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Assessment of the impact of soil water saturation at the Malyshevske deposit on the stability of quarry structures

Abstract. A high groundwater level and significant wettability of ore sands at the Malyshevske deposit create substantial risks for the stability of foundations, base soils, and structures within the quarry field. The study of these factors is critically important for ensuring the safety and reliability of mining and construction facilities. The objective of the paper was to determine the physical and mechanical properties and to assess the influence of ore sands on the stability of foundations, base soils, and structures within the quarry zone of the Malyshevske deposit, as well as to develop recommendations for their stabilisation. A comprehensive set of research methods was applied, including hydrogeological, geophysical, hydraulic analyses, and mathematical calculations. The investigation of hydrogeological conditions was used to identify the groundwater level and its impact on structural stability. Testing of ore sands was conducted to determine their physical and mechanical characteristics, including permeability and filtration properties. Key factors affecting foundation stability in high moisture zones were identified. Recommendations were developed to increase the bearing capacity of base soils and foundations through drainage systems, soil injection stabilisation, and the use of special materials with low permeability. The actual average filtration coefficient of ore sands at the Malyshevske deposit was determined using the piezometric head method. For the first time in this region, integrated measures were proposed that include a combination of drainage and filtration systems to reduce groundwater levels, along with mathematical modelling to forecast the impact of these changes on the stability of quarry structures. The study has considerable practical significance for the design and operation of quarries under conditions of elevated groundwater levels and high soil moisture saturation. The proposed methods and measures allow for effective risk reduction associated with fluctuations in groundwater levels and ensure the stability of quarry structures, which in turn enhances the safety of mining operations and reduces maintenance costs for engineering facilities

Keywords: hydrogeology; groundwater; wettability; drainage; soil stabilisation; safety

Introduction

The stability of foundations and bases under complex hydrogeological conditions is a critically important factor for the safe operation of industrial and construction facilities within the quarry area. The high groundwater level and considerable wettability of ore sands at the Malyshevske deposit pose significant engineering challenges, directly affecting the reliability of structures and the safety of personnel working in the

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extraction zone. Deformation of water-saturated soils in an open-pit environment can lead to subsidence, uneven settlement of foundations, loss of bearing capacity of structures, and the development of landslide processes. This poses a threat both to the integrity of infrastructure and to the lives of workers located within the hazardous zone. Additional negative factors include atmospheric precipitation, the hydrodynamic impact of filtration flows, seismic loads, and seasonal fluctuations in the groundwater level, which may lead to uncontrolled deformations and emergency situations.

D. Babets *et al*. (2020) studied the impact of water saturation on the strength characteristics of sedimentary rocks. They found that increased moisture significantly reduces rock strength, which may cause deformation and failure of structures founded on such soils. This highlighted the importance of considering water saturation in the design of foundations and other engineering structures. H.N. Ngugi *et al*. (2021) examined the effect of soil moisture variation on deformation and differential settlement of frame structures in the Nairobi area. They concluded that moisture changes can lead to significant differential settlement, negatively affecting building stability and integrity. This study underlined the importance of moisture control in soils to ensure structural stability.

L. He *et al*. (2024) analysed the mechanisms of destabilisation and landslide prevention technologies in open-pit mines with soft interlayers under the influence of rainwater infiltration. They found that water infiltration into such layers significantly reduces their strength, which can result in landslides and collapses. The authors proposed a set of measures to improve slope stability, including drainage systems and soil reinforcement. V. Ivanov *et al*. (2020) studied the role of water in the stability of shallow landslides, based on experimental tests. They found that increased soil moisture reduces its strength and increases the risk of landslides. The researchers emphasised the need to consider hydrogeological conditions when assessing slope stability and designing engineering measures.

The researchers J. Ślusarek & M. Łupieżowiec (2020) analysed the influence of soil moisture on the stability of buildings situated on slopes. They concluded that increased moisture could lead to a reduction in soil strength and foundation deformation, negatively affecting the structural stability of buildings. The authors recommended the use of drainage systems and waterproofing to minimise the adverse effects of moisture. The scientists M. Maknoon & M. Aubertin (2021) studied the use of terracing to improve the stability of mine waste embankments. They found that the creation of terraces reduces the rate of water infiltration and enhances slope stability. This research highlights the importance of structural solutions for managing water saturation in mining dumps. The researchers Y. Abramov *et al*. (2022) conducted a study aimed at substantiating an experimental method for determining fluid percolation parameters in bulk materials. They identified key relationships between infiltration rate and the physical and mechanical characteristics of porous media. This study is valuable for assessing the water permeability of ore sands at the Malyshevske deposit, which is an important factor in evaluating the stability of quarry structure foundations.

