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# TECHNICAL AND ECONOMIC ASSESSMENT OF TECHNOLOGICAL SCHEMES FOR RECLAMATION OF WATERED QUARRY RESIDUAL SPACES

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**Abstract**. The work aims to establish effective technological schemes for reclamation when creating a coastal strip in watered mined quarry areas. The influence of the watered quarry space parameters on the technical and economic indicators of reclamation when creating a recreational zone in the watered residual space has been determined. The influence of the type of rock when forming a coastal strip by embankment on the technical and economic indicators of reclamation has been established. The total costs of applying the specified technological scheme using rocks, sands, and loams have been determined. It is established that the use of sand is the most expensive process, due to its low stability when forming watered slopes of dumps and the need to increase the volume of mining reclamation. When using sand in constructing a coastal strip with an area of 0.5 ha, the costs of reclamation increase by 1.6–1.8 times compared to rocks or loams due to the increased volume of mining and haulage works. The technical and economic indicators of the technological scheme of reclamation have been determined, in which the rock from the non-watered part of the quarry side is excavated and moved outside the quarry when creating a beach zone of given parameters. Under this scheme, an increase in the coastal strip from 0.5 ha to 1.0 ha leads to an increase in the volume of reclamation works to 392,000–496,000 m$^3$, depending on the type of rocks from which the quarry slope is formed. When using the second scheme, the lowest costs for reclamation works are determined when developing the non-watered part of the quarry slope, composed of loamy rocks. It is determined that the reclamation of the hard rock mass according to this scheme requires an increase in costs by 3.6–4.3 times that of developing loamy rocks, depending on the height of the non-watered quarry slope. The established dependencies allow us to evaluate the choice of the technological scheme of reclamation in the presence of the parameters of the watered quarry residual space, the rocks from which the non-watered quarry slope is formed, and the available volumes of waste rocks near the quarry, which can be used to create a recreational zone in the watered quarry residual space.

**Keywords**: quarry, watered residual space, reclamation, recreational zone, coastal strip, technical and economic indicators

## 1. Introduction

The reclamation of watered residual spaces of building material quarries [1] has a significant relevance for community development [2], as such places are a potential resource for the creation of recreational areas for rest and sports [3]. Since the chemical composition of water in building material quarries [4] in most cases does not pose a danger to people, these water bodies have a vast potential for recreational use [5].

Historically, the residual spaces of building materials quarries [6] are subsequently watered by groundwater and turn into artificial freshwater lakes [7]. Therefore, many people visit these locations in summer, especially when the region has limited access to water resources [8].

To create a high-quality and safe recreation area [9] near a reservoir that many people can visit, it is necessary to determine effective parameters of mining and technical reclamation [10], taking into account the parameters of the quarry slopes during the period of mining operations completion [11].

Since the residual space of the quarry is filled with groundwater only to a certain degree [12], and not to the full depth, a situation arises where we have a lake [13], to which it is necessary to descend the mining workings from the surface of the quarry [14]. In this case, the water level in the reservoir depends on the capacity of the underground water horizons [15] and is adjusted by surface waters throughout the year [16].

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The quarry lake can only be reached by trenches [17], which were previously used as quarry roads [18] for dump trucks to haul the rock mass from the quarry to the surface [19]. After the quarry activity closure [20], traffic on these roads stopped, so people used them to access the water [21].

Despite the availability of roads to access the reservoir [22], there are many problems. For example, when the reservoir is located at a considerable distance from the surface of the earth [23], it can be reached by an existing trench [24], but there is a lack of free space for the arrangement of a beach area [25]. This is due to the small width of the haulage berms in the quarry [26], which can be 10 m and is highly insufficient to accommodate even a small group of people [27].

The small width of the berm causes the main problem, which is that it does not allow access to the reservoir for many vacationers [28]. In this regard, a safe coastal strip within the adjacent area of the reservoir surface must be arranged to the slope of the building material quarry.

The analysis of the research conducted in [2] allowed us to determine the general directions of quarry reuse to combine the main concepts of quarry reclamation, considering environmental problems and sustainable development. The research proposed an innovative matrix for classifying technological schemes of reclamation, which can be used to improve approaches to practical application. However, the article does not pay enough attention to the issues of using water resources of abandoned quarries for the recreational needs of communities.

The research carried out in [3] is devoted to the reclamation of the residual spaces of quarries to create reservoirs using various methods. Methodological approaches to forming a coastal zone on artificial reservoirs created in mined spaces of quarries are presented. The parameters of quarries suitable for swimming and recreation due to creating a coastal zone are analyzed. However, the article does not consider the technical and economic comparison of reclamation technological schemes, which does not allow for determining the influence of quarry parameters on the need for partial backfilling of the residual space or the development of the non-watered part of the quarry slope when creating a coastal strip.

In the studies [5], the issues of quarry reuse are considered using a two-stage methodology with site assessment and territory verification for usability. The proposed method can be applied to the reuse of abandoned quarries, considering the social factors and the needs of megacities. The disadvantage of the work is the lack of consideration of the physical and mechanical characteristics of the mining massifs of quarries. These residual spaces will be used for recreational purposes in the future.

In the article [6], new strategies for the reuse and restoration of quarry landscapes are outlined. The processes that need to be evaluated to establish possible changes in landscapes, in accordance with the disturbed areas' architectural, historical, and cultural value, are determined. However, the paper does not consider applied issues that allow determining safe parameters of recreational zones formed on the site of watered residual spaces of quarries.

