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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
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ХАБАРЛАРЫ

ИЗВЕСТИЯ

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АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

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INVESTIGATION OF THE BLOCK CAVING GEOTECHNOLOGY AT DEEP HORIZONS

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Abstract. The purpose of the work is to develop a new modification of the process chart of the block caving geotechnology with vibration ore drawing for the safe and sustainable development of underground mining of chromite deposits that ensures an increase in the production capacity of blocks in the deep horizons of the "10th Anniversary of Independence of Kazakhstan" mine.

Theoretical and methodological rationale of the results reliability is based on the explanation of the nature of the development using effective options of the new modification of the process chart of the block caving geotechnology with vibration ore drawing under the artificial stope sill during underground mining of chromite reserves of the "10th Anniversary of Independence of Kazakhstan" mine.

The methodology and geomechanical assessment of parameters of structural elements and the interaction of draw points (the methodology of Professor D. Laubscher) have been developed for the block caving geotechnology with vibration ore drawing under the artificial stope sill in difficult mining conditions as exemplified in a deep mine in Kazakhstan. The essence of the proposed development lies in the fact that within the level of the underground mining, to apply the new modification of the process chart for development of ore deposits using the block

caving geotechnology, the process chart is used in combination with the vibration ore drawing under the artificial stope sill according to the detailed process chart for layered development of an artificial funnel with subsequent transportation of the withdrawn ore mass from the production block by the mine electric locomotives to the lifting shaft.

In accordance with the proposed block caving geotechnology with vibration ore drawing in the mining conditions of the "DNK" mine corresponding to the above-described production processes in conjunction with the process chart for this geotechnology, we recommend the use of technological equipment and complexes for performing underground driving as well as for the construction of artificial stope sills made of reinforced concrete.

Keywords: mine, underground mining, block caving, artificial stope sill, stress-strain state, process chart

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ТЕРЕҢ ШАХТАЛАРДАҒЫ ГОРИЗОНТТАРДЫҢ ӨЗДІГІНЕН ҚҰЛАУ ГЕОТЕХНОЛОГИЯСЫН ЗЕРТТЕУ

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Аннотация. Жұмыстың мақсаты – «Қазақстан Тәуелсіздігінің 10 жылдығы» шахтасының терең горизонттардағы блоктардың өндірістік қуатын арттыруды қамтамасыз ететін хромит кен орындарын жерасты өндіруді қауіпсіз және тұрақты игеру үшін руданы діріл әдісімен шығаруды өздігінен құлау геотехнологиясының технологиялық схемасының жаңа модификациясын әзірлеу арқылы гозизонттардың өздігінен геотехнологиясын зерттеу.

Зерттеу нәтижелердің дұрыстығын теориялық және әдіснамалық қамтамасыз ету «Қазақстан тәуелсіздігінің 10 жылдығы» шахтасының хромит қорларын жерасты қазу кезінде блоктың жасанды түбінің астындағы кенді дірілмен шығарумен өздігінен құлау геотехнологиясының технологиялық схемасын жаңа модификациялаудың тиімді нұсқаларын әзірлеудің мәнін негіздеу арқылы горизанттаардың құлау технологиясын қарастырылды.

Конструктивті элементтердің параметрлерін геомеханикалық бағалау және Қазақстанның терең шахтасының мысалында күрделі тау-кен жағдайларында блоктың жасанды түбінің астындағы кеннің діріл шығаруымен өздігінен құлау геотехнологиясының шығару пункттерінің кернелі-деформациялық жағдайына (профессор Д.Лобширдің әдіснамасы) байланысты ұсынылды. Ұсынылып отырған игерудің мәні мынада: жерасты тау-кен жұмыстарының алдыңғы қабатының шегінде өздігінен құлау геотехнологиясы бойынша таужыныстарын игерудің технологиялық сұлбасның жаңа модификациясын қолдану үшін технологиялық сұлбада блоктың жасанды түбінің астындағы кенді дірілмен шығару мақсатында жасанды шұңқырдың құрылымын қабатты өңдеудің сұлбасын зерттеу арқылы оларды сипаттап, зерттеу нәтижесінде шығарылтын кен сілемін игерудегі блогтан тасымалдаумен бірге оқпанға дейін қолданылатын көтергіш құрылымдары жұмыс жасай алады.

Мақалада зерттелген ғылыми зерттеу нәтижесі өндірістік процестерге сәйкес келетін «Қазақстан Тәуелсіздігінің 10 жылдығы» шахтасының тау-кен жағдайларында кеннің дірілмен шығарылуымен ұсынылған өздігінен құлату геотехнологиясына сәйкес, осы геотехнология бойынша технологиялық схемамен байланыстыра отырып, жерасты тау-кен жұмыстарын игеру мақсатында технологиялық жабдықтар мен кешендерді, сондай-ақ темір-бетон материалдарын пайдалана отырып, жасанды конструкцияларын қолдануды ұсынып отыр.

Түйін сөздер: шахта, жерасты игеру, өздігінен құлау, жасанды блок түбі, кернеулі-деформациялақ жағдай, технологиялық сұлба

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ИССЛЕДОВАНИЕ ГЕОТЕХНОЛОГИИ САМООБРУШЕНИЯ НА ГЛУБОКИХ ГОРИЗОНТАХ ШАХТЫ

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Аннотация. Цель работы – разработка новой модификации технологической схемы геотехнологии самообрушения с вибровыпуском руды для безопасного и устойчивого развития подземной добычи хромитовых залежей, обеспечивающих повышение производственной мощности блоков на глубоких горизонтах шахты «10-летие независимости Казахстана».

