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JUSTIFICATION OF THE SAFE PARAMETERS OF RECREATIONAL ZONES DURING THE RECLAMATION OF WATERED RESIDUAL QUARRY SPACES

Purpose. To determine the safe parameters of the recreational zones created in the residual space of the quarry taking into account the physical and mechanical properties of waste rocks in a watered state.

Methodology. The Bishop Simplified Method is used to determine the influence of the irrigation level of the residual quarry space on the stability of the embankment from different types of mining rocks when creating a recreational area during reclamation works.

Findings. The safe parameters of recreational areas during their construction in the watered residual space of the quarry were established taking into account the physical and mechanical properties of embankments made of sand, loam, and crushed rock by determining the stability of their slopes. The obtained results are necessary for the implementation of project works on the development of technological schemes for the reclamation of the residual spaces of construction materials quarry for the recreational direction of post-mining.

Originality. The influence of the height of the rock embankment formation on the stable angle of inclination of the watered slope was established, which allowed determining that with an increase in the aggregates embankment height from 20 to 80 m, the safe angle of the slope will decrease from 46 to 26°. It was determined that the lowest FOS indicator is 0.57 when using sand rocks for an embankment height of 80 m at a water content of 40 %. It was established that with partial flooding of the rock embankment by 45–50 % for sandy, loamy and rocky rocks, there is a significant decrease in the coefficient of the reserve of stability by 1.4–1.5 times, in contrast to the absence of water or complete flooding, which confirms the negative impact of partial flooding of embankments and reducing the stability of their slopes.

Practical value. It was determined that when forming an embankment 20 m high from loamy rocks, the volume of reclamation works will be 1.34 times less compared to sandy rocks, but 1.02 times larger than rocky rocks. When the height of the embankment increases to 80 m, the volume of reclamation works when replacing loam with sand will increase to 1.87 and 1.12 times when using crushed stone. However, taking into account the market value of materials, when using loam, the cost of construction will decrease by 2.5 times compared to sandy rocks and 3.2 times – to crushed stone, with an embankment height of 20 m. When the embankment height increases to 80 m, the cost of materials will increase by 3.5 and 3.8 times when loamy rocks are replaced by sand or crushed stone, respectively.

Keywords: *quarry, reclamation, recreation area, physical and mechanical properties of rocks, watered residual space*

Introduction. Intensive mining of minerals by the surface method leads to the formation of significant areas of disturbed lands, which for a long period are eliminated from economic activity. The main objects of the functioning of the quarries after their completion are the residual spaces, external dumps, as well as tailings in the case when the beneficiation processes were involved. The most widespread in terms of quantity are construction material quarries, which are relatively small in size, which is due to the low productivity of aggregates mining enterprises [1].

These quarries, as a rule, are located at small distances from populated areas to minimize transport costs when delivering minerals to consumers [2]. Completion of mining operations at these enterprises occurs in connection with the achievement of the final parameters of the quarry or in the event of unplanned flooding of pit workings with groundwater [3].

Almost all closed quarries of construction raw material are subsequently flooded with groundwater [4], which turns their residual spaces into artificial reservoirs with a relatively safe chemical composition for humans and animals [5].

Thus, after working out, quarries of construction materials are attractive objects for recreational purpose [6], the effectiveness of their use depends on the favourable topography of the surface, which was formed during the reclamation works [7].

In turn, carrying out reclamation works of irrigation of the residual spaces of quarries [8] is a difficult task because water affects the stability of the slopes of bulk rocks used in laying out the slopes of the quarry [9].

Flooding of the quarries residual spaces occurs as a result of water entering the residual spaces from ground sources or surface water and has a negative impact on the production process, labour safety and the environment [10]. Among the main causes of residual spaces flooding [11] are hydrogeological conditions, since underground water can penetrate through porous rocks or cracks formed in the mining massif of the quarry slopes during mining with subsequent water accumulation in the quarry residual space.

Also, pit flooding [12] occurs during improper use of water-lowering wells during mining operations. Inadequate safety measures, such as improper sealing of the residual spaces [13] or insufficient use of waterproofing materials during reclamation, can lead to flooding of the residual space of the quarry after the completion of mining operations.

The world experience of quarry residual spaces protecting from flooding [14] shows that the following measures are used to minimize the impact of groundwater on production processes: drainage systems are implemented that allow the accumulated water to be removed from residual spaces and help manage irrigation processes; protective structures are used, which use waterproofing materials and measures to seal the surfaces of the residual spaces; development and implementation of technologies for managing irrigation of residual spaces, which ensures a decrease or increase in the final water level in the quarry worked out spaces [15].

Decreasing the volume of irrigation of residual quarry spaces requires internal control, proper planning and careful implementation of safe and effective groundwater management methods.

Since the process of flooding the residual spaces of construction materials quarries is in most cases irreversible, there is a need for maximum control over it, which will allow creating attractive recreational areas [16] for the local population and development of the tourist potential of the region.

The experience of developed countries [17] confirms the expediency of creating recreation areas in the residual spaces of quarries after the completion of mining. The main directions of recreational restoration are the creation of natural and recreational facilities [18] which include reservoirs, parks, nature reserves, mountain and forest resorts or botanical gardens.

During the creation of reservoirs [19], the formation spaces of quarries can be transformed into objects used for recreation and entertainment [20]. These can be both lakes and ponds, where people can engage in fishing or water sports.

