Substantiation the safety open pit wall parameters in the conditions of a reduced protective zone near State critical infrastructure

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Abstract. The research is focused on topical issues of determining the safe parameters of pit edges in the conditions of a reduced protective zone near a critical infrastructure facility. Considering the extraction of soft rocks that are prone to landslides and deformations, the permissible safe distances from the upper edge of the pit on the surface to the industrial infrastructure facility are determined and established. Based on the physical and mechanical properties of the rocks, the parameters of geomechanical models of the pit edges were developed and substantiated to study their stability and stress state in the conditions of the Eastern section of the Chabanivske clay deposit. A brief description of the deposit under study and its geological structure is given. Computer modeling was carried out to determine the safety factor, and changes in the stress state of the massif near the pit edge were determined by the finite element method. Taking into account the mining technology were determined the safe parameters of the pit edges. Safe distances from high-pressure pipelines of state importance are substantiated. A rational pit edge angle of 28 – 31 degrees is recommended, and the appropriate safety distance for the rocks of the Chabanivske deposit in the western section should be at least 95 m.

1 Introduction

Ukraine has a potent raw material base for the extraction of non-metallic minerals [1, 2]. The most representative of these include deposits where minerals are extracted to produce construction materials: granites, limestones, migmatites, syenites, gneisses, quartzites, sandstones, clays, and sands. They are the basis for enterprises of various capacities that are part of the ferrous and non-ferrous metallurgy, construction materials, and chemical

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industries. Among them, building materials quarries are the second largest in volume of production [3, 4]. They operate in many regions of the country. Most deposits of construction materials in Ukraine are mined to a depth of 10 to 150 m (to the bottom of the deposit, or the level of estimated balance reserves) [5 – 8]. Deposits of soft non-metallic minerals to produce construction materials are developed on average to a depth of 10 to 45 m, their depth is always limited by the thickness of the mineral layer, [9 – 11].

Non-metallic raw materials are a large group of minerals widely distributed in the Earth's crust and diverse in their properties [12]. Urbanization and intensive growth in residential, industrial, and road construction necessitate a steady increase in the extraction of construction materials and the need to rebuild residential and industrial infrastructure in the post-war period [13, 14].

Clay is one of the main minerals for construction, used to produce bricks and other building materials [15, 16]. The technology and main indicators of the development of these deposits are influenced by several factors:

a) spatial dimensions of the deposits (length, width). This factor depends on the transverse dimensions of the rock deposit or the quality of the exploration. The boundaries of deposits and their reserves are often determined not by natural conditions, but by requirements that depend on the production capacity of the projected enterprise, the capacity of the mineral, limitations on the capacity of overburden, etc. The size of the deposits is limited by the established conditions, the maximum thickness of the overburden, etc. [7, 17 – 19].

b) depth of proven mineral reserves. At the time of designing non-metallic mineral deposits, exploration was carried out to a depth of 15 to 150 m. The natural boundary of the explored part of the deposit based on its depth was often taken to be the water level in the river, especially when it is heavily filtered and created by an excessively large inflow of water [4, 20 – 22].

c) changes in the hydrogeological regime in adjacent settlements and agricultural lands located near the deposits. During the development of non-metallic mineral deposits, the highest water content is observed in areas of tectonic faults and weathering crust [4, 23, 24]. In undisturbed rock masses, water inflow is extremely low in such deposits [1, 25].

d) economic indicators of rational extraction of raw materials - the cost of extraction per 1 m^3, the level of profitability [8, 21, 26 – 29]. At present, the criteria that are crucial for establishing the rational depth of deposit development are divided into two categories: mining and technological and economic.

e) built-up areas near quarry fields and the presence of natural objects, which limits their spatial dimensions and leads to the loss of balanced mineral reserves. Limiting the size of the quarry on the surface is often caused by the presence of development zones and infrastructure, such as roads, high-voltage lines, buildings, and structures [6, 8, 27, 29]. According to [30], the sanitary protection zone (SPZ) for ore and non-metallic mining companies ranges from 100 to 1500 m, and the protection zone (PZ) for certain industrial infrastructure facilities ranges from 25 to 1500 m. It has significantly affected the reduction of the mining allotment boundaries, as quarries for the extraction of non-metallic raw materials to produce construction materials are mostly located near settlements [21, 29, 31 – 36].

Research [4, 21, 29, 30] has shown that a significant part of the above-mentioned deposits are located in the SPZ or the PZ. These limits the possibilities of developing these fields and causes loss of reserves. Table 1 shows the actual loss of balance sheet reserves and the reasons for their occurrence at some Ukrainian deposits producing raw materials to produce construction materials [4].

Thus, the factor of built-up area and the presence of natural objects near the quarry fields limits their spatial dimensions and causes the presence of exclusion zones from roads, high-voltage lines, buildings, and structures, such as rivers, resulting in loss of balance reserves reaching 90% of the approved reserves.

Considering their location with residential buildings, public buildings, green construction facilities, etc., which determines the size of the sanitary protection zone, a detailed registration was carried out for each group of basic (typical) non-metallic quarries. The results of the registration are given in references [8, 21, 29].

Table 1. Loss of balance reserves in protective zones at Ukrainian quarries.

Deposit	Restriction type	SPZ/PZ, m	Volume of loss of balance sheet reserves, thousand. m^3	Loss of inventory on the balance sheet, %
Mala-Kakhnovskyi	Infrastructure construction	300	2250	34
	river Dnipro	250	8764	
Liubymivske and Chaplynske granite deposits	power line	50	2822	10
Sofiivske gneiss deposit	river Ingul	100	905	18
	asphalted road	25	254	
Western section of the Chabanivske deposit of fire clay	oil pipeline	350	190.4	35.7
	gas pipeline	200	501,2	94

From the works [8, 21, 29, 31, 32] it can be concluded that more than 30% of all considered deposits subject to systematization are located near settlements (residential buildings, public buildings, facilities, etc.), i.e. within the existing SPZ and PZ.

Analyzing the data in Table 1, on the example of the Chabanivske deposit, we can observe the large loss of balance reserves of raw materials suitable to produce construction materials, which is due to the built-up area near the explored deposits. This problem can be solved by optimizing the field development parameters by justifying the safe parameters for setting the pit edge to the design position in terms of its proximity to infrastructure facilities. These provisions determine the relevance of developing technical solutions to justify the safe parameters of the pit edge in the conditions of a reduced protection zone near critical infrastructure of state importance. It will minimize the loss of minerals and ensure the rational use of subsoil.

The technology of mining operations should ensure minimal disturbance of areas and land fertility [33, 34], use of electrified and maximally environmentally friendly equipment [29, 35-37]; application of modern environmentally friendly methods of dust suppression and dust collection during production processes [38 – 40]; maximum use of the created quarry spaces, extraction of minerals [41 – 43]; reclamation and revitalization of lands disturbed by mining operations to the most environmentally acceptable landscapes and their recreation; and taking into account the development of clean high technologies in the development of deposits of various types of origin and technologies of their development [44 – 47].

