

WATER EFFECT ON THE ROCKS AND MINE ROADWAYS STABILITY**¹Slashchova O.A.**¹*Institute of Geotechnical Mechanics named by N. Poliakov NAS of Ukraine***ВПЛИВ ВОДИ НА СТІЙКІСТЬ ПОРІД І ГІРНИЧИХ ВИРОБОК****¹Слащова О.А.**¹*Інститут геотехнічної механіки ім. М.С. Полякова НАН України***ВЛИЯНИЕ ВОДЫ НА УСТОЙЧИВОСТЬ ПОРОД И ГОРНЫХ ВЫРАБОТОК****¹Слащева Е.А.**¹*Інститут геотехнической механики им. Н.С. Полякова НАН Украины*

Annotation. The article is devoted to solving of a live scientific problem of improving methods for predicting stability of mine roadways under mining-and-geological conditions of the rock watering. Research methods: analysis of experimental data on assessing state of water-saturated rock massif; statistical processing of laboratory research results on the strength properties of rock samples; mathematical modeling of the rock massif stress-strain state by the finite element method; mine studies of deformations of water-saturated rocks. Specific effect of water on the rock strength properties was investigated. The generalized correlation dependences of the strength reduction of sandstones, mudstones and siltstones at their saturation with water relatively to their initial strength in natural state were obtained. By method of mathematical modeling, regularity of changes in the stress-strain state of the rock massif depending on rate of preparatory roadway watering were established and confirmed by the mine observations. The correlations were proposed for calculating probable water inflows into the mine roadways basing on the assessment of volume of broken elements in the geomechanical model, parameters of open porosity and fracturing. Nature of deformation of water-saturated rocks in the roof, walls and floor of the mine roadway was determined. It is established that intense deformations starts in the drift walls and manifest themselves in the form of weak rock slips in the coal seam roof and floor. The most dangerous areas are the upper lateral corners of the mine roadway, which are prone to falls under the effect of water, when the roof bolting system loses its bearing capacity. Such manifestations of rock pressure are reliably predicted by analytical method and are verified by data of mine experiments, making it possible to undertake in advance additional measures for proper supporting the mine roadways. It is stated that implementation of a set of measures aimed at reducing water flows into the mine roadway improves its stability due to the smaller size of inelastic deformation zones in the walls and roof of the mine roadway in the stationary abutment-pressure zone, reduced contours of the mine roadway deformation, and decreased rate of horizontal and vertical convergence.

Keywords: stability of mine roadways, water-saturated rocks, rock massif stress-strain state, mathematical modeling, finite element method.

Introduction.

Today, preparatory roadways are mined in the rocks of medium and low strength. In the active mine roadways, effect of underground and technical waters on the rock massif stability is often ignored. At the same time, clay rocks, even in the drained state, are characterized by relatively weak strength, and, under the moisture effect, can completely lose their bearing capacity. Numerous visual observations and instrumental measurements of the displacements of preparatory roadway contour in the coal mines [1, 2] show that stability of the mine roadways is significantly reduced at presence of the water-saturated clay rocks. In this case, sudden roof fall and caving, as well as intensive floor rising occur in the mine roadways.

There are two main reasons for the increase of moisture content in clay in the mine roadway floor and roof. The first reason is seepage of water from aquifers along the fracture systems through the rock massif disturbed by mining operations. These

cracks are developed around the goafs at inelastic deformation of rocks [3-5]. The second reason for the rock watering is penetration of water into the mine roadways during technological processes with the use of technical liquids in significantly great volumes. In particular, a great amount of water flows into the roadway floor at the borehole drilling, plugging and concreting and during the anti-dust irrigation. Ignoring of the rock watering factor leads to significant economic losses, since hydrogeological processes contribute to intensive uncontrolled deformation of preparatory roadways. Therefore, prediction of changes in the stress-strain state of the water-saturated rock massif and assessment of expected water inflows into the mine roadways is an important scientific problem, and its solution will allow timely undertaking proper measures in order to improve stability of the mine objects.

Methods

Analysis of experimental data on assessing state of water-saturated rock massif; statistical processing of laboratory research results on the strength properties of rock samples; mathematical modeling of the rock massif stress-strain state by the finite element method; mine studies of deformations of water-saturated rocks.