Research [7] studies the hydrological reclamation of quarry residual spaces. This approach allows the creation of a new water area for various species of plants and animals. The presented article also studies the experience of the impact of hydrological reclamation on the environment from an ecological and socio-economic point of view. However, the methodological approaches presented in the work can be applied only to quarries with soft overburden rocks, since the conditions for developing a brown coal open-cast mine are considered.

In the work [8], the main attention is paid to creating quarry lakes, considering water quality, slope stability, and safety. The article's relevance is associated with many abandoned areas, the reprofiling of which allows the creation of areas for active recreation, nature conservation, educational purposes, and research. Recommendations are also developed at all stages of planning the closure of quarries, for successful use in the future.

An architectural approach to rehabilitating abandoned quarries and landscapes is discussed in [19]. The developed methodology for the reuse of abandoned quarries is aimed at exploring innovative solutions for the restoration of quarry areas. The proposed solutions allow the restoration of abandoned places, further affecting the local economy and land management. This approach promotes a circular economy by resuscitating neglected landscape components.

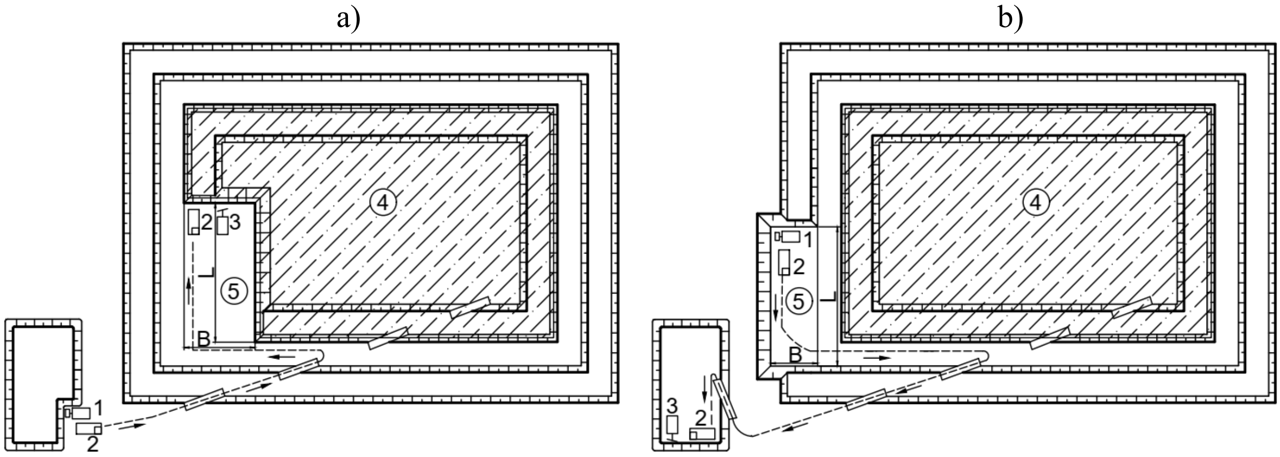
## 2. Methods

The determination of an effective scheme for the formation of a coastal strip primarily depends on the parameters of the quarry mining operations after its closure [29], as well as on the water level in the reservoir after flooding the residual space. It is worth noting that a significant impact on the cost of works on the construction of a coastal strip in the residual space of the quarry will be the distance between the quarry surface and the water level in the reservoir. The choice of a reclamation scheme will depend on this indicator, which may involve backfilling with solid rocks part of the mined space or excavation of part of the quarry slope to increase the parameters of haulage berms and create the necessary sites of a given area for the arrangement of a safe coastal strip.

In this regard, the justification the choice of an effective technological scheme for reclamation can be achieved by solving the following tasks: to determine the influence of the watered slope height of the quarry on the technical and economic indicators of reclamation when forming an embankment in the watered residual space of the quarry; to establish the influence of the height of the non-watered slope of the quarry, from which the rock is excavated and moved beyond the residual space when creating a beach zone of given parameters, on the technical and economic indicators of reclamation works; to compare the effectiveness of the proposed technological schemes for the reclamation of watered residual spaces of building materials quarries when creating recreational areas and to develop recommendations for choosing their effective parameters.

## 3. Theoretical part

During the reclamation of the quarry residual spaces of building materials, two of the most common technological schemes can be used to create a coastal strip. In the first case, the coastal strip is created by filling in a part of the watered area of the quarry with solid rocks, considering the reservoir's stable water level (Fig. 1 a). The second technological scheme involves excavating rocks from the quarry's selected slopes to the mark of the stable water level in the reservoir (Fig. 1 b). In this way, a niche with specific parameters is created on the slope of the quarry, which will have a horizontal surface and later be used as a coastal strip.