Thus, the purpose of this work is to substantiate the safe parameters of the pit edge in the conditions of a reduced protective zone near the main gas and oil pipelines. To achieve this goal, the authors set and solved the following scientific and practical tasks:

– assess the mining and geological characteristics of the object of research, identify the main problem areas that may affect the efficiency of mining operations in the vicinity of main gas and oil pipelines;

– based on computer modeling, the parameters of changes in the safety factor of the pit edges depending on the mining and geological conditions were substantiated with further comparison with regulatory documents;

– safe distances from the top of the pit edge to the pipelines were determined, which is the basis for determining the impact of mining operations with a reduction in mineral loss.

2 Study area

The Chabanivske deposit is situated on the northern outskirts of Chabanivka village in Uzhhorod district, Zakarpattia region, 20 km northeast of the district and regional center of Uzhhorod (Fig.1) [48].

The geological structure of the deposit consists of undivided sand, gravel, and pebble deposits of the Onokska Suite and modern deposits, with light-colored clay deposits in the lower part of the deposit. The top mineral resource at the deposit is light-colored clay (from white to light cream), which is suitable to produce building materials [48].

The average geological section uncovered by the holes is presented as follows:

1. Soil and vegetation layer with a thickness of 0.2 – 0.3 m.
2. Yellow-brown clay, dense, viscous, plastic. The average thickness is 5 meters.
3. Light grey to white clay, dense, viscous, plastic, oily to the touch. The thickness is from 0.5 m to 14 m.
4. Variegated clay: yellow-brown to red with a slight admixture of sand. In the contact zone with pebble deposits, in some places, it is heavily sandy, turning into clayey sand. The thickness is up to 7 m.
5. Sand, gravel, and pebble deposits up to 5 meters thick.
6. Liparitic tuff, weathered to clayey state with fragments of less weathered tuff. The determined thickness is up to 0.5 m.

The clays of the Chabanivske deposit consist mainly of hydrochloride, montmorillonite, and kaolinite in their mineral composition. The clay may contain quartz, mica, illite, and other impurities.

Minerals are on average semi-acidic in terms of alumina content. The average silica content is 54.5%. Calcium oxides range from 0.1% to 0.28%, and magnesium from 0.1% to 0.5%. Coloring oxides: Fe_2O_3 – from 1.15% to 7.0%; TiO_2 – from 0.58% to 3.7%. The chemical composition of the raw material is quite suitable to produce coarse ceramics and building materials.

The physical and mechanical properties of the deposit rocks are shown in Table 2. The bulk weight of clays was determined in the field during pitting and made up 2.0 t/m^3 for both variegated and light-burned varieties.

Table 2. Physical and mechanical properties of rocks.

Type of rocks	Indicators		
	density, kN/m^3	cohesion, kN/m^2	internal friction angle, degree
QIV colourful clay	19.22	24.52	16
QIV light-burned clay	19.42	34.32	23
QIV white clay with sand	20.59	37.56	20
QII-III$_{on}$ Quartz, mica, clayey sand of fine to medium grain	18.04	21.38	28
QII-III$_{on}$ sand, gravel and pebble deposits with clay impurities	20.01	17.65	30
QII-III$_{on}$ weathered andesite tuff	23.54	18.63	34

In general, the clay raw material meets the requirements of regulatory documents and is suitable to produce solid and hollow ceramic bricks by plastic molding. The expected brick grade is between 100 and 175.

The Chabanivske deposit consists of two sites: eastern and western (Fig. 1). According to the special permit for subsoil use, the western part of the site covers 7.27 ha., the eastern part of the site – 8.63 ha, for a total of 15.9 ha. The mineral resource is fusible clay suitable to produce construction materials. The total volume of B+C_1 reserves is 2052 thousand m^3, including B – 633 thousand m^3; C_1 – 1419 thousand m^3.

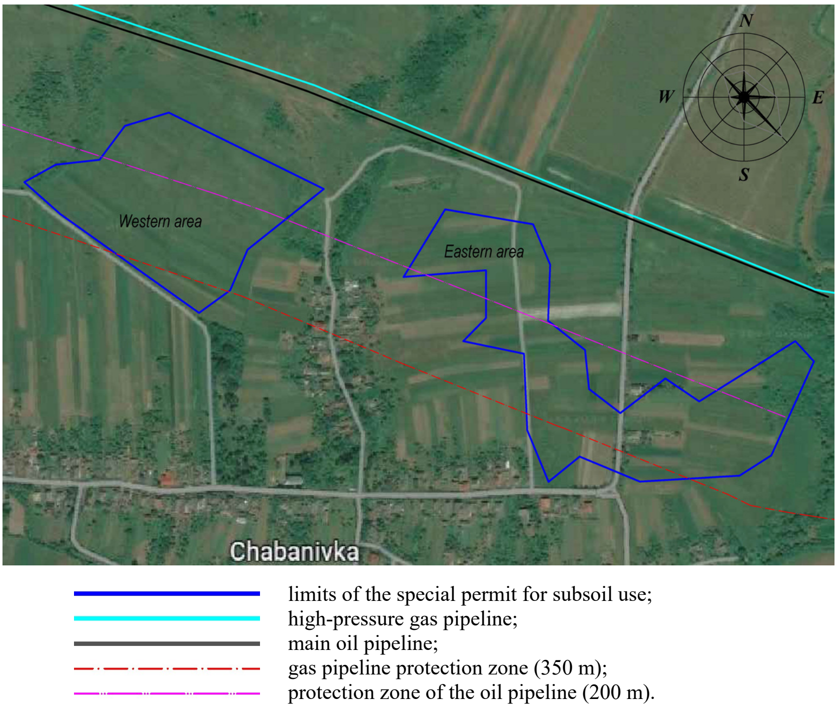

Fig. 1. Overview map of the deposit areas and infrastructure protection zones.

Fig. 1 shows an overview map of the location of the deposit areas and protection zones of the state infrastructure facilities (gas and oil pipelines). It should be noted that the presence of infrastructure facilities affects the indicators of mineral loss, which, in some cases, can reach 94% of the total balance sheet reserves (Table 1).

According to the State Sanitary Rules for Planning and Development of Settlements [49], the size of the protection zone may be reduced when calculations and laboratory tests conducted for the area where the enterprises or other production facilities are located show that there will be no negative impact on infrastructure [50].

In this case, a safety factor must be determined to ensure the stability of the pit edges. As a [51], a non-working pit edge composed of clay or fractured rocks may have a safety factor depending on the service life of the pit edges and slopes:

for slopes with a service life of up to 3 years – 1.2;

for slopes with a service life of 3 to 10 years – 1.25;

for slopes with a service life of more than 10 years – 1.3.

