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«Central Asian Academic Research Center» LLP is pleased to announce that “News of NAS RK. Series of Geology and Technical sciences” scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of Geology and Technical Sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

«Орталық Азия академиялық ғылыми орталығы» ЖШС «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

ТОО «Центрально-азиатский академический научный центр» сообщает, что научный журнал “Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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DRAINAGE METHODS OF THE PIT WALL MASSIF FOR EFFICIENT GROUNDWATER INTERCEPTION IN OPEN-PIT MINES

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Abstract. Relevance. The stability of pit walls is a key factor determining the safety and efficiency of open-pit mining operations. Excessive groundwater inflow and the presence of water-saturated zones often lead to slope instability, landslides, and reduced productivity. Therefore, developing effective methods for dewatering pit wall massifs is of great practical significance for ensuring sustainable mining operations. **Objective.** The objective of this study was to develop and implement a comprehensive system for draining the pit wall massif using newly designed horizontal and slightly inclined boreholes with camouflet cavities to enhance slope stability. **Methods.** The research methodology involved advanced groundwater interception in formation zones beyond pit boundaries and interception of surface runoff along pit slopes using horizontal, slightly inclined boreholes with camouflet cavities. Experimental investigations were carried out using a polarization optical setup to analyze stress distribution within the rock mass. Field studies included

drilling horizontal boreholes in areas of maximum groundwater accumulation, creating camouflet cavities by controlled blasting, and assessing stress redistribution in the dewatered rock mass. The *results* demonstrated that camouflet cavities formed beyond the rock mass displacement line act as stress concentrators that effectively unload the near-contour zone and enhance slope stability. The introduction of horizontal, slightly inclined boreholes with camouflet cavities ensures efficient drainage of the contour massif, reduces stress concentrations at the slope base, and stabilizes the overall pit wall structure. The proposed set of measures can be widely applied at mining enterprises under similar geological and hydrogeological conditions, contributing to improved safety and productivity in open-pit mining.

Keywords: open-pit mine, drainage, camouflet cavity, borehole, water interception, stability, massif, rock

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КАРЬЕРЛЕРДЕ ЖЕРАСТЫ СУЛАРЫН ТИІМДІ ҰСТАП ҚАЛУ ҮШІН БОРТ МАҢЫ ЖЫНЫС МАССИВІН ҚҰРҒАТУ ӘДІСТЕРІ

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Аннотация. *Өзектілігі.* Карьер борттарының тұрақтылығын қамтамасыз ету — ашық тау-кен жұмыстарының негізгі міндеттерінің бірі болып табылады. Контурға жақын массивте жер асты және жер үсті суларының болуы кернеудің жоғарылауына, тау жыныстарының беріктігінің төмендеуіне және құлау ықтималдығының жоғарылауына әкеледі. Сондықтан аспаптық массивтерді құрғатудың тиімді әдістерін әзірлеу тау-кен кәсіпорындарының қауіпсіздігі мен өнімділігін арттыру үшін өте маңызды. *Зерттеудің мақсаты* Карьер бортының тұрақтылығын арттыру үшін камуфлет қуыстары бар

көлденең және сәл көлбеу ұңғымалардың жаңа конструкцияларын пайдалана отырып, аспаптық массивті құрғату бойынша шаралар кешенін әзірлеу және енгізу. *Әдістері.* Зерттеу әдістемесі Карьер алаңынан тыс жерлерде жер асты суларын алдын-ала ұстап алуға, сондай-ақ камуфляж қуыстары бар көлденең, сәл көлбеу ұңғымалар арқылы беткейлерден жер үсті суларын ұстап қалуға негізделген. Мұндай ұңғымалардың тау жыныстары массивіндегі кернеуді қайта бөлуге әсерін зерттеу үшін поляризациялық оптикалық қондырғы қолданылды. Далалық жұмыстарға жер асты сулары көп жиналатын жерлерде Ұңғымаларды бұрғылау, жарылғыш әдіспен камуфляж қуыстарын құру және құрғатылатын жерде жыныстардың кернеулі-деформацияланған күйін талдау кірді. *Нәтижелер мен қорытындылар.* Нәтижелер массивтің ығысу сызығының артында орналасқан камуфляж қуыстары кернеу концентраторлары ретінде қызмет ететінін, контур маңындағы аймақты түсіретінін және аспаптық жыныстардың тұрақтылығын арттыратынын көрсетті. Камуфляж қуыстары бар көлденең сәл көлбеу Ұңғымаларды қолдану массивтің тиімді дренажын қамтамасыз етеді, көлбеудің төменгі бөлігіндегі кернеу концентрациясын төмендетеді және карьер бортының жалпы түсірілуіне ықпал етеді. Әзірленген іс-шаралар кешені ұқсас гидрогеологиялық жағдайлары бар тау-кен кәсіпорындарында кеңінен енгізу үшін ұсынылады, бұл Ашық тау-кен жұмыстарының қауіпсіздігі мен өнімділігін арттыруға мүмкіндік береді.