In order to transform the remaining residual spaces of the quarries into recreational parks, it is necessary to provide during the reclamation works the special landscaping of areas for walks, bicycle routes, footpaths, or playgrounds for sports and other activity.

If there are large areas of reclaimed land for recreational purposes, nature reserves can be created on the territories of former quarries. For this purpose, special nature reserve objects are created in the residual spaces of the quarries, where local ecosystems and flora and fauna are preserved. The created objects of such nature reserves will enable visitors to organize rest and observe wildlife. In case of free territories availability with favourable conditions for various types of vegetation, botanical gardens can be created in the residual spaces of quarries with the aim of creating educational facilities for excursions and training.

The given examples prove that, in most cases, the residual spaces of the quarries are favourable for the creation of recreational areas which expand opportunities for rest and entertainment, contribute to the preservation of the natural environment, and become useful in educational activities and leisure.

In accordance with the topicality of the restoration problem of the territories disturbed by mining operations, there is an urgent task of substantiating the safe parameters of the pit slopes and the stability of the internal dumps formed in the flooded space of the pit during reclamation.

Literature review. The recreational zones formation with safety parameters in the flooded spaces of quarries is a multifactorial problem, the solution of which should first of all allow creating coastal strips along the steep slopes of the sides of the quarries after exploitation [21]. The main requirement for such objects is resistance to landslide processes, as the safety of vacationers and tourists will depend on it.

The analysis of directions for the disturbed lands restoration allows establishing that quarry sites [22] with rugged terrain can be used to create mountain and forest resorts. In this case, the residual spaces of the quarries can be sites for the creation of ski tracks, which are built in combination with hotel complexes and entertainment facilities.

The existing experience and methods for calculating the safe parameters of the slopes of external and internal dumps in most cases do not take into account the destructive effect of the flooded residual space, which contributes to the washing away the mining massif and weakening its resistance to landslides [23]. Therefore, there is an urgent task to investigate the impact of irrigation of the mining massif on its stability using modern information technologies based on the operating principles of Bishop's simplified method.

Unsolved aspects of the problem. According to the previous research, unsolved problem consists in necessity to substantiate the safe parameters of the quarry residual space reclamation, taking into account the physical and mechanical properties of the rocks. For solving this task it is required to perform a number of the following tasks: to establish the influence of the water level of the remaining residual space of the quarry on the stability of the internal dump during the formation of the recreational zone; to determine the safety angles of the internal dump slopes inclination when forming a recreational zone from sandy rocks, loam and crushed stone mass; to investigate the influence of the physical and mechanical properties of waste rocks on the reclamation works volume when creating a recreation area.

Methodology. In order to establish the influence of the water level of the remaining residual quarry space on the slope stability of the internal dump during the formation of the recreational zone, a number of studies on the modelling of the mining rock massif stability are performed. Since the formation of the recreational zone within the watered residual space of the quarry is carried out at the stage of mining reclamation, the planning works will be carried out using mining haulage equipment.

Different types of rocks found in external dumps or warehouses of unconditional minerals can be used for partial backfilling of the final residual spaces [24]. The most common types of overburden that can be used in mining reclamation are: sands, loams, clays and crushed rock stone mass.

Since these rocks have different physical and mechanical properties, the impact of watering on them will also occur in dissimilar ways. Therefore, when substantiating the parameters of recreational zones in the residual spaces of quarries, it is necessary to establish the dependence of the safe angles of the dump slopes [25] on the height of the embankment and the level of flooding of the tranches, taking into account the physical and mechanical properties of the rocks.

Let us consider the influence of the residual space water level of the quarry on the stability of the internal dump, which will be used in the future as a site for the creation of a recreational area (Fig. 1). In accordance with the technological scheme for the location of the recreation area in the residual space of the quarry (Fig. 1), the following parameters are used: W_b is the width of the coastal strip; L_b is the length of the coastal strip; H_b is embankment height; H_k is pit depth; H_w is water level in the residual space of the quarry; α is the resulting angle of quarry slope inclination; β is a safe angle of mining rocks inclination when they are dumped into a flooded space.

In order to determine the stable slope of the embankment β in the residual space of the quarry, the flooding of the flooded massif was simulated in the K-MINE software complex. During the research, engineering methods of stability calculation based on the limit equilibrium of the mining massif were used.

For different configurations of the slope, the minimum and maximum level of groundwater affecting the rocks of the flooded massif was established, which made it possible to determine the average value of the groundwater surface. During the modelling, the basic condition was adopted that the minimum groundwater level corresponds to the lower edge of the slope and the maximum level corresponds to the upper edge of the slope.

In order to obtain a sliding surface, an analysis of the sensitivity of the change in the stock factor to the change in the water level H_w in the residual space was carried out. These studies were carried out by modelling taking into account the physical and mechanical properties of mining rocks, which are

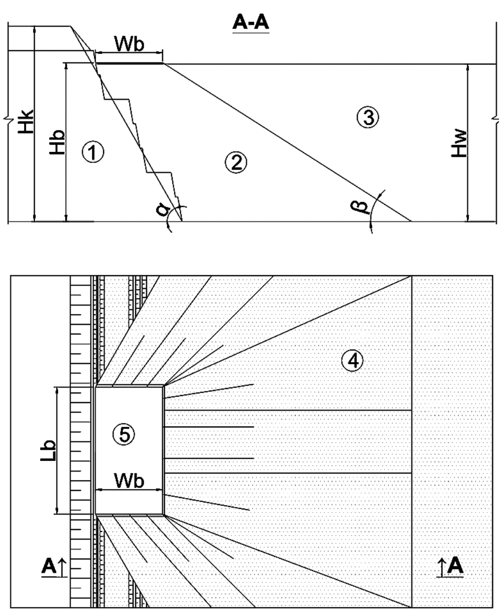

Fig. 1. Scheme of the recreational zone location in the residual space of the flooded quarry:

1 – slope of the quarry, 2 – embankment for the construction of the recreational zone, 3 – flooded space of the quarry; 4 – water surface; 5 – the surface of the recreation area

the most common for use during reclamation works. Such rocks include sands and loams, which are most common in the upper layers of overburden, as well as crushed rock overburden, which is mixed in external dumps.