Results and discussion

Evaluation of the strength properties of water-saturated rocks

Since it is impossible to reproduce the whole complex of factors affecting the rock deformations in a single model of geomechanical processes, therefore, it is necessary to choose the most important parameters. In the first place, it is physical-mechanical properties of the rocks and effect of water saturation on them. Since mudstones and weak siltstones almost completely get soaked in water for 20 days, and sandstone strength is reduced by about 1.5-2.0 times [6], therefore, presence of water in the pores of rocks in an amount close to water saturation drastically changes their behavior in the rock massif. In addition to the rock strength reduction when soluble minerals are washed-out from them, water saturation changes nature of the bonds between the particles, and, in case of the rock deformations, cohesive forces between the rock blocks and seams are reduced.

Three thousand one hundred twenty (3120) rock samples taken from the Western Donbas were studied and tested in laboratory of the Institute of Geotechnical Mechanics, and the obtained results were statistically processed. The rock samples were studied at their saturation with the distilled water, since the so-called "mine water", even taken from different roadways of one and the same mine, features greatly different mineralization. Besides, content of dissolved acids and alkalis in the mine water drastically differs, so it is permissible to use it for analyzing only when solving specific problems for one concrete roadway, or horizon, or, less often, mine. In case of hard sandstone and limestone, strength of water-saturated rocks relatively to their initial strength in their natural state decreases according to the following correlation dependence:

$$\sigma_e^w = 1.92 + 0.79\sigma_e, \quad R=0.67, \quad (1)$$

where σ_e^w is ultimate strength of rocks in their water-saturated state, MPa; σ_e is ultimate strength of rocks in their natural state, MPa; R is coefficient of variation.

Many of the clay rocks samples got completely soaked, therefore, the residual strength of these samples at water-saturation is equal to the strength of the destroyed rocks for the closed volume of the rock massif $\sigma_e/3$ [7], then, the generalized correlation dependence for the mudstones and siltstones is written in the following way:

$$\sigma_e^w = -2.5 + 0.67\sigma_e, R=0.76. \quad (2)$$

When assessing probability of water seeping through the hardly-permeable formations, it should be borne in mind that the determining factor for formation of the rock massif permeability is its fracturing. The highest permeability is observed in zones of rock rupturing failure, where crack opening increases under the effect of winning operations. In such conditions, forecast of the rock pressure manifestations can be based on geomechanical models, which determine stage of main cracks developing.

For the soils, it is established that, depending on depth, their saturation W with water takes place in accordance with hyperbolic regularity, while their density ρ first increases and then decreases by parabolic dependence (Fig. 1), which, in this case, is associated with the soil subsidence and compaction in the upper clayey seam.