Түйін сөздер: карьер, құрғату, камуфлетті қуыс, ұңғыма, суды ұстап қалу, тұрақтылық, массив, тау жынысы

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МЕТОДЫ ОСУШЕНИЯ ПРИБОРТОВОГО МАССИВА ДЛЯ ЭФФЕКТИВНОГО ПЕРЕХВАТА ГРУНТОВЫХ ВОД НА КАРЬЕРАХ

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Аннотация. *Актуальность.* Обеспечение устойчивости бортов карьеров является одной из ключевых задач открытых горных работ. Наличие грунтовых и поверхностных вод в прибортовом массиве приводит к росту напряжений, снижению прочности пород и повышению вероятности обрушений. Поэтому разработка эффективных методов осушения массивов имеет важное значение для повышения безопасности и производительности горных предприятий. *Цель.* Разработать и внедрить комплекс мер по осушению прибортового массива с использованием горизонтальных и слабо наклонных скважин с камуфлетными полостями для повышения устойчивости бортов карьера. *Методы.* Исследования основаны на принципе опережающего перехвата подземных вод в зонах их формирования за пределами карьерного поля и перехвата поверхностных вод с откосов посредством горизонтальных и слегка наклонных скважин с камуфлетными полостями. Влияние скважин на перераспределение напряжений изучалось с использованием поляризационной оптической установки. Полевые работы включали бурение скважин, создание камуфлетных полостей взрывным способом и анализ напряжённо-деформированного состояния пород в осушаемом участке. *Результаты и выводы.* Установлено, что камуфлетные полости, расположенные за линией сдвига массива, выполняют функцию концентраторов напряжений, разгружают приконтурную зону и повышают устойчивость прибортовых пород. Применение горизонтальных и слабо наклонных скважин с камуфлетными полостями обеспечивает эффективное осушение массива, снижает концентрацию напряжений в нижней части откоса и способствует общей разгрузке борта карьера. Разработанный комплекс мероприятий рекомендуется к внедрению на горных предприятиях с аналогичными гидрогеологическими условиями для повышения безопасности и эффективности открытых горных работ.

Ключевые слова: карьер, осушение, камуфлетная полость, скважина, перехват воды, устойчивость, массив, горные породы

Introduction. In deep quarries with complex hydrogeological conditions, it is necessary to use effective methods of protecting mine workings (Bosikov et al., 2023; Klyuev et al., 2024) from groundwater, since the presence of a saturated aquifer in the slope zone significantly reduces the stability of the sides, leads to additional loads on the massif and contributes to the development of deformation processes, including landslides and displacements. In conditions of increased water inflow, drainage systems aimed at preemptive action are especially relevant, allowing to minimize filtration flows even before their contact with the quarry slopes. Currently, various drainage methods are used, including vertical dewatering wells,

absorption and injection columns, trench drainage, as well as shallow horizontal drainage systems placed in benches or directly in the slopes of quarries. However, the effectiveness of traditional methods is limited by the geological and filtration properties of the massif, as well as the possibility of clogging of filter elements and the need for continuous operation of expensive pumping units. World practice shows that horizontal directional drilling, especially in conditions of complex rock mass structure, is one of the most effective approaches to marginal zone drainage (Müller et al., 2011; Galperin, 2003). However, even with this method, up to 40% of groundwater can reach the quarry edge, which creates additional risks and complicates open-pit mining (Buragohain, et al., 2024). Groundwater reaching the slope leads to waterlogging of the edge mass, reduces the strength characteristics of rocks and increases the likelihood of bench failure, especially during long-term quarry operation in conditions of seasonal floods or close occurrence of aquifers.

