MINING ROCK PROPERTIES. ROCK MECHANICS AND GEOPHYSICS

Research paper

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Effect of water inflows on the strength characteristics of the Lovozero rare-metal deposit rocks

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Abstract
The Lovozero rare-metal deposit is represented by a series of sheet-like ore bodies of small and medium thickness exposing on the northwestern slopes of the Lovozero massif. The purpose of the work is to assess the impact of water inflows on the strength characteristics of the rocks of the Lovozero rare-metal deposit developed by the Karnasurt mine. The data on water inflow into Karnasurt mine workings, which exploits two ore bodies of the Lovozero rare-metal deposit, are considered. Statistical processing of the data on water volumes collected by the mine over the latest 4 years was performed, with assessment of their changes during a calendar year. The peculiarities associated with calendar climatic changes were identified. The main purpose of the study was to assess the effect of water inflows on the strength characteristics of the rocks composing the support pillars. The analysis and calculations of precipitation accumulation within the mine allotment and water inflows into the mine workings were performed and compared with actual data on mine waters. The samples of the most representative rocks of the deposit were collected and tested for dry and water-saturated compressive and tensile strength. The quantitative indicators of the changes in the strength characteristics of rocks due to water saturation were determined. It was found that the water saturation led to a decrease in the rock strength by up to 10–20%, especially for compressive strength values.

Keywords
mine, extraction, water inflows, rocks, pillars, properties, strength, water saturation, rockburst hazard, Lovozero rare metal deposit, Karnasurt mine

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The paper was written on the basis of initial data prepared by Alexander V. Lovchikov, Dr. Sci. (Eng.). For more than 60 years A.V. Lovchikov dealt with the issues of the geotechnical safety of the Lovozero deposit mining, and, in fact, the last task of his life was to study the effect of rock watering on the stability and rockburst hazard of the pillars of the Karnasurt mine.

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СВОЙСТВА ГОРНЫХ ПОРОД. ГЕОМЕХАНИКА И ГЕОФИЗИКА

Научная статья

Влияние водопритоков на прочностные характеристики пород Ловозерского редкометалльного месторождения

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Аннотация
Ловозерское редкометалльное месторождение представлено свитой пластообразных пологопадающих рудных залежей малой и средней мощности, выходящих на поверхность на северо-западных склонах Ловозерского массива. Целью работы является оценка влияния водопритоков на прочностные характеристики пород Ловозерского редкометалльного месторождения, разрабатываемого рудником «Карнасурт». Рассмотрены данные о поступлении воды в горные выработки рудника «Карнасурт», отрабатывающего две согласно залегающие рудные залежи Ловозерского редкометалльного месторождения. Выполнена статистическая обработка объемов воды, собираемой рудником за последние 4 года, с оценкой динамики их поступления в течение календарного года. Выявлены особенности, связанные с календарными климатическими изменениями. Основной целью работы являлась оценка влияния

водопритоков на прочностные характеристики пород, слагающие опорные целики. Выполнены анализ и расчеты осадконакопления в пределах горного отвода рудника и формирующихся водопритоков в горные выработки, а также сравнение их с фактическими данными по рудничной воде. Отобраны образцы наиболее представительных пород месторождения и выполнены испытания их на прочность на сжатие и растяжение в сухом и водонасыщенном состояниях. Определены количественные показатели изменения прочностных характеристик пород вследствие водонасыщения. Установлено, что водонасыщение привело к снижению прочности пород до 10–20 %, особенно для значений на сжатие. Полученные результаты дают основание для необходимости учета обводненности пород при расчете устойчивости как опорных целиков, так и обнажений пород в выработках рудника «Карнасурт».

Ключевые слова
рудник, добыча, водопритоки, горные породы, целики, свойства, прочность, водонасыщенность, удароопасность, Ловозерское редкометалльное месторождение, рудник «Карнасурт»

Благодарности
Статья написана на основе исходных данных, подготовленных доктором технических наук Ловчиковым Александром Васильевичем. А. В. Ловчиков более 60 лет занимался вопросами геомеханической безопасности отработки Ловозерского месторождения, и фактически последней задачей его жизни было исследование влияния обводненности пород на устойчивость и удароопасность целиков рудника Карнасурт.