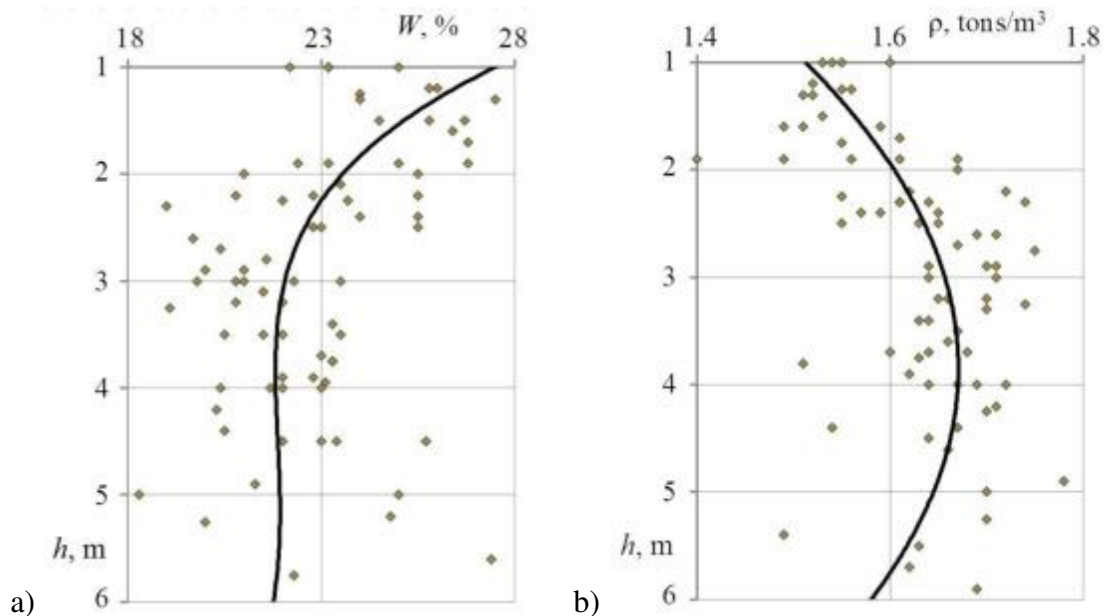


Figure 1 – Dependences of change of relative humidity W (a) and density ρ (b) of the soil with the depth during its long-term watering

Modeling of water-saturated rock massif

Rock massif is a complex structure with pronounced seaming and plasticity properties, which present certain difficulty for describing mechanical processes of its deformation. Complexity and multifactor nature of such description requires using of elastoplastic geomechanical models, which can be realized with the help of modern computer technologies based on combination of continuum mechanics methods

(solutions are obtained by the finite element method [8]) and theory of limiting states of rocks (is implemented by method of initial strains [7]) subject to discrete analogs of the law of energy conservation for each element separately and the design scheme as a whole. Such approach to solving problems of estimating the stress-strain state of the water-saturated rock massif was implemented in the computer system "GEO-RS[®]", developed by the Institute of Geotechnical Mechanics with participation of the author of this paper.

Changes in the rock massif stressed state during its watering were studied on the example of operation of drift 535, coal seam C_5 , in the "Samarska" Mine. Data given by the geological department of the Mine and the established correlation relations (1) and (2) were used as initial data. Despite the small depth of the coal seam bedding ($h=130$ m), the mining and geological conditions for its development are complex. Roof and floor of the coal seam are presented by mudstones and siltstones with compressive strength $\sigma_c=10-20$ MPa. In the immediate floor, weak siltstones ($\sigma_c=11.8-15.0$ MPa) occur. At water saturation, the rocks are very unstable and prone to sudden fall. Coal strength is $\sigma_c \sim 40$ MPa. Water-saturated sandstone ($\sigma_c=11-14$ MPa) occurs zonally in the roof. The coal seam has a complex hypsometry, distance from the floor to the coal seam changes along the drift length within $\sim 0.6-1.6$ m.

In order to determine water saturation effect on the rock pressure manifestations and stability of preparatory roadway, the calculations were performed for water-saturated and dry rocks. Analysis of distribution of maximum principal stresses (Fig. 2, a) showed that stresses at the ends of the coal seam were $(2.1-3.6)\gamma h$ (γ is volume weight of rocks, t/m^3 ; h is depth, m). Due to the fact that the coal seam is $\sim 2-3$ times harder than the lateral rocks, the roof rocks and the coal seam floor are intensively pressed out into the roadway in the watering zones. And, on the contrary, roadway floor is unloaded from stresses. These are signs of existing deformations and floor rising.

As it is shown in Figure 2, b, maximum changes in the rock massif stress at their water saturation occur in extremely stressed rocks of immediate and main roof above the ends of the coal seam to the height of up to 14 m, and also in the roadway wall in the area of abutment pressure at a distance of ≈ 17 m. As a result of intensification of the water-saturated rock massif deformations, maximum principal stresses in the roadway wall from the side of the coal pillar and over the goaf are decreased by 0.3-1.1 MPa. On the contrary, stresses of the overlying rocks are increased by 0.1-0.4 MPa. These negative effects of watering lead to the intensive development of zone with inelastic deformations.

Analysis of breakdown zones allows determining the water-seepage paths and volumes of probable water inflows including volumes of aquifers and water accumulation zones. If no hydrogeological data are available, it is proposed to solve the problem on determining the water seepage volume in two stages: first, to determine zones of broken elements by solving the geomechanical problem, and then to calculate potential water inflows.