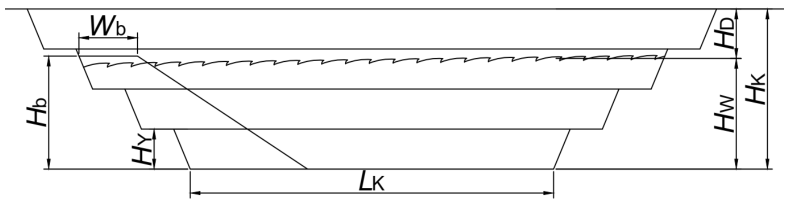



1 – excavator; 2 – dump truck; 3 – bulldozer; 4 – watered quarry residual space; 5 – newly formed coastal strip

Figure 1 – Typical schemes for reclamation of quarry residual spaces when creating a recreational zone with a coastal strip with:
a) a partial backfilling of the space; b) an excavation of quarry slope

The main barrier to using the considered technological schemes of reclamation in practice is the need for extremely high costs for excavation and haulage works, and in the case of rock mining from the quarry slope, drilling and blasting preparation for extraction is also added. The total costs will depend on the volume of reclamation works, which will determine the term of mining and haulage equipment involvement.

The advantage of the first or second technological scheme of reclamation in practice will be determined by the minimum level of economic costs due to the total volume of mining, haulage, and auxiliary works. The volumes of reclamation works for each scheme will depend on the stable water level in the mined space relative to the depth of the quarry (Fig. 2).




HK – quarry depth; LK – length of the quarry; HW – water level in the watered area; HD – height of the non-watered slope of the quarry; Hb – height of the embankment; Wb – width of the embankment when creating the coastal strip; HY – the height of the bench

Figure 2 – Scheme of the watered residual space of the quarry to determine the volume of reclamation works when creating a recreational zone with a coastal strip

To determine the initial design conditions under which it is economically feasible to apply the first reclamation scheme with the creation of an embankment in the watered mined space of the quarry, safe parameters of watered embankments were previously established [30]. The established dependencies allow us to state that the volume of mining and technical reclamation work will depend on the size of the beach area, the physical and mechanical properties of the rocks from which the embankment is formed, as well as the water level in the watered space of the quarry $H_W$.

When comparing two technological schemes, it is not enough to determine the volume of dumping work when filling the watered space or the volume of work to create a coastal strip by developing the above-water part of the watered quarry slope, since the second scheme provides for drilling and blasting work to prepare the rock mass for excavation. Therefore, their comparison should be carried out through a feasibility study that considers the parameters of the watered residual space of the quarry and the recreational zone with the coastal strip.

**4. Results and discussion**

The use of the technological scheme of reclamation with partial backfilling of the residual space should be ensured by the availability of free material to create a recreational area, as well as the costs of excavation and haulage work. When using the second technological scheme, the costs of drilling, blasting, excavation, and haulage work should be considered to transfer this material from the quarry slope to its surface in an external dump or in a watered residual space. In this case, the costs of reclamation work can be reduced, since the distance of material haulage to the unloading site will be reduced.

During the research, the following initial data are accepted: quarry depth up to 90 m; water level in the watered mined space from 0 to 60 m; size of the recreational area with a coastal strip, width from 50 to 100 m, length – 100 m; rocks for filling the watered space – sand, loam, rock dump rocks.

The calculation method [15] and the parameters of dump stable slopes in a watered environment [30] were used to calculate the volume of mining reclamation work. Foremost, the first technological scheme of reclamation was considered, which involves partial backfilling of the mined space (Fig. 1 a). According to the initial data, the possibility of forming a recreational zone with a coastal strip in the watered space of the quarry by backfilling the internal dump was considered. In this case, the range of water level in the watered space can be from 10 to 60 m, corresponding to the height of the internal dump on the surface of which the recreational zone will be located. The results of calculating the volume of reclamation works during the construction of a recreational zone with a coastal strip 100 m long and 50 m wide, with an embankment height of 0–60 m made of sandy, loamy, and hard rocks are presented in Fig. 3.

According to the established dependencies (Fig. 3), when forming a coastal strip measuring 50 by 100 m, a threefold increase in the height of the embankment from 20 to 60 m will lead to an increase in the volume of reclamation works by 5.4–7.3 times to 2.20 million m3, depending on the type of rock from which the embankment is formed. According to the results obtained, for the given initial parameters, the most effective material from which the embankment will be formed is loam and hard rock, which have better stability characteristics in a watered state compared to sand. Due to the increased stability characteristics of the rocks, an increase in the safe angles of inclination of watered benches is achieved, which allows reducing the volumes of materials required for backfilling when creating a recreational zone of the same area.

