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Methodology enhancement for determining parameters of room systems when mining uranium ore in the SE “SkhidGZK” underground mines, Ukraine

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Abstract

Purpose. The present paper aims to enhance methodology for determining the safety and stability parameters of room mining systems with backfilling of the mined-out area when mining uranium ores in underground mines of the State Enterprise “Skhidnyi Mining and Beneficiation Plant” (SE “SkhidGZK”).

Methods. The analytical research method used in the presented paper includes the analysis of previous relevant instructions and reports on the research performed at the SE “SkhidGZK”, as well as publications on the subject, operational geological survey documentation containing monitoring data on the stress-strain state of the rock mass surrounding the formed cavities and the actual state of the mined-out blocks in all underground mines of SE “SkhidGZK”.

Findings. The research performed enables development of a new instruction for determining the safety and stability parameters of the room systems with backfilling when mining uranium ores in the SE “SkhidGZK” underground mines. Based on the developed new instruction, the stability of outcrops in mined-out rooms has been calculated, considering the actual time of their life. The obtained parameters fully correspond to actual stability of rooms in blocks of all underground mines. This indicates that the new instruction is more advanced as compared to the current Instruction and its implementation will contribute to mine safety enhancement.

Originality. The increased depth of mining uranium ore in the SE “SkhidGZK” underground mines and the increase in lifetime of mined-out rooms require regular adjustment of the methodology for determining their safety and stability parameters. Based on the accumulated production experience, the observations conducted and a thorough analysis of the actual state of cavities, new and adjusted current dependences have been obtained that more accurately consider the impact of both determined factors and those unprovisioned in the current Instruction for determining the safety and stability parameters of rooms.

Practical implications. The advanced methodology for determining the safety and stability parameters of room systems in comparison with the methodology described in the current Instruction at the “SkhidGZK” underground mines provides higher accuracy when determining the design parameters of rooms in the stoping blocks and greater reliability of predictive stability of both individual outcrops and rooms in general.

Keywords: *uranium ores, room mining system with backfilling, geometrical parameters, stability, safety*

1. Introduction

1.1. Setting of a problem and its connection with scientific and practical tasks

The modern uranium industry of Ukraine is developed in accordance with the State Target Economic Program “Nuclear Fuel of Ukraine”. At the beginning of the 21st century, Ukraine’s own production of natural uranium ranges from 500 to 800 tons annually, which provides about a third of the demand in the national nuclear power industry. However, there are plans to significantly increase these volumes in order to provide the country with 100% of its own uranium production in the future [1]-[4].

In Ukraine, the main uranium reserves are concentrated in the Kirovohrad uranium ore region (estimated reserves are more than 100 thousand tons), where uranium ores are mined by underground methods at SE the “SkhidGZK” plant, which comprises three underground mines: Inhulska, Smolinska and Novokostiantynivska. Uranium ore deposits, Vatutinske, Michurinske, Tsentralne and Novokostiantynivske are currently in operation [1], [2].

Given the rather high strength and stability of both country rocks and uranium ore deposits, mining operations in the SE “SkhidGZK” underground mines is carried out mainly by room systems with subsequent backfilling of mined-out areas with hardening mixtures. This stems from the need to pre-

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serve the daylight surface, which is conditioned by occurrence of deposits near and under residential facilities of the city of Kropyvnytskyi (Inhulska Mine), the urban-type Smoline settlement (Smolinska Mine) and the village of Oleksiivka (Novoconstantinivska Mine), as well as under the Inhulets River. This also makes it possible to avoid radioactive contamination of the surface and improve the mineral extraction rates.

According to [5], in the underground mining of ores, it is first of all necessary to ensure the safety of operations. To determine the geometrical parameters of rooms at the stage of project works, the "Instruction for substantiating the safety and stability parameters of stoping blocks at the SE "SkhidGZK" mines is applied [6] which is currently valid for all mines of the plant. For various reasons, the main of which is the underfunding of the plant, and, accordingly, of its structural units, in all underground mines there is a rather significant delay in backfilling of the mined-out rooms [7], [8]. As a result, with the planned 1-2-year lifetime of the room, the actual lifetime of unbackfilled or partially backfilled rooms is 5-10 years, and in some cases it is 15-20 years or more. At the same time, the state of the rooms and the rock mass surrounding them is quite stable, although, according to calculations based on the above Instruction, many of them should have exhausted their stability margin long ago. That is, practical experience shows that the determined dependences used in this Instruction do not accurately describe the behavior of the rock mass with cavities in the form of mined-out rooms.