Теоретическим и методологическим обеспечением достоверности результатов, являются обоснование сущности разработки эффективных вариантов новой модификации технологической схемы геотехнологии самообрушения с вибровыпуском руды под искусственным днищем блока при подземной отработке хромитовых запасов шахты «10-летие независимости Казахстана».

Разработана методика и геомеханическая оценка параметров конструктивных элементов и взаимодействие пунктов выпуска (методология профессора Д. Лобшира) геотехнологии самообрушения с вибровыпуском руды под искусственным днищем блока в сложных горнотехнических условиях на примере глубокой шахты Казахстана. Сущность предлагаемой разработки заключается в том, что в пределах этажа ведения фронта подземных горных работ для применения новой модификации технологической схемы отработки рудных залежей по геотехнологии самообрушения используется технологическая схема в комбинации с вибровыпуском руды под искусственным днищем блока, подробно расписанной технологической схемой послойной отработки создания конструкции искусственной воронки с последующей транспортировкой выпущенной рудной массы из эксплуатационного блока шахтной электровозной логистикой до подъемного ствола.

В соответствии с предлагаемой геотехнологией самообрушения с вибровыпуском руды в горнотехнических условиях шахты «ДНК» соответствующей вышеописанным производственным процессам в увязке с технологической схемой по данной геотехнологии нами рекомендуется применение технологического оборудования и комплексов для выполнения подземных проходческих горных работ, а также по сооружению искусственных конструкций днища блока, образуемых с использованием железо-бетонных материалов.

Ключевые слова: шахта, подземная разработка, самообрушение, искусственное днище, напряженно-деформированное состояние, технологическая схема.

Introduction

Rationale of the essence of effective options of the new modification of the process chart of block caving geotechnology with vibration ore drawing under the artificial stope sill during underground development of chromite reserves of the

"10th Anniversary of Independence of Kazakhstan" mine. The components of the methodological rationale for the application of the new modification of the block caving geotechnology with vibration ore drawing under the artificial stope sill in complex mining and geomechanical conditions of the Don mining and processing plant are the goal, idea and main tasks, the novelty of the results obtained in the development of the new modification of the process chart of block caving geotechnology with vibration ore drawing for safe and sustainable development of underground mining of chromite deposits, ensuring an increase in the production capacity of blocks at deep horizons of the "10th Anniversary of Independence of Kazakhstan" mine of the Don mining and processing plant and the 1.5 and 2.0 increase in the productivity of the operating block.

The necessary analysis of technical characteristics helps to select vibratory vehicles used for the ore drawing under the artificial stope sill during the development of chromite reserves using the block caving geotechnology by means of high-performance vibratory loading and hauling equipment.

The obtained results will be used in testing the block caving technology and vibration ore drawing, which ensures increased productivity in the mine blocks at deep levels of the DNK mine of the Don mining and processing plant of JSC "Transnational company Kazchrome".

Today, the issues related to the efficient use of underground mining systems and exploitation of chrome reserves with due account for the mining, geological and mining technical features of deep mine horizons, remain urgent, and this requires the solution of a number of scientific and practical problems related to determining rational design parameters and optimal technological solutions.

Research materials and methods

The mining conditions of the chromite deposit development are classified as very complex due to the instability and high fracturing of the ores and host rocks developed by the DNK mine and are characterized by a strength coefficient of the host rocks of about 8÷10, and that of the ores – 6÷8. Moreover, due to structural weakening and the phenomenon of the extensive scale effect, the strength coefficient of the ores and rocks does not actually exceed 4-6.

These properties of the rock mass create certain conditions for the use of the block caving. However, the instability and tendency to uncontrolled caving are the source of constant strong manifestation of rock pressure during all mining operations at the mines of the Don mining and processing plant. In most cases, the supports of development workings and stopes, even despite double support, get destroyed and go out of order long before the completion of the mining.

With all its advantages in terms of maximum production capacity and the lowest cost, the use of the block caving technology in the mines of the Don mining and processing plant is a forced technical solution for underground mining of chromites.

The work on the selection of technological options for developing the deposit, finding ways to overcome the negative aspects of mining and geological conditions and increasing the overall efficiency of underground chromite mining has been performed by many Institutes and laboratories – the Mining Institute after the D.A. Kunayev, the Mining Institute of the Ural Branch of the Russian Academy of Sciences, the Ust-Kamenogorsk Institute "KAZGIPROTSVETMET", the VIOGEM and VSEGINGEO Institutes, as well as the plant's own research group. These studies have produced the expected results and have met the requirements in the relevant periods (Lushniko, et al, 2013; Neverov, et al, 2003).

However, today there are pressing problems in the development of chromite deposits of the Kempirsay field, which are mined using the underground method at the DNK mine:

- a high degree of structural disturbance of the rock mass of the Don chromite deposits has been established, where 4 main systems of cracks with an intensity of 3 to 20 per linear meter and spatial orientation have been identified. As the development goes deeper, no significant positive changes in these indicators have been established that allows the use of the block caving technology in the development of lower horizons and adjacent deposits;
- based on the identified qualitative and quantitative indicators of the rock mass, taking into account the influence of geotechnological factors, the Don chromite ore mass is classified as the lowest fifth category of stability;
- for safe mining operations and the balance of the main technological processes in the system of development with block caving, the preferred type of support in the mine is a three-layer support with prefabricated metal support made of special profiles SVP-27;
- the VNIITsvetmet Institute is performing experimental industrial testing of the development system with downward layer cut-and-fill mining;
- further underground mining of chromites and expansion of production capacity at the mines of the Don mining and processing plant are associated with the involvement of deeper deposits of the Kempirsay field into the operation.