The scientist T.K. Tokunaga (2020) proposed a simplified Green-Ampt model for assessing soil permeability and predicting infiltration processes. The researcher studied water filtration mechanisms in porous media and concluded that it is necessary to take capillary effects into account when modelling hydrogeological conditions. These findings can be applied to forecasting soil behaviour under quarry conditions with high moisture levels. The research by V. Oliinyk *et al*. (2022) was dedicated to developing a method for the experimental determination of water infiltration parameters in soil. The authors demonstrated that the structure of the pore space and the moisture content significantly affect the water penetration rate, which may be useful for evaluating potential risks of foundation base erosion under quarry conditions.

Thus, the analysis of scientific literature indicated that previous studies have mostly focused on the physicochemical properties of ore sand components, methods for their determination, and the influence of these characteristics on technological processes. Despite the considerable body of scientific research, the comprehensive impact of ore sand water saturation on the stability of quarry structures at the Malyshevske deposit remains insufficiently explored. Systematic studies that combine hydrogeological, mechanical, and mathematical aspects of structural stability forecasting are lacking. The issue of developing effective measures for stabilising foundations and bases under high moisture conditions remains particularly relevant. In this context, the aim of the study was to determine the physical and mechanical properties of ore sands and assess their influence on the stability of bases, foundations, and structures within the quarry zone of the Malyshevske deposit. As part of the study, recommendations were also developed for soil stabilisation and groundwater level reduction using drainage systems and specialised construction materials.

Literature Review

To assess the stability of structures under quarry conditions, it is necessary to consider the effects of soil water saturation, changes in their physical and mechanical properties, as well as environmental aspects associated with mining waste. Research in this area covers a wide range of issues, from soil mechanics and geotechnical fundamentals to slope stability analysis and long-term environmental risks. This review considered recent scientific studies that highlighted these aspects and are important for understanding the processes affecting the safety of construction and operation of engineering structures in mining regions.

M. Zotsenko *et al*. (2004), in their textbook on engineering geology, examined soil mechanics, the fundamentals of foundation and basement structure design. The authors provided a detailed analysis of the physical and mechanical properties of soils and their interaction with the surrounding environment. This work serves as an important theoretical basis for assessing the stability of building structures in areas with a high level of soil water saturation, particularly under mining conditions. Professor V. Suiarko (2019) investigated engineering geology and geotechnical fundamentals, focusing on the mechanical properties of soils, their stability, and their use in the design of foundations and structures. The author emphasised the importance of hydrogeological analysis to ensure the stability of geotechnical structures. This study is a valuable resource for assessing the impact of high groundwater levels on construction safety, which is directly related to the subject matter of this work. B. Vriens *et al*. (2020) underlined the importance of sustainable management of mining waste to prevent adverse hydrogeochemical processes that may affect the environment and soil stability. Their study also pointed to the necessity of monitoring and controlling emissions from waste as a vital aspect of mine safety. This research is significant as it provides an assessment of the impact of waste on soil stability and suggests measures to minimise negative consequences. B.O. Otunola & O.O. Ololade (2020) investigated the properties of clay minerals, which can significantly enhance the processes of removing heavy metals due to their adsorption characteristics. Their findings highlighted the importance of using clays for soil stabilisation and for reducing the concentration of pollutants in hydrogeochemical systems. This is particularly relevant in areas containing mining waste, where heavy metals may affect the ecological balance and the structural stability of constructions.

Y. Taha *et al*. (2021) studied the environmental behaviour of concrete produced using mining waste, in particular its ability to leach toxic elements. This research made it possible to assess the long-term environmental risks associated with the use of waste materials in construction, and the impact of such materials on infrastructure stability in mining regions, where soil stability is critically important for operational safety. G. Yang *et al*. (2023) examined the stability of slopes composed of water-sensitive shales under different moisture conditions. They noted that moisture significantly alters the physical and mechanical properties of soils, which can lead to landslides and slope failures. This study is essential for assessing the impact of meteorological factors, particularly precipitation, on quarry slope stability and the safety of mining operations.

L. Shu *et al*. (2024) emphasised that moisture significantly affects the mechanical properties of materials, particularly the strength of gas shales. Their study showed that fluctuating moisture conditions may result in a reduction in material strength, which is an important factor when assessing the stability of geotechnical structures. These findings are key to the subject of this research, as they help to determine the influence of moisture on the stability of soils and structures, especially under the high groundwater levels typical of mining environments. A general analysis of the literature indicated that the stability of soils and materials under mining conditions is largely influenced by moisture content, hydrogeochemical processes, and the use of mining waste in construction. All of these factors are critically important for ensuring the safety of mining operations, and the studies reviewed provide valuable data for managing risks, maintaining structural stability, and ensuring environmental safety in complex hydrogeological conditions.