Since the extended time period, the availability of greater production experience and practical data enable scientific substantiation of implementing the certain adjustments to current methodology and dependences, it becomes necessary to develop a more advanced methodology and on its basis, a new instruction for determining the safety and stability parameters of stoping blocks in the SE "SkhidGZK" underground mines.

1.2. Research and publications analysis

To determine the safety and stability parameters of room systems with backfilling of a mined-out area in the SE "SkhidGZK" underground mines, from the beginning of mining, the instructions [9], [10] have been applied, adjusted on the basis of accumulated production experience and increased volumes of actual data on the stability of mined-out rooms. The analysis of the Instruction [6], which is valid in the underground mines of the plant, allows determining a number of its significant shortcomings. In particular, incorrect consideration of the influence of the mining depth and lifetime of the rooms on their stability, as well as ignoring the influence of the inclined outcrop slope angle, conditions of outcrop contour restraints, tectonic disturbances in the rock mass and its strength on stability of outcrops and rooms [11]-[13].

The impact of the mining depth on the stress-strain state of the mass and the parameters of main structural elements of mining blocks are studied in many scientific works, in particular, in researchers from Ukraine [14]-[17] and foreign researchers [18]-[22]. Special attentions are given to providing readiness for mining [23]-[25].

Significant changes in the stress-strain state of the mass, depending on physical and mechanical properties of rocks, are proved in [26]-[30]. The study of the impact of physical and mechanical properties of rocks on the geometrical dimensions of rooms and the mining technology tailored for the conditions of the "SkhidGZK" underground mines are presented in [31]-[34]. The works [35]-[38] deal with the impact of the mass stress-strain state on the stability of mine workings and parameters of mining operations. The works [39]-[42] present the results of the research into development and implementation of seismic-resistant technologies for mining uranium ores at the "SkhidGZK" underground mines. Impacts of the room lifetime and outcrops in them, as well as the contour restraint conditions on their stability are described in detail in [43]-[46]. The results of studying the impact of slope angle of inclined outcrops on their stability are presented in [10], [47]-[49]. Comprehensive consideration of the impact of rock strength and the degree of the rock mass fracturing on its stability is proposed in [50]-[52].

1.3. Problem statement

As a result of a critical analysis of the current Instruction in the underground mines of the plant [6], a number of its shortcomings have been revealed, namely:

– incorrect consideration of the impact of time and certain contradictions associated with the impact of the room mining sequence on the stability of both individual outcrops and rooms in general;

– failure to determine the safety parameters of vertical outcrops (only horizontal and inclined ones have been determined), as well as the impact of contour restraints of outcrops on their stability;

– non-consideration of rock strength and the impact of the slope angle of inclined outcrops on their stability when determining the outcrop parameters;

– ignoring the possible impact of tectonic disturbances available in some blocks on stability of rooms and outcrops in them.

Therefore, updating the current Instruction [6] that allows taking into account the impact of factors not previously considered on the stability of rooms and outcrops in them, as well as making certain adjustments to it by implementing the above-mentioned research results in order to eliminate the identified shortcomings, is a topical issue.

2. Research methodology

The analytical method of research is used in the presented paper. To achieve the goal set, previous relevant instructions and reports on the research performed at SE "SkhidGZK", as well as publications on the subject, operational geological survey documentation comprising monitoring data on the stress-strain state of the rock mass surrounding the formed cavities and the actual state of the mined-out blocks, is thoroughly analyzed. The performed analysis and assessment of the current state of cavities enable determining the main factors affecting the stability of cavities and developing an algorithm for determining the safety and stability parameters of stoping blocks in these underground mines, taking into account the obtained dependences.

The data collected during the research reflects the actual condition of the mined-out rooms in all underground mines of the plant. As of November 1, 2019, out of more than 170 mined-out blocks, 87 have rooms that are partially backfilled and 41 blocks are not completely backfilled. The linear dimensions of the rooms in the blocks vary over a very wide range: the room width ranges from 4-6 to 31 m; length – from 17-20 to 80 m; vertical height – from 15-17 to 80 m. The actual room volumes range from several thousand to 70-72 thousand m^3 and their lifetime ranges from 1-3 to 15-20 years or more.

The vast majority of rooms, despite their rather significant geometrical dimensions and long lifetime, are stable, and only 8 of them have disturbed stability in the form of rockfalls. In 5 blocks, these are very small rockfalls (about several tens of cubic meters in volume) of rocks from the roof and hanging wall of the room, as well as the backfill from the walls of previously mined-out and backfilled rooms, which do not pose any hazard. But it should be noted that, when mining the rooms of the second and third stages, problems may occur with the stability of vertical outcrops of the artificial backfill mass. However, the current Instruction [6] does not provide for determining the safety parameters for such outcrops. In two blocks (1a-2-10t and 1a-2-6t, Inhulska Mine), the volume of rockfalls is 135 and 225 m^3 of rocks from the roof and hanging wall of the rooms, which indicates their reaching the stability boundary, since according to the Instruction [6] rockfalls of 300 m^3 or more are considered critical. And only in one block (15-48t, Inhulska Mine), 4 rockfalls from the hanging wall with a volume of 360 to 550 m^3 each were recorded (early March – late October, 2019). This indicates that this outcrop has practically exhausted its stability and may be hazardous for the safety of mining operations in this block.