In this regard, the transition to greater depths entails exaggeration of mining conditions, mainly geomechanical but also technological. This, in turn, causes new difficulties in ensuring safe working conditions, has an even more negative impact on the labor intensity and on the quality and completeness of extraction, and ultimately entails an increase in the cost of production (Eremenko, et al, 2016; Eremenko, et al, 2015; Analysis of the possibility No. 04-3.1.4-9-52 2019).

Based on the current real situation related to the development of chromite reserves, we propose the new modification of the process chart of the block caving geotechnology with vibratory ore drawing for the safe and sustainable development of underground mining of chromite deposits. The modification will ensure the solution of an urgent production and technical problem and increase the production capacity of blocks by more than 1.5-2.0 times in complex mining and geomechanical conditions at deep horizons of the DNK mine of the Don mining and processing plant using high-performance vibration units installed under artificial technological structures of the stope sill (Eremenko, et al, 2016; Tishkov, 2018; Couto, et al, 2018).

Results of the experiments

The idea of the proposed development is that within the level of underground mining operations, for the application of the new modification of the process chart for the development of ore deposits using the block caving geotechnology, the process chart is used in combination with vibratory ore drawing under the artificial stope sill (Figure 1 - a, b, c). A technological structure of a sill pillar is constructed in the form of a funnel using reinforced concrete backfill mass in layers, and is located above and between the haulage roadways using high-performance self-propelled drilling and loading and hauling machines. This ensures safe and sustainable development of chromite reserves with a 1.5-2.0 increase in the production capacity of the block by installing adaptive high-performance vibration feeders in the artificial discharge chamber of the stope sill. The chamber is made of reinforced concrete backfill at the draw level at the deep horizons of the DNK mine of the Don mining and processing plant, from where the drawn ore mass is transported from the production block by means of mine electric locomotives to the hauling shaft.

In order to ensure the 1.5-2.0 increase in the completeness of underground mining of chromites in the given mining and technical conditions at deep horizons of the DNK mine, in accordance with the above concept of the proposed block caving geotechnology with vibratory ore drawing under the artificial stope sill, it is necessary to perform the underground mining operations in the block section in the following directions:

- Performing mining operations to prepare the block.
- Driving the workings to create a technological structure of the artificial stope sill made of layers of reinforced concrete backfill above and between pillars located respectively under and between the haulage roadways, as well as an artificial structure of a chamber with a vibration feeder associated with the haulage roadway;
- Driving the haulage roadway and connecting the artificial chamber in order to install the vibration feeder.

A - A

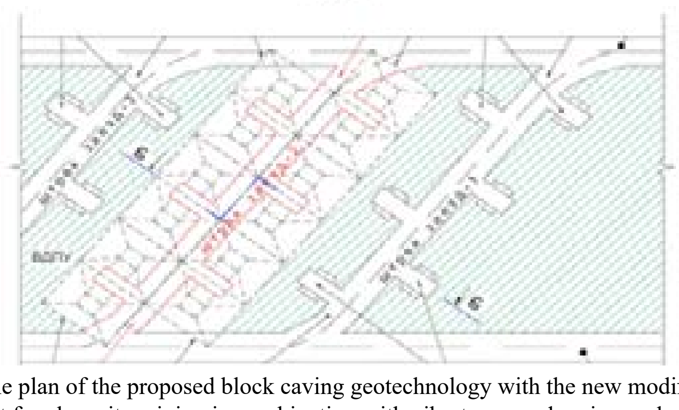

Figure 1a. The plan of the proposed block caving geotechnology with the new modification of the process chart for chromite mining in combination with vibratory ore drawing under the artificial stope sill at deep levels of the mine.

Б - Б

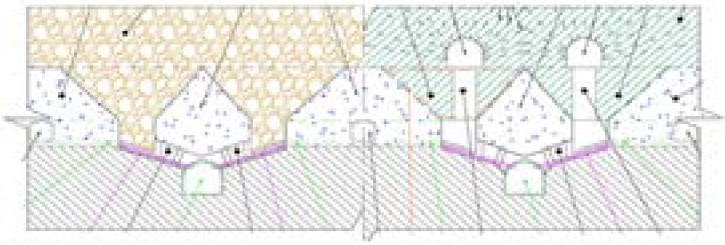

Figure 1b. Section along Б-Б line of the proposed block caving geotechnology with the new modification of the process chart for chromite mining in combination with vibratory ore drawing under the artificial stope sill at deep mine levels.