The conducted study is aimed at solving these problems by developing and applying a method of advanced interception of groundwater before it reaches the slope. In particular, a system of horizontal and slightly inclined wells with camouflage cavities is proposed, which are formed within the massif by means of a directed blast and act as effective accumulators and concentration zones for water outflow (Baymirzaev et al., 2023; Baymirzaev et al., 2021; Toshov et al., 2024). This approach ensures remote collection of water from both upper and lower horizons, reducing filtration loads on slopes, and also redistributing the stress state of the massif due to the formation of an artificial free cavity, which is confirmed by both field measurements and optical experiments on stress diagrams. The borehole design takes into account the use of special explosive charges and fast-hardening waterproofing materials, which allows not only to form camouflage cavities of a given shape and volume, but also to exclude the reverse penetration of water to the lower levels of the massif (Klyuev et al., 2024; Zykova et al., 2019; Malozyomov et al., 2024). In addition, the created vacuum effect in the pear-shaped cavity promotes active water collection due to the rarefaction effect, which further increases the efficiency of the drainage system without the need for a constant power supply. Based on the introduction of a new design of drying gently inclined boreholes with a camouflage cavity, an engineering complex has been developed that combines both proactive interception of water in places of its formation outside the quarry (Shishkin et al., 2024) field and collection of water from the surface of slopes. This allows almost completely eliminating the filtration penetration of groundwater into the edge zone, restoring the stability of the massifs and ensuring stable mining operations at long horizons (Kulikova et al., 2024; Shishkin et al., 2024). The efficiency of the proposed scheme is confirmed by pilot tests, including those at coal and ore quarries in Uzbekistan, where traditional drainage methods proved ineffective in conditions of low permeability of semi-rocky rocks. The test results indicate a significant decrease in rock moisture, a decrease in the number of emergency areas and an increase in labor productivity. Thus, conducting

comprehensive hydrogeological studies, point design of the drainage system, choosing rational drilling parameters and configuration of camouflage cavities, as well as the construction of pumping or water collection stations with the connection of drainage pipelines are key stages in the implementation of an effective system of preventive drainage. These measures ensure sustainable protection of the marginal massif from flooding, allow the scheme to be adapted to various geological conditions and make a significant contribution to improving the industrial and environmental safety of open-pit mining.

Materials and methods. The bulk of deposits in Uzbekistan are located in mountainous or hilly areas. In these places, water inflows are formed mainly along the sayas, where water flows along the surface only during flood periods. That is, on average, about one or two months a year. The rest of the time, the water forms an aquifer under the surface of the saya, which, reaching the quarry, open-pit mine, moistens the marginal massif.

However, in addition to this, groundwater can also be formed from other sources, rivers, lakes, canals, etc. This water enters the open-pit mines, quarries, moistening the marginal massif (Mekhtiyev et al., 2023; Gutiérrez et al., 2014). Moistening of the marginal rocks reduces the stability of mine workings, reduces productivity, etc. Currently, there are a large number of methods and ways of draining the marginal massif. Each of them has its advantages and disadvantages.

The closest to the proposed method, in design, is the method with horizontal drains (Fig. 1). The method consists of laying a horizontal drain, which creates an outflow and reduces the flow pressure forces. This method of draining the massif works well with high filtration properties of rocks. In clayey and semi-rocky rocks, this method is ineffective, since in semi-rocky rocks the filtration properties of rocks are not enough, and in clayey rocks, rapid silting of the drain channel occurs. To intercept trench waters, outside the quarry field, we have developed a design of a slightly inclined well with a camouflage cavity. At the end of a low-angle borehole, an accumulating camouflage cavity is created in the massif by explosive means, which, due to the special design of the explosive charge during the explosion, compacts the lower part of the cavity and isolates it from water with a special waterproof composition. Thus, the lower horizons are reliably protected from flooding. Creation of a free surface allows for the accumulation of groundwater in the camouflage cavity. Since groundwater, being in a compressed environment, tends to fill the free capacity, acting on the principle of least resistance.