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Introduction

The Lovozero rare-metal deposit is represented by a series of sheet-like ore bodies of small and medium thickness exposing on the northwestern slopes of the Lovozero massif [1]. At present, two ore bodies (I-4 (urtites) and II-4 (malignites)) with a thickness of 1.0–1.2 m each, occurring at a vertical distance of about 100 m from each other, are being mined by the Karnasurt mine. The mine applies room-and-pillar mining method with breast stoping and support of an undercut rock strata by chain pillars. Both bodies are mined by panels along their strike. The panels are cut at 20–40 m vertical intervals by drifts (adits at the upper levels), with leaving support chain pillars near the drifts. The panels are divided into blocks 60–120 m long, between which inter-block support chain pillars are left [1]. The deposit is classified as rockburst hazardous in mining conditions and characterized by increased seismicity and manifestations of tectonic rockbursts [2, 3].

At the current stage of the deposit mining, the support near-drift and inter-block pillars are 3 to 10 m wide. Their total area for each mined ore body can reach up to 25% of the mined out space. The mining depth is the lower ore body II-4 ranges from 30 m to the surface at the upper levels to 700 m at the deepest level +280 m.

The Karnasurt mine has a large mining allotment: the length along the lower ore body II-4 is about 8 km, with a maximum width of 2.6 km. Moreover, the issue of adding another 1.5 km to the west of the mining allotment is being considered [2]. Thus, the length of the mine field in the lower ore body at the final stage of development will reach 10 km with a width of up to 2.6 km, which in terms of area will amount to 26 km^2. The area of the upper ore body is slightly smaller, but of the same order of magnitude. This allows to confidently categorize the Karnasurt mine as one of the largest mines in the western part of the Russian sector of the Arctic.

At present, ore body II-4 within the mining allotment is only half mined-out, from the outcrops to the level +280 m. The dimensions of the mined out area are 6.5 km along the strike with a maximum width down dip of 1.3 km. In ore body I-4, mined out only in the Karnasurt area, the length of the mined-out space is 3.1 km along the ore body strike, with a maximum down dip width of 0.8 km and a depth of 50 to 350 m to the surface.

Water inflows into the Karnasurt mine workings are mainly due to surface precipitation. Water formed on the day surface due to rainfall, spring snowmelt and runoff from nearby mountains penetrates through numerous joints and structural heterogeneities in the overlying rock mass and enters the mine workings.

Water from mine workings of all mining areas is collected at the drifts' haulage levels and brought to the surface of the drifts – the drifts' floor – through the drifts' drainage channels. Thus, water flows through the floor of all mine drifts to lower levels. They are partially collected at the haulage levels and pumped from the mine workings to the surface by water pumping stations. As for the remaining volumes, both further water infiltration deep down into the underlying rock mass and abundant widespread water saturation of workings floor and pillar walls occur.

The issues of water inflow generation at coal seams mining by underground method were investigated in works [4, 5], including changes in surface natural sources [6, 7] and the mechanism of surface water infiltration into mine workings [8]. For ore deposits in hard rock masses, the effect of rock water content on the energy saturated state [9] and the manifestations of seismicity [10] has been considered. The peculiarities of rock water content were investigated in [11, 12], and the effect of the water content factor on the sustainable state and safety of the natural environment was studied in [13–15].

At the same time, taking into account that for the conditions considered in this work the water flows move directly along the lower parts of the support near-drift pillars of the rockburst-prone deposit, it is necessary to pay special attention to the effect of water content of rocks. Therefore, the purpose of the work is to assess the impact of water inflows on the strength characteristics of the rocks of the Lovozero rare-metal deposit developed by the Karnasurt mine.