В - В

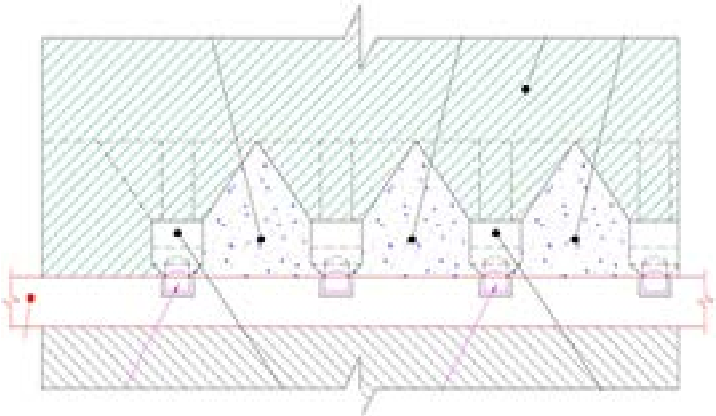

Figure 1c. Section along B-B line of the proposed block caving geotechnology with the new modification of the process chart for chromite mining in combination with vibratory ore drawing under the artificial stope sill at deep mine levels.

To this end, according to the sequence of mining of the reserves of the Almaz-Zhemchuzhina deposit from the 480 m horizon, first of all, to prepare the block we need to drive a haulage roadway from the southwestern drift and hole it through the southeastern drift (Figure 1a, b, c). After that, from the ventilation drift, it is necessary to drive a haulage roadway to the border of a safety pillar, then to drive a main opening above the haulage roadway. At the same time, the air flow onto the upper haulage roadway in this section goes through the ventilation and manway raise, which is connected in this area of the block. From the haulage roadway it is necessary to drive two workings: one will serve to lift the material, the second will be a manway raise. All exhaust air will go through the haulage roadway (Bekbergenov, 2017; Imansakipova, et al, 2020).

In this regard, with the use of high-performance self-propelled drilling plants and loading and hauling equipment at the stages of road heading for the construction of artificial workings, at the undercut level it is also possible to use self-propelled equipment with due account for the recommendations of the Don mining and processing plant. At the same time, at the undercut level, a stope drift is driven using self-propelled equipment with one drill drift, and fan holes are drilled with self-propelled drilling plants in both directions at the height of 10-15 m in order to reduce the preparatory development operations. In this regard, it is necessary to do additional research on the selection and rationale of technological parameters and the corresponding self-propelled equipment in the geological and mining-technological conditions of the DNK mine, and of a technological solution to optimize the drilling and blasting for breaking the undercut rock mass in the production block.

The proposed process chart of the block caving geotechnology with vibration ore drawing under the artificial stope sill in the form of a 3D model is represented in Figure 2.

In conclusion, it should be noted that according to the proposed new modification of the process chart using the block caving geotechnology with vibration ore drawing under the artificial stope sill (which ensures a 1.5-2.0 increase in production capacity during underground mining of chromite reserves), after breaking the undercut volume of ore, it is drawn and delivered using high-performance adaptive vibration units from the chamber with the vibration feeder. The units are located just above the level of a mine car, into which the drawn ore mass is loaded for further transportation by electric locomotives and delivered to the skip shaft of the DNK mine of the Don mining and processing plant and then onto the surface.

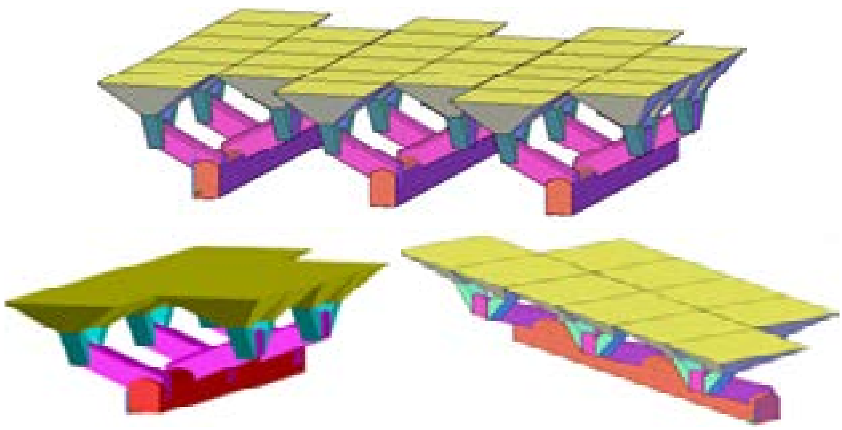

Figure 2. The proposed design of the process chart of the block caving geotechnology with vibration ore drawing under the artificial stope sill in the form of a 3D model

Discussion of the experimental results

Today, vibratory haulage vehicles are used at underground mines in the CIS countries and abroad: the "Molybden" mine of the Tyrnauz plant, in the mines of

Siberia (Abakan, Kaz, Tashtagol, Sheregesh), in the KMA mine after Gubkin, in the iron ore mines of Ural, Ukraine, in the Kryvbas basin as well as in the underground non-ferrous mines in Russia and Kazakhstan: "Altai" Ltd., "Kazzinc", Irtysh and Ridder-Sokolny polymetallic complex, at the apatite-nepheline mine of the Kola Peninsula, Kirovsk and the "Molodezhnaya" mine of the Don mining and processing plant (Xu, et al, 2023; Zhou, et al, 2022; Tishkov, 2018; Couto, 2018).

At these mines, to increase productivity and safety during the ore drawing, vibrating machines have been used installed in the chambers for vibration feeders of the stope sill, as illustrated below in Figure 3 and exemplified in the Sheregesh mine.