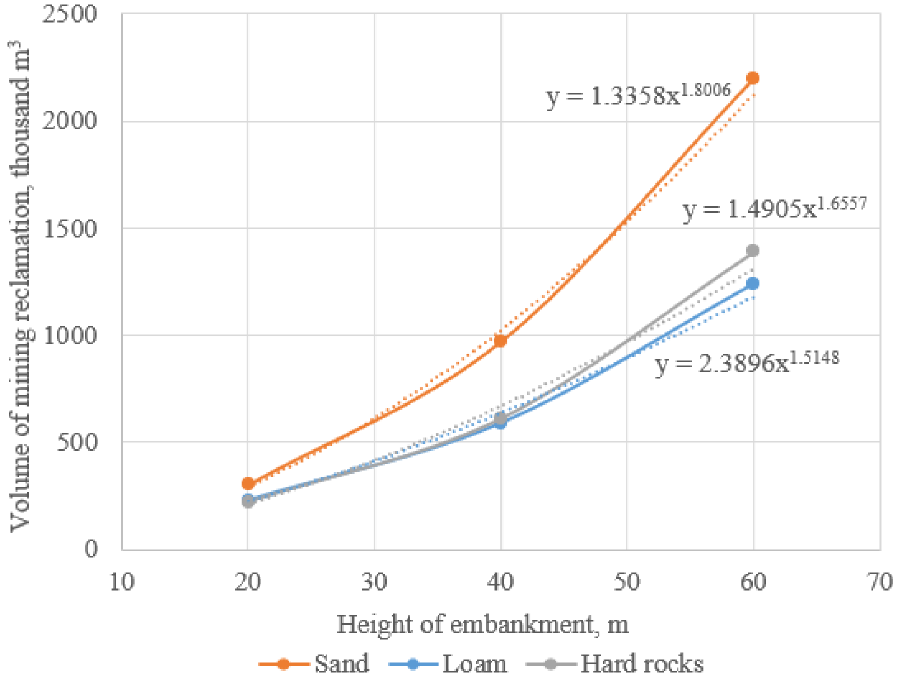



Figure 3 – Influence of embankment height on the volume of mining reclamation when creating a coastal strip of sand, loam and hard rocks with an area of 0.5 ha

If it is necessary to increase the area of the recreational zone with a coastal strip in the quarry watered area, a section 100 m long and 100 m wide was also considered, which allows creating a beach with an area of up to 1.0 ha. Calculation methods similar to the previous ones were used to determine the volumes of mining parameters. The results of assessing the influence of the embankment height with an area of 1.0 ha on the volumes of reclamation works during its construction in the watered mined area of the quarry using sand, loam, and hard rocks are presented in Fig. 4.

The established dependencies (Fig. 4) allow us to state that increasing the size of the coastal strip from 0.5 to 1 hectare leads to a significant increase in the volume of mining reclamation. At the same time, the most significant increase of 2.04 times is observed when forming an embankment 20 m high, reaching 450,000 $m^3$. When creating a sand embankment 60 m high, increasing the area of the coastal strip from 0.5 to 1 ha leads to an increase in the volume of reclamation work of 1.56 times to 3.45 million $m^3$. This indicates the effectiveness of increasing the area of the recreational zone when using sand as a material for forming the embankment.

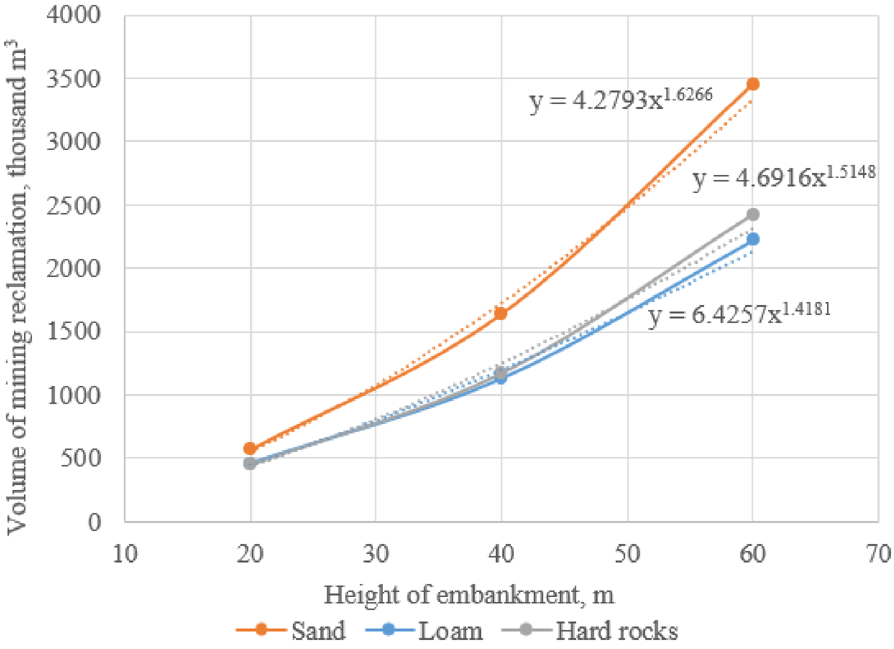



Figure 4 – Influence of embankment height on the volume of mining reclamation when creating a coastal strip of sand, loam and hard rocks with an area of 1.0 ha

The determined influence of the embankment height on the volume of reclamation works (Fig. 4) confirms that an increase in the height of the embankment from 20 to 60 m will lead to an increase in its volume by 4.8–6.1 times, depending on the backfill material. The smallest increase in work volume to 2,220,000 m3 is observed when using loamy waste rock, which is 4.8 times. This indicates the effectiveness of using the specified material when creating embankments in watered mining operations. The use of crushed rock requires the use of from 450,000 m3 to 2,420,000 m3 of material to create an embankment of a recreational zone with a height of from 20 to 60 m. This confirms the high cost-effectiveness of using this material compared to the volumes of sand and rocks; however, due to the shortage in dumps and the significant cost of crushed rock raw materials, their use in mining reclamation may be accompanied by a list of difficulties.

The obtained dependences confirm that the increase in the embankment's height in the quarry's watered residual space, which is associated with the groundwater level, leads to a significant increase in the volume of reclamation works and the cost of constructing a recreational zone. With a further increase in the water level in the watered space of the quarry, an urgent problem arises of finding alternative options for creating a recreational zone in a certain area to reduce the reclamation cost.