3. Results and discussion

When analyzing the actual state of the mined-out rooms at the mines of the plant, it has been determined that as a result of a significant lag in the rates of backfilling, there is a significant increase in the room lifetime: instead of the terms set by the project, depending on the volume of a particular room, the intensity of stoping and backfilling operations (duration of which, as a rule, ranges from six months to 2-3 years), the actual lifetime of cavities is from several to 15-20 years, and sometimes longer. At that, the time factor is perhaps one of the most influencing on the outcrop stability, and it is this factor that determines their maximum permissible values in rooms. Therefore, the stability of outcrops in the mined-out rooms is initially determined according to the methodology described in the current Instruction [6], taking into account the actual lifetime of these rooms. The results of calculations of the so-called “problem” blocks, the rooms of which should already have lost stability, are given in Table 1.

The data obtained demonstrate that in 47 out of 87 blocks, i.e. in more than half of them (54%), some or all room outcrops should have become unstable, since the actual values of the equivalent spans sometimes exceed their maximum permissible values. This is especially indicative in blocks with rooms of large volumes and a very long lifetime. At the same time, as shown by the analysis of the actual state of the mined-out rooms (this has already been noted), only three blocks have demonstrated significant rockfalls that testify to exhausted stability of these outcrops. This indicates that the rooms and their outcrops in most cases have a very high safety margin, which indicates some imperfection in the methodology for determining the safety parameters of such outcrops in accordance with the current Instruction [6] and, accordingly, the need to adjust it.

Analyzing the above, the basic dependence, first of all, requires a certain adjustment, according to which a stable equivalent span is determined considering the outcrop lifetime (formula (8.9), [6]), namely:

$$L = \sqrt{\frac{A}{t}}, \tag{1}$$

where:

A – a constant for weakly-, medium- and highly-fractured ores and rocks, the values of which depend on the properties of the rock mass and are determined from the practical experience of underground mining operations and are equal to 220000, 88000 and 26800 for horizontal outcrops and 1060000, 320000 and 75000 for hanging wall rock outcrops, respectively;

t – the lifetime of outcrops, days.

From our point of view, the main shortcoming is that the current Instruction does not provide for any time limits, although paragraph 8.2.8 of this Instruction states that “...if the outcrop is stable for 2.0-2.5 years, then a further increase in its lifetime does not practically affect its stability” (courtesy translation). Approximately the same time frames are introduced in the instructions of the State Research Mining Institute (NIGRI) [39], which is valid for mining the iron ore deposits in the underground mines of Kryvbas (Kryvyi Rih iron ore basin) using room mining systems. Therefore, we believe that it is quite expedient to limit the maximum outcrop lifetime to 24 months (720 days), and for the actual longer outcrop lifetime (over 2 years), accept t = 720 days.

Also, paragraph 8.1.6 of the Instruction [6] says that the criterion for a stable state of the rock mass is to comply with the condition that the equivalent outcrop span L_{equ} does not exceed the value of this outcrop boundary span L, calculated by Expression 1 and reduced by 10%, namely:

$$L_{equ} = \frac{L}{1.1}. \tag{2}$$

That is, there occurs a certain precaution, caused by an increase in the stability margin of outcrops, which is already excessively high. This fact has been actually revealed in the course of studying the actual state of mined-out rooms. Besides, there is no such a precaution in the above-mentioned NIGRI instruction [39], but this fact does not interfere with determining the room safety parameters, since the time period for the use of these systems at the Krivbass mines is much longer and the found dependences describe the behavior of rock mass outcrops more accurately.

Thus, we propose to determine the maximum permissible value of outcrops by Expression 1, guided by the already found values of the constant A, obtained in the course of previous studies and given both in the current Instruction [6] and in earlier instructions [9], [10]. But at the same time, certain adjustments will be made by applying correction factors obtained in the course of the research performed and as a result of a detailed analysis of previous instructions and studies of other scientists.