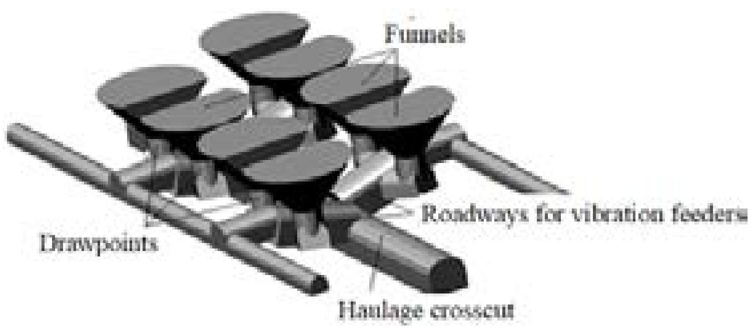

Figure 3. Design of the base for VDPU-4TM vibration ore drawing in the conditions of the Sheregesh mine

Based on the data analysis and the technical characteristics of vibrating units used in the mines of the CIS countries and Kazakhstan, the types of vibrating machines mainly used are VDPU-4M, VDPU M-6, VVDR-5 with the corresponding technical productivity: 250-400, 300-600 and 500-900 tons per hour. At the same time, the main parameter of the production block is the ore drawing productivity when using the geotechnologies during underground mining of mineral deposits.

Analyzing the practical experience of using high-performance machines, it is possible to say that the most widely used vibration unit for the ore drawing is VDPU-4TM created by the Mining Institute of the Siberian Branch of the USSR Academy of Sciences (Bekbergenov, 2017, Analysis of the possibility No. 04-3.1.4-9-52 date 2019, No. 03-23-21-747 date 2019).

The advantages include the relatively low cost and simplicity of design, which allows to manufacture the units at machinery repair shops of mining enterprises, their ability to work in difficult conditions under bulk ore and the possibility to load the ore of almost any strength and size. It is possible to crush oversized pieces of ore using all methods, including blasting with pressure charges. The appropriate volume of ore drawing by one unit is at least 30 thousand tons.

Among the disadvantages, it should be noted that as the mining goes deeper and the rock pressure increases, the use of VDPU-4TM units becomes difficult or its efficiency decreases, since their angle must be 18-20°, which entails loss of ore reserves as well as the need for additional tunneling work in accordance with safety requirements (Conclusion on mining No. 03-23-21-747 date2009; No. 03-23-21-691 date 2009; Final report for 2022).

Summarizing the analysis of the effective use of geotechnology with vibratory ore drawing in underground mines of the CIS and in Kazakhstan (Eremenko, et al, 2016; Imansakipova, et al, 2020), which ensures high productivity of the mining system in terms of ore drawing, we select the adaptive vibratory VPDU-4M haulage vehicle for trial use in production conditions according to the proposed block caving geotechnology with vibration ore drawing under the artificial stope sill for mining chromite reserves in difficult mining conditions at the deep levels of the DNK mine.

The rock mass is composed of metamorphic rocks, which are divided into two sections according to its composition and properties. To a depth of 910 m, the rock mass is composed mainly of amphibolites, including gabbro-amphibolites. The rocks are fractured, but in most cases have quartz-siliceous fracture filler, the internal friction angle of which is 30-42° (φ = 32°); adhesion 2.4 - 4.5 MPa (C = 3.1 MPa).

At a depth of 800-1,000 m, serpentinites occur (dunite, amphibolite, peridotite). The rocks are fractured. According to the VIOGEM Institute, three groups of rocks can be distinguished in this section based on the physical and chemical characteristics of fracture fillers: talc-mica filler: φ = 17-44° (φ = 33°); C = 0.45-3.1 MPa (C = 19 MPa); serpentinite with slip planes: φ =20-43° (φ = 350); serpentinite: φ =30-44° (φ = 35°); C = 1.8-9.6 MPa (C = 6 MPa).

In serpentinites and serpentinized rocks at a depth of 800-1,000 m, due to the concentration of stresses around the workings, a zone of disturbed rocks is formed. Rock disturbance is accompanied by movements and opening of cracks, which leads to a sharp decrease in the deformation modulus of the rock mass and, accordingly, to an increase in loads on the mine workings (Conclusion on mining No. 04-3.1.4-9-204 dated 11.07.2019, No. 03-23-21-747, dated 2009).

Table 1. Mechanical properties and characteristics of rocks

Layer number	Rock	H, m	y, $1 \cdot 10^2 \frac{MH}{м^3}$	σ_c, MPa	φ, degree	ε_0, hPa	V_0
I	Medium and slightly fractured gabbro-amphibolites	800	2.9	21.9	41	15.0	0.29
II	Medium fractured serpentinites	900	2.55	15.4	33	9.0	0.31
III	Slightly fractured serpentinites	1000	2.64	25.3	40	14.0	0.3

Table 1 shows the mechanical characteristics of rocks in the undeformed and unwetted state. It is important to understand that when rocks are deformed and moistened during roadheading, first of all the characteristics of crack fillers change. This is especially true of ultrabasic rocks –serpentinites – at a depth of 800÷1,000m. Due to the moistening of the rocks as a result of the water influx into the working, the characteristics of crack fillers, and therefore the rock mass surrounding the working, change sharply: the angle of internal friction decreases from 35-40 to 17-20°, adhesion decreases from 4-6 to 0.8-1.5 MPa, which is accompanied by crack opening. Accordingly, the rock strength decreases, and a zone of destroyed rocks is formed around the working, a radius of which increases as the rocks moistening continues. This process leads to a sharp decrease in the deformation modulus of the surrounding rocks, which results in the increase in support pressure loads, if there is any.