Findings

According to the hydrogeological service of the Karnasurt mine, the volume of water collected by the mine is about 8 million m3 per year. At the same time, the dynamics of the volumes for the latest 4 years of observations remains practically monotonous: from January to May the volumes decrease, in June they increase significantly, followed by slightly lower values in July–September, and from October to December the volumes of water inflows decrease again (Fig. 1).

The histograms on the figure below show that the monthly water inflow into the mine workings ranges from 40 to 110 thousand m^3. The least amount of the water inflow, from 40 to 50 thousand m^3, is observed in May each year. This is due to the fact that from October to April precipitation falls as snow and due to negative temperatures accumulates on the surface without infiltration of water from the surface into the mine workings. The largest amount of the water inflows, between 70,000 and 110,000 m^3, occurs in June–September (summer–autumn period) of each year. It is obvious that the increase in the amount of water entering the mine during summer and autumn period is due to both intensive snow melting (in May–June) on the mountain slopes within the mine field surface and precipitation in the form of rain during this period (Fig. 2). Data on rain and snow precipitation volumes for the Karnasurt mine allotment area during the calendar year were obtained based on the analysis and processing of the information from the following sources[1].

[1] Atlas of the Murmansk region, 1971; Report on the environmental condition and protection in the Murmansk Region in 2022. 2023, 151 p. (In Russ.) URL: https://ru.weatherspark.com/y/98660/Обычная-погода-в-Ревда-Россия-весь-год