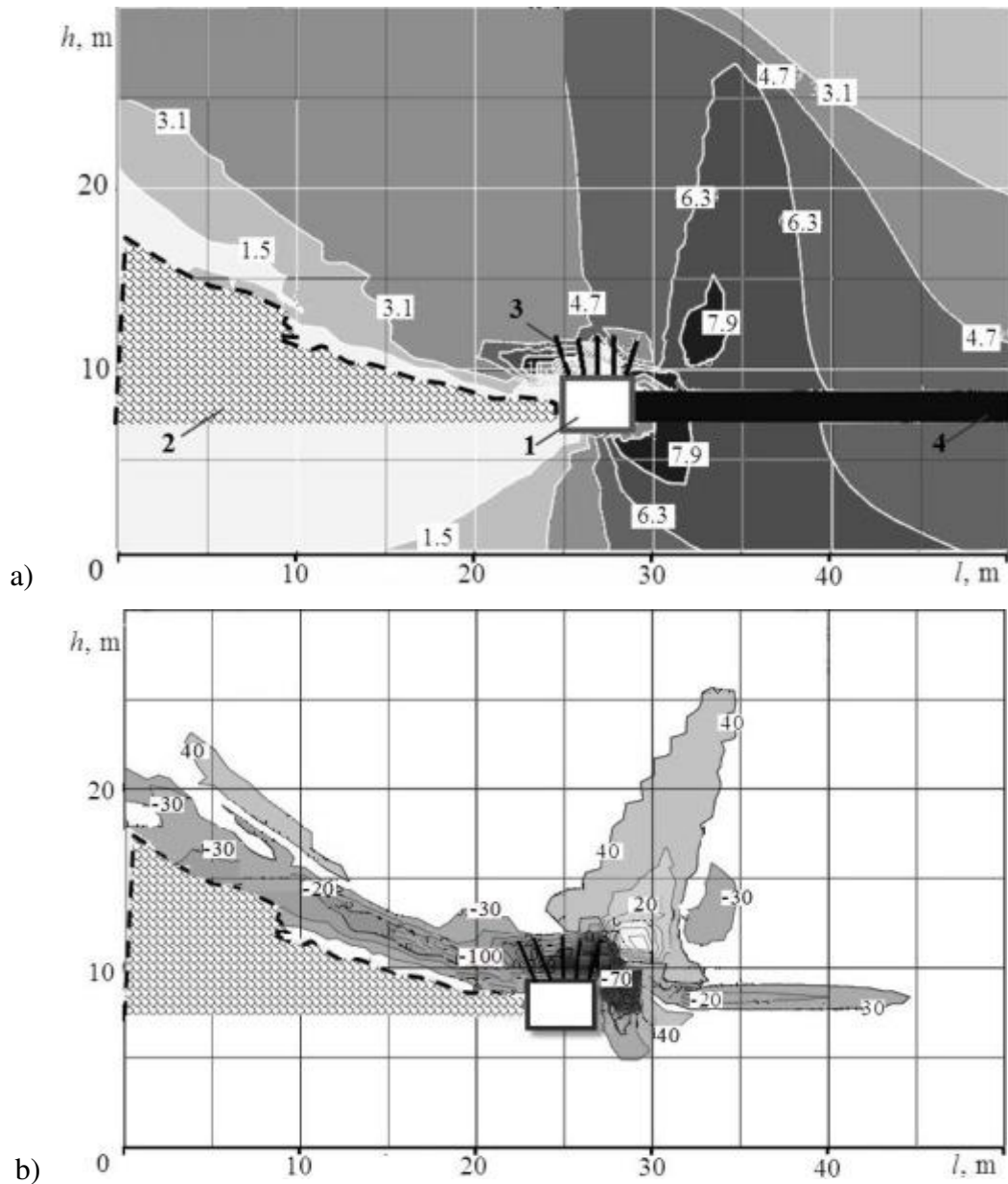


Figure 2 – Regularity of changes in the stressed state of water-saturated rock mass around the drift 535, coal seam C_5 , in the “Samarska” Mine: a – distribution of maximum principal stresses around the drift, MPa; b – zones where stress-strain state of the rock mass changes at its watering (numerals show difference between maximum principal stresses when physical and mechanical properties of water-saturated and drained rocks are considered), kPa; 1 – mine roadway; 2 – mined-out space; 3 – roof bolting system; 4 – coal seam

