TECHNOLOGY OF UNDERGROUND BLOCK LEACHING AT UNDERGROUND MINES OF "VOSTGOC"

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Annotation

The article is aimed at enhancement of the uranium ore mining technology at underground mines of the state enterprise "VostGOK". The investigation task consists in determining impacts of various factors on the crown stability when mining uranium ore deposits by vertical double blocks applying underground block leaching.

In the course of the investigation there is used mathematical modelling of the stress-strain state of crowns applying the finite-element technique, analytical study of the degree of crown disturbance caused by mining and laboratory study of uranium ore strength under impacts of block leaching reagents.

To cut costs for final products, vertical double blocks are suggested for underground mining of uranium ores by block leaching.

There are determined impacts of deposit dips and workings on the stress-strain state of crowns. Correction of crown thickness is suggested taking into account the above factors and applying corresponding coefficients.

There is also determined the degree of impact of acid solutions used in underground leaching on uranium ore strength depending on the exposing time.

The determined dependencies enable correcting the crown thickness when mining uranium deposits by vertical double blocks applying the underground block leaching technology and therefore provides safety of works.

Introduction

The state enterprise *Vostochnyi Mining and Processing Works* (SE “VostGOK”) is one of the world’s 28 uranium production centers. It is the largest in Europe and the only one in Ukraine in mining uranium ore and concentrating natural uranium. The enterprise comprises three underground mines: Ingulskaya, Smolinskaya and Novokonstantinovskaya. The enterprise is among the first ten uranium producers (about 2% of the world’s production) supplying uranium raw materials to about 40% of national nuclear power stations.

In Ukraine uranium deposits are mainly exploited in densely populated areas under various protected objects (water bodies, buildings and facilities). To protect the environment from possible emissions of radioactive elements room mining is applied with subsequent backfilling of the dead area with consolidating mixtures.

This technology is cost intensive if the ore body morphology is complex and economically reasonable at deposits with the increased uranium content. For economic and environmental reasons, underground block leaching should be used for mining lean uranium-containing ores to exclude a number of labour-consuming and environmentally dangerous operations from the production process [1, 2]. This enables, on the one hand, reaching maximum values of mineral extraction and, on the other hand, avoiding considerable material expenditures on backfilling mixture preparation and backfilling dead rooms as, when applying underground block leaching, they are almost completely backfilled with the muck pile, and on utilization of waste after the mined ore primary processing (barren rocks and off-balance ores) on the daylight surface.

1. Enhancement of Uranium Ore Mining Technology through Underground Block Leaching

Application of this technology enables further cut of costs through mining deposits by vertical double blocks. Ore body 10 of the Michurinskoye deposit is supposed to be mined in blocks 10-2 and 10-3 at the 325-184 m level at the Ingulskaya mine (Fig.1).

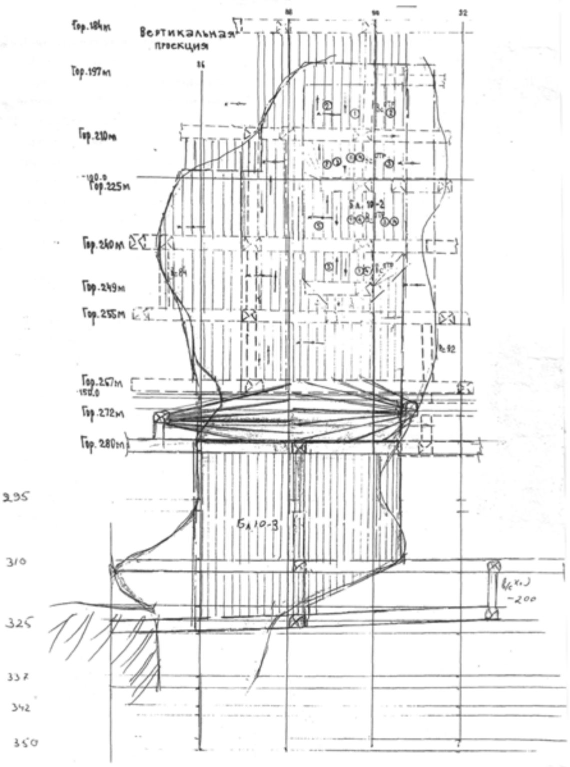


Fig.1. The vertical plane of blocks 10-2 and 10-3 (ore body 10 of the Michurinskoye deposit)