According to the State Construction Standards of Ukraine [30], engineering protection of the territory, buildings, and structures from hazardous geological processes should prevent emergencies and ensure:

– overall stability of facilities and territories under basic and emergency load combinations;

– normative medical and sanitary living conditions of the population, sanitary and hygienic, social, and recreational conditions of the protected area;

– reliable operation of infrastructure facilities located in these territories;

– protection of the environment, rational use of land and natural resources, and protected objects.

Taking into account the peculiarities of the geological structure of the deposit, mining, technical and hydrogeological conditions of the deposit development [48], the project envisages the development of the deposit by open-pit mining.

The design decisions on the development technology of the clay deposit under research were made taking into account the geological structure of the deposit and, hydrogeological and mining conditions of the deposit development. They are utterly consistent with the standards of technological design [51, 52] and the Rules of Labour Protection during the Development of Mineral Deposits by Open-Pit Mining [53]:

– overburden rocks, which are represented only by soil and vegetation layer rocks, will be mined using the mining transport system with the use of cyclic equipment (bulldozer, hydraulic excavator, loader, motor vehicles) [54]. At the initial stage of the open pit operation, the topsoil will be stored separately in a temporary warehouse located near or within the licensed area of the deposit [55]. Subsequently, the rocks will be used for reclamation of the pit edges as the deposit is developed;

– the mineral, represented by light-burning clays ranging in thickness from 0.5 m to 14.2 m with an average deposit thickness of 5.35 m, and variegated clays ranging in thickness from 1.9 m to 15.9 m with an average deposit thickness of 6.54 m, will be mined using a transport system with cyclic equipment (bulldozer, hydraulic excavator, and motor vehicles).

The following mining mechanization systems are used in the development of the deposit: SEM 816 bulldozer, CAT 330 D2L hydraulic excavator, SEM 656B front loader, IVECO TRAKER, and RENAULT K440 P84 dump trucks.

3 Materials and method

To substantiate the stability of the slopes of the pit edges, the project calculated the stability of the pit edges. Determined safe distances from the upper edge of the pit edge slope to the curved sliding surface [55]. By the geological, hydrogeological conditions of deposits, and physical, and mechanical properties of the rocks (Table 3), which consist of the pit edges, the safety factor was calculated.

Table 3. Physical and mechanical properties of rocks of the Chabanivske deposit.

Type of rocks	Names of indicators	Indicators	Notation, kN/m²
QIV colourful clay	Cohesion, t/m²	2.5	24.52
	Internal friction angle, degree	16	–
	Density, t/m³	1.96	19.22
QIV light-burned clay	Cohesion, t/m²	3.5	34.32
	Internal friction angle, degree	23	–
	Density, t/m³	1.98	19.42
QIV white clay with sand	Cohesion, t/m²	3.83	37.56
	Internal friction angle, degree	20	–
	Density, t/m³	2.10	20.59
$QII\text{-}III_{on}$ Quartz, mica, clayey sand of fine to medium grain	Cohesion, t/m²	2.18	21.38
	Internal friction angle, degree	28	–
	Density, t/m³	1.84	18.04
$QII\text{-}III_{on}$ sand, gravel and pebble deposits with clay impurities	Cohesion, t/m²	1.8	17.65
	Internal friction angle, degree	30	–

To justify the stability of slopes and areas of possible impact of mine workings, it is necessary to determine the sliding surface and the width of the prism of possible slide on the ground. One or two detailed engineering and geological sections are constructed along each homogeneous section crosswise to the slope. The section shows the position of the surface of the pit edge and the position, of the most stressed surface. Then, layers or groups of rock layers characterized by shear resistance (angle of internal friction and cohesion) are identified.

The methods recommended for determining the parameters of the pit edges, benches, and slopes are based on the theory of limit equilibrium of rocks. The assumptions on which the calculation methods are based are as follows:

a) the stability of the side (bench or slope of the dump) is disturbed in the form of collapse or slippage of the rocks that form the pit edge along the sliding surface;

b) in the absence of unfavorably located rock weakening surfaces in the slope, the sliding surface is monotonous, close in shape to a circular-cylindrical surface; in a section, the sliding surface will look like a smooth curved line close in appearance to the arc of a circle.

The stability of pit edges is determined by a complex of engineering, geological, hydrogeological, and technological factors, among which the following indicators have the greatest impact on the stability of the edges: strength, layering, and fracturing of rocks, their susceptibility to weathering, swelling and creep, as well as tectonic faults and hydrogeological conditions, such as waterlogging of rocks and the position of the groundwater level in the nearside of the massif.

The engineering, geological, and hydrogeological factors affecting the stability of the pit edges were taken based on the mining and geological conditions of the deposit development and the physical and mechanical properties of the containing rocks.

The stability was calculated using transverse geological sections I – I, and II – II (Fig. 3) with the boundaries of all lithological rock types and the profile of the idle pit edge. According to geological data, the deposit is not watered. The geological cross-sections show rock layers characterized by shear resistance (ρ and k).

The required safety factor n is added to the shear resistance characteristics along the layer contacts and other weakening surfaces, and the design characteristics k_n, k'_n, ρ_n, and ρ'_n are determined (for slopes with a service life of more than 10 years, n = 1.3):

$$k_n = \frac{k_{ev}}{n}; \quad k'_n = \frac{k'}{n}; \quad tg\rho_n = \frac{tg\rho_{ev}}{n}; \quad tg\rho'_n = \frac{tg\rho'}{n}, \text{ MPa}, \tag{1}$$

where k_n is the cohesion (calculated value), changed by the value of the safety factor, t/m^2; ρ is the angle of internal friction of rocks, deg; ρ' is the angle of internal friction along the contacts of weakened surfaces of the massif, deg; ρ_n is the angle of internal friction (calculated value), changed by the value of the safety factor, deg.

Further calculations of the slope parameters are carried out according to these modified characteristics under the condition of limit equilibrium.

The value of the safety factor of pit sides, slopes of benches, and dumps is set depending on the reliability of the initial mechanical characteristics, as well as their variability over time (including due to creep).

The sliding surface of the prism of possible displacement has a smooth curved shape close to a round cylindrical shape. The location of the most stressed surface in the rock mass adjacent to the slope coincides with the location of the design surface with the minimum safety factor. This surface was found by determining the center and radius.

The calculations were obtained on a computer using the Slide software and Phase2 software. The calculations were made by manual and automatic mode to find the most stressed (weak) sliding surface over several calculated sliding surfaces. As a result, a set of sliding surfaces was received from the calculated engineering and geological sections, which were used to determine K_y (safety factor). The sliding surface with the lowest K_y

value is potentially hazardous.

The Phase2 program, designed specifically for solving geotechnical problems, is a two-dimensional analysis with elastic and elastic-plastic formulation using the strength reduction method. The strength reduction method is characterized by a strength reduction factor, which is equivalent to the slope safety factor. The calculation of the strength reduction factor is based on the repeated recalculation of the strength characteristics using stepwise loading of the massif model to its ultimate state, i.e., when the stresses caused on the slope reach the shear strength limit. When using the finite element method, the sliding surface is generated during the calculation.