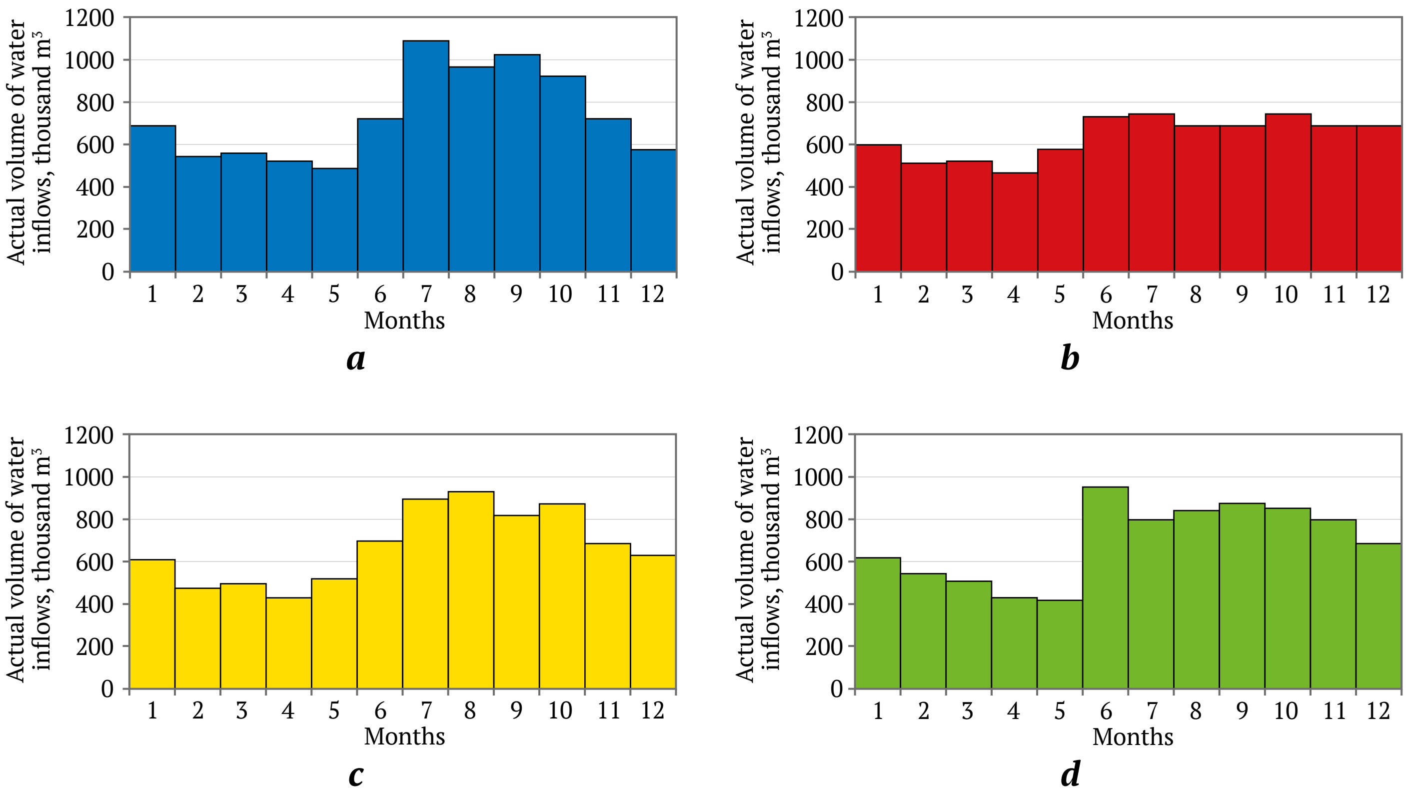

Fig. 1. Data on actual volumes of water collected and pumped out by the Karnasurt mine: *a* – 2017; *b* – 2018; *c* – 2019; *d* – 2020

For comparative analysis, the dynamics of total precipitation volumes on the surface of the mining allotment and actual volumes of water collected in the mine workings for 2017–2020 were considered (Fig. 3). The analysis of the data presented in Fig. 3 confirms the above mentioned opinion about the predominant effect of two periods: snow accumulation (approximately 2,400–3,000 thousand m^3/month from October to April) and snowmelt (May–June), as well as rainfall (approximately 1,200–1,800 thousand m^3/month from May to September).

The calculations have determined that during the period from October through April, snow accumulation on the mine allotment exceeds 21,700 thousand m. At the same time, the volume of actual water inflows into the mine workings decreases from 800 to almost 400 thousand m^3 due to reduced and virtually no water infiltration from the surface. The abundant snowmelt and rains in May–June lead to a sharp, more than 2-fold (from 400 to 850 thousand m^3/month) increase in water inflows into mine workings, reaching 70–80% of the surface precipitation. Such volumes of water inflows are recorded monthly from May until October, when rainfall is replaced by snowfall and negative ground temperature is established with subsequent decrease through April of the next year.

Thus, water inflows into the mine workings are generated by rainfall and snowmelt during periods with positive air and soil temperatures, as well as from natural surface water bodies and underground aquifers recharged by precipitation. The nature of their accumulation is more gradual than for the precipitation due to the above mentioned reasons. Visually, the boundary variations in the water inflow volumes clearly correlates with the identified climatic periods (see Fig. 3).

