JUSTIFICATION OF FACTORS AFFECTING THE EFFICIENCY OF DRILLING AND BLASTING OPERATIONS

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Abstract: The article examines the influence of the degree of water saturation of a rock mass on the parameters and efficiency of drilling and blasting operations (DBO) under open-pit mining conditions. It is shown that the presence of water in fractures and pores of rocks significantly alters the physical and mechanical properties of the rock mass, reduces its strength characteristics, and affects the propagation of the blast wave. An analysis of the main factors determining changes in rock fragmentation efficiency at various levels of moisture saturation is carried out. Methods for compensating the negative impact of water saturation on blasting results are described, including the selection of optimal types of explosives, the use of water-resistant emulsion compositions, borehole sealing, and adjustment of drilling pattern parameters. The research results can be used in the design and optimization of drilling and blasting operations in water-saturated sections of quarries and mines, contributing to increased productivity and safety of mining operations.

Keywords: water saturation of the rock mass, drilling and blasting operations, explosives, fragmentation efficiency, open-pit mining, water-resistant explosives, explosion energy, seismic impact.

Аннотация: В статье рассматривается влияние степени водонасыщенности горного массива на параметры и эффективность буровзрывных работ (БВР) в условиях открытых горных работ. Показано, что наличие воды в трещинах и порах горных пород существенно изменяет физико-механические свойства горного массива, снижает его прочностные характеристики и влияет на распространение взрывной волны. Проведен анализ основных факторов, определяющих изменение эффективности дробления горных пород при различных уровнях влагонасыщенности. Описаны методы компенсации негативного влияния водонасыщенности на результаты взрывных работ, включая выбор оптимальных типов взрывчатых веществ, использование водостойких эмульсионных составов, герметизацию скважины и корректировку параметров схемы бурения. Результаты исследований могут быть использованы при проектировании и оптимизации буровзрывных работ на водонасыщенных участках карьеров и шахт, способствуя повышению производительности и безопасности горных работ.

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Ключевые слова: водонасыщенность горного массива, буровзрывные работы, взрывчатые вещества, эффективность дробления, открытые горные работы, водонепроницаемые взрывчатые вещества, энергия взрыва, сейсмическое воздействие.

Annotatsiya. Maqolada tosh massasining suv bilan to'yinganligi darajasining ochiq kon sharoitida burg'ulash va portlatish ishlarining (DBO) parametrlari va samaradorligiga ta'siri ko'rib chiqiladi.h massasining suv bilan to'yinganligi darajasining ochiq kon sharoitida burg'ulash va portlatish ishlarining (DBO) parametrlari va samaradorligiga ta'siri ko'rib chiqiladi. Tog ' jinslarining sinishi va teshiklarida suv borligi tosulosa: maqolada tosh massasining suv bilan to'yinganligi darajasining ochiq kon sharoitida burg'ulash va portlatish ishlarining (DBO) parametrlari va samaradorligiga ta'siri ko'rib chiqiladi. Tog ' jinslarining sinishi va teshiklarida suv borligi tosh massasining fizik-mexanik xususiyatlarini sezilarli darajada o'zgartirishi, uning mustahkamlik xususiyatlarini pasaytirishi va portlash to'lqinining tarqalishiga ta'sir qilishi ko'rsatilgan. Namlikning to'yinganligining turli darajalarida tog ' jinslarining parchalanish samaradorligining o'zgarishini aniqlaydigan asosiy omillar tahlili o'tkaziladi. Suv bilan to'yinganlikning portlash natijalariga salbiy ta'sirini qoplash usullari, shu jumladan portlovchi moddalarning maqbul turlarini tanlash, suvga chidamli emulsiya kompozitsiyalaridan foydalanish, quduqni muhrlash va burg'ulash naqshlari parametrlarini sozlash tasvirlangan.uv bilan to'yinganlikning portlash natijalariga salbiy ta'sirini qoplash usullari, shu jumladan portlovchi moddalarning maqbul turlarini tanlash, suvga chidamli emulsiya kompozitsiyalaridan foydalanish, quduqni muhrlash va burg'ulash naqshlari parametrlarini sozlash tasvirlangan. Tadqiqot natijalaridan konlar va konlarning suv bilan to'yingan uchastkalarida burg'ulash va portlatish ishlarini loyihalash va optimallashtirishda foydalanish mumkin, bu esa kon ishlarining unumdorligi va xavfsizligini oshirishga yordam beradi.