The idea consists in the following. Another room is located under the temporary pillar-crown below the dead room backfilled with the muck pile. Under this pillar in the block located further down the dip a compensatory room is placed to which reserves of this block are broken and the temporary crown is brought down. The solution for leaching uranium ores is fed from the existing workings over the room of the upper block. At this, volumes of mining are cut and pipes are again used for feeding the working solution to blocks.

The technology is distinguished from the traditional one by both levels of stress in main structural units and in the enclosing rock massif and the condition of the crown (the degree of its disturbance caused by workings and deep holes). Besides, the crown is affected by reagents for underground block leaching. Due to all that, factors impacting the crowns' stability and mine safety on the whole require urgent investigations.

Main regulatory documents on determining permissible dimensions of main structural units of room mining systems [3, 4] do not consider the impact of the ore body dip and are not intended for determining the safe thickness of a crown. The technology of underground block leaching of uranium ores in vertical double blocks has not been used at VostGOK underground mines and requires scientific support.

2. Study of the Stress-Strain State of Crowns When Mining Uranium Ores by Vertical Double Blocks

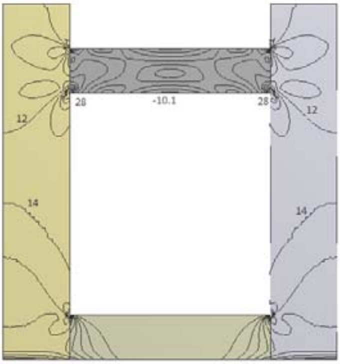
The stress-strain state and stability of crowns depending on the ore body dip angle was studied by mathematical modelling applying the finite-element technique. There were studied conditions of the above mentioned blocks but the range of boundary conditions of the impacting factors included values characteristic of all the underground mines of "VostGOK". Uranium ore hardness varied from 9-11 to 14-16 on the Protodyakonov scale, that of the enclosing rock - 13-15, the ore body dip made from 60^o to 90^o (in increments of 10^o). The stress-strain state was registered for crowns of 10 to 14 m thick. For calculating the stress field characteristics *Ansys 18* was used.

Fig 2, 3 and 4 exemplify results of modelling the stress-strain state of 10 m thick crowns in ores of various hardness with the ore body dip angles of 90^o, 70^o and 60^o.

As the figures show, the tension stress zone in the lower central part of the crown is the most dangerous. This corresponds to the classical concepts of stress field development in the so called "stress relief arch" that occurs when the massif is undermined by the lower block room. As ore hardness reduces, absolute values of stress in the crown decrease slightly (by 0.1…0.5 MPa, i.e. from 1…2 to 6…7%). This can be explained by the fact that less hard ores are less liable to accumulate stress as they get relieved through deforming towards a free surface (i.e. the room) and, on the opposite, harder ores tend to accumulate stress due to smaller deformations. However, stability of less hard ore crowns decreases due to reduction of their ultimate strength.

For instance, with the ore body dip angle $\alpha = 90^\circ$ and hardness of 14-16 points, the value of tension stress in the lower part of the crown reaches 10.1 MPa (Fig. 2,a). However, as ultimate tension stress of such ores is about 11 MPa, these stresses will not cause failures. When the crown is made of ores of 10-11 points (Fig. 2,d), the tension stress level makes 9.9 MPa. With the ultimate strength of the ores of 7.7 MPa this will cause rock falls of about 100…150 m^3 (according to "Instructions…" [4] used at "VostGOK" mines, rock falls of over 250…300 m^3 are considered critical).