The method of strength reduction is implemented in programs based on the finite element and finite difference methods (Plaxis8, GEO5, Phase2, FLAC). Fracture prediction is calculated by simultaneously reducing both shear strengths.

The essence of the Slide program is that a square is built in which the centers of the radii of the curved sliding surfaces are placed, then the program finds the coefficients for the curved surfaces according to all points of the centers and radii and indicates the lowest value. Therefore, to obtain stability, the operator must manually determine the coefficient. The horizontal scale (*X*) corresponds to the distances between the points of the slopes and platforms on the respective horizons. The vertical scale (*Y*) corresponds to the elevation of the respective horizons and quarry surfaces.

Thus, in automatic mode, or with all lines taken into account, it is possible to determine the slope stability, including on the surface.

When placing the side in the limited position, the main parameters of the development system are adopted in compliance with the "Norms of technological design" [51], "State Construction Standards" [57], and "Rules of labor protection during the development of mineral deposits by open-pit mining" [53].

According to the design standards, the slope angles of the benches and sides should not exceed a maximum:

– when mining overburden:
- working – 50º;
- non-working – 45º.

– when mining low-melting clays:
- working – 50º;
- non-working – 45º;

– natural slope angle (when placed in the limit position) – 35º.

The width of the safety berm between the benches in the limit position is 4 m:

$$b_{sb} = \frac{1}{3} \cdot 2 \cdot h_b, \tag{2}$$

where h_b is the height of a bench, m.

When the commercial reserves of the Western area are completely developed, the eastern and western areas will have the following view when the side is set to the limit position (Figs. 2 and 3). The resulting angles of the pit edges at total extraction of minerals are shown in Table 4.

Table 4. Resulting slope angle when placing the side in the designed position.

Area	North	East	South	West
Western	28º– 31º	28º– 31º	29º– 31º	23º– 29º

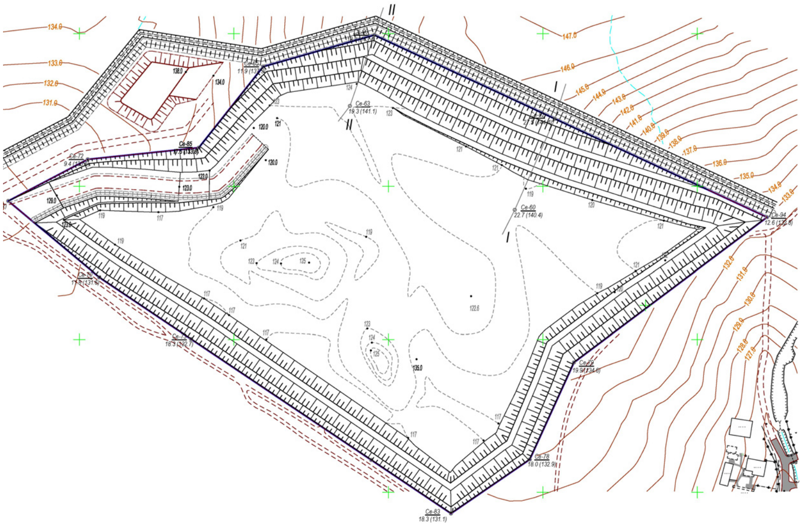

Fig. 2. The western area in the designed position.

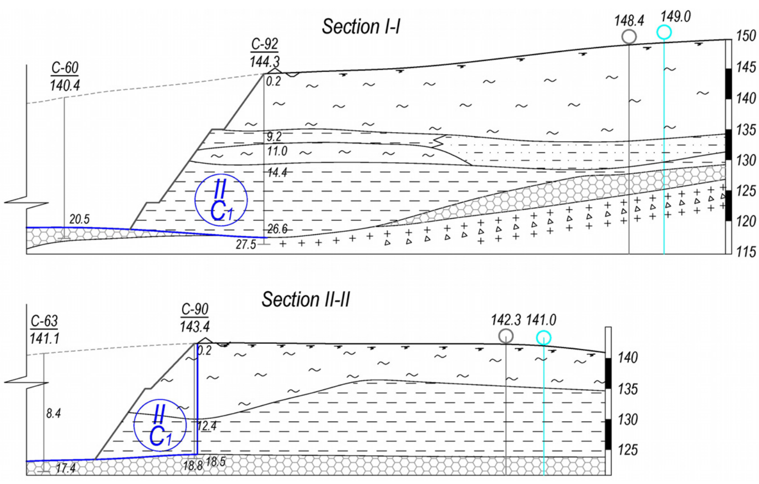

Fig. 3. Sections of the western area in the designed position.

4 Research results

The stability of the pit's idle edge along the pipeline protection zone was calculated based on the physical and mechanical properties of the rocks that comprise the idle pit edge. At the same time, it is planned to construct an upland drainage ditch along the pipeline protection zone to prevent soil erosion due to precipitation.

The basic data on the physical and mechanical properties of the rocks for the design scheme are given in Table 3. The top data for calculating the stability (safety) factor (K) and the safe distances from the upper edge (A) to the outlet of the circular cylindrical surface to the upper platform are given in Table 5. The calculations were performed in the software product using the Fillenius method, and the Phase2 program was used to determine the most unstable surfaces that could move. The calculations were carried out by the software in the mode of searching for safe distances with the determination of the stability factor and using limiting factors in the manual mode.

Table 5. Calculated values of slope safety factors in natural condition and with the added coefficient n = 1.3 and the distance along the surface of the prisms of possible displacement.

Sections	Natural state (Slide programme by Fillenius method)		With the added coefficient n = 1.3					
			Slide program by Fillenius method				Program Phase2	
	Automatic calculation		Automatic calculation		Found by searching		Automatic calculation	
	K_y	A	K_y	A	K_y	A	K_y	A
I	1.415	9.9	1.073	10.1	1.22	14.7	1.09	13.3
II	1.667	5.12	1.271	6.2	1.412	21.8	–	–

Notes: K_y – safety factor, A – distance from the top edge of the slope to the curved sliding surface intersecting the top platform.

Taking into account the obtained cross-sections and physical and mechanical properties of the rocks, the stability coefficients for sections I-I and II-II were determined using Slide and Phase2 software. The cross-sections are located along the northern edge of the pit (see Fig. 2).

The calculations were conducted for the current time, and the sediments represented by clays and loams have rheological properties (their physical and mechanical properties change downward over time). The rheology of the rocks and changes in their properties were taken into account by adding a safety factor of 1.3 to the design characteristics for idle pit edges with a service life of more than 10 years.

Fig. 4 shows a diagram for determining the safety factor for section I-I, and Fig. 5 shows a general picture of the stress distribution in section I-I, considering the safety factor n = 1.3.