Water volumes are calculated by total area of the broken elements in the model and by coefficient of loosening or volume porosity of the rocks, which is average for the zone under the study. In the program for geomechanical calculations area under the study is divided into a grid of triangular elements. Let's assume that breakdown zones consist of triangular elements, in which one, two or three bonds have broken. For any of the three points $A(x_1, y_1)$, $B(x_2, y_2)$, $C(x_3, y_3)$ area of triangular element S_{ABC} is calculated by the known formula:

$$S_{ABC} = \pm \frac{1}{2} [(x_2 - x_1)(y_3 - y_1) - (x_3 - x_1)(y_2 - y_1)], \text{ m}^2. \quad (3)$$

In the formula, sign “+” means that the expression is positive, and sign “-” means that the expression is negative. Value of the zone area is always positive. Area of the loosening zone S_z is equal to sum of n areas of the broken elements in the model:

$$S_z = \sum_{i=1}^n |S_i|, \text{ m}^2. \quad (4)$$

If it is necessary to calculate breakdown zones with several sections, then supposed volume of water accumulation is equal to volume of the water-seepage zone multiplied by coefficient, which characterizes the rock open porosity and fracture m_0 :

$$V_w = V_z m_0 = \frac{\sum_{i=1}^n |S_i| + 2 \sum_{i=1}^m |S_i| + \dots + \sum_{i=1}^k |S_i|}{2} \times L_z m_0, \text{ m}^3, \quad (5)$$

where V_w and V_z are volumes of water and water-saturated zone, m^3 ; m_0 is coefficient of open porosity, in rel. unit; L_z is length of the zone along the mine roadway, m.

In accordance with obtained results on determining zones of the rock massif loosening and breakdown, volumes of probable water inflows into the mine roadways are calculated by the known methods and instructions [1, 2]. Based on these data, changes in the stress-strain state of the rock massif and expected water inflows are predicted, and measures are developed for improving stability of the mine objects.

Mine research of water-saturated rock deformations

In order to clarify and verify the calculated data, visual observations and measurements were carried out in the drift 535, coal seam C_5 , in the “Samarska” Mine [9]. The observations showed that most of the rock falls were confined to the watering zones. For example, in the area of the stake 62 (at a distance of 620 m from the main drifts), water occurs, and host rocks in the roadway walls get soaked resulting in long longitudinal cracks formed in upper corners of the drift (Fig. 3), while water-saturated roof of the mine roadway is warped, exfoliates (Fig. 3, a) and, in some locations, falls (Fig. 3, b).

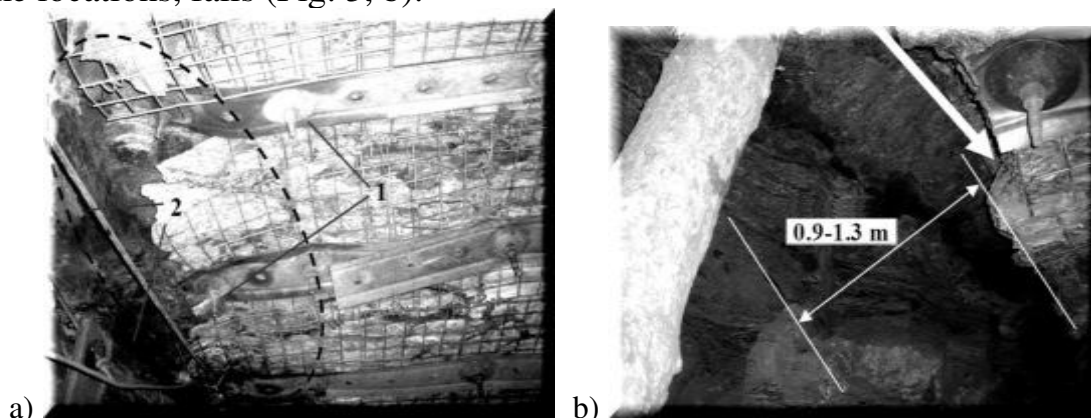


Figure 3 – Rock pressure manifestations at the rock water saturation: a – destruction of the upper corners in the mine roadway (section between 640-670 meters of the drift); b – lateral pressing of water-saturated rocks and falls of the mine roadway walls (sections at 360 m and 736 m of the drift); 1 – roof bolting system; 2 – falls zone