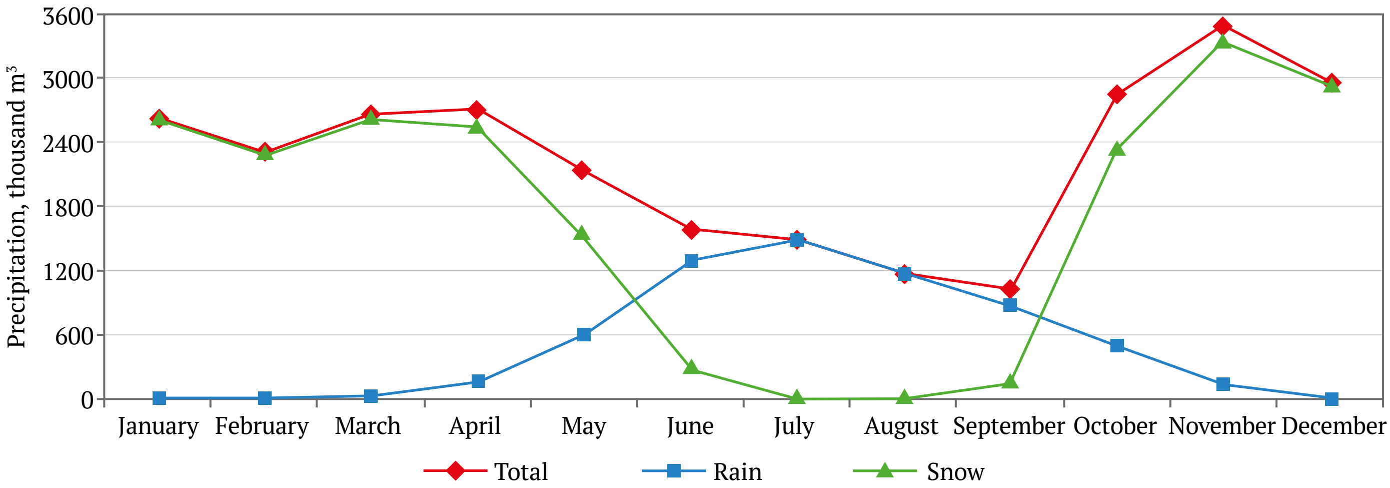

Fig. 2. Distribution of precipitation volumes on the surface of the Karnasurt mine allotment during a calendar year

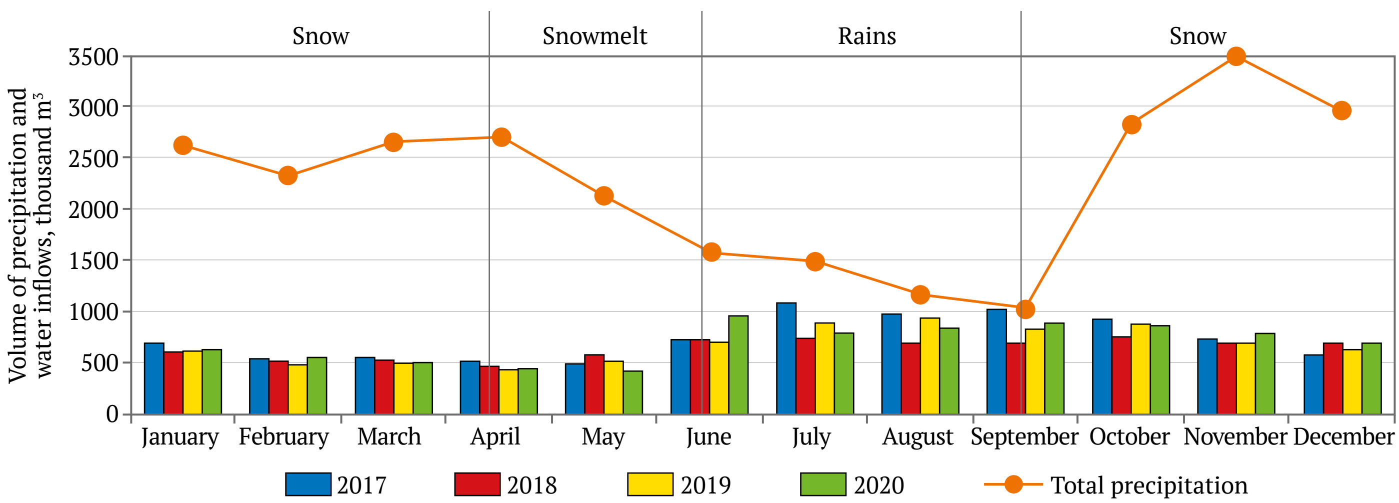

Fig. 3. Dynamics of total precipitation volumes on the surface of the mining allotment and actual volumes of water collected in the mine workings for 2017–2020

Special tests were conducted on rock samples to determine the effect of water saturation on the strength properties of the mine rocks. At ore body I-4, urtite rock hand specimens were taken as the most common rock variety in the drift at level +400 m (survey mark PK4), from which rock samples for testing were subsequently produced. For each type of test, 8–9 cube-shaped specimens (34 in total) with a cube face length of 4 cm were produced. The samples for tests in water-saturated condition were placed for a month into a vessel with water, and then tested for tension and compression. The specimens were tested for compression and tension in dry and water-saturated conditions in accordance with GOSTs[2].