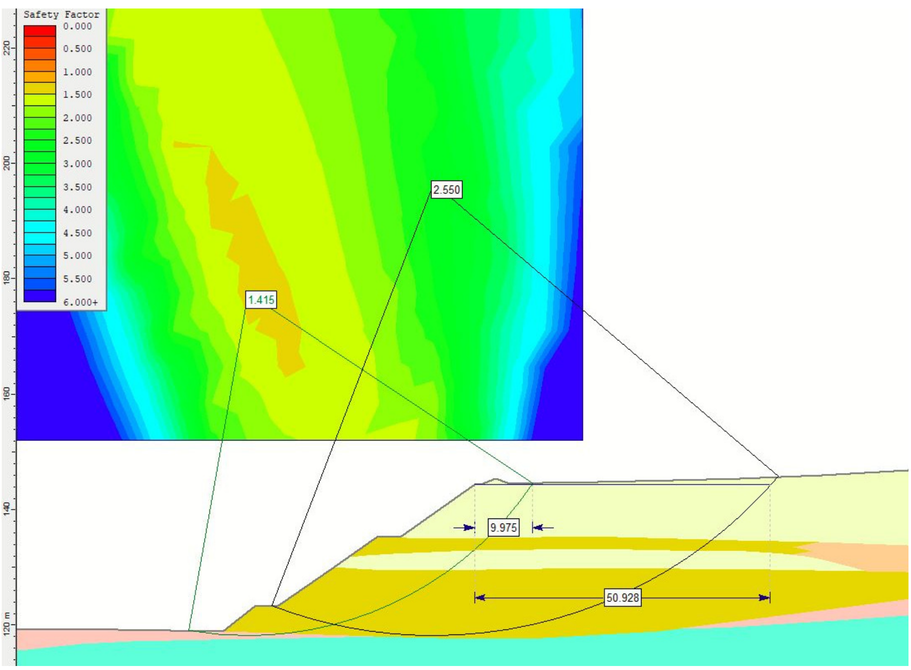

Fig. 4. Scheme for determining the safety factor for section I.

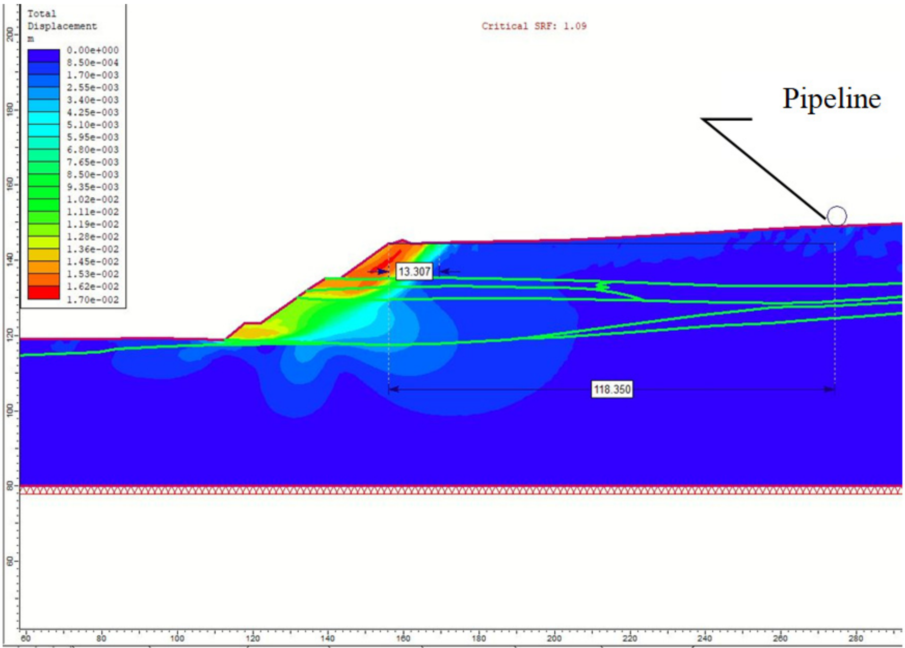

Fig. 5. Scheme of modeling the stress state of the slope in section I (with the addition of n = 1.3).

Fig. 6 shows the diagram for determining the safety factor for sections II-II, and Fig. 7 shows a general picture of stress distribution in sections II-II, taking into account the safety factor n = 1.3.

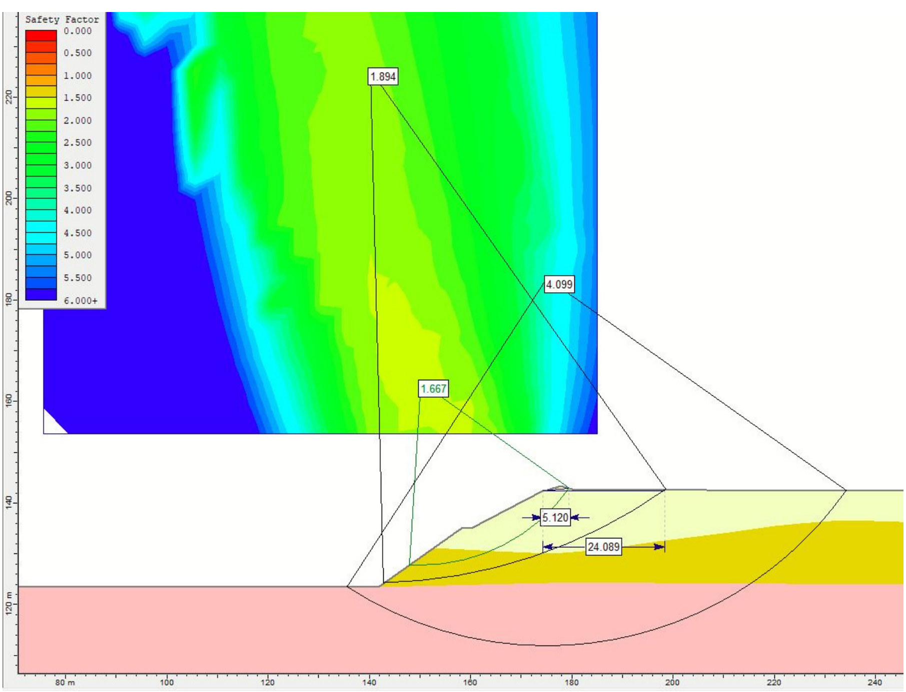

Fig. 6. Scheme for determining the safety factor for section II.