When determining the impact of the residual space watering in the quarry on the slopes stability of the internal dumps, the main physical and mechanical properties of the rocks, which depend on the flooded rock massif stability, were taken into account: the specific gravity of the rocks, the angle of internal friction and adhesion.

Table 1 shows the physical and mechanical properties of sand, loam and crushed rock taken into account.

As is known from the practice of surface mining, the stability of the dump depends on its height and slope angle; however, when forming an embankment in the quarry flooded space, the water level will play a significant role. When determining the influence of the water level of the residual space on the stability, an embankment made of sandy, loamy, and rubble rocks with a height of H_b from 20 to 80 m was considered, while the water level was taken from 0 to 100 %.

To carry out research on the influence of the flooded level of residual space on the stability of the embankment during the forming of a recreational zone, the Simplified Method of Bishop simulated in the K-MINE was used. The basis of the method is the principle of dividing the area under investigation into vertical sections, followed by the analysis of limit equilibrium. Since the specified method is based on the balance of moments and vertical forces, it allows analyzing different rock taking into account the influence of flooding.

Table 1

Physical and mechanical properties of rocks affecting the stability of flooded embankments

Breed	Specific weight, kN/m^3	Angle of internal friction, degrees	Coupling, kPa
Sand	14.1	25	2.0
Loam	18.6	27	34.4
Rubble	18.8	30	20.0

The results of determining the influence of the water level of the residual spaces on the coefficient of stability reserve (FOS) when creating a recreational zone from sandy rocks are shown in Fig. 2.

According to the obtained dependencies (Fig. 2), it was established that the flooding of the residual space has a significant effect on the stability of the sand rocks from which the recreational zone with a height of 20 to 80 m will be formed. The least stable properties are recorded when the embankment is watered up to 40–50 % in height, which is confirmed by a decrease in the safety factor to 1.1–1.2, depending on the height of the embankment. However, when the water level is raised to 95 % of the height of the sand embankment, the FOS indicator increases to 1.5–1.78, depending on the height of the embankment, which indicates a stable condition. Thus, the formation of a sand embankment with a slope angle of 20° at a height of 20 to 80 m is safe, provided that the water level is at least 95 % of the embankment height.

Further research made it possible to establish the influence of flooding of the sand embankment on the coefficient of stability reserve at a slope angle of 30° (Fig. 3).

According to the established effect of the water level in the residual space on the stability of a sand embankment with a slope angle of 30° (Fig. 3), it can be stated that under all possible flooding options, the FOS will not exceed 1.5, that is, the formation of a recreational zone from sandy rocks will be dangerous. A similar danger was established when creating a recreational zone with a slope angle of 40° from sand (Fig. 4).

When forming a recreational zone from sandy rocks with a slope angle of 40° the FOS will not exceed 0.93, which means a significant danger and lack of stability of the embankment.

Thus, the use of sand rocks in the formation of a landslide-safe embankment in the flooded part of the quarry is possible only with a slope angle of 20°. This applies to the range of em-

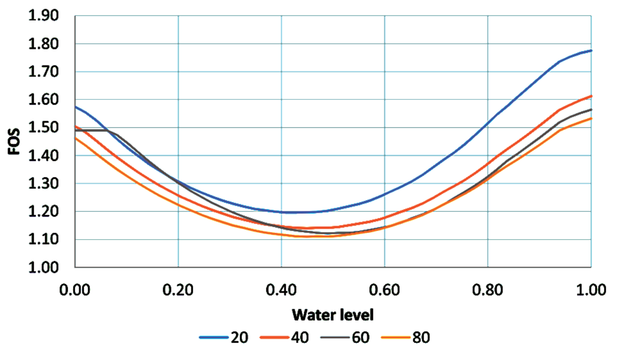

Fig. 2. Dependence of the stability reserve coefficient (FOS) of a flooded dump from sand rocks on the flooded level of the remaining space at an embankment slope angle β of 20°

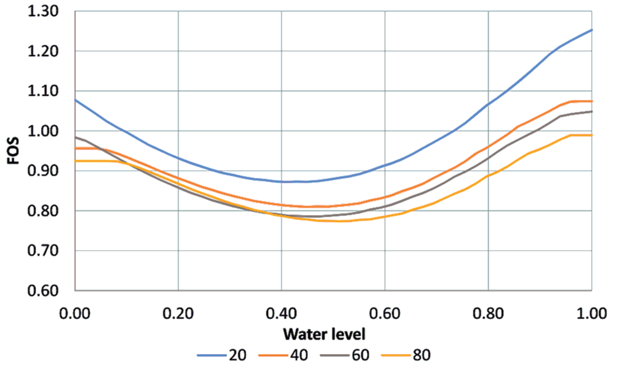

Fig. 3. Dependence of the stability reserve coefficient (FOS) of a flooded dump from sand rocks on the flooded level of the remaining space at an embankment slope angle β of 30°