In this regard, it is necessary to consider the mining performance of the second technological scheme with the development of quarry slope rocks (Fig. 1 b). The advantage of this scheme is its effectiveness in the reclamation of quarries with a high level of watering of the residual space. The range of distances between the quarry surface and the water level in the watered residual space $H_D$ from 0 to 30 m was considered when conducting research. As in previous studies, three types of overburden rocks were considered, from which the non-watered quarry slope was formed. The volume of reclamation work is established when changing the height of the non-watered quarry slope $H_D$ to when creating a recreational zone (Fig. 5).

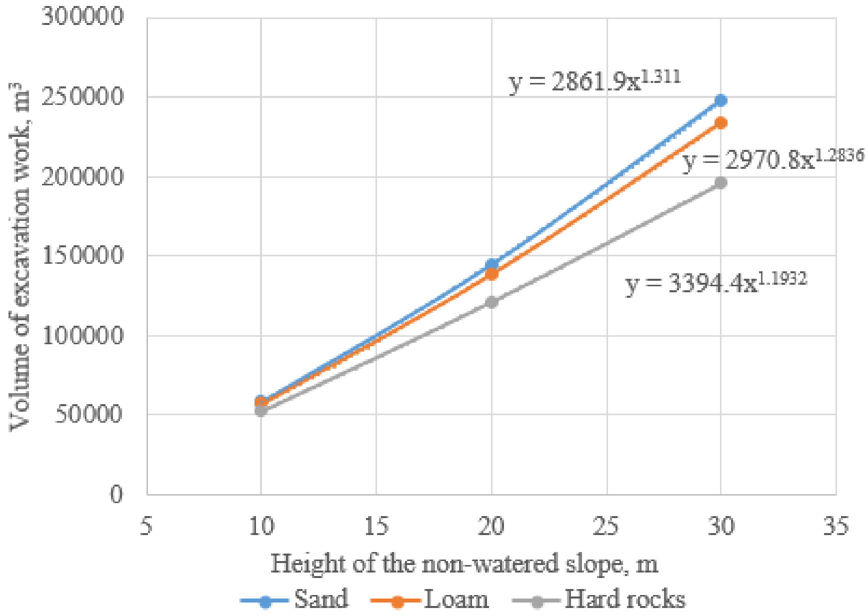



Figure 5 – Influence of the height of the non-watered slope of the quarry $H_D$ on the volume of reclamation works when creating a recreational area of 0.5 ha by excavating rocks

According to the established dependencies (Fig. 5), the volume of mining reclamation works has a nonlinear dependence on the height of the non-watered part of the quarry slope, the rocks of which must be excavated. The volumes of reclamation works have a nonlinear dependence when the height of the non-watered part of the quarry side increases from 10 to 30 m. The most significant volume of excavation works in the second technological scheme of reclamation is observed when developing the non-watered slope of the quarry composed of sand. When using sand to create a recreational zone with an area of 0.5 ha, from 59,000 to 248,000 m3 will be required, depending on the height of the non-watered part of the quarry slope. That is, when the slope height increases three times to 30 m, the volume of mining reclamation works will increase by 4.22 times. The smallest volume of excavation work in a given range of non-watered bench heights is observed when developing a slope composed of rock. When the bench height increases threefold to 30 m, the volume of excavation work will increase 3.7 times and reach 196,000 m3.

To analyze the parameters of mining operations when increasing the area of the recreational zone to 1.0 ha using the second technological scheme with the development of slope quarry rocks (Fig. 1 b), the influence of the non-watered part height of the quarry slope on the volume of reclamation works was additionally determined (Fig. 6).

Increasing the area of the recreational zone with a coastal strip from 0.5 to 1.0 ha when applying the second technological scheme of reclamation leads to an increase in the volume of reclamation works to 392,000 – 496,000 $m^3$, depending on the type of rocks from which the quarry slope is formed. As in the case of forming a coastal strip 50 m wide, the most significant volume of excavation works is observed when developing a part of the non-watered bench composed of sand. The smallest volume of excavation works is 106,000 $m^3$, which corresponds to the conditions for creating a bench 10 m high, formed from hard rocks.

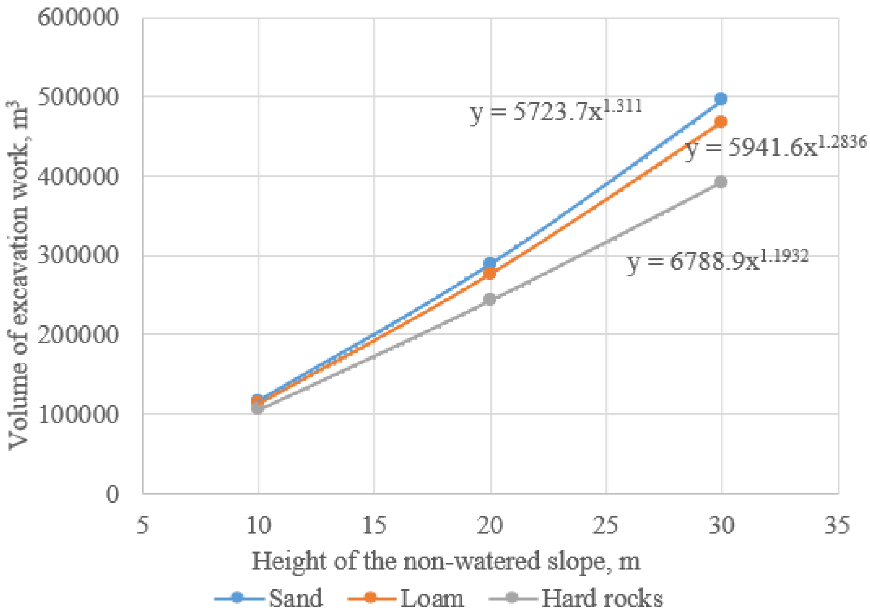



Figure 6 – Influence of the non-watered slope height of the quarry $H_D$ on the volume of reclamation works when creating a recreational area of 1.0 ha by excavating rocks