The rock masses were classified by such scientists as M.M. Protodyakonov (*f*), N.S. Bulychev (*S*), D. Deere (RQD), L. Muller, D. Franklin, K. Terzaghi, R. Lin, D. Lunde, N. Barton (Q), Z. Bieniawski (RMR), M. Roman (SMR), D. Laubscher (MRMR), P. Terbrugge, A. Haines and others (Conclusion on mining No. 04-3.1.4-9-204 dated 11.07.2019).

D. Laubscher's rating classification (MRMR - Mining Rock Mass Rating) in world practice is considered to be the most multifunctional and practical. Based on the data from this classification, it is possible to make a preliminary calculation of pillars' stability, a diagram of possible collapse zones, a timbering design, etc. (Final report for 2022).

In general, the algorithm for determining the rock mass rating according to this classification can be presented in the form of a flow diagram. The MRMR consists of in-situ ratings (IRMR) with due account for the strength characteristics of the rock mass, quantitative and qualitative characteristics of fracturing, which, in turn, is multiplied by correction factors reflecting the degree of rock weathering, the orientation of cracks in the rock mass, parameters of the stress state, and hydrogeological conditions.

According to SNiP-II-94-80 (construction rules and regulations), the stability of a haulage roadway is assessed by the value of rock displacement on the cross-sectional outline of the haulage roadway over its entire service life without support. Depending on the displacement value, rocks are divided into four stability categories.

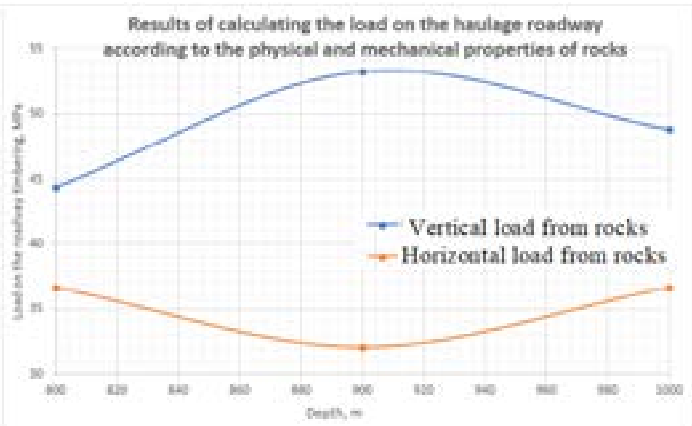

Figure 4. Results of calculating the load on the haulage roadway according to the physical and mechanical properties of rocks

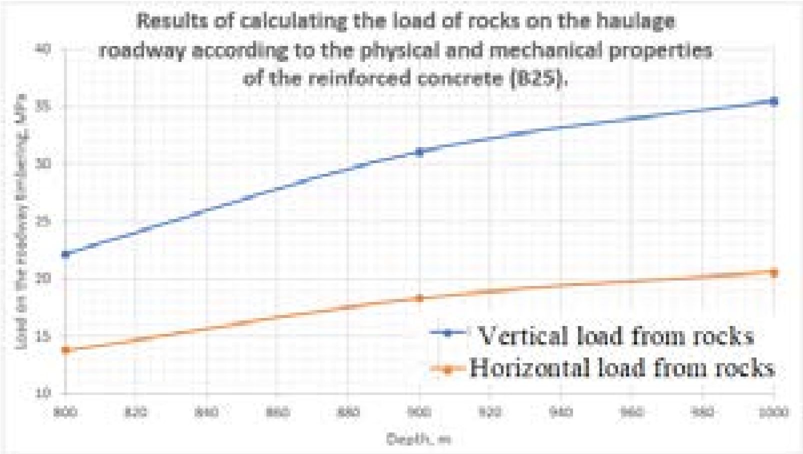

Figure 5. Results of calculating the load of rocks on the haulage roadway according to the physical and mechanical properties of the reinforced concrete (B25).

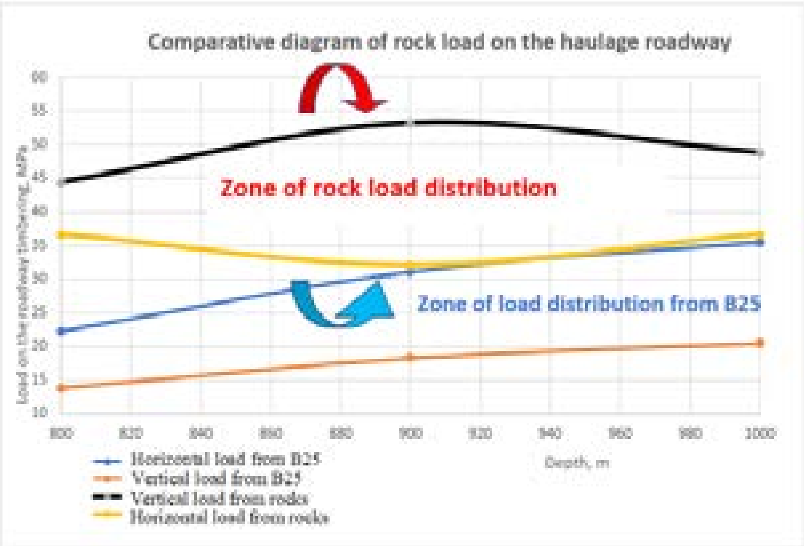

Figure 6. Comparative diagram of rock load on the haulage roadway
Зона распределения нагрузки от горных пород - Zone of rock load distribution

The calculation results and constructed comparative graphs show that the proposed design of the artificial stope sill is 40-50% more stable for vertical loads and 36% more stable for horizontal loads compared to the natural environment of the rock mass. Figures 4-6 show the zone of load distribution.