When pumping water from the camouflage cavity through an inclined well, it can lead to a decrease in water inflow, in this case, a pear-shaped void directed upwards is formed in the camouflage cavity, creating a vacuum effect. Under the influence of vacuum, water begins to be sucked out of the aquifer, which significantly increases the water outflow from it. Therefore, water leakage past the wells is practically excluded. With a two-week flush, almost spring water will flow out of the wells. This water can be used both for drinking and for irrigation of

agricultural land. In the conditions of Uzbekistan, obtaining clean water is very important, while the marginal massif will be completely drained and the stability of the rocks will be restored (Toshov et al., 2024; Zairov, Nomdorov, Ravshanova, 2023). The drainage works start with hydrogeological studies around the quarry field in order to detect groundwater, determine its capacity and water inflow, as well as the chemical components of the water itself. Based on the data obtained by hydrogeologists on the location of the aquifer, the development of a project for draining the perimeter massif begins. According to the project, work begins on the construction of a water intake station. At the beginning (Fig. 1), a bench is built - 1, from which gently inclined wells are drilled - 2 to the aquifer - 3, by means of an explosion, camouflage cavities are formed - 4, the explosions are carried out with a delay, which does not allow the destruction of the lower aquifers.

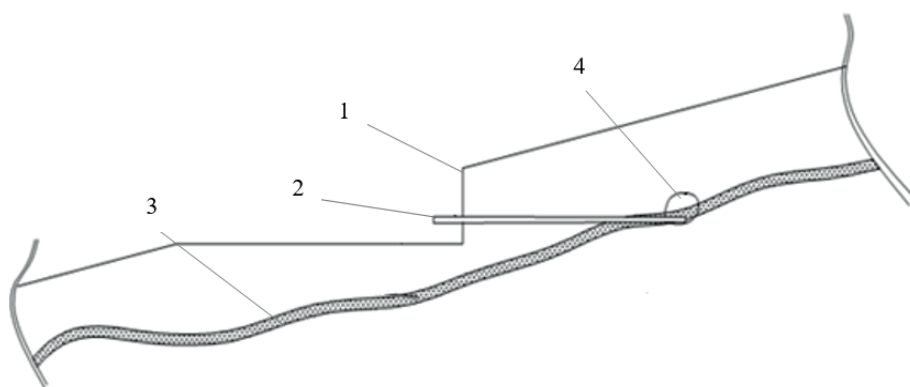


Figure 1. Groundwater diversion project, where: 1 – bench, 2 – slightly inclined well, 3 – aquifer, 4 – camouflage cavity

The design of the casing pipe with a camouflage charge attached to (Fig. 2). After the bench construction and well drilling, a metal casing pipe - 1 is inserted into them, in which the camouflage charge - 2 is located, the size of which is calculated in accordance with the thickness of the aquifer. Under the action of the explosion, a camouflage cavity is formed with a size of the thickness of the aquifer. Under the action of the explosion, a container with a quickly hardening waterproof mass - 3 located under the charge is squeezed out to the bottom of the camouflage cavity, under the action of a metal wad - 4 located between the container and the charge, below the container with a quickly hardening waterproof mass, a window is made in the pipe - 5, which serves for faster squeezing out of the quickly hardening waterproof mass by the explosion, thereby creating a waterproof layer that prevents water from penetrating to the lower horizon. In addition, under the influence of the explosion, the pipe opens, for which purpose in its upper part, above the explosive charge, cuts are made for the length from the beginning of the charge to the end of the pipe, by 2/3 of the pipe wall thickness - 6, in the opened

part of the pipe the lower part of the camouflage cavity is additionally compacted, thereby eliminating the possibility of squeezing the pipe out under the action of water pressure and serves to reduce silting of the camouflage cavity. In the center of the explosive charge there is a detonator - 7. In order to isolate the explosive and the quickly hardening waterproof mass, the pipe is covered with a waterproof shell (polyethylene). A polyethylene wad is placed behind the charge, which protects against gas penetration into the well and locks in water – 8. To intercept water seeping into the well, a perforated section of the pipe is made – 9, a thread is cut behind the perforated section of the pipe – 10. After the explosion and the formation of a camouflage cavity, the metal pipe is unscrewed and a plastic pipe is attached to the water-collecting section of the pipe by means of a threaded connection – 11. At the end of the pipe, a small skirt with a cone towards the center is made – 12, which additionally reduces water penetration into the well.