Materials and Methods

The engineering protection of territories and buildings from natural hazards is regulated by normative documents, in particular DBN V.1.1-46:2017 (2017) and DBN A.2.2-1:2021 (2021), which include requirements for environmental impact assessment and the prevention of landslides and collapses. However, these regulations do not provide specific recommendations for ensuring the stability of foundations and structures under complex hydrogeological conditions, such as those found at the Malyshevske deposit, characterised by a high groundwater level. The Malyshevske titanium-zirconium ore deposit is located in an area of an active aquifer, and its geological structure includes highly permeable hydrophilic sands, which significantly complicates mining operations and necessitates detailed analysis of the stability of foundations and structures. Within the scope of this research, the physical and mechanical properties of ore sands and their hydraulic conductivity were analysed, allowing the assessment of the influence of groundwater on the stability of quarry slopes. A comprehensive approach was used, combining hydrogeological investigations, geophysical measurements, and experimental determination of water filtration parameters through ore sands.

To obtain reliable data on the hydraulic conductivity of the ore sands under investigation, experimental tests were conducted in a specialised laboratory of the Technical Control Department (TCD) at the Vilnohirsk Mining and Metallurgical Plant (MMP). The tests were carried out using one of the most widely applied methods – the hydraulic head analogy – which consists in measuring the time required for water to pass through a specific layer of ore sands.

According to the described methodology, the following stages were completed:

1. Sample preparation. The selected samples of ore sands were standardised by particle size and density.

2. Formation of a hydraulic system. Water was passed through the ore sand sample under hydrostatic pressure, implemented by creating a hydraulic head.

3. Measurement of filtration time. The time interval required for water to pass through the sample was recorded.

4. Calculation of hydraulic conductivity. The calculation was performed based on the obtained experimental data using a formula that takes into account the hydraulic radius and other parameters.

To calculate the hydraulic conductivity, Darcy's law was used, which describes the relationship between the velocity of fluid flow through a porous medium and the hydraulic pressure gradient. Darcy's formula is expressed as:

$$Q = -K \cdot A \cdot \left(\frac{dh}{dx}\right), \qquad (1)$$

where Q – fluid flow rate through the test section, m^3/s; K – hydraulic conductivity coefficient, m/s; A – cross-sectional area of the sample, m^2; $\frac{dh}{dx}$ –hydraulic pressure gradient.

The calculation was carried out for each sample, considering the different content of components in the ore sands. Since hydraulic conductivity depends on the size and shape of particles, porosity, and the presence of clay inclusions, all possible factors were taken into account in the calculations. Initial research data: water flow rate – l/s = m^3/s; cross-sectional area – m^2. To calculate hydraulic pressure based on the height of the water column, the following equation was used:

$$P = \rho g h, \text{ Pa}, \qquad (2)$$

where ρ – density of water, 1,000 kg/m^3; g – acceleration due to gravity, m/s^2; h – height of the water column, m.

Results

To ensure the uninterrupted operation of mining activities within the quarry, industrial and auxiliary structures are located, each performing an important technological or infrastructural function. The main facilities are listed in Table 1.

Table 1. *Industrial and auxiliary structures of the quarry*

Structure	Functionality
Crushing and screening complexes	Primary processing of extracted ore, ensuring continuation of the technological process
Conveyor and transport galleries	Efficient transfer of raw materials between key production units
Pumping stations	Drainage of mine and quarry water, prevention of its uncontrolled accumulation
Power infrastructure (substations, transformer units, power transmission lines)	Provision of stable power supply to all quarry facilities
Control rooms and maintenance facilities	Coordination of mining equipment operation and its technical maintenance
Storage facilities for various purposes	Safe storage of materials, including structural stability of foundations
Administrative and sanitary-domestic buildings	Creation of comfortable working conditions for personnel, operation of laboratories and control units

Notes: *the listed facilities are located within Quarry No. 7, whose raw material base is the Malyshevske placer deposit*
Source: *compiled by the author based on original research*

Each of these structures must comply with heightened requirements for stability and safety, taking into account the complex engineering and geological conditions of the quarry environment. Ensuring the reliability of these facilities under challenging geotechnical conditions is essential for minimising the risk of accidents and protecting the lives of personnel working within the quarry (Popov & Popova, 2022). Therefore, particular attention should be given to the development of effective measures for waterproofing, drainage, soil stabilisation, and deformation monitoring.

The Malyshevske deposit belongs to alluvial placers and is characterised by a complex stratigraphic structure that includes several main geological layers:

- quaternary deposits – loams, sandy loams, and sands that form the upper layer, with a thickness ranging from 3 to 15 m;
- neogene deposits – located beneath the Quaternary layer and composed of clayey sandstones, loams, and thin layers of clay. The thickness of this layer varies from 10 to 30 m;
- sarmatian sands – containing a high concentration of heavy minerals, including ilmenite, rutile, and zircon. This is the primary mining layer, with a thickness ranging from 5 to 25 m;
- precambrian crystalline rocks – comprising granites, gneisses, and quartzites that form the basement of the deposit. Due to their high density and low hydraulic conductivity, these rocks influence the formation of aquifers.