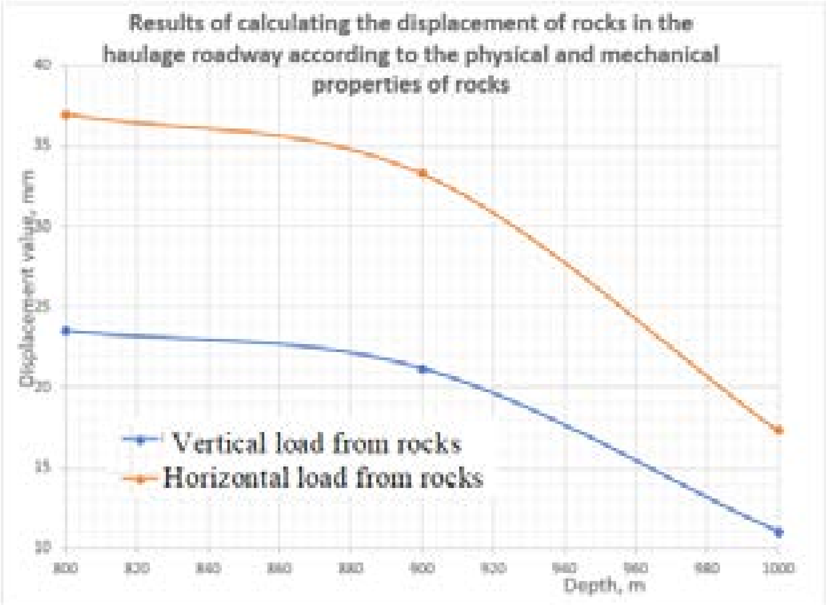

Figure 7. Results of calculating the displacement of rocks in the haulage roadway according to the physical and mechanical properties of rocks

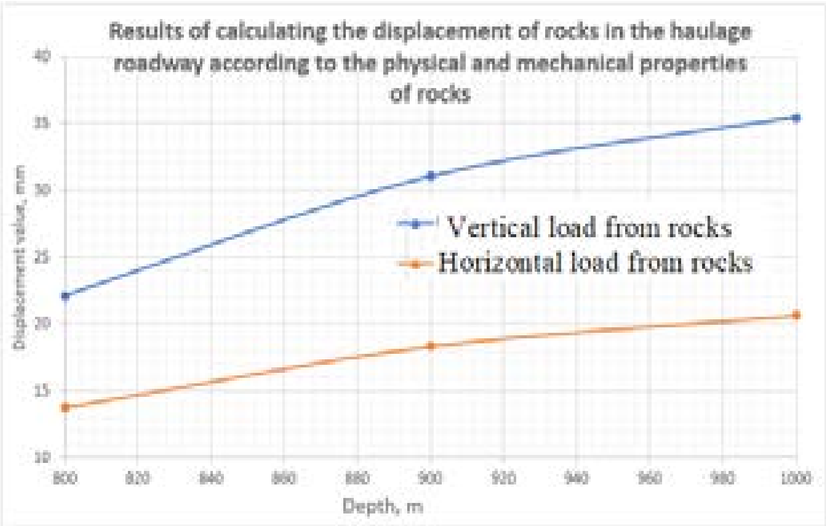

Figure 8. Results of calculating the displacement of rocks in the haulage roadway according to the physical and mechanical properties of the reinforced concrete (B25)

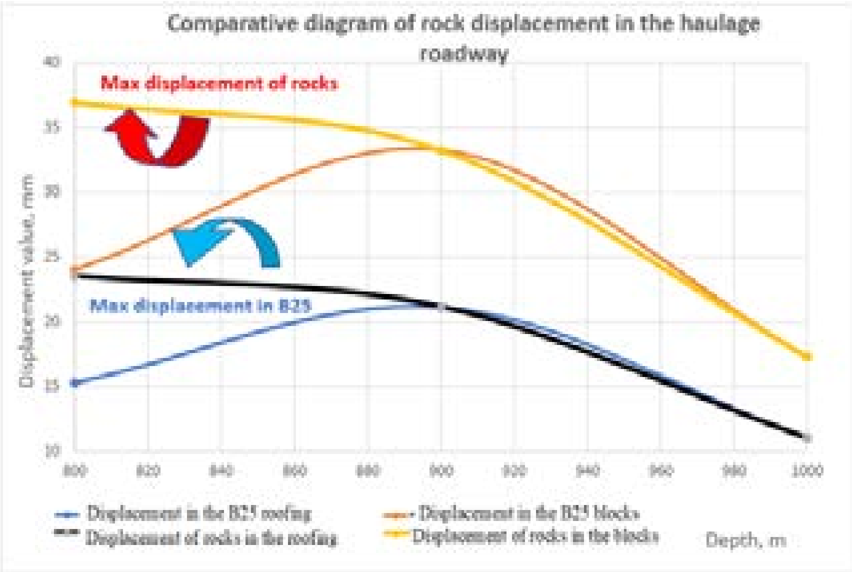

Figure 9. Comparative diagram of rock displacement in the haulage roadway

The results of calculating the possible displacement of the structure emphasize the advantage of the proposed design of the artificial stope sill. The displacement is 36% less in the vertical directions and 36% less in the horizontal directions compared to the natural environment of the rock mass. Figures 7-12 show the maximum and minimum displacements of the two options.