a



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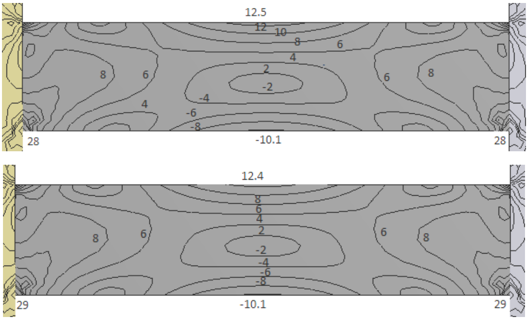


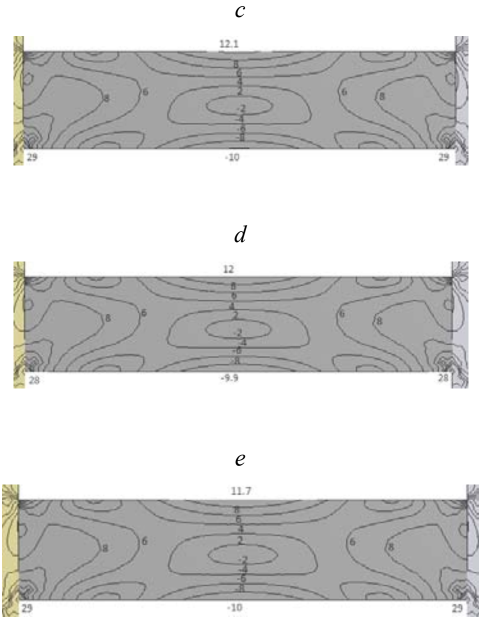
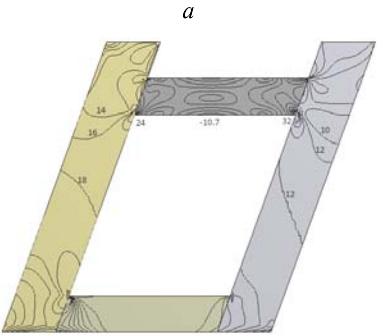


Fig. 2. Stress field development in 10 m crowns with the ore body dip of 90°, MPa; *a-e* – the crown of ores of 14-16, 13-15, 11-13, 10-11 and 9 points respectively



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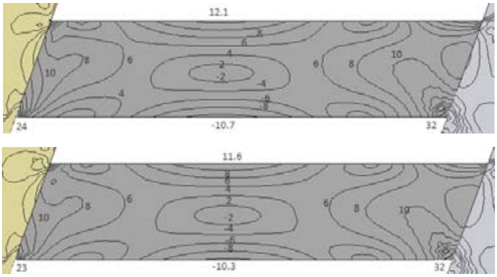
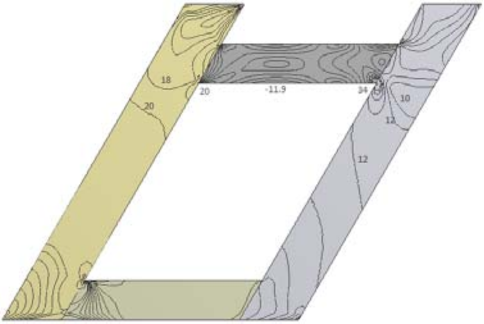


Fig. 3. Stress field development in 10 m crowns with the ore body dip of 70°, MPa; *a-b* – the crown of ores of 14-16 and 10-11 points respectively

With the dip angle *α*=70° and ores of 14-16 points crown failures do not practically occur (Fig. 3*a*), with α=60° small rock falls (3-5 m^3) may occur even in crowns of ores of the same hardness (Fig. 4*a*). In crowns of ores of 10-11 points with α=70° (Fig. 3*b*) and α=60° (Fig. 4*b*) the volume of rock falls will make from 150 to 200…220 m^3, sometimes to 400…450 m^3 respectively. These values testify to the critical condition of the crown at angles about *α*=70°, at about *α* = 60° the crown will fail.

a



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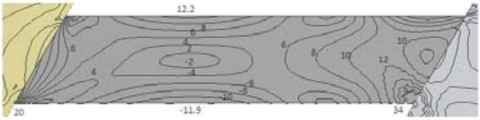