Kalit so'zlar: tosh massasining suv bilan to'yinganligi, burg'ulash va portlatish ishlari, portlovchi moddalar, parchalanish samaradorligi, ochiq usulda qazib olish, suvga chidamli portlovchi moddalar, portlash energiyasi, seysmik ta'sir.

INTRODUCTION.

The efficiency of drilling and blasting operations (DBO) under conventional conditions is achieved through comprehensive consideration of the physical characteristics of the rock mass, proper selection of explosives, and strict adherence to the design parameters of drilling and blasting. Any deviation from the calculated values leads to deterioration of technical and economic indicators, excessive consumption of energy and materials, as well as an increase in seismic effects and technogenic risks.

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In modern mineral extraction conditions, with the continuous increase in open-pit mining depth, rock masses are increasingly characterized by a high degree of water saturation. This is caused by the penetration of groundwater and surface water into the mining area, the intersection of aquifers during borehole drilling, as well as the presence of tectonic disturbances and zones of increased fracturing [1].

The presence of water causes significant changes in the physical and mechanical properties of rocks: particle cohesion decreases, compressive and tensile strength limits are reduced, and deformability increases. Water, filling pores and fractures, acts as an elastic and viscous medium capable not only of absorbing but also of reflecting part of the explosion energy, which changes the dynamics of shock wave propagation and the nature of rock разрушение [2].

Methods and Materials. In study [3], it was established that the higher the coefficient of energy losses due to the interaction of the explosive charge with water, αw (the fraction of energy lost as a result of reduced sensitivity of explosives to detonation, attenuation of the shock wave by water, leaching of charge components, weakening of the "charge–rock" contact, and distortion of the detonation front), the greater the energy losses associated with the presence of water in the borehole, i.e.:

$$E_{eff} = E0 \cdot (1 - \alpha w), J \quad (1)$$

where: E_{eff} – effective explosion energy, i.e., the amount of energy actually used for rock mass fragmentation, J;

E_0 – total explosion energy without accounting for losses, i.e., the theoretically possible energy released during complete detonation of the explosive under ideal conditions, J;

αw – coefficient of energy losses due to interaction of the charge with water (αw is a dimensionless value, $0 < \alpha w < 1$).

Under ideal dry conditions, $\alpha w \to 0$, and thus $E_{eff} \to E0$. Under highly water-saturated conditions, $\alpha_w \to 0.4–0.5$, and the efficiency of energy utilization decreases sharply.

Results and Discussion. Water saturation has a negative effect on almost all key parameters of drilling and blasting operations, which necessitates revision of the blasting technology, selection of special water-resistant explosives, enhanced borehole sealing, and the use of geomechanical modeling prior to blasting. Table 1 presents the influence of borehole water saturation on blasting parameters [4].

The physical cause of energy losses lies in the fact that part of the detonation energy is expended on compressing and heating the water in pores and fractures, as well as on the formation of cavitation bubbles that dissipate energy. In addition,

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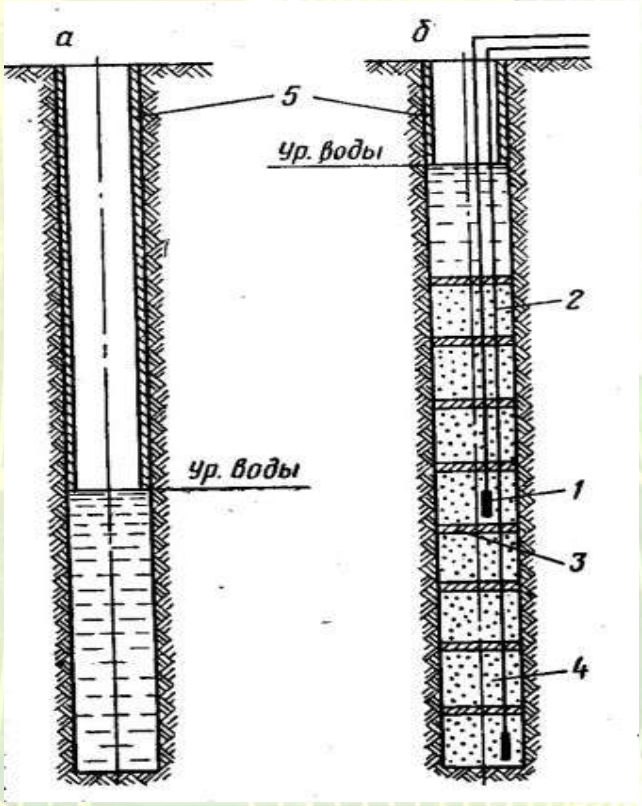
excess water pressure hinders effective crack propagation and reduces the explosion energy utilization coefficient.