The structural features of the deposit determine the uneven distribution of ore sands and the variability of their physical and mechanical properties. A detailed understanding of the geological structure allows for optimisation of extraction activities and the development of measures to mitigate the impact of groundwater on slope stability, road washouts, and related hazards. One of the key factors influencing the stability of quarry slopes is the degree of water saturation in the rock mass and the dynamics of both underground and surface water. Figure 1 presents a diagram of the aquifer systems and the processes contributing to the waterlogging of the quarry field.

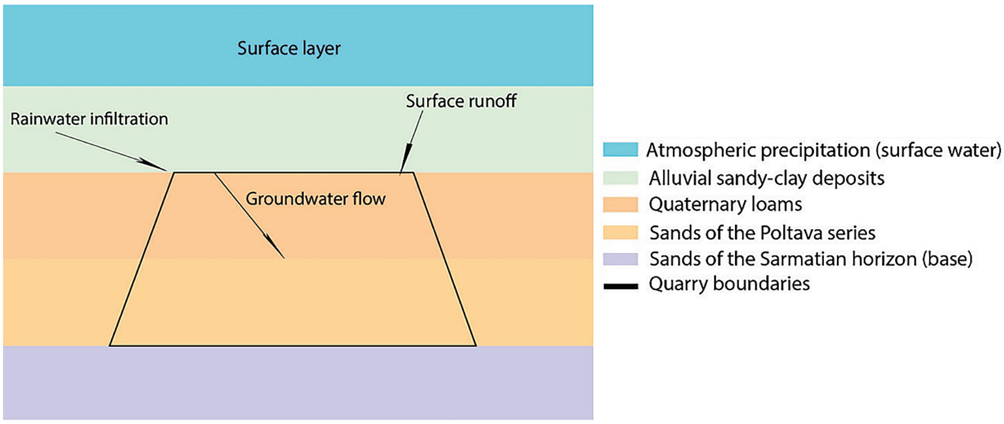

***Figure 1.** Schematic representation of aquifers and waterlogging of the quarry field*

***Notes:** the diagram illustrates the processes of quarry waterlogging, including surface runoff, rainwater infiltration, and subsurface flow. Colour coding indicates the main geological horizons that affect the hydrogeological conditions of the deposit*

***Source:** developed by the author based on hydrogeological studies by S. Vasylenko (2015)*

The waterlogging scheme illustrates the key hydrogeological processes that determine the operating conditions of the mining site. Figure 1 presents the following main factors:

1. Surface runoff – atmospheric precipitation falling on the quarry slopes, causing erosion processes, landslide formation, and increased load on the drainage system.
2. Rainwater infiltration – the penetration of precipitation into aquifers, which alters groundwater levels and increases the risk of flooding within the quarry space.
3. Subsurface flow – water movement through aquifers, which determines the saturation level of rock masses and, in turn, affects the stability of quarry slopes.

An analysis of the hydrogeological conditions of the Malyshevske deposit revealed a complex structure of aquifers that directly affect quarry operation and mine safety. It has been established that the groundwater level lies at a depth of 10-25 m from the surface and experiences seasonal fluctuations, rising in spring and falling in summer. At the same time, chemical analysis of groundwater indicated increased aggressiveness, particularly due to high concentrations of sulphates and chlorides, which cause corrosion of metal structures. A significant level of mineralisation (1.5-3.5 g/l) has also been identified, creating additional challenges for drainage and necessitating the implementation of water treatment technologies (Solodovnik & Yakymenko, 2021). The hydrogeological features of the deposit significantly influence the stability of rock masses. The high moisture content of the ore sands contributes to the development of landslides, and the softening of overburden rocks due to wetting complicates material transport and mining operations. Elevated moisture levels in the rock mass require constant water removal to maintain quarry slope stability.

Effective management of the quarry's water balance can be achieved through a combination of technical solutions. The use of drainage wells reduces groundwater levels and localises areas of excessive moisture, while open drainage ditches collect surface runoff and prevent flooding of operational zones. Filtration systems using sand and gravel materials contribute to water purification, improving drainage performance. Additional protection of production areas from infiltration is ensured by waterproofing barriers such as geomembranes and bentonite mats. The results obtained emphasise the need for an integrated approach to regulating the quarry's water regime. Implementing modern monitoring technologies and groundwater level control will not only improve the efficiency of developing the Malyshevske deposit but also minimise the risks associated with waterlogging processes. However, to ensure the stability of mining operations, it is essential not only to manage the water balance but also to assess the physical and mechanical properties of the rock masses, which determine their stability under changing hydrogeological conditions.