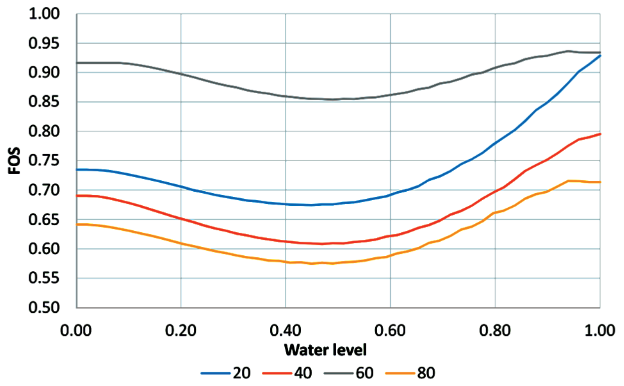

Fig. 4. Dependence of the stability reserve coefficient (FOS) of a flooded dump from sand rocks on the flooded level of the remaining space at an embankment slope angle β of 40°

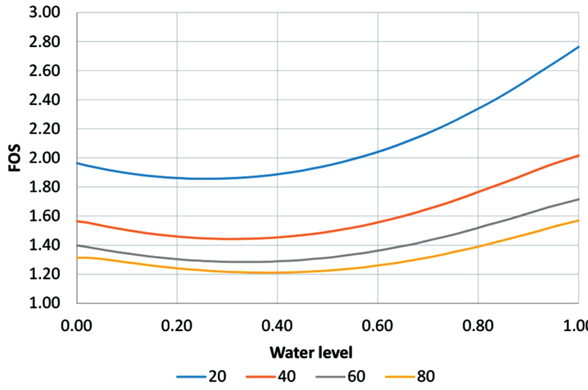

Fig. 6. Dependence of the stability reserve coefficient (FOS) of a flooded dump from loamy rocks on the flooded level of the remaining space at an embankment slope angle β of 30°

bankment height from 20 to 60 m. When forming an embankment with a height of 80 m, the slope angle must be reduced.

The next stage of the research includes the determination of the stable properties of loamy rocks for comparing the effectiveness of it use with sand rocks. Fig. 5 shows the dependence of FOS on the water level of the embankment when loamy rocks are used at an embankment slope angle of 20°.

According to the determined dependencies (Fig. 5), loamy rocks have a higher resistance to shear processes during the formation of embankments in flooded conditions. The highest indicator of the FOS safety factor was recorded at an embankment height of 20 m. It varies from 2.3 to 3.5 depending on the water level of the residual space, while it should be noted that the FOS for loamy rocks increases when the water level rises. The smallest demonstrable safety factor corresponds to the highest height of the embankment, which is 80 m and varies from 1.7 to 2.2. All these values are safe when forming an embankment to create a recreational zone.

Since loamy rocks have more stable indicators when forming an embankment in the residual space than sandy ones, there is an opportunity to increase the slope angle of the embankment to 30°. Provided that the FOS safety factor is maintained at a level of at least 1.5, it is possible to form an embankment of the required height using a smaller volume of material, which will have a positive effect on the technical and economic indicators of reclamation.

The dependence of FOS on the water level of the embankment when using loamy rocks at slope angle of 30° is shown in Fig. 6.

The established dependencies (Fig. 6) allow determining that the safest embankment will be 20 m high, because under these conditions, at any level of water, the FOS will be in the range of 1.8–2.7. When the height of the embankment is increased from 40 to 80 m, ensuring the stability of waterlogged rocks is achieved by filling the residual space of the quarry to a mark of 50 to 95 % of the embankment height.

The conducted research made it possible to establish the fact that dry clay rocks, unlike sand, can be stable in a flooded state even if the slope of the embankment is formed at an angle of 40°. In practice, this will make it possible to reduce the volume of mining reclamation works during the construction of a recreational zone in quarry residual space (Fig. 7).

According to the established influence of the embankment water level on the stability reserve coefficient (Fig. 7) when using loamy rocks, the formation of a recreational zone with a height of 20 m in the flooded space of the quarry is possible at an angle of slope of the embankment of 40°, at any water level. With a further increase in the height of the embankment, a safe slope angle can also be reached at a height of 40 m, provided that the embankment is flooded by 95 % in height. It was also established that the formation of a recreational zone with a height of 60–80 m is dangerous at an embankment slope angle of 40° at any water level, due to the low FOS safety factor in the range of 1.0–1.4.

In addition to sandy and loamy rocks, crushed rocks were also considered in the study, since they can be stored in the external dumps of construction material quarries and represent an available material for filling the flooded residual space.

The dependence of FOS on the water level of the embankment of crushed rocks at an internal dump slope angle of 20° is shown in Fig. 8.