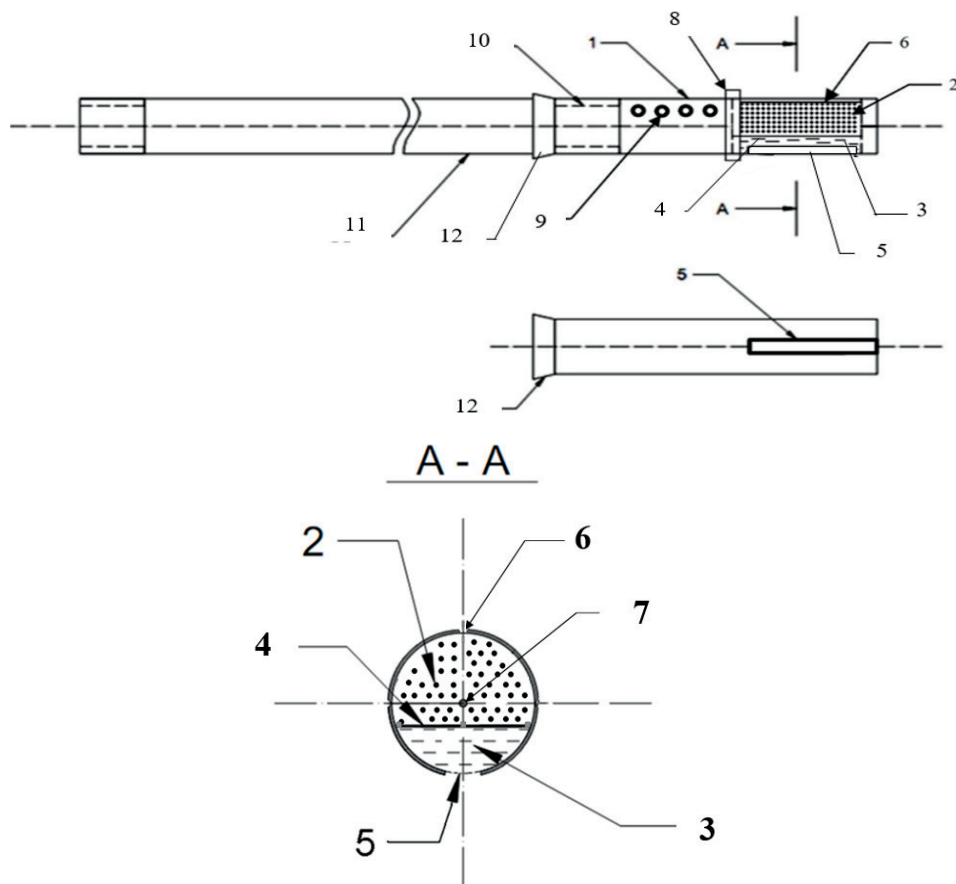


Figure 2. Casing pipe design with a camouflage charge.

1 – casing pipe, 2 – camouflage charge, 3 – fast-hardening waterproof liquid, 4 – metal wad, 5 – window, 6 – cut, 7 – detonator, 8 – polyethylene wad, 9 – perforated section of pipe, 10 – thread, 11 – plastic pipe, 12 – skirt

Results and discussion. Water in the aquifer, trying to fill the free cavities, rushes from the front and sides into the camouflage cavity, from where it comes out to the surface through the casing pipe. The casing pipes are connected to the pipe of the bypass water conduit. Its size is calculated taking into account the maximum flood along the sai. Along the entire length of the bench, these pipes are perforated from above and on the sides to collect surface water during the flood. On the bench platform, behind the pipe of the bypass water conduit, a shaft is made to collect flood waters. On the upper part of the bench, reinforcement is mounted, on which a chain-link mesh is stretched, which will retain debris. The advantage of this method of advanced drainage is as follows: interception of groundwater before the formation of an aquifer, the absence of energy-intensive equipment during operation, no need for power grids, ease of preventive and repair work, no need for constant monitoring. In addition, the possibility of obtaining clean drinking water, which can be sent through pipes to neighboring cities or villages, reliable protection of lower horizons from flooding.

However, hydrogeologists do not always find all available water inflows or in the immediate vicinity of the quarry field there are rivers, lakes, reservoirs, canals, etc. creating additional aquifers, which are opened during mining operations with the release of water to the surface of the bench or slope of the side. In such cases, we propose a method of intercepting water with a horizontal (slightly inclined) well with a camouflage cavity, which serves for the advanced interception of water beyond the sliding plane of a possible landslide. This creates conditions for avoiding the formation of landslides and other deformations. The condition of limit equilibrium for the algebraic addition of forces on the most stressed surface is written in the following form:

$$n_{set} = \frac{tg\varphi_p \cdot \sum P_i \cdot g \cdot \cos\varphi_i + C_p \cdot \sum l_i}{\sum P_i \cdot g \cdot \sin\varphi_i}$$