The next shortcoming of the Instruction is the imperfection of the methodology for considering the mining depth impact on the outcrop stability. As in the earlier instructions [9], [10], it recommends adjusting this impact by applying the correction factor K_H, the value of which is determined by the Expression:

$$K_H = \sqrt{\frac{H_0}{H_1}}, \tag{3}$$

where:

H_0 – the outcrop location depth, for which a stable equivalent span is known, m;

H_1 – the outcrop location depth, for which a stable equivalent span is determined, m.

Table 1. Calculated parameters of equivalent spans of room outcrops according to the Instruction [6]

No.	Block	Room volume, thousand m^3		Room lifetime, years	Calculated outcrop parameters (equivalent spans, m) and their stability									Occurrence of rockfalls
					Horizontal outcrop of the room roof			Inclined outcrop of hanging wall rocks			Vertical outcrop			
		After completion of stoping	As of November 1, 2019		Actual	Maximum permissible	Stability	Actual	Maximum permissible	Stability	Actual	Maximum permissible	Stability	
Inhulska underground mine														
1	30-42-46	15.3	15.3	24.5	16.7	4.0	IS	19.2	8.7	IS	ND	ND	ND	–
2	10-100	34.6	34.6	15.5	17.9	4.0	IS	29.3	8.3	IS	ND	ND	ND	–
3	1-69-73	11.2	10.7	4.5	10.4	9.7	IS	23.3	20.7	IS	ND	ND	ND	–
4	5-2	26.6	26.6	4.0	12.9	8.5	IS	23.6	17.2	IS	ND	ND	ND	–
5	5-49-53	27.2	24.4	2.5	16.0	8.7	IS	27.4	18.4	IS	ND	ND	ND	–
6	15-48t	43.9	41.9	1.2	17.4	8.4	IS	31.5	18.6	IS	ND	ND	ND	h/w rockfall
7	10-2	20.4	20.4	1.7	12.2	9.5	IS	22.7	18.9	IS	ND	ND	ND	–
8	4-1t	71.7	71.7	5.0	21.1	11.6	IS	43.2	25.4	IS	ND	ND	ND	–
9	1a-1-1	43.4	32.9	23.0	14.4	4.3	IS	31.2	10.1	IS	ND	ND	ND	–
10	1a-2-1	16.1	15.1	20.0	11.2	2.2	IS	24.0	4.0	IS	ND	ND	ND	–
11	1a-5-6t	9.9	9.5	7.0	10.7	5.8	IS	17.5	12.5	IS	ND	ND	ND	–
12	1a-5-5	48.1	29.8	6.0	17.9	8.9	IS	28.3	18.8	IS	ND	ND	ND	–
13	1a-5-2t	38.2	38.2	7.3	18.5	8.0	IS	30.7	17.0	IS	ND	ND	ND	–
14	1a-3-1	30.9	24.7	5.0	11.4	4.8	IS	21.0	8.5	IS	ND	ND	ND	–
15	1b-3-2	55.2	55.2	5.2	7.0	5.6	IS	25.3	10.0	IS	ND	ND	ND	–
16	1a-2-6t	27.7	27.7	3.1	8.8	4.7	IS	24.0	8.7	IS	ND	ND	ND	h/w rockfall
17	1a-16-1	19.7	19.7	3.0	10.6	9.4	IS	14.6	16.7	ST	ND	ND	ND	–
18	1a-2-8t	61.6	22.6	1.5	8.7	6.0	IS	22.4	10.9	IS	ND	ND	ND	–
19	1a-2-1t	13.0	13.0	2.0	10.7	5.8	IS	21.9	10.8	IS	ND	ND	ND	–
20	1a-48-2	55.9	55.9	3.1	13.0	8.1	IS	30.9	14.8	IS	ND	ND	ND	–
21	1b-3-XII-XIII	15.6	15.6	3.5	10.4	6.2	IS	16.6	12.6	IS	ND	ND	ND	–
22	1a-2-10t	15.6	5.8	0.9	15.6	7.0	IS	13.5	13.9	ST	ND	ND	ND	Roof rockfall
Smolinska underground mine														
1	135-9	15.5	15.5	7.0	13.8	8.1	IS	30.4	17.7	ST	ND	ND	ND	–
2	704-7	20.4	20.4	1.5	13.2	11.6	IS	19.8	25.0	ST	ND	ND	ND	–
3	554-3S$_d$	10.3	10.3	4.3	5.8	6.1	ST	18.9	13.8	IS	ND	ND	ND	–
4	464-35^v	47.8	29.7	7.5	15.6	5.6	IS	16.0	11.7	IS	ND	ND	ND	–
5	315-142	29.8	29.8	2.3	4.5	11.8	ST	26.9	24.9	IS	ND	ND	ND	–
6	305-155	29.5	18.5	6.8	13.9	7.4	IS	31.3	21.1	IS	ND	ND	ND	–
7	295-157	9.4	9.4	6.0	9.7	7.0	IS	29.1	14.9	IS	ND	ND	ND	–
8	564-2c	23.7	20.3	8.0	12.4	4.6	IS	19.5	6.6	IS	ND	ND	ND	–
9	295-1.2	17.0	17.0	7.5	10.4	7.1	IS	26.1	15.2	IS	ND	ND	ND	–
10	235-165	20.5	15.5	4.2	6.3	9.8	ST	28.6	20.2	IS	ND	ND	ND	–
11	115-8	11.9	10.5	5.3	8.7	4.8	IS	19.9	6.3	IS	ND	ND	ND	–
12	105-1	13.6	13.6	3.5	9.2	6.8	IS	20.4	12.6	IS	ND	ND	ND	–
13	344-8	10.3	10.3	13.0	9.8	6.2	IS	23.1	13.7	IS	ND	ND	ND	–
14	344A-1.2	32.7	14.7	17.0	8.8	6.0	IS	13.4	10.5	IS	ND	ND	ND	–
15	344A-4.5	39.1	23.1	15.0	9.8	3.9	IS	38.0	12.9	IS	ND	ND	ND	–
Novokostiantynivska underground mine														
1	329-3 (1-2 o)	35.2	35.2	6.4	11.2	10.2	IS	25.1	13.9	IS	ND	ND	ND	–
2	310-1	23.7	24.5	2.6	8.0	5.9	IS	17.6	10.9	IS	ND	ND	ND	–
3	235-4	30.7	14.0	2.2	8.5	7.0	IS	19.2	12.9	IS	ND	ND	ND	–
4	235-2	24.7	23.4	3.6	5.3	5.5	ST	21.9	10.1	IS	ND	ND	ND	–
5	310-2	20.5	20.5	2.1	6.1	6.5	ST	21.0	12.0	IS	ND	ND	ND	–
6	341-6	20.5	20.5	1.5	17.2	8.0	IS	27.9	17.0	IS	ND	ND	ND	–
7	341-7	24.7	24.7	1.0	12.0	11.5	IS	28.0	24.5	IS	ND	ND	ND	–
8	341-5	44.5	44.5	2.2	17.5	17.6	ST	29.9	22.3	IS	ND	ND	ND	–
9	329-2	43.7	43.7	4.1	12.1	8.9	ST	22.3	9.0	IS	ND	ND	ND	–
10	329-1	40.1	40.1	2.7	9.8	6.1	IS	21.9	11.1	IS	ND	ND	ND	–