The results of the specimens' compression and tensile tests in dry condition are given in Tables 1 and 2. As can be seen from these tables, the established value of compressive strength, which is σ_c = 181 MPa, and the value of tensile strength

[2] GOST 21153.2–84 Rocks. Methods for determining uniaxial compressive strength (Description update date: 01.07.2023); GOST 21153.3–85 Rocks. Methods for determining uniaxial tensile strength (Description update date: 01.07.2023).

Table 1

Results of dry rock specimens compression strength tests

Index	X, cm	Y, cm	Z, cm	Volume, cm³	Weight, g	Bulk density, g/cm³	Loading area, cm²	Rupturing load, kN	Ultimate compressive strength, MPa
2	4.53	4.57	4.60	95.1	247.54	2.60	20.67	374.9	145
3	4.52	4.49	4.57	92.8	242.05	2.61	20.29	408.2	161
4	4.52	4.53	4.59	93.7	243.65	2.60	20.44	579.7	227
5	4.56	4.70	4.58	98.1	248.73	2.53	21.43	520.0	194
6	4.52	4.51	4.64	94.5	246.40	2.61	20.39	494.4	194
11	4.56	4.52	4.61	94.9	229.60	2.42	20.60	493.6	192
14	4.50	4.50	4.60	93.3	243.26	2.61	20.28	358.6	141
16	4.51	4.53	4.54	92.8	242.42	2.61	20.44	497.4	195
17	4.65	4.65	4.54	98.2	259.51	2.64	21.61	489.5	181
Min	4.50	4.49	4.54	92.8	229.60	2.42	20.28	358.6	141
Max	4.65	4.70	4.64	98.2	259.51	2.64	21.61	579.7	195
Average	4.54	4.56	4.59	94.82	244.80	2.58	20.68	468.48	181.11

Table 2

Results of dry rock specimens tensile strength tests

Index	X, cm	Y, cm	Z, cm	Volume, cm³	Weight, g	Bulk density, g/cm³	Loading area, cm²	Rupturing load, kN	Ultimate compressive strength, MPa
1	4.56	4.67	4.56	97.1	254.92	2.26	21.30	39.4	19
7	4.66	4.56	4.62	98.2	245.20	2.50	21.27	31.9	15
8	4.55	4.50	4.59	94.1	247.63	2.63	20.50	26.9	13
9	4.63	4.56	4.62	97.4	244.90	2.52	21.08	30.1	14
10	4.55	4.56	4.61	95.5	248.27	2.60	20.72	42.5	21
12	4.56	4.56	4.60	95.7	250.62	2.62	20.82	31.5	15
13	4.62	4.55	4.59	96.4	242.00	2.51	20.98	19.3	9
15	4.57	4.53	4.59	95.1	231.85	2.44	20.72	17.7	9
18	4.54	4.54	4.63	95.4	250.47	2.62	20.59	29.3	14
Min	4.54	4.50	4.56	94.1	231.85	2.26	20.50	17.7	9
Max	4.66	4.67	4.63	98.2	254.92	2.63	21.30	42.5	21
Average	4.58	4.56	4.60	96.10	246.21	2.52	20.89	29.84	14.33

σ_t = 14.3 MPa correlate well with similar data of previous studies [1, 2].

The water-saturated specimens for the compression and tensile tests had the same dimensions as dry ones, but due to water saturation their weight increased slightly (3–5%). The results of their tests are presented in Tables 3 and 4.

Findings Discussion

For detailed analysis, the strength properties of all the tested specimens were plotted and ranked according to the values obtained (Fig. 4). The solid line indicates the mean value; the dotted line indicates a 20% decrease from the mean.