Calculations taking into account the water content of the massif were made using the well-known formula (Mochalov, Popov, Eremin, 2016):

$$n = \frac{\sum (P_i \cdot \cos\varphi_i - D_i) + k_i \cdot l_i}{\sum P_i \cdot \sin\varphi_i},$$

Work on the creation of a water interception station begins with the development of a project, which includes calculations and construction of the plane of displacement of the marginal rocks. Based on the project (Fig. 3), gently inclined wells are drilled. The length of the well is determined by adding the distances from the slope surface to the massif displacement line (A) and the magnitude of the seismic impact of the explosion during the formation of a camouflage cavity in the massif (B).

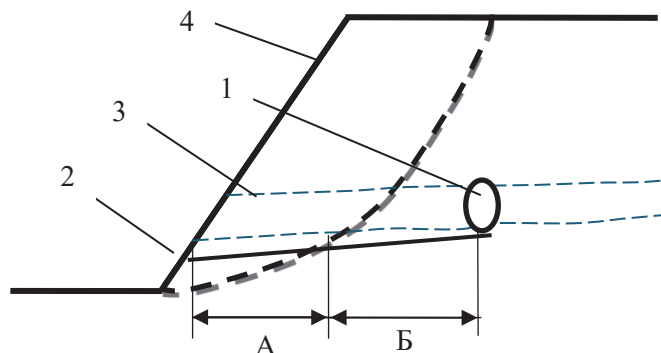


Figure 3. Determining the distance from the surface to the camouflage cavity.
1 – camouflage cavity, 2 – well, 3 – aquifer, 4 – bench

To form a camouflage cavity and drain water into the well, a casing pipe is inserted at the end of which a nozzle made of the proposed design of an explosive charge is located. The nozzle consists of a pipe section - 1, at the end of which an explosive charge - 2 is placed, opposite to which a slit - 3 is made for the width of the cumulative recess - 4. After the explosion, an elongated pear-shaped cavity is formed due to the energy jet from the cumulative charge. To strengthen the lower part of the pipe, a metal insert - 5 is installed under the charge. During the explosion, the upper part of the pipe opens due to a cut - 6 from the slit to the end of the pipe for the entire length of the explosive charge. The opened part of the pipe, due to the energy of the explosion, is pressed into the lower part of the camouflage cavity, thereby compacting the lower horizon. This will significantly reduce water penetration to the lower horizons, in the opened part of the pipe it additionally compacts the lower part of the camouflage cavity, thereby eliminating the possibility of squeezing the pipe out under the action of water pressure and serves to reduce silting of the camouflage cavity. In the center of the explosive charge there is a detonator - 7. In order to isolate the explosive and the quickly hardening waterproof mass, the pipe is covered with a waterproof shell (polyethylene). A polyethylene wad is placed behind the charge, which protects against gas penetration into the well and locks in water - 8. To intercept water seeping into the well, a perforated section of the pipe is made - 9, a thread is cut behind the perforated section of the pipe - 10. After the explosion and the formation of a camouflage cavity, the metal pipe is unscrewed and a plastic pipe is attached to the water-collecting section of the pipe by means of a threaded connection - 11. At the end of the pipe, a small skirt with a cone towards the center is made - 12, which additionally reduces water penetration into the well.