Note: IS – instable; ST – stable; ND – not determined; h/w – hanging wall

However, if the earlier instructions require adjustments for outcrops located at a depth of over 300 m, then when mining the reserves located at a depth of less than 150 m from the surface, the current Instruction [6] (paragraph 8.3.3) proposes to determine the factor H_0 value by the cubic dependence, which is explained by the negative influence of the daylight surface. If the depth is greater, i.e. 150 m and deeper, quadratic dependence should be applied (Formula 3).

During the research performed, it has been revealed that this assumption is not confirmed, since several rooms located in the near-surface area exist for 4-7 years and are stable. However, according to the calculations based on the Instruction [5], they should have lost their stability. Therefore, we propose to reconsider the impact of mining depth on the stability of outcrops according to the methodology of earlier instructions [9], [10], i.e. according to Expression 3 with the correction of the outcrop location depth influence starting from H_0 = 300 m.

Also, as the analysis of the actual state of the mined-out rooms in the underground mines at the plant shows, under certain conditions, when mining the rooms of the second and third stages, there may arise problems with the stability of vertical outcrops in the backfill artificial mass. But the current Instruction does not provide for determining the safety parameters for vertical outcrops at all. Therefore, in addition to horizontal and inclined outcrops, it is proposed to determine the value of the vertical outcrop equivalent span by the expression, m:

$$L_{equ}^{v} = \frac{b \cdot h_{vert}}{\sqrt{m^2 + h_{vert}^2}}, \tag{4}$$

where:

b – the room size across the strike, m;

h_{vert} – the outcrop vertical height in the room, m.