According to the results of the mine observations and calculations by the finite element method, nature of deformation of water-saturated rocks in the roof, walls and floor of the mine roadway was determined (Fig. 4). It is established that intense deformations starts in the drift walls and manifest themselves in the form of weak rock slips in the coal seam roof and floor. The most dangerous areas are the upper lateral corners of the mine roadway, which are prone to falls under the effect of water, when the roof bolting system loses its bearing capacity. Such manifestations of rock pressure are reliably predicted by analytical method and are verified by data of mine experiments, making it possible to undertake in advance additional measures for proper supporting the mine roadways.

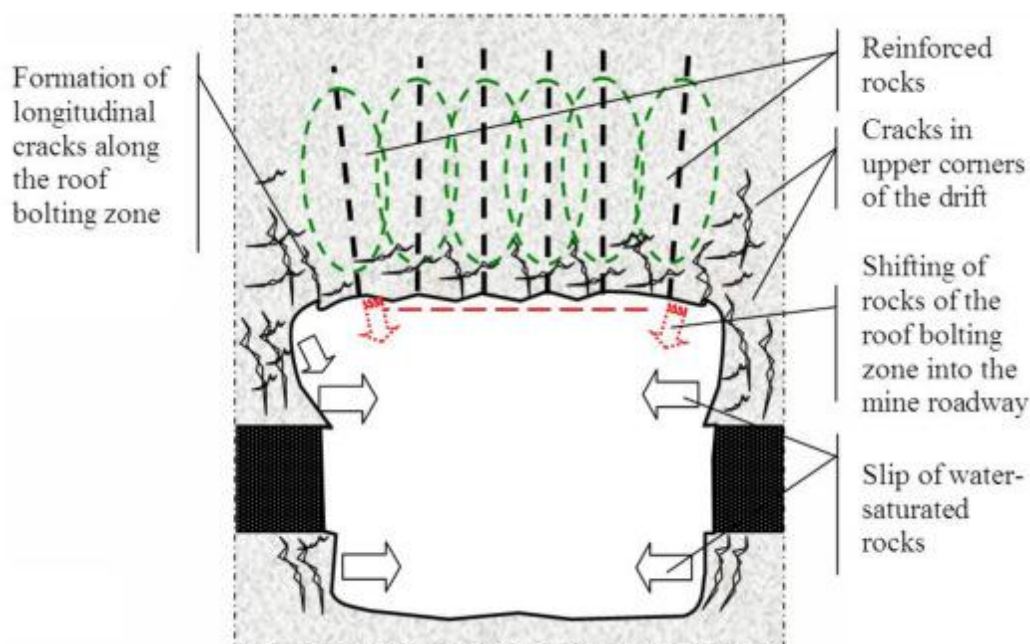


Figure 4 – Manifestations of water-saturated rock deformations in the drift 535, coal seam C_5 , in the “Samarska” Mine, reproduced in accordance with results of calculations and mine observations

Conclusions

As a result of the research, specific effect of water on the rock strength properties was determined. The generalized correlation dependences of strength reduction of sandstones, mudstones and siltstones at their saturation with water relatively to their initial strength in natural state were obtained. The correlations were proposed for calculating probable water inflows into the mine roadways basing on the assessment of volume of broken elements in the geomechanical model, parameters of open porosity and fracturing. Regularity of changing of the rock-massif stress-strain state depending on rate of preparatory roadway watering were established, which allowed, for the conditions of the “Samarska” Mine, to determine degree of effect of water saturation of the rocks on their stress-strain state and manifestations of rock pressure in the preparatory mine roadways. On the basis of mathematical modeling, it is established that implementation of a set of measures aimed at reducing water flows into the mine roadway improves its stability, namely: it reduces area of inelastic deformation zone in the walls and roof of the mine roadway in zone of stationary

abutment pressure, diminishes deformation of the roadway contour and decreases rate of horizontal and vertical convergence.