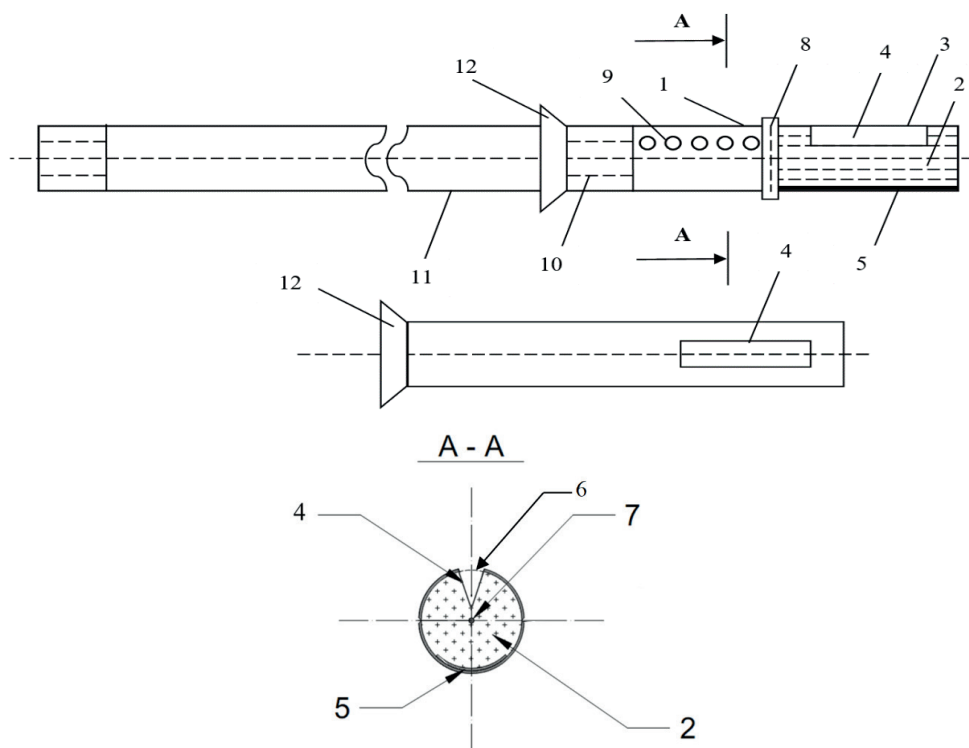


Figure 4. Casing pipe design. 1 – metal pipe, 2 – explosive, 3 – slot, 4 – cumulative recess, 5 – metal insert, 6 – cut, 7 – detonator, 8 – polyethylene wad, 9 – perforated section of pipe, 10 – thread, 11 – plastic pipe, 12 – skirt

The application of the presented engineering solution (Figure 4) allows for the implementation of a localized and targeted drainage effect, which focuses on the point interception of groundwater within the most saturated sections of the massif. Unlike traditional vertical or inclined dewatering wells, where the coverage area depends on the natural distribution of filtration flows, the use of slightly inclined wells with controlled formation of a camouflage cavity ensures precise spatial positioning of the discharge volume. This is especially important in conditions where the aquifer has an intermittent or variable structure, and its filtration properties complicate the application of classical drainage methods. An additional advantage is the possibility of geometric control over the direction of the drainage effect, which makes this method applicable in situations where it is necessary to avoid opening the lower horizons or contact with particularly vulnerable structural zones of the massif. The change in the stress state near the cavity created as a result of blasting operations has a relieving effect on the adjacent section of the edge massif, reducing the level of horizontal and tangential stresses at the most critical points. This ensures not only efficient water removal, but also stabilization of the structural integrity of the massif in conditions requiring special control over slope stability.

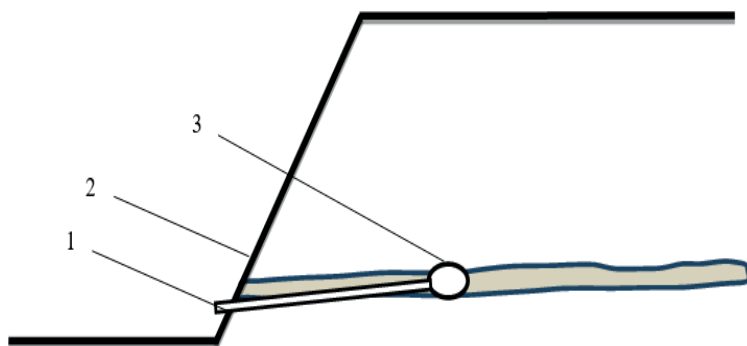


Figure 5. Designs of horizontal drainage wells with a camouflage cavity. 1 – well, 2 – bench, 3 – camouflage cavity

The diagram in Figure 5 demonstrates the versatility of the technology in field conditions where it is impossible to organize fixed benches or where prompt intervention is required without large-scale engineering preparation. Unlike the previously described option, this method can be used regardless of the current stage of mining development, which is especially important when there is a need for a quick response to local filtration zones or unexpected water shows. The ability to drill horizontal or gently inclined wells with an outlet to the desired aquifer allows you to vary the intervention parameters taking into account the actual hydrogeological conditions. Due to the autonomy of the design, a closed and targeted water interception system is created, where the groundwater flow is stabilized due to the free cavity and the created vacuum. This arrangement makes it possible to not only drain the edge massif, but also ensure its long-term protection from over-moistening without the need for constant maintenance or power supply. In addition, the system is easily adapted to the existing pumping infrastructure of the quarry, and in some cases can function by gravity, reducing operating costs. All this makes this method particularly effective in mountainous regions with seasonal instability of aquifers and developed rock fracturing, where traditional drainage methods demonstrate limited effectiveness.