The determined influence of the rock embankment water level on the coefficient of stability reserve (Fig. 8) allows establishing that with an embankment slope angle of 20°, any height of the recreational zone in the range of 20–80 m will be safe. The highest coefficient of the stability reserve is achieved when

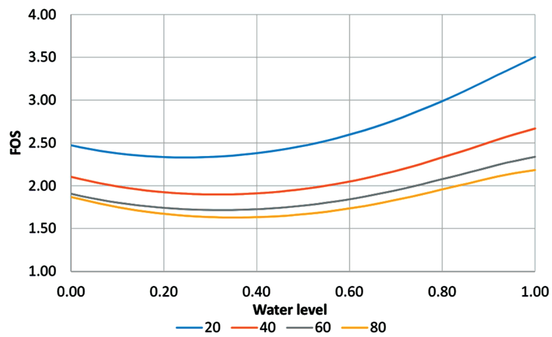

Fig. 5. Dependence of the stability reserve coefficient (FOS) of a flooded dump from loamy rocks on the flooded level of the remaining space at an embankment slope angle β of 20°

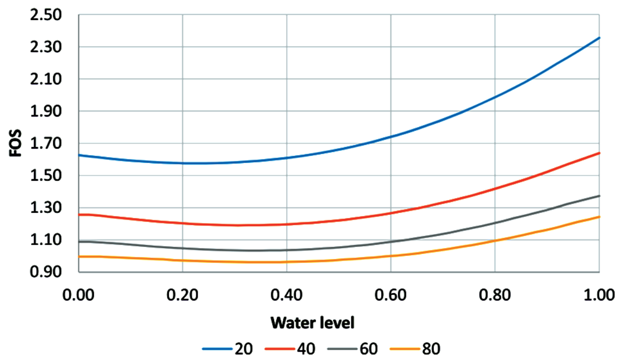

Fig. 7. Dependence of the stability reserve coefficient (FOS) of a flooded dump from loamy rocks on the flooded level of the remaining space at an embankment slope angle β of 40°

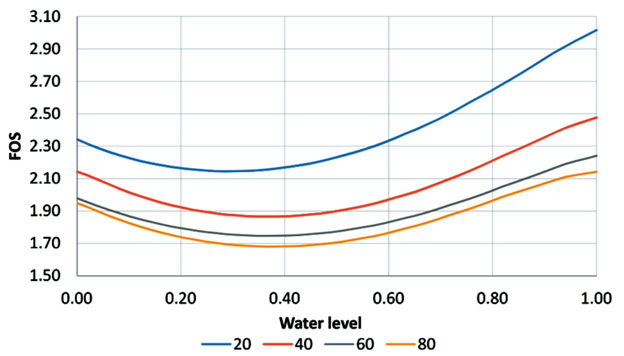

Fig. 8. Dependence of the stability reserve coefficient (FOS) of a flooded crushed hard rocks dump on the level of residual spaces filling with water at an embankment slope angle of 20°

the embankment is completely flooded at a height of 20 m and is 3.0. At the same time, the smallest FOS will be 1.7 at an embankment height of 80 m, provided that it is partially flooded by 40 %. The dependence of FOS on the flooded level of the rock embankment at a slope angle of 30° is shown in Fig. 9.

According to the established dependences of FOS on the flooded level of the crushed stone embankment (Fig. 9), the formation of an internal dump with a height of 20 m is safe in case of any flooding. If the crushed stone embankment is watered more than 95 % in height, it can be formed up to 60 m high, since in this case the FOS will be 1.58. The formation of an embankment with a height of 80 m, at any level of flooding, is dangerous, since the FOS is in the range of 1.21–1.44.

During studies of the influence of the flooded level of the crushed stone embankment on the coefficient of stability reserve, the embankment slope angle of 40° was considered (Fig. 10).

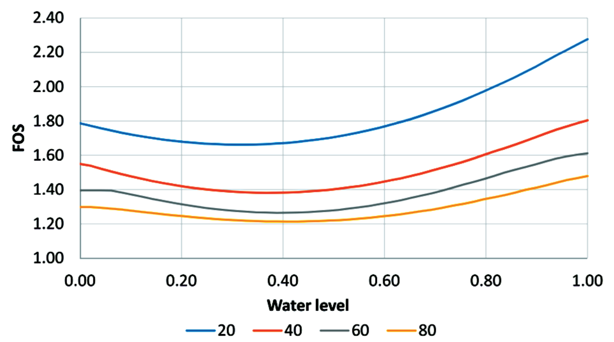

Fig. 9. Dependence of the stability reserve coefficient (FOS) of a flooded crushed hard rocks dump on the level of residual spaces filling with water at an embankment slope angle of 30°

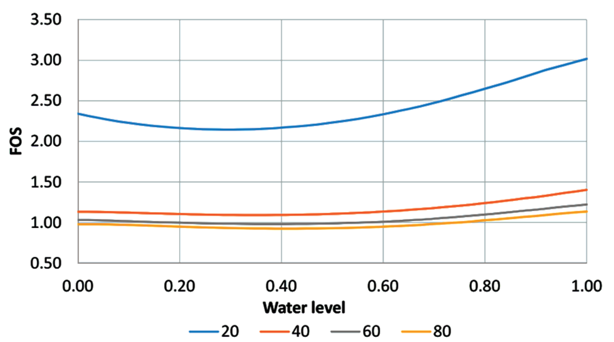

Fig. 10. Dependence of the stability reserve coefficient (FOS) of a flooded crushed hard rocks dump on the level of residual spaces filling with water at an embankment slope angle of 40°

According to the dependencies shown in the graph (Fig. 10), the safe formation of a crushed stone embankment is possible only at a height of 20 m with an embankment slope angle of 40°. In this case, the range of FOS indicators is 2.2–3.0. When the embankment height increases to 40 m, the value of FOS decreases to 1.4, which cannot guarantee the safety of the recreation area. The smallest FOS indicator is 0.9 and is achieved when the height of the embankment is increased to 80 m, provided that it is flooded by 40 %.