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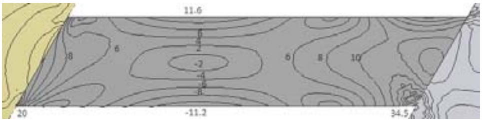

Fig. 4. Stress field development in 10 m crowns with the ore body dip of 60^o, MPa; *a* – *b* – the crown of ores of 14-16 and 10-11 points respectively

Thus, the obtained results testify to the considerable impact of the ore body dip angle on the stress-strain state of crowns and their stability. On the basis of the research conducted to be sensitive to this impact we suggest to apply the correction factor K_α, whose numerical values are given in Fig. 5. So, when determining the minimum permissible thickness of the crown in certain conditions, its value obtained without this factor should be corrected through multiplying it by the corresponding value K_α.

Technological workings in the crown rock cause changes in the existing stress fields, increase of absolute values of current stresses and, consequently, decrease of the crown stability.

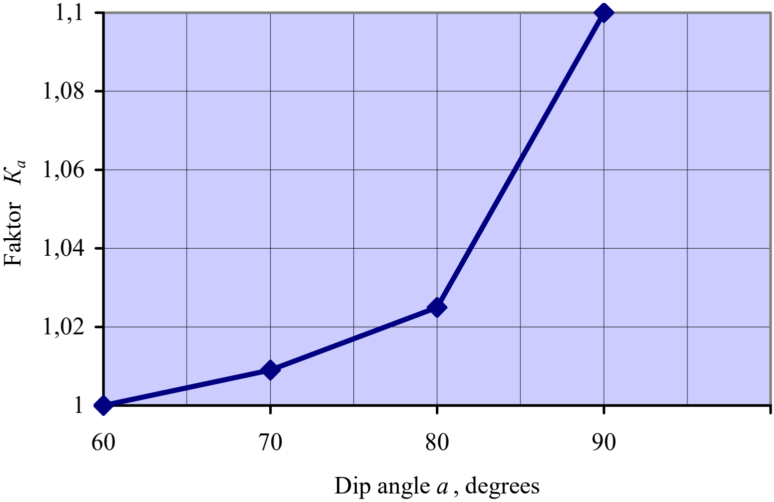

Fig. 5. K_α values depending on the ore body dip angle α

According to this, when determining safe dimensions of exposures and pillars, they are corrected considering the accepted criteria. In the first case, the crown thickness is determined according to conditions of the room mining order in compliance with the instructions developed by NIGRI (Research Ore Mining Institute) [3]. In the second case, the correction factor is applied.

We suggest correcting thickness of the crown with workings using the expression, m

$$h_{cr}^{\,n} = h_{cr} \cdot K_{dist}, \tag{1}$$

where h_{cr} is thickness of the monolith crown, m; K_{dist} is the factor considering disturbance of the crown resulted from mining, unit fraction.

As the disturbance degree of the crown depends on the number of workings in it, their geometrical dimensions and thickness of the crown itself, we suggest determining the numerical value of K_{dist} as the product of separate universal factors. Each of these factors differentially takes into account the impact of a particular working on the crown stress-strain state and, consequently, on its stability, as follows, unit fraction

$$K_{dist} = K_1 \cdot K_2 \ \ldots \ K_n\,, \tag{2}$$

where n is the number of workings in the crown.

Numerical values of these factors calculated individually for each working can tentatively be determined as follows, unit fraction

$$K_i = \sqrt{1 + \left(h_i^{w} / h_{cr}\right)}, \tag{3}$$

where $h^{w}{}_{i}$ is the *i-th* working height (width), m.

For instance, according to the calculations, the minimum permissible thickness of the crown not disturbed by workings is h_{cr} =10 m. In case of workings of 2,5, 3,0, 3,5 and 4,0 m, the correction factors for each of them determined by (3) will equal 1,12; 1,14; 1,16 and 1,18 respectively. Thus, the crown thickness should be increased to 11,2; 11,4; 11,6 and 11,8 m respectively.

If there are 2 workings of 3,0 m and 3,5 m in the crown, the correction factor will make K_{dist}=1,14·1,16=1,32. Correspondingly, the disturbed crown thickness should be increased to 13,2 m.