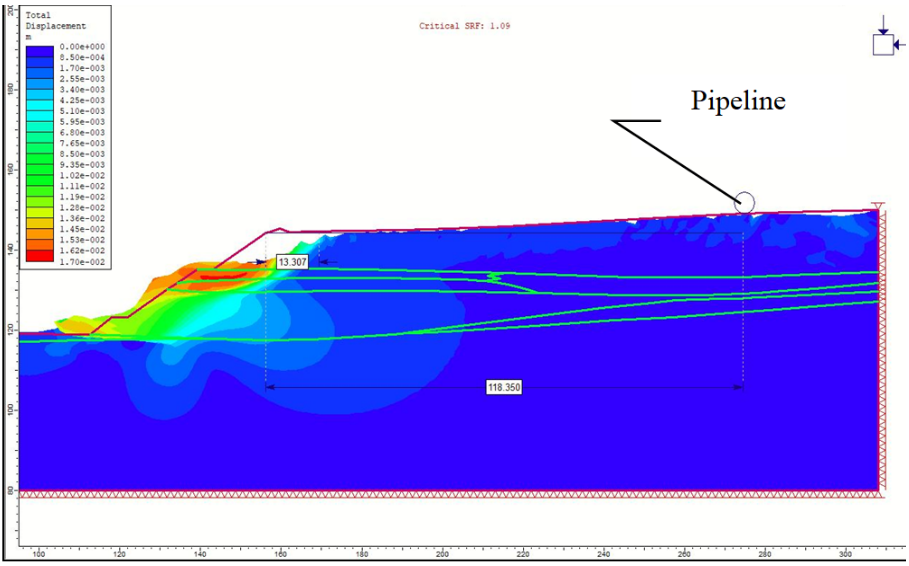

Fig. 7. Scheme of modeling the slope stress forces in section II (with added n = 1.3).

Analysis of the data in Figs. 4 and 5 in section I-I confirms the condition of stability of the slope of the pit edge. Namely, the safety factor is 1.22 with a service life of more than 10 years. The safe distance from the top edge of the slope is 14.7 m. The distance from the top edge of the pit to the pipeline is 118 m, so there will be no negative impact on the pipeline facilities.

The analysis of the data in Figs. 6 and 7 for sections II-II confirms the condition of stability of the pit edge slope. Namely, the stability coefficient is 1.271 for the side with a lifetime of more than 10 years. The safe distance from the top of the slope is 6.2 m. The distance from the upper edge of the pit to the pipeline is 101 m, so there will be no negative impact on the pipeline facilities.

Based on carried out the calculations, the estimated values of the slope stability factors in the natural state and with the added coefficient n = 1.3 were obtained. The distances along the surface of the prisms of possible displacement were also determined (see Table 5).

The analysis of the data in Table 5 indicates a high convergence of the obtained results in terms of the values of the slope stability factors and the distance along the surface of the prisms of possible displacement of 76 – 98%. This confirms the feasibility of the selected methods for substantiating the safe parameters of the pit edge in the conditions of a reduced protective zone near the main gas and oil pipelines.

5 Conclusions

As a result of the studies, safe distances from the top edge of the pit to state infrastructure facilities, such as the main gas and oil pipelines, were established. The safety factor of the pit edge from the side of pipelines is 1.22 to 1.271. At the same time, the distance from the top of the pit to the pipeline varies between 101 and 118 m. The studies conducted are the basis for reducing the loss of minerals and establishing the impact of mining operations on main gas and oil pipelines.

Analysing the above, it can be stated that the optimal safe parameters were used to justify the technology of placing the side in the limit position. The development of all balance reserves of minerals in the conditions of a reduced protection zone does not have a negative impact on the high-pressure gas pipeline. Based on the calculations, it is recommended to set the protective zone of the pipeline at 90 m.

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References

1. Pivnyak, G.G., Gumenik, I.L., Drebenshtedt, C., & Panasenko, A.I. (2011). *Nauchnye osnovy ratsyonalnogo prirodopolzovaniya pri otkrytoy razrabotke mestorozhdeniy*. Dnipropetrovsk, Ukraina: NMU, 568 s.
2. Dychkovskyi, R., Saik, P., Sala, D., & Cabana, E.C. (2024). The current state of the non-ore mineral deposits mining in the concept of the Ukraine reconstruction in the post-war period. *Mineral Economics*, 1-11. https://doi.org/10.1007/s13563-024-00436-z
3. Simonenko, V.I. (2004). *Razrabotka energosberegayushchey tekhnologii dobychi skal'nykh nerudnykh poleznykh iskopaemykh Ukrainy*. PhD Thesis. Dnipropetrovsk, Ukraina: NGU.
4. Cherniaiev, O.V. (2021). *Obhruntuvannia hlybyny rozrobky nerudnykh rodovyshch skelnykh korysnykh kopalyn z vnutrishnim vidvaloutvorenniam*. PhD Thesis. Dnipro, Ukraina: NTU "Dniprovska politekhnika".
5. *State research and production enterprise "State information geological fund of Ukraine"*. (2017). Retrieved from http://geoinf.kiev.ua
6. Chernyaev, O.V. (2017). Systematization of the hard rock non-metallic mineral deposits for improvement of their mining technologies. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 11-17. http://ir.nmu.org.ua/handle/123456789/150684
7. Cherniaiev, O., Pavlychenko, A., Romanenko, O., & Vovk, Y. (2021). Substantiation of resource-saving technology when mining the deposits for the production of crushed-stone products. *Mining of Mineral Deposits*, *15*(4), 99-107. https://doi.org/10.33271/mining15.04.099
8. Symonenko, V.I. (2011). *Tekhnolohichni osnovy ekoloho- i enerhozberihaiuchoho vyrobnytstva pry vydobutku tverdoi nerudnoi syrovyny v mezhakh sanitarno-zakhysnykh zon.* Zvit DR 011U000532.
9. Bondarenko, A.O., Shustov, O.O., Pavlychenko, A.V., & Adamchuk, A.A. (2023). Substantiation of technological resource-saving conditions for the use of equipment in the sand deposit mining. *IOP Conference Series: Earth and Environmental Science*, (1269), 012024. https://doi.org/10.1088/1755-1315/1269/1/012024
10. Chebanov, M., Borys, S., & Mykhailo, P. (2024). Substantiating the rational parameters for a complicated non-transport system when mining low-thickness fireclay deposits. *IOP Conference Series: Earth and Environmental Science*, *1319*(1), 012001. https://doi.org/10.1088/1755-1315/1319/1/012001
11. Lozhnikov, O.V. (2021). *Tekhnolohichni osnovy kompleksnoho osvoiennia mineralnoi syrovyny pry rozrobtsi obvodnenykh rozsypnykh rodovyshch*. PhD Thesis. Dnipro, Ukraina: NTU "Dniprovska politekhnika".
12. Sobko, B., Lozhnikov, O., Levytskyi, V., & Skyba G. (2019). Conceptual development of the transition from drill and blast excavation to non-blasting methods for the preparation of mined rock in surface mining. *The Mining-Geology-Petroleum Engineering Bulletin*, 21-28, https://doi.org/10.17794/rgn.2019.3.3
13. Petlovanyi, M., Saik, P., Lozynskyi, V., Sai, K., & Cherniaiev, O. (2023). Substantiating and assessing the stability of the underground system parameters for the sawn limestone mining: Case study of the Nova Odesa deposit, Ukraine. *Inżynieria Mineralna*, *1*(51), 79-89. https://doi.org/10.29227/IM-2023-01-10