The conducted studies allow us to proceed to the generalization of the safe parameters of embankments in the watered residual space of the quarry for the creation of a recreational zone, which in the future will allow us to establish the volumes of mining reclamation.

On the basis of the established results, the safe angles of inclination of the internal dump slopes are determined during the formation of the recreational zone from sandy rocks, loam and rock crushed mass. Taking into account the established dependence of the reserve ratio on the water level in the slope during the filling of the residual space, it was found that with partial flooding of the embankment by 45–50 % for sandy, loamy and rocky rocks, the reserve ratio can decrease by 1.4–1.5 times, which confirms the negative impact of water on slope stability.

The analysis of the obtained dependencies allows us to establish that with an increase in the reserve factor, the minimum of the function shifts to the left, i.e., the critical height of water in the flooded massif becomes lower. Thus, to prevent the specified risks of embankment collapse in practice, during the formation of a recreational zone in the residual spaces, it is necessary that the water level in the residual spaces should be slightly lower than the height of the recreational zone surface.

According to the obtained research results, let us consider the reclamation area when creating a recreational zone in the flooded space of the quarry, provided that a horizontal platform is formed, the level of which is slightly higher than the water level in the reservoir. In this case, the scenario is investigated when the water level is as close as possible to the surface of the embankment. During the research, the safest level of the embankment flooding was accepted to be 95 %.

The results obtained when determining the FOS safety factor for the three previously considered types of mining rocks with an embankment height of 20–80 m and a water level of 95 % are shown in Table 2.

Table 2

Safety factor indicators FOS for different types of mining rocks used in the reclamation of the flooded residual space of the quarry at the level of embankment flooding at 95 %

Embankment height, m	The slope angle of the embankment, degrees	The coefficient of stability reserve (FOS) for different types of mining rocks at the level of irrigation of the embankment at 95 %		
		Sand	Loam	Crushed stone
20	20	1.74	3.34	2.91
	30	1.21	2.63	2.18
	40	0.88	2.23	2.91
40	20	1.56	2.57	2.41
	30	1.06	1.95	1.75
	40	0.78	1.57	1.35
60	20	1.52	2.27	2.19
	30	1.04	1.66	1.58
	40	0.94	1.32	1.19
80	20	1.49	2.13	2.11
	30	0.98	1.52	1.44
	40	0.72	1.19	1.10

According to the established indicators of the FOS safety factor when changing the height and slope angle of the embankment (Table 2) for rocks with different physical and mechanical properties, safe parameters of the recreational area during reclamation are determined in further studies. In order to develop recommendations for choosing safe embankment parameters taking into account the physical and mechanical properties of rocks, the condition that the value of the FOS safety factor should be at least 1.5 is accepted. Thus, at lower values of the FOS safety factor, the stability of the state of mining rocks for a long time will be considered insufficient. The obtained indicators of the safe slope angles of the embankment made of sandy, loamy and crushed hard rocks when they are flooded by 95 % in height are given in Table 3.

The established safe angles of embankment slopes inclination (Table 3) allow proceeding to the solution of the next task of determining the volume of mining reclamation works during the construction of a recreational zone from different types of rocks in the residual spaces of a flooded quarry.

The results. According to the established dependencies, it becomes possible to determine the influence of the physical and mechanical properties of waste rocks on the volume of reclamation works when creating a recreational zone in the flooded quarry. The choice of recreational zones' parameters in the quarry residual space depends on the solution of this task, since they will affect the cost of reclamation works. Considering the fact that the recreational direction of reclamation is considered extremely expensive, it can be chosen only on the condition of the request of local communities and the availability of tourism potential of the territory. Factors that minimize the reclamation work cost due to the optimal parameters will also be taken into account.

The previously conducted studies [26] made it possible to develop methodical approaches to determining the volume of mining reclamation during the construction of a recreational zone on the flooded pit slopes, taking into account the parameters of the resulting slope angle.

In accordance with the developed recommendations, the following initial data are accepted for calculating the volume of mining reclamation works: the resulting slope angle of granite quarry, on which the reclamation is carried out – 60°; the length of the recreation area beach is 100 m; the area of the horizontal site of the recreation area above the watered surface is 0.5 ha; the width of the beach of the recreation area is 50 m; embankment height is from 20 to 80 m; type of rocks for the embankment formation – sand, loam, crushed stone; the level of the embankment flooding according to its height is 95 %; safe slope angles of embankment in quarry residual space – in accordance with Table 3.

The results of the studies on the influence of the embankment height on the safe angle of its inclination and the volume of reclamation works, taking into account the irrigation of the mining massif by 95 %, are shown in Fig. 11.