Investigating the strength, hardness, and other physical and mechanical parameters of the rock masses at the Malyshevske (Samotkanske) placer deposit of ilmenite-rutile-zircon sands makes it possible to evaluate their capacity to maintain structural integrity under saturation and mining-induced loads. Given the mineralogical composition of the ore sands, which includes quartz (on average 75%) and clay minerals (approximately 20%), as well as other heavy ore minerals such as leucoxenised ilmenite, leucoxene, rutile, zircon, kyanite-sillimanite, staurolite, tourmaline, and chromite, the main factors influencing their hydraulic conductivity can be identified. The general physical and mechanical characteristics of ore sands containing these minerals are presented in Table 2.

Table 2. *General overview of the physico-mechanical characteristics of ore sands, considering their composition and the content of major minerals*

Characteristic	Ore sands
Chemical composition	Quartz (SiO_2) – approximately 75%; clay minerals – around 20%; other heavy minerals (leucoxenised ilmenite, leucoxene, rutile, zircon, kyanite-sillimanite, staurolite, tourmaline, chromite) – remainder
Hardness (Mohs)	From 7 (quartz) to varying values for other minerals
Density (g/cm³)	Depends on sand composition, typically around 2.65 g/cm³ (as in quartz)
Colour and appearance	Varies from light brown to yellowish-white or red, depending on impurities and minerals; texture ranges from fine-grained to coarse-grained
Magnetic properties	Absent or very weak, although certain heavy minerals may exhibit magnetic behaviour

Notes: *the characteristic values may vary depending on the specific deposit and bedding conditions of the sands. The data are provided for typical samples with a dominant quartz content*

Source: *developed by the author based on laboratory studies and analysis of literature sources by V. Biletskyi (2004) and the US Geological Survey (2020)*

The composition of ore sands directly affects their strength, wear resistance, and technological properties. At the same time, an important aspect is not only the general characteristics of the ore mass, but also the properties of each type of mineral contained in the rock. Ilmenite ores, whose main component is $FeTiO_3$, exhibit high resistance to corrosion processes and are widely used in the production of titanium and its alloys, pigments, and abrasive materials. Rutile ores (TiO_2) are key sources of titanium compounds used in various industries, including pigment production, ceramics, and titanium alloys. Zircon ores containing $ZrSiO_4$ are applied in the manufacture of ceramics, glass, abrasives, and special alloys. For a deeper understanding of the differences between these types of ores and their mechanical behaviour, a comparative analysis of their physico-mechanical characteristics has been carried out, with the results presented in Table 3.

Table 3. *Comparative overview of the physico-mechanical characteristics of three different types of ores: ilmenite, rutile and zircon*

Characteristic	Ilmenite ore	Rutile ore	Zircon ore
Chemical composition	$FeTiO_3$	TiO_2	$ZrSiO_4$
Hardness (Mohs)	5-6	6-6.5	6.5-7
Density (g/cm³)	4.7-4.8	4.2-4.3	4.6-4.7
Color and appearance	variable, metallic lustre, crystalline or granular structure	black or dark brown, metallic lustre, crystalline structure	various colours, crystalline structure, metallic lustre
Fusibility	variable texture	variable texture	variable texture
Magnetism	magnetic	non-magnetic	non-magnetic

Notes: *the presented characteristics are average values for typical samples and may vary depending on the conditions of occurrence and metamorphic processes*

Source: *developed by the author based on laboratory analyses and geological research data by B. Sobko & M. Chebanov (2018)*

The physico-mechanical properties of ore sands largely determine the characteristics of their hydraulic transportation, the choice of technological equipment, and its service life. In calculations of hydraulic transport, such parameters are taken into account as the density of the material, its porosity, wettability, solubility, granulometric composition, grain shape, hydraulic coarseness, abrasiveness, and grindability during transportation. One of the key factors determining the hydraulic conductivity of ore sands is the quartz content, as this mineral has high permeability. With an increase in the proportion of quartz in the sands, their filtration capacity also increases. The filtration coefficient of quartz sands depends on the granulometric composition, degree of compaction, and other factors, and according to reference data, has the following average values:

- coarse-grained quartz sand: 10^{-2} – 10^{-3} m/s;
- medium-grained quartz sand: 10^{-3} – 10^{-4} m/s;
- fine-grained quartz sand: 10^{-4} – 10^{-5} m/s.

Clay minerals also significantly affect hydraulic conductivity, especially in cases of the formation of clayey inclusions, which reduce the porosity and permeability of the material. At the same time, other heavy ore minerals may possess different properties: some of them are permeable, while others considerably decrease the water conductivity of the environment. Overall, the hydraulic conductivity of ore sands is the result of the interaction of all these components, and its values can vary considerably depending on local conditions and the mineralogical composition of the material. This characteristic plays an important role in the mining and construction industries, as it determines the possibilities for effective water drainage, rock stability, and technological parameters of processing. Specialised testing methods are used for the precise determination of the hydraulic conductivity of ore sands, including the evaluation of the filtration coefficient and water permeability tests. Measurements are usually carried out in units of the filtration rate of liquid through the material, such as metres per day or centimetres per hour.

