stability of a has been established. The nature of the change in the width of the possible landslide prism, the safe distance of the dragline location has been established. The prospects for the formation of a high single-tier dump in the regime of controlled deformations are substantiated. For high single-tier dump the ordinary method of slices was justified and used to calculate the safety factor. Recommendations on the use of draglines available in Ukraine for forming the high single-tier dumps of overburden rock have been issued.

Keywords: *slope stability, single-tier dump, safety factor, method of slices*

1. Introduction

The demand for steel has always been big [1–4]. Iron ore mining is a highly developed and important part of the Ukrainian economy [5–8]. Ukraine is one of the leaders in the export of iron ore products [9–12]. 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. After the victory, Ukraine will need to rebuild its destroyed infrastructure. This will significantly increase domestic demand for construction materials, including steel.

Despite the relatively small overburden ratio, the total volume of overburden stockpiling in external dumps is colossal [13–18]. Even though during the development of coal deposits [19–22], the overburden ratio is an order of magnitude higher, there is a possibility of stockpiling rocks during their extraction in the spent space of an active mine. During the development of iron ore deposits, such stacking of rocks is significantly limited. This is due to the conditions of occurrence of iron ore deposits. Therefore, during their development, external piles of overburden rocks are formed until they are fully developed. In addition, with an increase in the depth of development of an iron ore deposit, the volume of extraction and storage of overburden rocks also increases. Accordingly, an increase in the volume of iron ore mining will increase the necessary volume of stockpiling of overburden. At the same time, even more lands are wasted.

An effective solution is the storage of overburden rocks and the construction of dumps in used-up abandoned open pit mines [23–25]. PJSC "ArcelorMittal Kryvyi Rih" has such an experience, which puts overburden rocks from its mine No. 2-bis into the abandoned open-pit mine No. 1 of former mining and processing plant "Novokryvorizkyi Mining and Processing Plant (MPP)". Storage takes place with the help of draglines. Unloading takes place directly from the earth's surface, without vehicles entering the pit. Thanks to this, minimal costs are achieved. But over time, the backfill massif of a high single-tier dump begins to deform, which creates a danger for personnel and equipment.

2. Forming the single-tier internal dump

External dumps of overburden rocks are formed with the formation of safety berms in several tiers [26–28]. The height of such dumps rarely exceeds 100–120 m. The horizontal berms and slopes of the tiers of the external dump form a resulting angle of 13–15 degrees to the earth's surface. The berms of internal dumps during the development of horizontal deposits are formed according to the horizons of the installation of mining equipment.

The formation of a dump of overburden rocks in an abandoned deep pit is possible with the formation of berms. Then the transport delivers the rock through ramps built in the pit. However, they don't do that. Usually, transport delivers the rock to a reloading point on the surface near the pit. After that, the mining mass is unloaded into the produced space directly from the surface. A single-tier dump is formed in the abandoned open pit mine. This method allows you to reduce the transportation distance by 1.5 km. The practice of forming a single-tier dump is successfully applied at the abandoned mine No. 1 of former mining and processing plant "Novokryvorizkyi MPP" by employees of PJSC "ArcelorMittal Kryvyi Rih" [24].

2.1. Loading Rock on the Slope

Usually, the process of formation of overburden rock dump in an abandoned deep pit is as follows. Along the side of the mine, the dragline excavator forms a pit on the surface. Transport unloads overburden rock into this pit. Rocks from

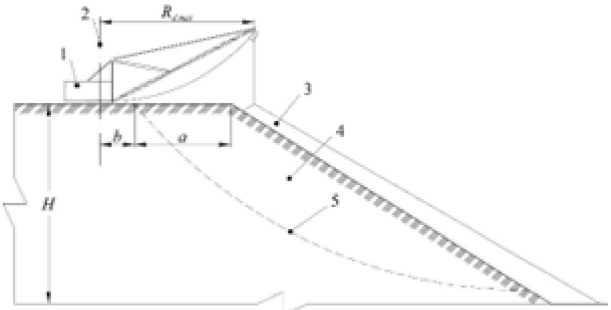

Fig. 1. Scheme of loading rock on the slope: 1 – dragline; 2 – dragline movement axis; 3 – rock loaded on the slope; 4 – possible landslide prism; 5 – curved sliding surface for the safety factor of 1.2; a – width of the possible landslide prism, m; b – safe distance of the dragline installation, m; H – height of the single-tier dump, m; $R_{d.max}$ – maximum dumping radius, m