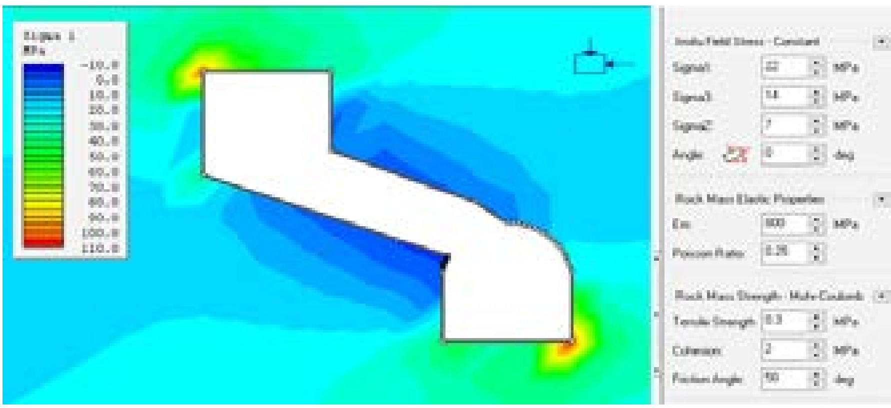

Figure 10. Stress-strain state of the proposed vibration feeder structure under the artificial mass at a depth of 800m (on the left side)

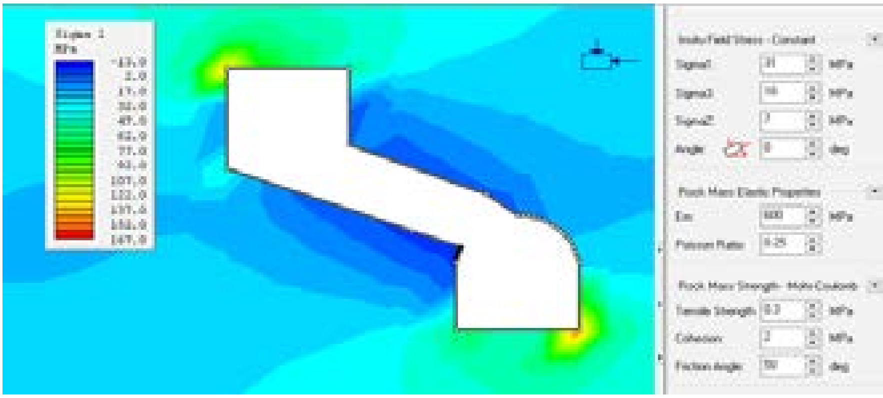

Figure 11. Stress-strain state of the proposed vibration feeder structure under the artificial mass at a depth of 900m (on the left side)

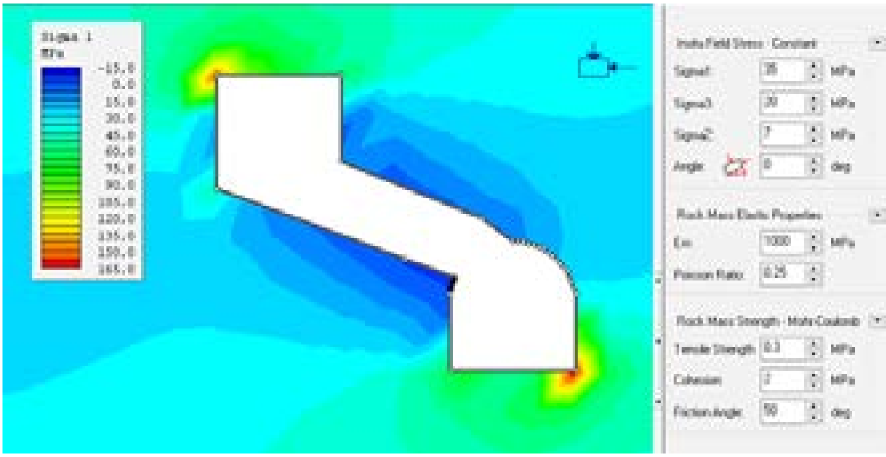

Figure 12. Stress-strain state of the proposed vibration feeder structure under the artificial mass at a depth of 1,000m (on the left side)

Conclusions

The research of the block caving geotechnology with vibration ore drawing for the safe and sustainable development of underground mining of chromite deposits ensures the solution of the urgent production and technical problem and the increase in the production capacity of blocks by more than 1.5-2.0 times in complex mining and geomechanical conditions at deep horizons of the DNK mine of the Don mining and processing plant using high-performance vibration units installed under artificial technological structures of the stope sill.

This geotechnology facilitates underground mining of chromites with increased block productivity by more than 1.5-2.0 times in the given mining conditions at the deep levels of the DNK mine. The pilot tests in production conditions on the selected experimental block of the mine ensure the solution of a scientific, technological, social, economic and pressing technical problem and the increase in the production capacity of the blocks by more than 1.5-2.0 times in complex mining and technical conditions of the deep DNK mine.

Outlooks

The calculation results and constructed comparative graphs show that the proposed design of the artificial stope sill is 40-50% more stable for vertical loads and 36% more stable for horizontal loads compared to the natural environment of the rock mass. Therefore, this design has advantages and is proposed as an artificial stope sill.

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CONTENT

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