14. Medvedieva, O., Semenenko, Y., Blyuss, B., & Skosyriev, V. (2022). Justification of the hydro-mechanical systems operating modes, used for restoring accumulation capacity of tailings storages. *IOP Conference Series: Earth and Environmental Science*, (970), 012043. https://doi.org/10.1088/1755-1315/970/1/012043
15. Chepushtanova, T.A., Yulussov, S.B., Baigenzhenov, O.S., Khabiyev, A.T., Merkibayev, Y.S., & Mishra, B. (2024). Review of methods for processing ore vanadium-containing raw materials. *Engineering Journal of Satbayev University*, *146*(1), 15-22. https://doi.org/10.51301/ejsu.2024.i1.03
16. Yu, L., Zhang, Y., Liu, H., Shen, X., & Yang, J. (2024). Comprehensive utilization of blast furnace slag, municipal sludge and kaolin clay in building brick manufacture: crystalline transformation, morphology observation and property assessment. *Cement and Concrete Composites*, (145), 105337. https://doi.org/10.1016/j.cemconcomp.2023.105337
17. Sobko, B.Yu., Lozhnikov, O.V., Chebanov, M.O., & Vinivitin, D.V. (2022). Substantiation of the optimal parameters of the bench elements and slopes of iron ore pits. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 26-32. https://doi.org/10.33271/nvngu/2022-5/026
18. Saik, P., Cherniaiev, O., Anisimov, O., Dychkovskyi, R., & Adamchuk, A. (2023). Mining of non-metallic mineral deposits in the context of Ukraine's reconstruction in the war and post-war periods. *Mining of Mineral Deposits*, *17*(4), 91-102. https://doi.org/10.33271/mining17.04.091
19. Chebanov, M.O., Pcholkin, H.D., Makurin, A.A., & Lozhnikov, O.V. (2023). Substantiation of the technological parameters of bucket-wheel excavator forward trench when mining titanium deposits. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 5-11. https://doi.org/10.33271/nvngu/2023-6/005
20. Blyuss, B., Semenenko, Ye., Medvedieva, O., Kyrychko, S., & Karatayev, A. (2020). Parameters determination of hydromechanization technologies for the dumps development as technogenic deposits. *Mining of Mineral Deposits*, *14*(1), 51-61. https://doi.org/10.33271/mining14.01.051
21. Simonenko, V.I. (2016). *Rozrobka ekolohobezpechnykh tekhnolohii vedennia hirnychykh robit z urakhuvanniam potreb v likvidatsii ta konservatsii hirnychodobuvnykh pidpryiemstv*. Zvit DR 0115U002301.
22. Lozhnikov, O., Shustov, O., Chebanov, M., & Perkova, T. (2022). Methodological principles of the selection of a resource-saving technology while developing water-bearing placer deposits. *Mining of Mineral Deposits*, *16*(3), 115-122. https://doi.org/10.33271/mining16.03.115
23. *Rabochiy proekt razrabotki Mala-Kakhnovskogo mestorozhdeniya: vozobnovlenie gornykh rabot: Poyasnytelnaya zapiska*. (2014). Kyiv, Ukraina: Ukrheolohstrom, 127 s.
24. Bazaluk, O., Sadovenko, I., Zahrytsenko, A., Saik, P., Lozynskyi, V., & Dychkovskyi, R. (2021). Forecasting Underground Water Dynamics within the Technogenic Environment of a Mine Field: Case Study. *Sustainability*, *13*(13), 7161. https://doi.org/10.3390/su13137161
25. Cherniaiev, O., Anisimov, O., Saik, P., & Akimov, O. (2024). Theoretical substantiation of water inflow into the mined-out space of quarries mining hard-rock building materials. *IOP Conference Series: Earth and Environmental Science*, *1319*(1), 012002. https://doi.org/10.1088/1755-1315/1319/1/012004
26. Prokopenko, V.I., Cherep, A.Yu. & Pilova, D.P. (2021). Justification of methodical approach to mining and processing efficiency evaluation *Goryi Zhurnal*, (8), 39-44.
27. Symonenko, V., Hrytsenko, L., & Cherniaiev, O. (2016). Organization of non-metallic deposits development by steep excavation layers. *Mining of Mineral Deposits*, *10*(4), 68-73. https://doi.org/10.15407/mining10.04.068
28. Mnzool, M., Almujibah, H., Bakri, M., Gaafar, A., Elhassan, A.A.M., & Gomaa, E. (2024). Optimization of cycle time for loading and hauling trucks in open-pit mining. *Mining of Mineral Deposits*, *18*(1), 18-26. https://doi.org/10.33271/mining18.01.018
29. Symonenko, V.I. (2013). *Rozrobka tekhnolohichnykh, upravlinskykh rishen, normatyvnoi dokumentatsii, systemy ekolohichnoho monitorynhu shchodo pryrodookhoronnoi diialnosti hirnychykh pidpryiemstv*. Zvit DR 0112U000875.