If there are 3 workings of 2,5 m, 3,0 m and 3,5 m in the crown, the correction factor will make K_{dist}=1,12·1,14·1,16=1.48. Under such conditions the crown thickness should be half as much as that of the monolith crown and make 14,8 m.

So, the crown thickness should be corrected considering decrease of its stability caused by workings. This will help avoid its complete or partial failure.

1. Study of Impacts of Underground Block Leaching Reagents on Uranium Ore Strength

One of the main components of underground block leaching of uranium ores is shrinkage stoping with sulphuric acid treatment. When applying the vertical double block technology, the crown separating the rooms will also be exposed to the sulphuric acid.

The research conducted enables the authors to assume that the longstanding (from 3-4 to 6 months) exposure to the sulphuric acid may negatively impact strength properties of the ore massif of the crown. This assumption is substantiated by data on the physical and mechanical properties of rocks of the Michurinskoye deposit, particularly albitites and migmatites which are the most representative rocks in uranium ore occurrence zones. Thus, the average compressive resistance of rocks in their natural humidity conditions and when water-saturated makes 164,4 MPa and 127,5 MPa for albitites and 153,1 and 112,4 MPa for migmatites respectively. That is, if compared with the natural state, water saturation of rocks reduces their compressive resistance by 22…27%.

To confirm the impact of the sulphuric acid solution on the crown stability the authors conducted the following investigation. Forty ore cubes with 50 mm sides were divided into two groups. The first group of 10 cubes was used to determine the uniaxial compressive resistance in the natural conditions, the remaining cubes were used for determining the degree of the sulphuric acid solution impact on the samples' strength.

To provide conditions of the crown contacting the acid solution, in the laboratory environment only one face of an ore sample contacted the acid solution. The other faces of the cubes were covered with two coatings of paraffin. These cubes were placed in a vessel with the sulphuric acid solution which is used for spraying the shrinked muck pile in underground mines of “VostGOK”. Tests of uniaxial compressive resistance were carried out 2.5, 4 and 6 months after dipping to determine the impact of the exposing time on the uranium ore strength. These periods correspond to the minimum and maximum time of the reagent impact in real conditions.

The laboratory bench for the research was equipped with a hydraulic press able to produce pressure up to 50 t. In relation to the cubes’ surface S=25 cm^2 the corresponding pressure makes about 2000 kg/cm^2, or 200 MPa. The press is coupled with a computer that sets the loading rate for the samples and forms the loading diagram for each of the samples with the automatic recording of the current load, maximum pressure at the moment of their destruction and calculates ultimate strength of each sample depending on its sizes. During the tests the minimum loading rate of 1 kN/s was set according to corresponding standards (from 1 to 5 kN/s).

Tests of the first group of the samples demonstrated that the average value of the uniaxial compressive resistance made about 130 MPa. According to the instructions [3] this value corresponds to the rock hardness ratio of 11 points. For the samples exposed to the sulphuric acid solution during 2,5-4 and 6 months, average strength values made 82…84.5, 79,5…805 and about 78 MPa respectively, i.e. their ultimate strength decrease (in relation to the samples of the first group) made 35…37%, 38…39% and about 40%.

The obtained results confirmed our assumption about the considerable impact of the acid solution on the uranium ore strength that will, no doubt, influence the stability of exposures and pillars. Thus, the determined dependencies should be considered in defining the safe crown thickness when applying the technology of underground block leaching of uranium ores.

Conclusions

So, the research conducted enabled determining the degree of impact of major factors (ore body dip, crown integrity loss caused by technological workings, impacts of reagent used when applying underground block leaching of uranium ores) on the crown stability. These factors should be taken into account when determining safe dimensions of exposures and pillars using corresponding correction factors. As a result, in concrete conditions it is necessary to correct parameters of structural units of blocks, particularly the crown thickness, considering the value of its stability changes caused by the above factors. This correction enables avoiding the crown failure and provides safety of works. The determined dependencies can then be corrected considering practical experience of "VostGOK" underground mines.

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