Rys. 1. Schemat załadunku skały na zboczu: 1 – koparka; 2 – oś ruchu koparki; 3 – skała załadowana na zboczu; 4 – możliwy pryzmat osuwiska; 5 – zakrzywiona powierzchnia ślizgowa dla współczynnika bezpieczeństwa 1,2; a – szerokość możliwego graniastosłupa osuwiskowego, m; b – bezpieczna odległość instalacji koparki, m; H – wysokość składowiska jednopoziomowego, m; $R_{d.max}$ – maksymalny promień zrzutu, m

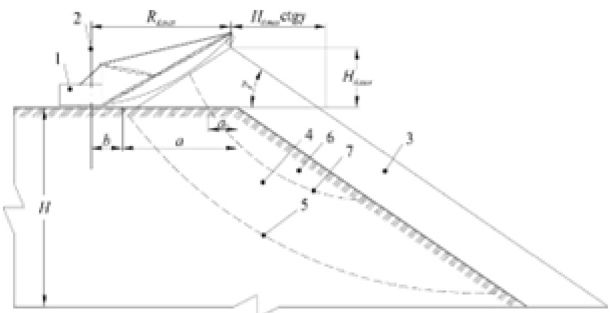

Fig. 2. Scheme of loading rock on the edge: 1 – dragline; 2 – dragline movement axis; 3 – rock loaded on the slope; 4 – possible landslide prism; 5 – curved sliding surface for the safety factor of 1.2; 6 – guaranteed landslide prism; 7 – curved sliding surface for the safety factor of 1.0; a – width of the possible landslide prism, m; a1 – width of the guaranteed landslide prism, m; b – safe distance of the dragline installation, m; H – height of the single-tier dump, m; $R_{d.max}$ – maximum dumping radius, m; Rd.max – maximum dumping height, m; γ – dump slope angle, degrees

Rys. 2. Schemat załadunku skały na krawędzi: 1 – koparka; 2 – oś ruchu koparki; 3 – skała załadowana na zboczu; 4 – możliwy pryzmat osuwiska; 5 – zakrzywiona powierzchnia ślizgowa dla współczynnika bezpieczeństwa 1,2; 6 – gwarantowany pryzmat osuwiska; 7 – zakrzywiona powierzchnia ślizgowa dla współczynnika bezpieczeństwa 1,0; a – szerokość możliwego graniastosłupa osuwiskowego, m; a1 – szerokość graniastosłupa gwarantowanego osuwiska, m; b – bezpieczna odległość instalacji koparki, m; H – wysokość składowiska jednopoziomowego, m; Rd.max – maksymalny promień zrzutu, m; $R_{d.max}$ – maksymalna wysokość zrzutu, m; γ – kąt nachylenia wysypiska w stopniach

the pit are unloaded by the dragline into the created space of the abandoned mine on the slope of the formed overburden rock dump, as shown in Fig. 1.

The formation of an internal dump according to the scheme with the dumping of overburden rocks on a slope is effective and is used under the following condition:

$$R_{d.max} = a + b,\ m \tag{1}$$

In Ukraine, the regulations on design require compliance with the distance (a, m), at which the safety factor SF = 1.2. The safe distance of the dragline installation (b, m) is calculated based on its overall dimensions (b = 10…15 m).

2.2. Loading Rock on the Edge

If condition (1) is not fulfilled, effective use of the selected excavator model with the maximum dumping radius $R_{d.max}$ is not possible. Then there are two ways out of the situation. The first is to change the equipment to one in which the maximum dumping radius $R_{d.max}$ meets the condition (1). The second is to operate the available equipment in the mode of controlled deformations of the overburden rock dump by loading rock on its edge. This dump formation scheme allows to increase the dumping radius of the dragline by $H_{d.max}$ctgγ, as shown in Fig. 2.

The guaranteed landslide prism is a part of the dump, limited by its slope on one side and the farthest curved sliding surface for the safety factor of 1.0 on the other.

Using the scheme of loading rock on the dump edge is possible to increase dumping radius only on the following conditions:

$$R_{d.max} = a + b - H_{d.max} ctg\gamma,\ m \tag{2}$$

To work in the mode of controlled deformations of the overburden rock dump, it is necessary to create the following conditions:

$$R_{d.max} = a + b - a_1,\ m \tag{3}$$

If conditions (2) and (3) are not fulfilled, then further development of the overburden rock dump is not possible using the available equipment.

2.3. Draglines Manufactured in Ukraine

In Ukraine, draglines are manufactured at Novokramatorsk Machine-Building Plant (NKMZ). All draglines manufactured by NKMZ are equipped with a stepping eccentric stroke, which ensures high dragline maneuverability. Specifications of draglines listed in Table 1.