Table 1

Influence of Borehole Water Saturation on Blasting Parameters

Parameter	Dry conditions	Water-saturated conditions
Explosive consumption	0.35–0.95 kg/m³	0.60–0.75 kg/m³
Fragmentation efficiency	High	Low
Seismic impact	Moderate	Increased
Flyrock	Absent	High
Post-blast rock mass fracturing	Controlled	Enhanced

In Fig. 1, a schematic diagram is presented showing borehole charging under water-saturated conditions, in which the water level rises after the placement of the explosive charge [5].



a – water level position before charging; b – water level position after charging; 1 – intermediate detonator; 2 – detonating cord; 3 – drill cuttings plug (stemming plug);4 – explosive charge; 5 – drill cuttings crust (sludge layer).

Fig. 1. Formation of drill cuttings plugs during charging of a water-saturated borehole

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Table 1 provides an explanation of the borehole charging scheme in a water-saturated rock mass [5].

Table 1

Explanation of the borehole charging scheme in a water-saturated rock mass

No	Element	Description
a)	Water level position before charging	Shows the initial water level in the borehole before placing the explosive charge. This level is taken into account when planning the charge and selecting explosives to ensure proper detonation.
b)	Water level position after charging	After placing the explosive charge, the water level rises. This change affects the detonation conditions and must be considered to prevent energy loss.
1)	Intermediate detonator	Provides reliable initiation of the main explosive charge, ensuring proper propagation of the detonation wave.
2)	Detonating cord	Transfers the detonation from the intermediate detonator to the explosive charge along the borehole.
3)	Drill cuttings plug (stemming)	Seals the borehole, preventing water from interfering with detonation and increasing explosive efficiency.
4)	Explosive charge	Main explosive material placed in the borehole to fragment the rock mass.
5)	Drill cuttings crust	Formed at the top of the borehole after charging; acts as an additional seal to retain explosive energy within the borehole.

Influence of Water Saturation on Rock Failure Mechanisms. Experimental studies show that when moisture content in rock increases beyond 10–15%, tensile strength decreases by 30–40%. For fractured rocks, the reduction can reach up to 60%. However, this does not always lead to improved fragmentation, since increased moisture raises the viscosity of the medium, thereby reducing the propagation velocity of the detonation wave.

Water present in pores hinders crack development, as part of the shock wave energy is expended on deforming the fluid and overcoming hydrostatic pressure. As a result, part of the rock mass remains insufficiently fragmented, and the yield of fine fractions decreases.

Ways to Improve the Efficiency of Drilling and Blasting Operations under Water-Saturated Conditions.To improve the efficiency of drilling and blasting

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operations in water-saturated rock masses, the following measures are recommended:

- **Use of water-resistant explosives.** Emulsion and slurry explosives are the most effective, as they retain their detonation capability during prolonged contact with water.
- **Borehole sealing.** Plastic liners, polyethylene sleeves, and hydrophobic stemming compounds are used.
- **Adjustment of drilling parameters.** Reducing the drilling pattern spacing by 10–15% and decreasing the stemming height improve the uniformity of rock fragmentation.
- **Preliminary drainage or freezing of the site.** Applied in cases of significant water inflow.
- **Blast modeling.** The use of numerical modeling makes it possible to predict energy distribution and zones of insufficient fragmentation within the rock mass.

Modeling results have shown that when transitioning from cartridged ammonite explosives to emulsion explosives of the ERA-RV type, the efficiency of energy utilization increases by 12–18%, while losses due to water saturation are reduced by almost half.

Conclusion. Thus, conducting drilling and blasting operations under water-saturated conditions requires comprehensive adjustment of traditional approaches, including adaptation of drilling design parameters, application of water-resistant explosives (emulsion, slurry, and cartridged types), development of pre-charging stemming protection schemes, prediction of seismic effects taking into account the degree of rock mass saturation, and modeling of the filtration and stress–strain state of the rock mass using modern geomechanical software packages.

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