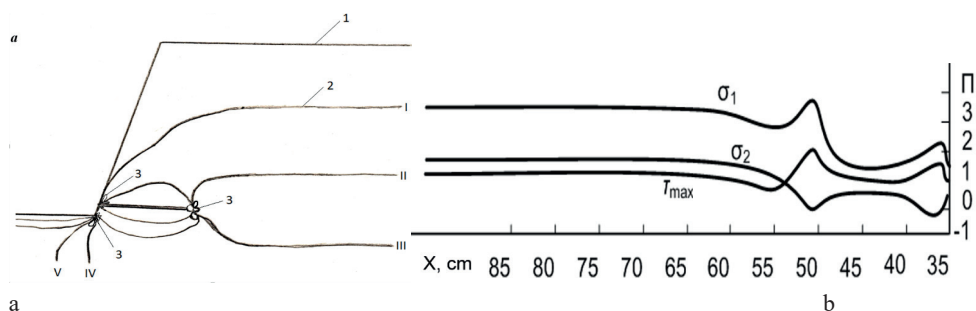


Figure 6. Pattern of bands in the presence of a camouflage cavity in the massif (a) and stress diagrams (b)

The results of laboratory studies, visualized in Figure 6, allow us to quantitatively and qualitatively evaluate the effect of redistribution of the stress state of the massif in the presence of a camouflage cavity. Under conditions of high massif stress, typical of quarries with steep slopes and significant development depth, the key stability factor is the reduction of tangential stresses in the zones of potential sliding planes. The presented patterns of bands and diagrams show that the creation of a closed cavity within the massif leads to the formation of an unloading zone covering both the volume immediately adjacent to the cavity and the lower part of the slope. This leads to a redistribution of stresses from potentially dangerous zones to more stable areas of the massif. The most pronounced effect is observed in the case of placing the cavity outside the shear line, which contributes to the destruction of equilibrium conditions in the zone of a possible landslide and the rupture of the hydraulic connection between the aquifer and the bench surface. Thus, the proposed technology works not only as a drainage element, but also as a geomechanical stabilizer, forming a protective barrier against the development of deformations. As a result, a complex effect is achieved: a reduction in water content, redistribution of internal forces and an increase in the overall stability of the rock mass, which is especially important in conditions of intensive development of minerals at great depths and in unfavorable geological conditions.

Conclusion. The study presented in the article is aimed at developing and substantiating a set of engineering and technical solutions that ensure effective drainage of the edge massif in deep quarries with complex hydrogeological conditions. Unlike traditional methods of dewatering based on vertical or shallow horizontal drains, the proposed technology includes the use of slightly inclined boreholes with the formation of camouflage cavities in the massif, which makes it possible to implement the principle of advanced interception of groundwater before it reaches the quarry slopes. Analysis of experimental and theoretical data showed that camouflage cavities located outside the massif displacement line perform a dual function: firstly, they serve as reservoirs for the accumulation of groundwater and points of effective drainage, and secondly, they act as stress concentrators, forming an unloading zone inside the massif and thereby contributing to an increase in its stability. This is confirmed by the results of modeling the stress state of the massif, performed using optical and geomechanical methods, as well as full-scale tests demonstrating a decrease in the level of filtration loads and shear stresses near the lower edge of the slope.

The developed method not only allows avoiding the use of energy-intensive pumping units and complex engineering infrastructure, but also adapts to various engineering and geological conditions of deposits. Due to the design flexibility and targeted nature of the impact, the system can be implemented both in conditions of active quarry production and in areas with limited access to the surface. The economic efficiency of the method is manifested in reduced operating costs, increased cycles between repairs and increased labor productivity due to stabilization of the mining situation.

Thus, the implementation of a set of drainage measures using gently inclined wells and camouflage cavities is a progressive and scientifically sound approach to solving the problem of quarry drainage. The technology has a high potential for wide practical application in mining enterprises, especially in areas with active water inflow and heterogeneous structure of the massif. The obtained results can be used as a basis for new design solutions for managing hydrogeomechanical risks during open-pit mining and form the basis for further applied and theoretical research in the field of slope stability and filtration-strength properties of marginal rocks.

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