The calculated values of hydraulic pressure for each case (2), and the following values were obtained:

$$P_1 = 1{,}000 \cdot 9.81 \cdot 0.192 \approx 1{,}886.8 \text{ Pa};$$
$$P_2 = 1{,}000 \cdot 9.81 \cdot 0.182 \approx 1{,}785.7 \text{ Pa};$$
$$P_3 = 1{,}000 \cdot 9.81 \cdot 0.196 \approx 1{,}923.1 \text{ Pa};$$
$$P_4 = 1{,}000 \cdot 9.81 \cdot 0.185 \approx 1{,}818.2 \text{ Pa};$$
$$P_5 = 1{,}000 \cdot 9.81 \cdot 0.182 \approx 1{,}785.7 \text{ Pa}.$$

From formula (1), the hydraulic conductivity coefficient K is expressed through known parameters:

$$K = -\left(\frac{Q}{A}\right) \cdot \left(\frac{dx}{dh}\right). \quad (3)$$

The calculation is performed for each of the five samples, taking into account that each sample has a different component content:

$$K_1 = -\left(\frac{0.01}{1}\right) \cdot 1{,}886.79 = 5.3 \cdot 10^{-6} \text{ m/s};$$
$$K_2 = -\left(\frac{0.01}{1}\right) \cdot 1{,}785.71 = 5.6 \cdot 10^{-6} \text{ m/s};$$
$$K_3 = -\left(\frac{0.01}{1}\right) \cdot 1{,}923.08 = 5.2 \cdot 10^{-6} \text{ m/s};$$
$$K_4 = -\left(\frac{0.01}{1}\right) \cdot 1{,}818.18 = 5.5 \cdot 10^{-6} \text{ m/s};$$
$$K_5 = -\left(\frac{0.01}{1}\right) \cdot 1{,}785.71 = 5.6 \cdot 10^{-6} \text{ m/s}.$$

Since the filtration coefficient K is a positive quantity, its absolute value is taken into account. For the generalised analysis, the average value is calculated. The obtained result is converted into metres per day:

$$Kser = 5.44 \cdot 10^{-6} \cdot 86{,}400 = 0.47 \text{ m/day}. \quad (4)$$

The obtained average value $Kser$ = 0.47 m/day indicates the generalised rate of water filtration through the studied material and takes into account all conducted experiments. The study made it possible to obtain quantitative indicators of the hydraulic conductivity of the ore sands of the investigated site. The results can be used for further modelling of hydrodynamic processes in the deposit and optimisation of technological solutions during mining operations. The schematic of the experimental setup is shown in Figure 2.

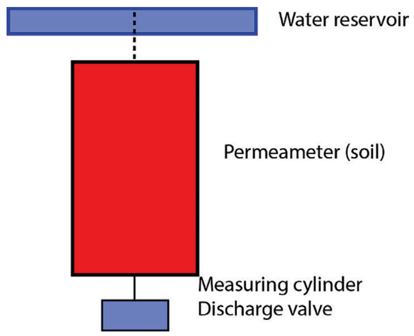

Figure 2. *Diagram of the experimental setup for testing soil permeability by the constant head method (Constant Head Permeability Test)*

Notes: *water reservoir – maintains a constant water level to support a stable gradient; permeameter (soil) – sample of the investigated soil through which water passes; measuring cylinder – used to collect filtrate and measure water volume; outlet valve – regulates water outflow and ensures controlled flow*

Source: *developed by the author based on the methodology for soil permeability testing*

The research results showed that the main safety risks in the quarry are associated with the high hydraulic conductivity of the ore sands, which leads to excessive saturation of the pit walls and can cause landslides. Increased water saturation of the rocks reduces their strength, affecting the stability of the slopes. Saturation of mining transport routes complicates the movement of equipment due to road erosion. The conducted studies of filtration coefficients for various ore sand samples allowed the determination of the average permeability of the rocks, which significantly affects drainage and water removal. Hydrogeological conditions are an important factor for mining safety. A high level of saturation causes a reduction in the bearing capacity of the rocks, which can lead to collapses. Water-saturated soils create problems for ore transportation and the operation of hydraulic monitors due to changes in water pressure.

To minimise the impact of saturation, it is necessary to apply drainage systems, control groundwater levels, and stabilise slopes to avoid critical changes in the quarry structure. High hydraulic conductivity promotes water penetration through ore sands, which requires additional water removal measures. In open-pit quarries, an effective water drainage system helps prevent flooding that could halt operations. Slope stability remains a critical factor, as water flows through porous layers can cause landslides and collapses. This is especially important for the development of ore sands, where soil stability is necessary for the safety of personnel and equipment. Increased moisture complicates material transportation and creates risks for quarry operations.