Besides, the current Instruction [6] provides for determining the equivalent spans of only rectangular and irregularly shaped outcrops with contour restraints along the entire perimeter. But, as the analysis of the actual room parameters shows, in many cases the outcrops are not continuous, but broken into benches, that is, they have a three-sided restraint. Such outcrops are more stable and their equivalent spans should be determined by other formulas. Numerical values of equivalent spans of flat outcrops with three-sided contour restraint are determined by the Formulas [39], m:

– for vertical outcrops:

$$L_{equ}^{v} = \frac{b \cdot \left(h_y + \frac{2}{3} h_{vert}\right)}{\sqrt{b^2 + \left(h_y + \frac{2}{3} h_{vert}\right)^2}}; \tag{5}$$

– for horizontal outcrops:

$$L_{equ}^{h} = \frac{b \cdot \left(a_y + \frac{2}{3} l_{hor}\right)}{\sqrt{b^2 + \left(a_y + \frac{2}{3} l_{hor}\right)^2}}; \tag{6}$$

$$l_{vert} = \frac{b \cdot h_y}{\sqrt{b^2 + h_y^2}}; \tag{7}$$

$$l_{hor} = \frac{a_y \cdot b}{\sqrt{a_y^2 + b^2}}, \tag{8}$$

where:

h_y, a – are the height and length of the bench, respectively, m;

l_{vert}, l_{hor} – equivalent spans of the vertical and horizontal benches, respectively, m.

Explanations of parameters for the outcrops with three-sided restraint along the contour are shown in Figure 1.

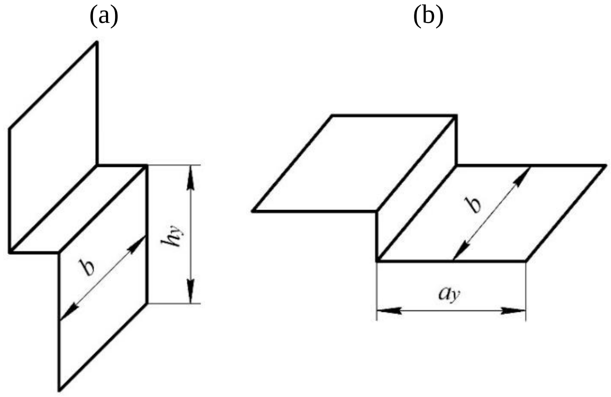

Figure 1. Parameters of outcrops with three-sided restraint along the contour: (a) the vertical bench; (b) the horizontal bench

Also, a significant impact of the inclined outcrop slope angle on its stability has been proven. This is confirmed by many studies, including our own ones [33], [34], [43], [44]. The corresponding correction factor is contained in the NIGRI instructions [39], which are currently valid for the Kryvbas iron-ore underground mines. The document [9] also contains this factor, but, for unknown reasons it is completely ignored in subsequent instructions, including the current one [6]. We believe that this factor should also be considered when determining the safety parameters of inclined outcrops. We propose to use the correction factor K_α when adjusting the stability of the hanging wall rock outcrops, depending on their slope angle that coincides with the deposit dip, which varies within 40-90° in the SE "SkhidGZK" underground mines. This factor is obtained by processing the dependency graph of the equivalent span on the outcrop slope angle, described in the instruction [9]. The correction factor K_α values, depending on the slope angle of the hanging wall rock oucrops and the degree of the rock mass fracturing, are given in Table 2.

Table 2. The factor K_α values depending on the slope angle of the hanging wall rock outcrops (the deposit dip) and the degree of the rock mass fracturing

Outcrop slope angle α, degrees	Rock mass fracturing		
	Weak	Medium	High
40°	0.790	0.823	0.850
45°	0.843	0.868	0.927
50°	0.896	0.914	0.932
55°	0.948	0.958	0.964
60°	1.0	1.0	1.0
65°	1.052	1.037	1.037
70°	1.092	1.077	1.069
75°	1.123	1.108	1.085
80°	1.145	1.126	1.103
85°	1.152	1.135	1.110
90°	1.158	1.140	1.115

Certain inconsistency related to the impact of room mining sequence on the stability of outcrops is another shortcoming of both actual and previous instructions. Thus, paragraph 8.3.10 of the current Instruction [6] indicates that "… the ratio of stable outcrop spans for the rooms of the first, second and third stages is 1.3: 1.07: 1.0" (courtesy translation). However, paragraph 8.8.2 of the same instruction states that the correction factors for the rooms of the first, second and third stages are 1.15: 0.87: 0.74, respectively. Thus, this leads to an overestimation of the stability margin of outcrops, which is noted when performing the calculations given in Table 1. According to the methodology of the current Instruction, the rooms should have lost their stability, but in fact they remain stable. Therefore, in order to consider the impact of the room mining sequence on the outcrop stability, we propose to take the value of the correction factor K_{pr} equal to 1.3: 1.07: 1.0 for outcrops of the first, second and third stages, respectively.