The results of the calculations (Fig. 11) allow establishing the influence of the embankment height on the volume of mining reclamation work when a recreational zone is constructed in the residual space of the quarry, taking into account the physical and mechanical properties of the rocks. According to the established dependencies, when the height of

Table 3

Indicators of safe embankments slope angles made of sandy, loamy and hard rocks when at the flooding by 95 %

Type of rocks	Embankment height, m			
	20	40	60	80
Sand	23	21	20	19
Loam	43	37	32	28
Crushed stone	46	35	29	26

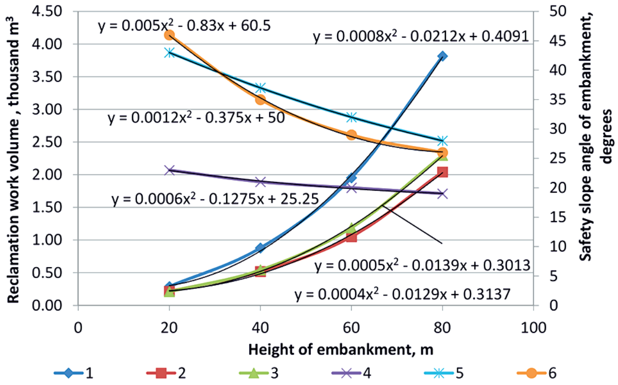

Fig. 11. Dependence of the reclamation work volume during the construction of a recreational zone in the quarry residual space (1 – sand; 2 – loam; 3 – crushed stone) and the safe slope angle of the embankment rocks (4 – sand; 5 – loam; 6 – crushed stone) from its height with an recreation area of 0.5 ha

the embankment increases by 4 times from 20 to 80 m, the safe slope angle of the embankment decreases by 1.21 times when using sand, 1.54 – loamy and 1.77 – rock crushed rocks.

The established dependences (Fig. 11) allow stating that with insignificant embankment heights of up to 35 m, rubble rocks have a more stable slope angle of the dump compared to loamy; however, with a further increase in the embankment height up to 80 m, the angle of stability of crushed stone rocks will be smaller than loam.

At the same time, for all types of rocks, an increase in the embankment height from 20 to 80 m leads to a significant increase in the volume of mining capital works with a constant indicator of the area of the recreational zone constructed above the water surface. During the research, the possibility of creating a recreational zone with an area of 0.5 ha was considered, which requires from 0.21 to 3.82 million m^3 of mining rocks.

Construction of an embankment from sandy rocks with a 4-fold increase in its height will lead to the need to use 13.2 times more materials, as the backfill volume will increase from 0.29 to 3.82 million m^3. When using crushed stone, the volume of reclamation works will increase 10.9 times from 0.21 to 2.3 million m^3. The minimum increase in the works volume when the embankment height is increased from 20 to 80 m, among the studied rocks belongs to loams. In this case, the work volume will increase 9.5 times from 0.22 to 2.04 million m^3.

Taking into account the established factors, loamy rocks are the most effective for use, since utilizing them requires the less volumes of mining reclamation work. It is also possible to use crushed stone rocks if they are available in external dumps of the quarry, or in the case of the close location of neighbouring mining enterprises which need to place overburden during exploitation.

This is primarily due to the high cost of crushed stone rock compared to sand and loam. In this regard, when developing recommendations for the selection of effective materials for the formation of a recreational zone in the quarry residual space, it is necessary to take into account the accessibility of available materials or, in their absence, to substantiate the technical and economic feasibility of attracting overburden from other quarries that exploitation in a region.

To predict the efficiency of using backfill materials, as minerals from other quarries, a calculation was made in accordance with the market value of sand, loam and crushed stone with delivery. According to open sources of information, the total cost of sand rocks is UAH 150/m^3, loams – UAH 80/m^3, crushed rocks – UAH 270/m^3.

The results of calculations for determining the cost of purchasing materials for the construction of a recreational area in the quarry residual spaces, depending on the type of rocks, the height of the embankment and taking into account its flooding by 95 %, are shown in Table 4.

Table 4

Parameters of embankments in the quarry flooded space during reclamation works

Embankment height, m	Type of mining rocks								
	Sand			Loam			Crushed stone		
	Angle of stability, degree	Volume of reclamation works, m^3	Cost of materials, UAH million	Angle of stability, degree	Volume of reclamation works, m^3	Cost of materials, UAH million	Angle of stability, degree	Volume of reclamation works, m^3	Cost of materials, UAH million
20	23	0.29	43.15	43	0.22	17.22	46	0.21	56.67
40	21	0.88	131.83	37	0.52	41.53	35	0.54	146.77
60	20	1.95	292.99	32	1.05	84.04	29	1.19	321.04
80	19	3.82	572.53	28	2.04	163.39	26	2.30	620.33

According to the established market value of the materials required for the construction of a recreational zone in the residual space of the quarry (Table 4), for any embankment height in the range of 20–80 m, the most effective is the use of loamy rocks (Fig. 12). It should be noted that the costs calculation does not include additional mining equipment operation that depends on mechanical features of rocks.

The established dependencies (Fig. 12) show that when forming an embankment 20 m high from loamy rocks, its cost will be 2.5 times less compared to sandy rocks and 3.2 times less than rocky ones. When the height of the embankment is 80 m, these values will increase to 3.5 and 3.8 times, respectively. This shows that the use of sand and gravel rocks has approximately similar efficiency when the height of the embankment increases.

Thus, for the creation of relatively low embankments (up to 20 m), sand and rock can be considered as an alternative option; however, with an increase in the height of the embankment and an increase in the volume of reclamation works, the low cost of loam allows you to significantly reduce the costs of constructing a recreation area. As a result of the mentioned works implementation during the quarry reclamation additional areas with light inclined slopes will be created in the coastal strip form, which makes it possible to ensure free and safe access of vacationers to the water.

Conclusions. The results of the research on establishing the safe parameters of recreational zones created in the residual spaces of the quarry, taking into account the physical and mechanical properties of mining rocks, allowed determining the influence of the water level on the stability of embankments made of sand, loam and crushed rock. The obtained results are necessary for the implementation of project works on the technological schemes development for the reclamation of the quarries flooded residual spaces for the recreational direction of post-mining.