Tab. 1. Draglines produced by the Novokramatorsk Machine-Building Plant (NKMZ) and their specifications

Tab. 1. Koparki produkowane przez Nowokramatorski Zakład Budowy Maszyn (NKMZ) i ich specyfikacje

Specifications	Dragline model					
	6.5/45	11/70	14/50	15/80	15/90	10/100
Bucket volume, m^3	6.5	11	14	15	15	10
Boom length, m	45	70	50	80	90	100
Maximum dumping radius, m	43,5	66,5	46,5	76,5	83	93,5
Maximum dumping height, m	19,5	27,5	20,5	32	37	42
Theoretical productivity, m^3/h	557	754	1292	931	900	600

PJSC "ArcelorMittal Kryvyi Rih" has experience in the use of NKMZ draglines to form the single-tier overburden rock dump in the abandoned mine No. 1 of former mining and processing plant "Novokryvorizkyi MPP". Dragline models they use are 6.5/45 and 11/70 with a maximum dumping radius of 43.5 m and 66.5 m respectively.

3. 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.

For the simulation of single-tier dumps of overburden rocks, their height (H, m) was taken from 100 m to 500 m with a step of 50 m, dumping height (H_d, m) 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.

4. Discussion

The practice of calculating the stability parameters of high single-tier dumps has shown that when calculating by the method of slices, it is advisable to use its ordinary variant, known as the Swedish circle method or Fellenius method. This method makes it possible to build a model the single-tier dump that is the closest to real conditions. The value of distance calculated by this method is the most 'pessimistic' compared with the other methods, which guarantee the safest dragline use conditions.

The results of modeling the slopes of a single-tier dump and the values of the width of the of possible landslide prism and the guaranteed landslide prism are presented in Fig. 3-6. Graphs have the form of a broken line. The analysis of the obtained data showed that loading rock on the edge of single-tier dump does not affect on its slope stability if loaded on 4…5% of dump height in conditions of the material with the given physical and mechanical properties. Guaranteed landslides possible only in conditions of 400 m, 450 m and 500 m high single-tier dump.

In Fig. 3 shown the dependence of the width of the possible landslide prism on the dragline dumping height for single-tier dumps of 100 m, 150 m and 200 m high. 100 m high dump starts with possible landslide prism 31 m wide, which does not change until achieve a critical point, then increases up to 70 m. 150 m high dump – 52 m wide possible landslide prism, loaded on 40 m height – 88 m. 200 m high single-tier dump not loaded has possible landslide prism 78 m wide, loaded on 40 m height – 107 m. Curved sliding surface for the safety factor less than 1.0 are not observed.

Forming of 100 m, 150 m and 200 m height single-tier dump in the mode of controlled deformations is impossible. Using the scheme of loading rock on the edge is unnecessary. 100 m height dump can be formed by any model of NKMZ dragline. 150 m height single-tier dump – by any model of NKMZ dragline but 6.5/45 and 14/50. 200 m height single-tier dump – by 10/100 using the scheme of loading rock on the slope and 15/90 using the scheme of loading rock on the edge.

Graphs in Fig. 4 have the similar form as it shown in Fig. 3. There are no guaranteed landslides on 250 m, 300 m and 350 m height single-tier dumps. Width of the possible prism have value of 107 m 130 m, 151 m for not loaded edge and 130 m 155 m 176 m maximally loaded for 250 m, 300 m and 350 m height single-tier dump respectively. There are no model of dragline in Ukraine capable to form single-tier dumps of such height, neither loading rock on the slope, nor on the edge.

The same situation is on the 400 m, 450 m and 500 m height single-tier dumps (Fig. 5). But there are guaranteed landslides shown in Fig. 6. Graphs of dependence of the width of the guaranteed landslide prism on the dragline dumping height have different shape. 400 m height dump graph exists between value of dumping height from 25 m to 40 m. It has concave up shape. 450 m height dump graph has increasing linear form. 450 m height dump graph has the similar broken line form as it shown in Fig. 3-5.

Despite the theoretical possibility of forming the single-tier dump in the mode of controlled deformations, can only be done by dragline with maximum dumping radius more than 150 m. There are no such dragline models. Moreover, calculations of width of the guaranteed landslide prism have been carried out using ordinary method of slices, which gets the biggest value comparing to another methods. Brief analysis of slope stability using Spencer method shows no sliding surfaces with safety factor less than 1. It means that that loading rock on the edge of single-tier dump does not guarantee to collapse it.