In our opinion, a very significant shortcoming of the current Instruction [6] is also taking into account the impact of only the mass fracturing on the outcrop stability and completely ignoring its strength. In the SE "SkhidGZK" underground mines, the mass can be represented either by rocks with a strength of 10-12 to 18 points (according to M.M. Protodiakonov's hardness scale) or an artificial backfill mass with a strength of 3-5 MPa (when mining the rooms of the second and third stages), which can be equated to rocks with a strength $f = 3\text{-}5$. Therefore, we believe that this factor should also be considered. Also, we propose to take into account the impact of rock hardness on their stability by considering the degree of mass fracturing and the hardness factor f according to the classification of masses by the rock stability presented in [46], which is given in Table 3.

Table 3. Classification of rock stability according to their fracturing and hardness

Rock fracturing			Rock hardness groups, t/m^2
weak	medium	high	
I	II	III	Too hard (σ_{com} > 15000, $f \geq 12$)
II	III	IV	Hard (σ_{com} = 8000-15000, $8 \leq f < 12$)
III	IV	V	Medium hardness (σ_{com} = 3000-8000, $3 \leq f < 8$)
IV	V	VI	Low hardness (σ_{com} = 1000-3000, $1 \leq f < 3$)
VI	VI	VI	Too low hardness (σ_{com} < 1000, $f < 1$)

In the SE "SkhidGZK" underground mines, in blocks mined by room systems, the mass has a low and medium fracturing degree and is composed of either too hard and hard rocks (i.e. I, II and III stability classes), or an artificial backfill mass, which, depending on its strength, can be equated to rocks of II, III and IV stability classes. We propose to comprehensively consider the impact of the mass fracturing and its hardness on the stability of outcrops by applying the correction factor K_f, for which we suggest the following values: class I – 1.05; class II – 1.0 (including backfill material compressive strength σ_{com} > 5 MPa); class III – 0.90 (including the backfill material compressive strength σ_{com} > 3 up to 5 MPa inclusive); class IV – 0.70 (backfill material compressive strength σ_{com} = 2-3 MPa inclusive).

Also, when analyzing the mining-geological and mining-technical conditions for the development of uranium ore deposits in the SE "SkhidGZK" underground mines, it has been revealed that in some cases tectonic disturbances of the rock mass in the form of a fault can occur in the mining blocks. Such disturbances, of course, have a negative impact on the stability of the host outcrop, and this should also be considered through the appropriate correction factor K_{tect}. When there are no significant tectonic disturbances in the block, we accept $K_{tect} = 1$. If a significant tectonic diturbance occurs directly within this block and affects the particular outcrop stability, we take $K_{tect} = 0.80$.

Thus, based on the above, the maximum permissible value of the equivalent span L_{max}, considering the outcrop lifetime, the room mining sequence, the mining depth, the mass strength, the outcrop slope angle and the presence of tectonic disturbances in the mass, is determined by the expression, m:

$$L_{\max} = \sqrt{\frac{A}{t}} \cdot K_{pr} \cdot K_H \cdot K_f \cdot K_a \cdot K_{tect}\,, \tag{9}$$

where:

K_{pr}, K_H, K_f, K_α, K_{tect} – correction factors for the room mining sequence, the mining depth, the mass strength, the slope angle of the outcrop and the impact of tectonic disturbances, respectively.

Applying this algorithm, the outcrop stability in the mined-out rooms is calculated again, considering the actual lifetime of the outcrop. The results are presented in Table 4.

The results obtained show that the calculated parameters of room outcrops, determined by the advanced methodology, fully correspond to their actual stability in the mined-out blocks of all underground mines. This indicates that the proposed methodology is more advanced as compared to the methodology used in the current Instruction [6] and provides higher accuracy when determining the design parameters of rooms in the stoping blocks and greater reliability of predictive stability of both individual outcrops and rooms in general.

Based on the performed research and advanced methodology, a new instruction has been developed, approved as a new regulatory document, to determine the safety and stability parameters of room systems with backfilling in the course of mining uranium ores in the SE "SkhidGZK" underground mines. In the future, based on the proposed methodology, it is planned to develop a specialized software that will automatically determine these parameters. The software will prevent erroneous results of calculating the safety and stability parameters for stoping blocks in the SE "SkhidGZK" underground mines, which will contribute to mine safety enhancement.

4. Conclusions

Practical experience in the SE "SkhidGZK" underground mines shows that the found dependences used in the current Instruction [6] to determine the geometrical dimensions of rooms does not accurately describe the behavior of the rock mass with cavities in the form of mined-out rooms. The detailed analysis of this Instruction allows determining a number of significant shortcomings. In particular, incorrect consideration of the influence of the mining depth, lifetime of the rooms and outcrops on their stability, failure to determine safety parameters of vertical outcrops (only horizontal and inclined ones), ignoring the influence of the inclined outcrop slope angle, conditions of outcrop contour restraints, tectonic disturbances in the rock mass and its strength on stability of outcrops and rooms in general.