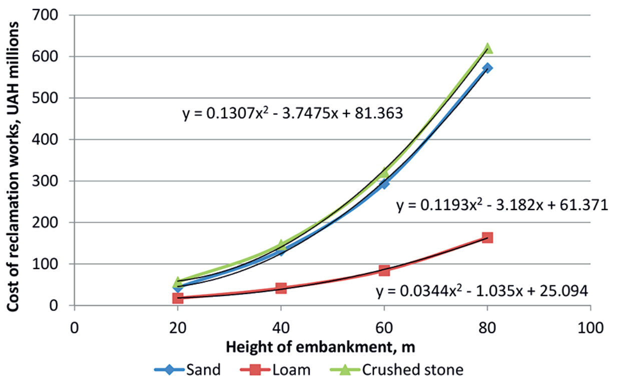

Fig. 12. Determination the embankment height influence during the construction of a recreational zone in the quarry residual spaces on the cost of reclamation works, taking into account the physical and mechanical properties of the rocks with an area of the recreational zone of 0.5 ha

It was determined that the use of loamy rocks for the formation of a recreational zone with a height of 20–40 m is possible at an embankment slope angle of 40°, at any water level. Further increase in the height of the embankment to 80 m is dangerous at this slope angle, due to the low factor of safety the FOS in the range of 1.0–1.4.

It has been proven that the formation of a crushed stone embankment is possible at a height of 20 to 80 m, provided that the slope angle is reduced from 46 to 26°, respectively. This is explained by the fact that when the embankment height increases to 40 m, the FOS value decreases to 1.4, which cannot guarantee the safety of the recreation area. The smallest FOS indicator is 0.9 and is achieved when the height of the embankment is increased to 80 m, provided that it is flooded by 40 %.

It was established that with partial flooding of the mining massif by 45–50 % for sandy, loamy and rocky rocks, the coefficient of stability reserve is significantly reduced by 1.4–1.5, which confirms the negative effect of the partial flooding of mining embankments on the slopes stability.

It was determined that when forming an embankment 20 m high from loamy rocks, the volume of reclamation works will be 1.34 times less compared to sandy rocks, but 1.02 times larger than crushed stone rocks. When the embankment height increases to 80 m, the volume of reclamation works will increase to 1.87 times the use of sand rocks and 1.12 times, respectively.

It was established that, taking into account the market value of materials for the creation of an embankment, when using loam, the cost of work will decrease by 2.5 times compared to sandy rocks and 3.2 times – with crushed stone rocks, with an embankment height of 20 m. When the embankment height increases to 80 m, the cost of materials will increase by 3.5 and 3.8 times when loamy rocks are replaced by sand or crushed stone, respectively.

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Обґрунтування безпечних параметрів рекреаційних зон при рекультивації обводнених вироблених просторів кар'єрів

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Мета. Визначити безпечні параметри рекреаційних зон, що створюються у виробленому просторі кар'єру, з урахуванням фізико-механічних властивостей відвальних порід в обводненому стані.

Методика. Для визначення впливу рівня обводнення виробленого простору кар'єру на стійкість насипу з різних типів гірничих порід при створенні рекреаційної зони під час рекультиваційних робіт використовується спрощений метод Бішопа (Bishop Simplified Method).

Результати. Встановлені безпечні параметри рекреаційних зон при їх спорудженні в обводненому виробленому просторі кар'єру з урахуванням фізико-механічних властивостей насипів з піску, суглинків і подрібнених скельних порід шляхом визначенням стійкості їх укосів. Отримані результати необхідні для виконання проєктних робіт із розробки технологічних схем рекультивації вироблених просторів кар'єрів під рекреаційний напрям постмайнінгу.

Наукова новизна. Встановлена залежність висоти формування щебеневого насипу від стійкого кута нахилу обводненого укосу, яка дозволила визначити, що зі збільшенням висоти насипу з 20 до 80 м безпечний кут укосу зменшиться з 46 до 26°. Визначено, що найменший показник FOS складає 0,57 при використанні піщаних порід за висоти насипу 80 м при обводненості 40 %. Встановлено, що при частковому підтоплені гірничого масиву на 45–50 % для піщаних, суглинистих і скельних порід відбувається значне зниження коефіцієнту запасу стійкості в 1,4–1,5 разів на відміну від відсутності води або повного затоплення, що підтверджує негативний вплив саме часткового обводнення насипів і зниження стійкості їх укосів.

Практична значимість. Визначено, що при формуванні насипу висотою 20 м із суглинистих порід об'єм рекультиваційних робіт буде в 1,34 рази менше в порівнянні з піщаними породами, але в 1,02 рази більшим у порівнянні зі скельними породами. При зростанні висоти насипу до 80 м, об'єм рекультиваційних робіт при заміні суглинків на піски збільшиться до 1,87 і до 1,12 разів – при використанні щебеню. Однак, з урахуванням ринкової вартості матеріалів, при застосуванні суглинків вартість спорудження зменшиться у 2,5 рази в порівнянні з піщаними породами і 3,2 рази – зі скельними, при висоті насипу 20 м. При зростанні висоти насипу до 80 м вартість матеріалів зросте у 3,5 і 3,8 разів при заміні суглинистих порід на піщані або щебеневі, відповідно.

Ключові слова: *кар'єр, рекультивація, рекреаційна зона, фізико-механічні властивості порід, обводнений простір*

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