Fig. 4 shows that water saturation of the rocks reduced their compressive strength by 20% in general, and by 40% for two samples. At the same time, the lower compressive strength remained rather high, above 110 MPa.

The tensile strength of the water-saturated specimens also generally decreased, but to a lesser extent, and the lower limit did not fall below 10 MPa. For visual comparison, the data of statistical processing are shown in Fig. 5.

Table 3

Results of water-saturated rock specimens compression strength tests

Index	Loading area, cm²	Rupturing load, kN	Ultimate compressive strength, MPa
4	20.68	417.3	161
5	21.15	376.0	142
7	20.82	360.5	138
8	21.22	441.2	166
9	21.14	381.8	145
10	20.19	279.0	111
11	20.80	458.8	176
14	21.44	297.6	111
Min	20.19	297.6	111
Max	21.44	458.8	176
Average	20.93	376.525	143.75

Table 4

Results of water-saturated rock specimens tensile strength tests

Index	Loading area, cm²	Rupturing load, kN	Tensile strength, MPa
1	21.24	23.9	11
2	20.80	28.6	14
3	20.13	32.6	16
6	20.87	30.6	15
12	21.30	31.9	15
13	20.53	27.0	13
15	20.99	27.6	13
16	21.28	30.8	14
Min	20.13	23.9	11
Max	21.30	32.6	16
Average	20.89	29.13	13.88