Saturation of the quarry working zones is caused by atmospheric precipitation and aquifers. The alluvial aquifer covers part of the deposit area but does not significantly affect the overall water inflow. The Quaternary aquifer is more widespread and can cause difficulties due to water-saturated clays, especially during the winter period. The Poltava aquifer overlies the ore sands, but its level remains stable.

As a result of saturation, the rocks become moist, complicating the operation of machinery, particularly in winter. Freezing of water-saturated ore sands on equipment increases energy consumption and requires frequent maintenance. Loss of slope stability due to moisture can cause landslides, posing danger to workers. The volumes of water inflow reach significant levels, necessitating systematic water removal. Moistening of working surfaces increases the risk of injuries, while landslides can damage equipment and communications. To reduce risks, a set of measures was proposed: installation of drainage systems to control water levels, soil reinforcement using cementation and silicatisation methods, application of geomaterials for sand stabilisation, and design of foundations with increased bearing area. This will contribute to improving work safety under complex hydrogeological conditions.

Discussion

The results of this study are consistent with the findings of previous research on the stability assessment of foundations and structures in complex hydrogeological conditions, particularly in mining environments. Several key studies have addressed similar issues, providing valuable insights into the influence of groundwater levels, soil permeability, and structural stability.

L.W. Abramson *et al.* (2001) conducted a comprehensive investigation of slope stability and stabilisation methods, emphasising the importance of groundwater management to prevent slope failures. Their study highlighted the role of appropriate drainage technologies, which corresponds with the conclusions of the present article, noting that a high groundwater level significantly affects the stability of foundations at mining sites such as the Malyshevske deposit. However, unlike the study by L.W. Abramson *et al.* (2001), which focused on general slope stabilisation methods, this study provided a more detailed specification of hydrogeological conditions and their impact on foundation stability. Y. Ait-khouia *et al.* (2023) studied sustainable management of mining waste through automated mineralogical and geochemical analysis. Their research demonstrated the importance of understanding the mineral composition of waste for assessing its geotechnical properties. The results obtained confirm their conclusions, as the analysis of the ore sands' composition and granulometric distribution played a key role in evaluating foundation stability. The main difference is that this study places greater emphasis on the impact of groundwater infiltration on these materials, rather than solely their composition.

Researchers B. Liu *et al.* (2020) investigated the effect of moisture on the mechanical and electrical characteristics of water-saturated sandstone during freezing. Their findings indicated that increased moisture content reduces material strength, making structures more prone to deformation. This observation aligns with the results obtained here, which show that higher moisture content in ore sands reduces foundation stability. However, whereas their study focused on frozen conditions, this study concentrates on variations in hydrogeological conditions throughout the year. O. Borziak *et al.* (2022) emphasised the importance of engineering-geological investigations for construction. They noted the necessity of detailed assessment of the physical and mechanical properties of soils and rocks prior to construction commencement. This study extended their conclusions by applying these principles to the conditions of the Malyshevske deposit, analysing the interaction between groundwater levels and soil stability in a high-moisture environment.

K. Guanira *et al.* (2020) proposed a methodological approach for the mineralogical characterisation of dumps from a skarn-type Cu (Au, Ag) deposit. Their work provided insights into the mineralogical properties influencing waste behaviour, which is similar to this study's investigation of ore sand composition. However, while their research predominantly focused on mineralogical characterisation for waste management, this study evaluated the impact of hydrogeological conditions on construction safety. N.N. Imam Robit *et al.* (2023) investigated the effect of moisture on the failure of bearing capacity in strip foundations on sandy loam soils. Their research demonstrated how increased moisture reduces soil strength, which corresponds with the results indicating that high groundwater levels adversely affect foundation stability. However, this study additionally incorporated hydrogeological monitoring and permeability testing to assess long-term risks to structures.

Researchers N. Saberi & B. Vriens (2024) studied the impact of moisture on the mineralogical and drainage properties of degrading mining waste. Their research demonstrated how changes in water saturation affect geotechnical properties over time, supporting the conclusions obtained here about the necessity of continuous groundwater monitoring to assess construction risks at mining sites. However, this study focused more on engineering solutions to mitigate these risks, whereas their research predominantly discusses mineralogical transformations. V. Shapoval *et al.* (2020) analysed slope stability considering excess pore water pressure. Their study emphasised the importance of accounting for excess pressure in geotechnical assessments, which was also considered in this study. However, unlike their work, which mainly concentrated on slope stability, this study extended the analysis to the stability of foundations under conditions of high groundwater levels.