However, it is worth noting that the development of hard rocks involves preliminary performance of the rock mass using drilling and blasting, which significantly increases the cost of the work. Also, their implementation is extremely expensive and requires a significant number of approvals from authorized institutions.

In this case, for a correct comparison of technological schemes of reclamation in the development of different types of mining rocks, in addition to determining the volume of excavation work, it is necessary to perform an assessment of technical and economic indicators. They should take into account the costs of excavation, haulage and bulldozer work when planning dump surfaces. Also, when developing rocks with increased strength, it is necessary to provide for drilling and blasting work.

The established volumes of mining and technical works allow comparing the technological scheme of reclamation when filling the watered mined space of the quarry with the scheme of rock excavation from the non-watered slope of the quarry to the mark of the stable water level in the reservoir. To further determine the technical and economic indicators of reclamation works, the duration of excavation works when using one CAT 365BL excavator was determined (Table 1). When determining the duration of reclamation works with the involvement of one excavator, a daily single-shift operation mode was assumed.

According to the specified terms of reclamation works when creating a recreational zone in the watered area of the quarry (Table 1), the highest indicators are observed when using sandy rocks, both when filling the watered mined area and when excavating the non-watered slope of the quarry. The lowest reclamation time indicators when filling the quarry's watered part are observed when using loam. In this case, the duration of backfilling is from 3 to 17 months when creating a coastal strip with an area of 0.5 ha, and from 7 to 30 months with an area of 1.0 ha. When using the second technological scheme of reclamation, the lowest indicators of excavation works were recorded when working out the slopes of hard rock. They are from 1 to 3 months when creating a coastal strip with an area of 0.5 ha, and from 2 to 7 months when increasing the area to 1.0 ha.

Table 1 – Time for performing work on creating a recreational zone in the watered residual space of the quarry when using two technological schemes of reclamation

| Technological scheme of reclamation | Height of embankment/ pit side* | Duration of reclamation works, months | | | | | |
|---|---|---|---|---|---|---|---|
| | | Site size 50 by 100 m (0.5 ha) | | | Site size 100 by 100 m (1.0 ha) | | |
| | | Sand | Loams | Rocks | Sand | Loam | Rocks |
| Backfilling of the residual space | 60 | 29.1 | 16.4 | 18.4 | 45.6 | 29.4 | 32.0 |
| | 40 | 12.8 | 7.8 | 8.1 | 21.7 | 14.9 | 15.5 |
| | 20 | 4.0 | 3.0 | 2.9 | 7.5 | 6.1 | 6.0 |
| Water level meets reclamation requirements | 0 | 0.0 | | | | | |
| Development of the quarry non-watered slope | 10* | 0.78 | 0.76 | 0.70 | 1.6 | 1.5 | 1.4 |
| | 20* | 1.91 | 1.83 | 1.61 | 3.8 | 3.7 | 3.2 |
| | 30* | 3.28 | 3.10 | 2.59 | 6.6 | 6.2 | 5.2 |

In general, it is determined that the duration of mining and technical works will continue from 1 to 45 months, depending on the type of rocks and the reclamation scheme, when involving one unit of excavation and loading equipment. If necessary, the time for carrying out reclamation works can be reduced by increasing the number of excavation and haulage machines involved in moving mining rocks.

The results obtained (Table 1) are the initial data for assessing the technical and economic indicators when carrying out mining and technical works during the creation of the coastal strip. To determine the costs of reclamation works, the following parameters were additionally taken: brand of dump truck - CAT D30D; number of dump trucks when servicing one excavator - from 3 to 5 depending on the distance of rock transportation; brand of bulldozer - CAT D10T; weighted average distance of rock haulage along the surface of the quarry - 500 m; cost of drilling and blasting works in preparation for rock excavation - 170 UAH/m3. When performing calculations to determine the costs of mining and technical works for backfilling the watered residual space, the cost of backfilling materials was not taken into account. The results of calculating the costs of reclamation works according to two technological schemes during the construction of a coastal strip with an area of 0.5 ha are shown in Fig. 7.

The established dependence of the reclamation works costs on the height of the embankment or the height of non-watered benches, which should be developed to create a coastal strip with an area of 0.5 ha (Fig. 7) allows us to determine that the most expensive process is the creation of an embankment 60 m high in the watered space of the quarry. The maximum costs for creating an embankment are recorded when using sand. They reach 106.7 million UAH, which is 1.6–1.8 times more compared to rock and loam, respectively. This is explained by the low stability of watered slopes of dumps formed from sandy rocks, and the increased volumes of mining reclamation.