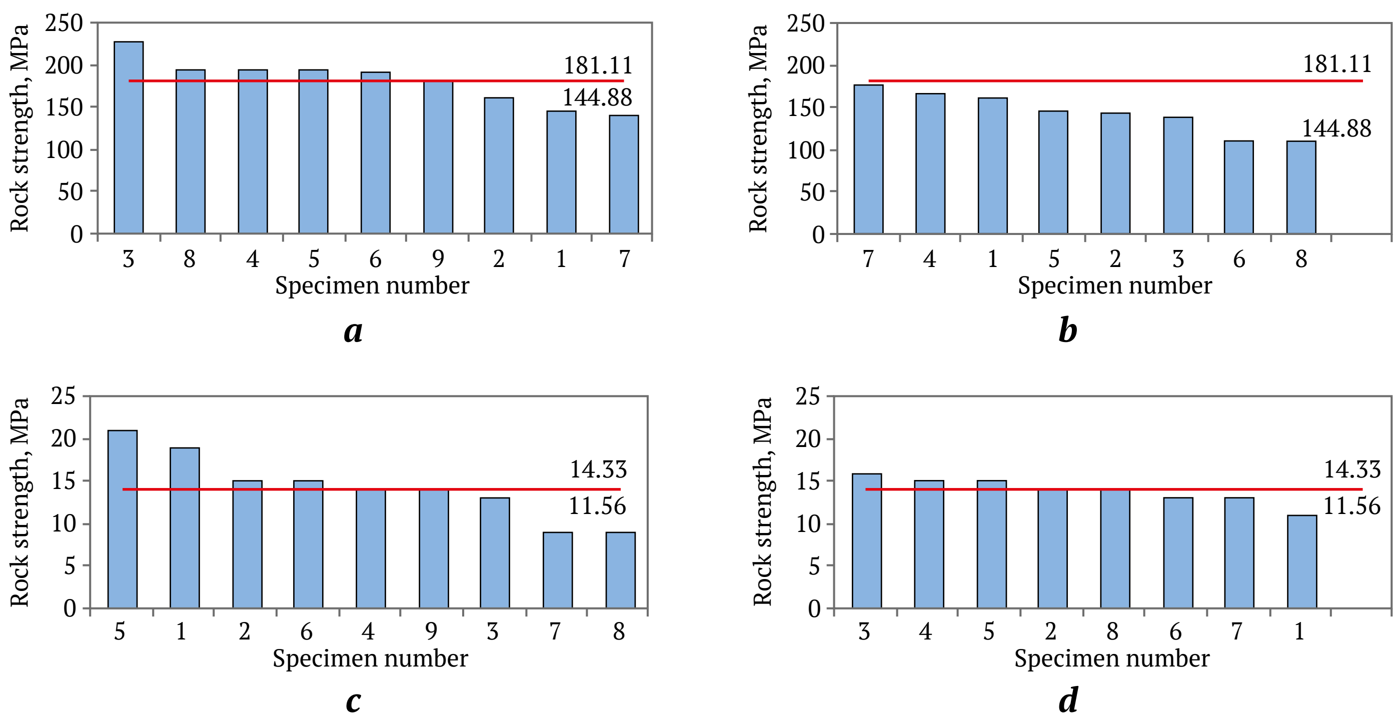

Fig. 4. Distribution of tested specimen compression (top row) and tensile strength values and tension tests: *a*, *c* – dry rock; *b*, *d* – water-saturated rock

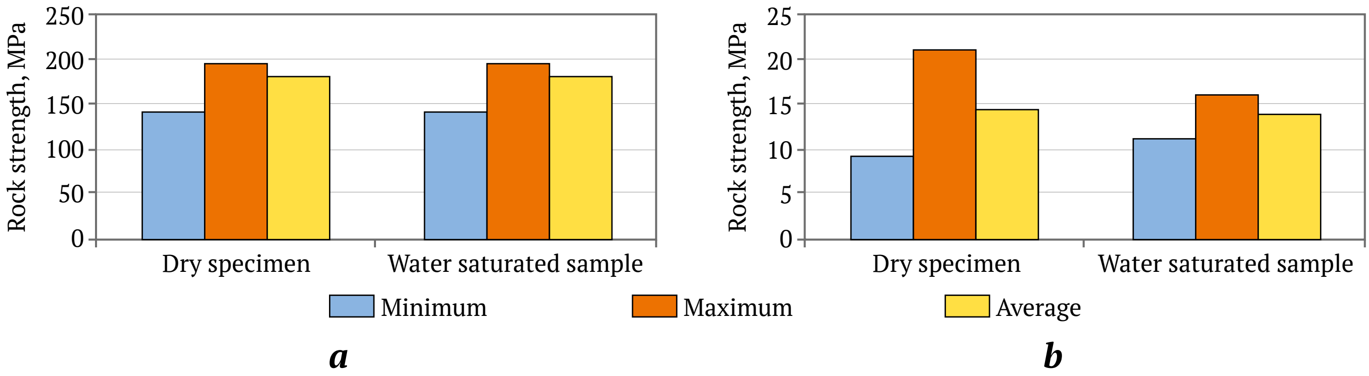

Fig. 5. Statistical distribution of strength characteristics of tested specimens:
a – compression strength; *b* – tensile strength

Thus, the tests results showed that water saturation reduces compressive and tensile strength of rocks by 10 to 20% or more. This circumstance should be taken into account when calculating the stability of both support pillars and rock outcrops in the Karnasurt mine workings, which are subjected to abundant water saturation.

Conclusion

The data of actual water volumes collected in the workings of the Karnasurt mine over the latest 4 years were processed and analyzed. It was determined that the annual volume of the collected water reached 8 million m^3 with distribution by months in accordance with seasonal-climatic precipitation. The analysis and calculations of the precipitation within the mine allotment and the water inflows into the mine workings were performed. They were compared with the actual data on mine water regime. The specimens of the most representative rocks of the deposit were collected, from which 34 cubes with dimensions of 4×4×4 cm were produced, half of which were placed into water for a month. The specimens (8–9 for each condition and test) were tested for compressive and tensile strength in dry and water-saturated conditions. It was found that the water saturation led to a decrease in the rock strength by up to 10–20%, especially for compressive strength values. The results obtained give the grounds for the necessity to take into account the water content of rocks when calculating the stability of both support pillars and rock outcrops in the Karnasurt mine workings.

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