D. Wang *et al*. (2022) investigated interactions between hydraulic fractures and natural fractures in mining conditions. Their research highlighted the role of hydraulic properties in determining fracture propagation, complementing the findings described here about groundwater flow through ore sands and its impact on structural stability. However, this study focused more on engineering measures needed to counteract these effects rather than on the fracture formation process itself. Scientists Y. Yao *et al*. (2025) presented a review of modern soil moisture monitoring technologies for slope stability assessment. Their research underlined the advantages of contemporary moisture monitoring systems for predicting slope failures, supporting the use of hydrogeological monitoring to evaluate seasonal groundwater fluctuations in this study. Although their study offered a broader overview of monitoring technologies, this study applied these concepts to a specific mining environment, emphasising their practical application in construction safety management.

In summary, the results of this study are consistent with the existing scientific literature regarding the impact of groundwater levels and soil moisture on the stability of foundations in mining conditions. The key contributions of this study include a detailed specific analysis of the Malyshevske deposit conditions, integration of hydrogeological monitoring with engineering assessments, and experimental evaluation of ore sands' permeability. These results highlighted the necessity of continuous monitoring and adaptive engineering solutions to ensure structural stability in highly moist mining environments.

Conclusions

The high groundwater level and significant moisture content of ore sands at the Malyshevske deposit present serious challenges to the stability of foundations, bases, and building structures. The presence of large amounts of water in the soil adversely affects the soil's bearing capacity, which can lead to increased settlements and create conditions for uneven structural deformations. This requires careful planning and the application of specific engineering solutions aimed at ensuring the long-term stability of structures.

One important aspect is the use of drainage systems that allow controlling the groundwater level and reducing its impact on structures. Additionally, to enhance foundation stability, it is advisable to apply geotechnical soil reinforcement and specialised foundation strengthening technologies capable of reducing the risks of deformation and destruction in the long term. It is equally important to consider dynamic loads and the impact of mining operations, as these factors can impose additional stresses on structures. The development of specialised foundation solutions that take these features into account is a necessary condition for ensuring the reliability of buildings under complex mining and geological conditions.

Thus, the application of comprehensive measures including drainage systems, soil reinforcement, and specialised foundation technologies is key to ensuring the stability and safety of structures at the Malyshevske deposit. Carefully planned engineering solutions can significantly reduce risks associated with adverse hydrogeological conditions and the impact of mining operations, thereby ensuring the reliability of structures over an extended period. The analysis of the physico-mechanical characteristics of ore sands confirmed their significant influence on mining safety. Hydraulic conductivity and moisture content are key risk factors that must be considered during the planning and operation of the quarry. Further research should be directed towards developing innovative methods for monitoring the condition of the quarry field and improving worker safety.

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Conflict of Interest

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Оцінка впливу водонасичення ґрунтів Малишевського родовища на стійкість конструкцій кар’єру

Анотація. Високий рівень ґрунтових вод і значна змочуваність рудних пісків Малишівського родовища створюють значні ризики для стійкості основ, фундаментів та конструкцій на кар'єрному полі. Дослідження цих факторів є критично важливим для забезпечення безпеки та надійності гірничих і будівельних споруд. Метою роботи було визначення фізико-механічних властивостей та оцінка впливу рудних пісків на стійкість основ, фундаментів і конструкцій у зоні кар’єру Малишевського родовища, а також розробка рекомендацій щодо їх стабілізації. У роботі застосовано комплекс різноманітних методів дослідження, зокрема гідрогеологічні, геофізичні, гідравлічні, та математичні розрахунки. Використано дослідження гідрогеологічних умов для визначення рівня ґрунтових вод та їхнього впливу на стабільність конструкцій. Здійснено випробування рудних пісків для визначення їх фізико-механічних характеристик, зокрема водопроникності та фільтраційних властивостей. Встановлено ключові фактори, що впливають на стабільність фундаментів у зонах підвищеної вологості. Розроблено рекомендації щодо підвищення несучої здатності основ і фундаментів за допомогою дренажних систем, ін’єкційного зміцнення ґрунтів та використання спеціальних матеріалів з низькою водопроникністю. Визначено фактичне середнє значення коефіцієнта фільтрації рудних пісків Малишевського родовища за допомогою методики водонапірного стовпа. Вперше для даного регіону запропоновано інтегровані заходи, що включають комбінацію дренажних і фільтраційних систем для зниження рівня ґрунтових вод, а також математичне моделювання для прогнозування впливу цих змін на стабільність конструкцій кар’єра. Робота має значну практичну значимість для проектування та експлуатації кар'єрів в умовах підвищеного рівня ґрунтових вод та високої вологонасиченості ґрунтів. Запропоновані методи і заходи дозволяють ефективно знижувати ризики, пов'язані зі зміною рівня ґрунтових вод, і забезпечити стабільність кар’єрних конструкцій, що в свою чергу дозволить підвищити безпеку гірничих робіт та знизити витрати на обслуговування інженерних споруд

Ключові слова: гідрогеологія; ґрунтові води; змочуваність; дренаж; стабілізація ґрунтів; безпека