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Анотація. Стаття присвячена вирішенню актуальної наукової задачі з вдосконалення методів прогнозування стійкості гірничих виробок в гірничо-геологічних умовах обводнених порід. Методи досліджень: аналіз експериментальних даних по оцінці стану масиву обводнених гірських порід, статистична обробка результатів лабораторних досліджень міцнісних властивостей зразків гірських порід, математичне моделювання напружено-деформованого стану породного масиву методом скінченних елементів, шахтні дослідження деформацій водонасичених гірських порід. Досліджено особливості впливу води на властивості міцності гірських порід.

Отримано узагальнені кореляційні залежності зниження міцності пісковиків, аргілітів і алевролітів при водонасиченні в залежності від їх початкової міцності в природному стані. Методом математичного моделювання встановлені і шахтними спостереженнями підтверджені закономірності зміни напружено-деформованого стану масиву порід в залежності від обводнення підготовчої виробки. Запропоновані співвідношення для розрахунку можливих водопритоків в гірничі виробки на базі оцінки об'ємів зруйнованих елементів геомеханічної моделі, параметрів відкритої пористості і тріщинуватості. Визначено характер деформування зволжених порід в покрівлі, боках і підшві виробки. Встановлено, що інтенсивні деформації починаються в боках штреку і проявляються у вигляді віджиму слабких порід в покрівлі та підшві вугільного пласта. Найбільш небезпечними місцями є верхні бокові кути виробок, які під впливом вологості схильні до вивалів, а система анкерного кріплення втрачає опору. Такі прояви гірського тиску надійно прогнозуються аналітичним методом і уточнюються за даними шахтних експериментів, що дозволяє завчасно застосовувати додаткові заходи з підтримання виробок. Показано, що здійснення комплексу заходів, що спрямовані на зниження надходження води в виробку, підвищує її стійкість за рахунок зниження розмірів зон непружних деформацій в боках і покрівлі виробки в зоні стаціонарного опорного тиску, зменшення деформацій контуру виробки, величини горизонтальної та вертикальної конвергенції.

Ключові слова: стійкість гірничих виробок, обводнені породи, напружено-деформований стан породного масиву, математичне моделювання, метод кінцевих елементів.

Анотація. Стаття посвячена решению актуальной научной задачи совершенствования методов прогнозирования устойчивости горных выработок в горно-геологических условиях обводненных пород. Методы исследований: анализ экспериментальных данных по оценке состояния массива обводненных горных пород, статистическая обработка результатов лабораторных исследований прочностных свойств образцов горных пород, математическое моделирование напряженно-деформированного состояния породного массива методом конечных элементов, шахтные исследования деформаций водонасыщенных горных пород. Исследованы особенности влияния воды на прочностные свойства горных пород. Получены обобщенные корреляционные зависимости снижения прочности песчаников, аргиллитов и алевролитов при водонасыщении в зависимости от их изначальной прочности в естественном состоянии. Методом математического моделирования установлены и шахтными наблюдениями подтверждены закономерности изменения напряженно-деформированного состояния массива пород в зависимости от обводненности подготовительной выработки. Предложены соотношения для расчета возможных водопритоків в горные выработки на базе оценки объемов разрушенных элементов геомеханической модели, параметров открытой пористости и трещиноватости. Определен характер деформирования увлажненных пород в кровле, боках и почве выработки. Установлено, что интенсивные деформации начинаются в боках штрека и проявляются в виде отжима слабых пород в кровле и почве угольного пласта. Наиболее опасными местами являются верхние боковые углы выработок, которые под влиянием влажности склонны к вывалам, а система анкерного крепления теряет опору. Такие проявления горного давления надежно прогнозируются аналитическим методом и уточняются по данным шахтных экспериментов, что позволяет заблаговременно применять дополнительные мероприятия по поддержанию выработок. Показано, что осуществление комплекса мероприятий, направленных на снижение поступления воды в выработку повышает ее устойчивость за счет снижения размеров зон неупругих деформаций в боках и кровле выработки в зоне стационарного опорного давления, уменьшения деформаций контура выработки, величины горизонтальной и вертикальной конвергенции.

Ключевые слова: устойчивость горных выработок, обводненные породы, напряженно-деформированное состояние породного массива, математическое моделирование, метод конечных элементов.

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