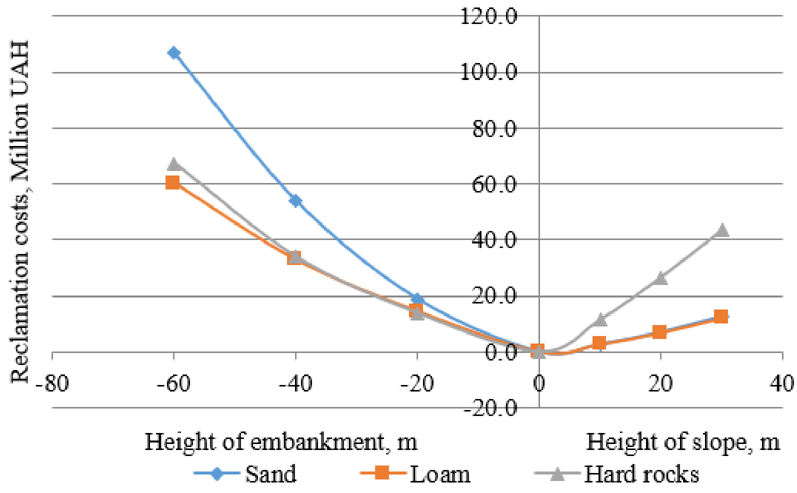



Figure 7 – Costs for creating a recreational zone with a coastal strip of 0.5 ha in a watered quarry according to two technological reclamation schemes

The use of the second technological scheme of reclamation assumes that the greatest costs will be 43.3 million UAH, when developing the non-watered part of the quarry slope formed from hard rocks. This is 3.4–4.3 times more than when excavating the non-watered slope of the quarry, formed from sand or loam. Such a significant increase in cost is explained by the need to perform drilling and blasting, which involve implementing additional processes.

The dependence of the reclamation works costs on the height of the embankment or the height of the benches when using two technological reclamation schemes, provided that the coastal strip area is increased to 1.0 ha, is presented in Fig. 8.

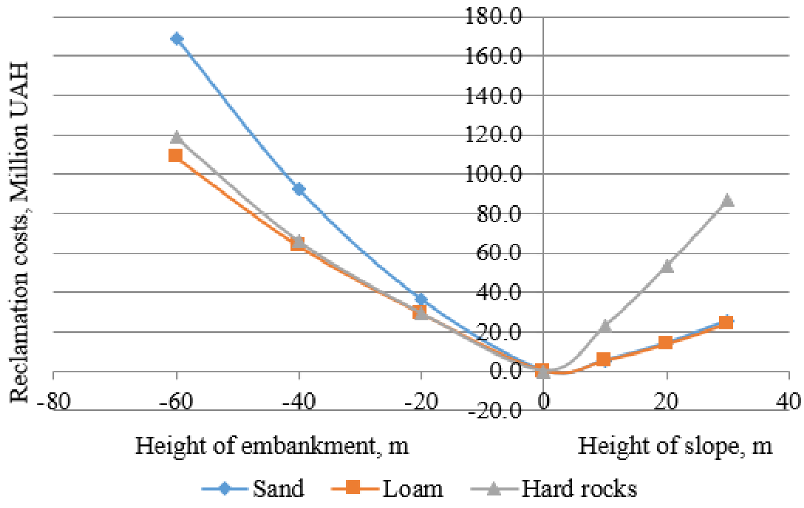



Figure 8 – Costs for creating a recreational zone with a coastal strip of 1.0 ha in a watered quarry according to two technological reclamation schemes

Analysis of the obtained dependences of the reclamation works cost on the parameters of the reclamation technological schemes (Fig. 8) allows us to establish that increasing the area of the coastal strip by two times to 1.0 ha leads to an increase in costs from 1.6 to 2.1 times depending on the height of the embankment. The most significant cost increase occurs when forming an embankment 20 m high from hard rocks and reaches 29.2 million UAH, while the smallest increase was recorded when forming an embankment 60 m high from sandy rocks and is 169.0 million UAH. When analyzing the indicators of the second technological scheme of reclamation, it was found that increasing the area of the coastal strip by two times to 1.0 ha will lead to an increase in the volume of excavation works by 2.02 times when the non-watered part of the quarry slope is composed of sandy rocks.

When comparing the indicators of the first technological scheme of reclamation, the most effective is the formation of an embankment 20 m high from loam or hard rocks in the watered mined space of the quarry. The total costs in this case are 29.2 million UAH, which is 3.7 times less than when forming such an embankment 60 m high from loam and 4.0 times less than from hard rocks. The most expensive in the first scheme will be the use of sand, since with an embankment height of 20 m the costs will be 36.1 million UAH, and with an increase in height to 60 m they will increase 4.7 times to 169.0 million UAH.

In the second technological scheme of reclamation, which involves the development of the non-watered part of the quarry slope to create a coastal strip, the lowest costs are 5.3 million UAH when developing a 10 m high bench of loam. If its height is increased to 30 m, the cost of reclamation works will increase 4.6 times to 24.2 million UAH. Similar indicators will be when developing benches represented by sand. With a bench height of 10 m, the costs of creating a coastal strip with an area of 1.0 ha will be 5.4 million UAH and will increase 4.7 times when the bench height is increased three times.