3. Conclusion

Forming the high single-tier dump of overburden rock in abandoned open-pit mines using available in Ukraine equipment is possible only up to 200 m. Analysis of single-tier dumping technology and its two schemes: loading rock on the slope and on the edge showed that the first variant is more

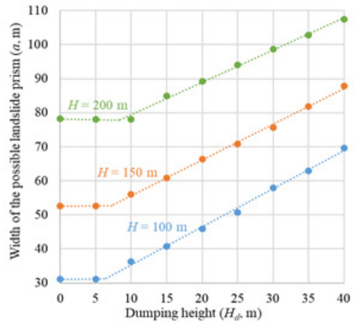

Fig. 3. Dependence of the width of the possible landslide prism (a, m) of 100…200 m height dump on the dragline dumping height (H_d, m)
Rys. 3. Zależność szerokości możliwego graniastosłupa osuwiskowego (a, m) wysokości zwału 100…200 m od wysokości zwału koparki (H_d m)

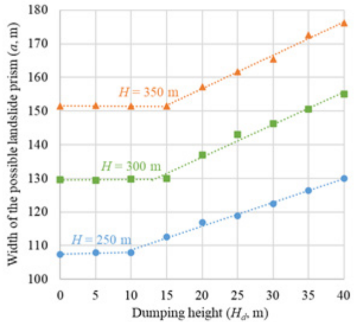

Fig. 4. Dependence of the width of the possible landslide prism (a, m) of 150…350 m height dump on the dragline dumping height (H_d, m)
Rys. 4. Zależność szerokości możliwego graniastosłupa osuwiskowego (a, m) o wysokości zwału 150…350 m od wysokości zwału koparki (H_d, m)

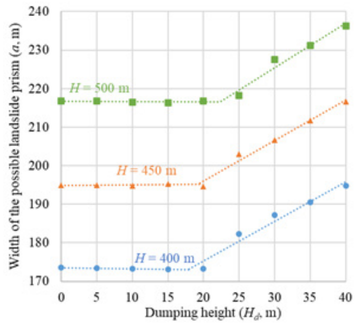

Fig. 5. Dependence of the width of the possible landslide prism (a, m) of 400…500 m height dump on the dragline dumping height (H_d, m)
Rys. 5. Zależność szerokości możliwego graniastosłupa osuwiskowego (a, m) zwału o wysokości 400…500 m od wysokości zwału koparki (H_d, m)

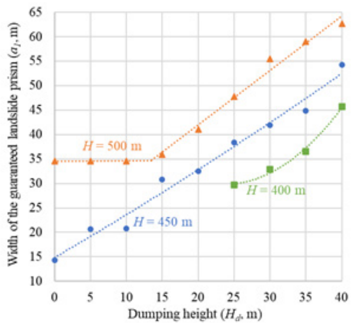

Fig. 6. Dependence of the width of the guaranteed landslide prism (a1, m) of 400…500 m height dump on the dragline dumping height (H_d, m)
Rys. 6. Zależność szerokości graniastosłupa gwarantowanego osuwiska (a1, m) zrzutu o wysokości 400…500 m od wysokości zwału koparki (H_d, m)

effective than the second one. Forming a pile of rock on the edge closes further access for dragline to work. Moreover, controlled deformations is not guaranteed. Loading the edge of the high single-tier dump on the 4–5% of its height does not affect on its stability. Loading rock on the edge may only be applied in conditions of 200 m height dump of overburden rock using 15/90 NKMZ dragline to increase its dumping radius from 83 m up to 97 m forming 10 m height pile of rock on the edge.

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Kontrola stabilności zrzutu załadunku skały na krawędzi wyrobiska

W artykule rozważono kwestię powstawania nadkładu skalnego podczas eksploatacji złóż rudy żelaza na Ukrainie. Przeprowadzono analizę technologii formowania zwałowiska wysokiego jednopoziomowego w nieczynnym wykopie głębokim. Rozważane są dwa warianty technologiczne: załadunek skały na zboczu wysokiego zwałowiska jednopoziomowego oraz na jego krawędzi. Określono wpływ zależności skały obciążającej od krawędzi zwałowiska wysokiego jednopoziomowego na jego stateczność. Ustalono charakter zmiany szerokości ewentualnego graniastosłupa osuwiskowego oraz bezpieczną odległość położenia liny zgarniającej. Możliwości powstania wysokiego zwałowiska jednopoziomowego w reżimie kontrolowanych deformacji są uzasadnione. Dla wysokiego zrzutu jednopoziomowego zasadna była zwykła metoda przekrojów, wykorzystana do obliczenia współczynnika bezpieczeństwa. Wydano zalecenia dotyczące wykorzystania dostępnych na Ukrainie koparek do formowania wysokich jednopoziomowych zwałów nadkładu.

Słowa kluczowe: *stateczność zbocza, zwałowisko jednopoziomowe, współczynnik bezpieczeństwa, metoda przekrojów*