30. *Pro zatverdzhennia Derzhavnykh sanitarnykh pravyl planuvannia ta zabudovy naselenykh punktiv*. (1996). Nakaz No. 173. Kyiv, Ukraina: Ministerstvo okhorony zdorovia Ukrainy.
31. Symonenko, V.I., Pavlychenko, A.V., Anisimov, O.O., Bondarenko, A.O., Cherniaiev, O.V., & Hrytsenko, L.S. (2022). *Tekhnolohiia ekolohobezpechnoi vidkrytoi rozrobky nerudnykh rodovyshch tverdykh korysnykh kopalyn*. Dnipro, Ukraina: Zhurfond, 365 s. Retrieved from https://ir.nmu.org.ua/handle/123456789/161914
32. Symonenko, V.I., Pavlychenko, A.V., Cherniaiev, O.V., & Hrytsenko, L.S. (2015). Ekolohichni aspekty rozrobky rodovyshch nerudnykh korysnykh kopalyn v umovakh zmenshenoi sanitarno-zakhysnoi zony. In *"Aktualni problemy naukovo-promyslovoho kompleksu rehioniv"* (pp. 175-178). Rubizhne, Ukraina: Instytut khimichnykh tekhnolohii SNU im. V. Dalia.
33. Bazaluk, O., Kuchyn, O., Saik, P., Soltabayeva, S., Brui, H., Lozynskyi, V., & Cherniaiev, O. (2023). Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline. *Scientific Reports*, (13), 19327. https://doi.org/10.1038/s41598-023-46814-5
34. Medianyk, V., & Cherniaiev, O. (2018). Technological aspects of technogenic disturbance liquidation in the areas of coal-gas deposits development. *E3S Web of Conferences*, (60), 00037. https://doi.org/10.1051/e3sconf/20186000037
35. Symonenko, V.I., Pavlychenko, A.V., Cherniaiev, O.V., & Hrytsenko, L.S. (2015). Ecology saving technology of mineral deposit mining in the conditions of the sanitary protection zone. *Mining of Mineral Deposits*, *9*(4), 469-476. https://doi.org/10.15407/mining09.04.469
36. Simonenko, V., Pavlychenko, A., & Cherniaiev, O. (2018). Assessment of the ecological efficiency of the open development of non-metallic deposits of useful minerals. *Technology audit and production reserves. Ecology and Environmental Technology*, *5*(*3*(43)), 11-17. https://doi.org/10.15587/2312-8372.2018.145602
37. Gumenik, I., Lozhnikov, O., & Maevskiy, A. (2012). Methodological principles of negative opencast mining influence increasing due to steady development. *Geomechanical Processes During Underground Mining – Proceedings of the School of Underground Mining*, 45-51. https://doi.org/10.1201/b13157-10
38. Cheberyachko, S., Cheberyachko, Y., Naumov, M., & Deryugin, O. (2022). Development of an algorithm for effective design of respirator half-masks and encapsulated particle filters. *International Journal of Occupational Safety and Ergonomics*, *28*(2), 1145-1159. https://doi.org/10.1080/10803548.2020.1869429
39. Bazaluk, O., Cheberiachko, S., Cheberiachko, Y., Deryugin, O., Lozynskyi, V., Knysh, I., Saik, P., & Naumov, M. (2021). Development of a Dust Respirator by Improving the Half Mask Frame Design. *International Journal of Environmental Research and Public Health*, *18*(10), 5482. https://doi.org/10.3390/ijerph18105482
40. Bazaluk, O., Ennan, A., Cheberiachko, S., Deryugin, O., Cheberiachko, Y., Saik, P., Lozynskyi, V., & Knysh, I. (2021). Research on Regularities of Cyclic Air Motion through a Respirator Filter. *Applied Sciences*, *11*(7), 3157. https://doi.org/10.3390/app11073157
41. Saik, P., Cherniaiev, O., Anisimov, O., & Rysbekov, K. (2023). Substantiation of the direction for mining operations that develop under conditions of shear processes caused by hydrostatic pressure. *Sustainability*, *15*(22), 15690. https://doi.org/10.3390/su152215690.
42. Shustov, O.O., Haddad, J.S., Adamchuk, A.A., Rastsvietaiev, V.O., & Cherniaiev, O.V. (2019). Improving the construction of mechanized complexes for reloading points while developing deep open pits. *Journal of Mining Science*, *55*(6), 946-953. https://doi.org/10.1134/s1062739119066332.
43. Anisimov, O., Symonenko, V., Cherniaiev, O., & Shustov, O. (2018). Formation of safety conditions for development of deposits by open mining. *E3S Web of Conferences*, (60), 00016. https://doi.org/10.1051/e3sconf/20186000016
44. Saik, P.B., Dychkovskyi, R.O., Lozynskyi, V.H., Malanchuk, Z.R., & Malanchuk, Ye.Z. (2016). Revisiting the underground gasification of coal reserves from contiguous seams. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 60-66.

45. Semenenko, Ye., Medvedieva, O., Medianyk, V., Bluyss, B., & Khaminich, O. (2023). Research into the pressureless flow in hydrotechnical systems at mining enterprises. *Mining of Mineral Deposits*, *17*(1), 28-34. https://doi.org/10.33271/mining17.01.028
46. Semenenko, Y., Medvedieva, O., Medyanyk, V., & Buketov, V. (2023). Study of parameters and regimes of pressureless flow in a channel with overboard overflow. *IOP Conference Series: Earth and Environmental Science*, (1156), 012030. https://doi.org/10.1088/1755-1315/1156/1/012030
47. Medvedieva, O., Lapshyn, Y., Koval, N., Zeynullin, A., & Gupalo, O. (2020). The resource-saving technology to restore the accumulation ability of tailing ponds. *E3S Web of Conferences*, (168), 00054. https://doi.org/10.1051/e3sconf/202016800054
48. *Robochyi proiekt rozrobky ta rekultyvatsii Chabanivskoi dilianky Chabanivskoho rodovyshcha hlyn*: *Poiasniuvalna zapyska.* (2023). Dnipro, Ukraina: NTU "Dniprovska politekhnika", Instytut z proiektuvannia hirnychykh pidpryiemstv, 212 s.
49. DSP 173-96. (1996). *Derzhavni sanitarni pravyla planuvannia ta zabudovy naselenykh punktiv*. Kyiv, Ukraina: Ministerstvo okhorony zdorovia.
50. Kamiński, P., Dyczko, A., & Prostański, D. (2021). Virtual Simulations of a New Construction of the Artificial Shaft Bottom (Shaft Safety Platform) for Use in Mine Shafts. *Energies*, *14*(8), 2110. https://doi.org/10.3390/en14082110
51. SOU-N MPP 73.020-078-1:2007. (2007). *Normy tekhnolohichnoho proiektuvannia hirnychodobuvnykh pidpryiemstv iz vidkrytym sposobom rozrobky rodovyshch korysnykh kopalyn. Nastanova ministerstva promyslovoi polityky Ukrainy*. Kyiv, Ukraina: Ministerstvo promyslovoi polityky Ukrainy.
52. *Normy tekhnolohichnoho proiektuvannia pidpryiemstv promyslovosti nerudnykh budivelnykh pidpryiemstv*. (1977). Budvydav, 366 s.
53. NPAOP 0.00-1.24-10. (2010). *Pravyla okhorony pratsi pid chas rozrobky rodovyshch korysnykh kopalyn vidkrytym sposobom*. Kyiv, Ukraina: Derzhavnyi komitet Ukrainy z promyslovoi bezpeky, okhorony pratsi ta hirnychoho nahliadu.
54. Bondarenko, A., Shustov, O., & Adamchuk, A. (2023). Studying the interaction process of a solid particles flow with the hydraulic classifier flowing part. *IOP Conference Series: Earth and Environmental Science*, *1254*(1), 012047. https://doi.org/10.1088/1755-1315/1254/1/012047
55. Dyczko, A. (2007). Thin Coal Seams, Their Role in the Reserve Base of Poland. *Technical, Technological and Economical Aspects of Thin-Seams Coal Mining, International Mining Forum*, 2007, 81-87. https://doi.org/10.1201/noe0415436700.ch10
56. Bazaluk, O., Anisimov, O., Saik, P, Lozynskyi, V., Akimov, O., & Hrytsenko, L. (2023). Determining the Safe Distance for Mining Equipment Operation When Forming an Internal Dump in a Deep Open Pit. *Sustainability*, *15*(7), 5912. https://doi.org/10.3390/su15075912
57. DBN V.1.1-24:2009. (2010). *Zakhyst vid nebezpechnykh heolohichnykh protsesiv, shkidlyvykh ekspluatatsiinykh vplyviv, vid pozhezhi. Osnovni polozhennia proektuvannia.* Kyiv, Ukraina: Ministerstvo rehionalnoho rozvytku ta budivnytstva Ukrainy.