The highest costs when using the second technological scheme arise when it is necessary to reclaim quarries of building materials from mining hard rocks. The maximum costs will be 86.8 million UAH in the case of developing the non-watered part of the quarry slope when constructing a coastal strip with an area of 1.0 ha. This is 3.8 times more than when developing a 10 m high bench from the same rocks. Compared to the development of loamy rocks, the costs under this scheme when mining hard rock will be 3.6–4.3 times higher, depending on the height of the non-watered part of the quarry slope.

It is worth noting that the established dependencies (Fig. 7 and 8) also allow choosing a technological scheme for reclamation based on the available initial data, which include the parameters of the watered residual space of the quarry. For example, consider a typical quarry for mining crushed stone products, the depth of which is 70 m, and the water level in the watered mined space is 40 m. In that case, the costs of creating a coastal strip with an area of 0.5 ha according to the first technological scheme will be 34.1 million UAH, provided that an embankment is formed from hard rocks. At the same time, using the second technological scheme involves the development of a non-watered part of the quarry slope with a height of 30 m, composed of hard rocks. The cost of performing preparatory and excavation works to create a coastal strip of the specified parameters is 43.3 million UAH. Thus, according to the obtained calculation results, the first technological scheme of reclamation is more effective than the second, and its use allows reducing the cost of work by 9.3 million UAH when constructing a coastal strip with an area of 0.5 hectares.

## 5. Conclusions

The influence of the watered area height of the quarry on the technical and economic indicators of reclamation in the first technological scheme of reclamation with the formation of an embankment in the watered mined area of the quarry has been determined, which allows us to establish the costs of reclamation works during the creation of a coastal strip with an area of 0.5–1.0 ha. According to the results obtained, loams are the most effective material for forming an embankment for the given initial parameters. When creating a coastal strip with an area of 0.5 ha, an increase in the height of the embankment from 18 m to 60 m will lead to an increase in the volume of reclamation works by 5.4–7.3 times to 1.39 million $m^3$, depending on the type of rock from which the embankment is formed.

It was found that the most expensive process is the creation of a 60 m high embankment in the watered area of the quarry using sand. The total costs reach 106.7 million UAH with a coastal strip area of 0.5 ha, which is 1.6–1.8 times more compared to hard rocks and loams, respectively. This is explained by the low stability of watered slopes of dumps formed from sand, and the increased volumes of mining reclamation.

The parameters of the second technological scheme of reclamation have been determined, in which rock from the non-watered part of the quarry slope is excavated and moved outside the quarry to create a beach zone of specified parameters. When applying the second scheme, increasing the area of the coastal strip from 0.5 to 1.0 ha leads to an increase in the volume of reclamation works to 392,000–496,000 m3, depending on the type of rocks from which the quarry side is formed.

The reclamation work cost when using the second technological scheme in the conditions of hard rock development is 43.3 million UAH, which is 3.4–4.3 times more than when developing sand or loam. The highest costs when using the second scheme are 86.8 million UAH when constructing a coastal strip with an area of 1.0 ha. The costs under this scheme when developing rock will be 3.6–4.3 times more than when developing loam, depending on the height of the non-watered part of the quarry slope.

The established dependencies allow for assessing the choice of technological schemes for reclamation in the presence of parameters of the watered residual space, rocks from which the non-watered pit slope is formed, and available volumes of waste rocks near the pit being reclaimed.

## Conflict of interest

Authors state no conflict of interest.

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## ТЕХНІКО-ЕКОНОМІЧНА ОЦІНКА ТЕХНОЛОГІЧНИХ СХЕМ РЕКУЛЬТИВАЦІЇ ОБВОДНЕНИХ ВИРОБЛЕНИХ ПРОСТОРІВ КАР'ЄРІВ

*Ложніков О., Адамова В.*

**Анотація**. Метою роботи є встановлення ефективних технологічних схеми рекультивації при створенні берегової смуги в обводнених вироблених просторах кар'єру. Визначено вплив параметрів обводненого простору кар'єру на техніко-економічні показники рекультивації при створенні рекреаційної зони в обводненому виробленому просторі кар'єру. Встановлено вплив типу гірничих порід при формуванні берегової смуги завдяки насипу на техніко-економічні показники рекультивації. Визначено загальні витрати при застосуванні зазначеної технологічної схеми з використанням скельних порід, пісків і суглинків. Визначено, що використання пісків є найбільш витратним процесом через їх низьку стійкість при формуванні обводнених укосів відвалів і необхідністю збільшення об'ємів гірничотехнічної рекультивації. Визначено техніко-економічні показники технологічної схеми рекультивації, в якій порода з необводненої частини борта кар'єру екскавується і переміщується за межі кар'єру при створенні пляжної зони заданих параметрів. При застосуванні цієї схеми найменші витрати на рекультиваційні роботи визначено при розробці необводненої частини борта кар'єру, складеного з суглинистих порід. Встановлено залежності, що дозволяють оцінювати вибір технологічної схеми рекультивації за наявності параметрів обводненого виробленого простору, порід з яких сформовано необводнений борт кар'єру і доступних об'ємів відвальних порід поблизу кар'єру, які можуть бути задіяні при формуванні рекреаційної зони в обводненому виробленому просторі.

**Ключові слова**: кар'єр, обводнені вироблені простори, рекультивація, рекреаційна зона, берегова смуга, техніко-економічні показники