Table 4. Calculated parameters of equivalent spans of room outcrops according to

No.	Block	Room volume, thousand m^3		Room lifetime, years	Calculated parameters of outcrops (equivalent spans, m) and their stability									Occurrence of rockfalls
					Horizontal outcrop of the room roof			Inclined outcrop of hanging wall rocks			Vertical outcrop			
		After completion of stoping	As of November 1, 2019		Actual	Maximum permissible	Stability	Actual	Maximum permissible	Stability	Actual	Maximum permissible	Stability	
Inhulska underground mine														
1	30-42-46	15.3	15.3	24.5	16.7	19.6	ST	19.2	47.0	ST	14.7	47.0	ST	–
2	10-100	34.6	34.6	15.5	17.9	19.6	ST	29.3	48.5	ST	18.1	42.8	ST	–
3	1-69-73	11.2	10.7	4.5	10.4	23.9	ST	23.3	57.2	ST	10.3	60.7	ST	–
4	5-2	26.6	26.6	4.0	12.9	19.6	ST	23.6	47.1	ST	14.7	42.8	ST	–
5	5-49-53	27.2	24.4	2.5	16.0	19.5	ST	27.4	45.0	ST	16.5	42.8	ST	–
6	15-48t	43.9	41.9	1.2	17.4	17.8	ST	31.5	31.2	IS	21.3	37.2	ST	h/w rockfall
7	10-2	20.4	20.4	1.7	12.2	12.9	ST	22.7	27.4	ST	14.4	25.5	ST	–
8	4-1t	71.7	71.7	5.0	21.1	23.9	ST	43.2	55.1	ST	23.7	60.7	ST	–
9	1a-1-1	43.4	32.9	23.0	14.4	23.9	ST	31.2	55.1	ST	16.7	60.7	ST	–
10	1a-2-1	16.1	15.1	20.0	11.2	11.8	ST	24.0	24.3	ST	11.4	23.5	ST	–
11	1a-5-6t	9.9	9.5	7.0	10.7	17.5	ST	17.5	48.4	ST	9.4	42.8	ST	–
12	1a-5-5	48.1	29.8	6.0	17.9	23.9	ST	28.3	60.0	ST	17.8	60.7	ST	–
13	1a-5-2t	38.2	38.2	7.3	18.5	23.9	ST	30.7	60.0	ST	17.8	60.7	ST	–
14	1a-3-1	30.9	24.7	5.0	11.4	11.8	ST	21.0	22.6	ST	14.6	23.4	ST	–
15	1b-3-2	55.2	55.2	5.2	7.0	11.0	ST	25.3	28.5	ST	19.2	31.2	ST	–
16	1a-2-6t	27.7	27.7	3.1	8.8	11.1	ST	24.0	22.4	IS	16.9	21.3	ST	h/w rockfall
17	1a-16-1	19.7	19.7	2.8	10.6	14.4	ST	14.6	29.5	ST	13.6	31.2	ST	–
18	1a-2-8t	61.6	30.6	1.5	8.7	12.6	ST	22.4	23.8	ST	16.6	26.5	ST	–
19	1a-2-1t	13.0	13.0	2.0	10.7	11.1	ST	21.9	22.4	ST	10.0	24.6	ST	–
20	1a-48-2	55.9	55.9	3.1	13.0	14.4	ST	30.9	31.1	ST	21.4	31.7	ST	–
21	1б-3-XII-XIII	15.6	15.6	3.5	10.4	11.1	ST	16.6	26.3	ST	14.8	31.8	ST	–
22	1a-2-10t	15.6	5.8	0.9	15.6	15.5	IS	13.5	30.4	ST	11.7	33.8	ST	roof rockfall
Smolinska underground mine														
1	135-9	15.5	15.5	7.0	13.8	23.9	ST	30.4	55.1	ST	14.2	60.6	ST	–
2	704-7	20.4	20.4	1.5	13.2	18.9	ST	19.8	45.8	ST	14.4	47.2	ST	–
3	554-3S$_d$	10.3	10.3	4.3	5.8	14.7	ST	18.9	31.7	ST	5.5	27.9	ST	–
4	464-35^v	47.8	29.7	7.5	15.6	17.6	ST	16.0	42.4	ST	16.0	34.3	ST	–
5	315-142	29.8	29.8	2.3	4.5	19.6	ST	26.9	43.9	ST	4.5	35.5	ST	–
6	305-155	29.5	18.5	6.8	13.9	23.9	ST	31.3	60.0	ST	14.4	60.6	ST	–
7	295-157	9.4	9.4	6.0	9.7	19.6	ST	29.1	47.1	ST	9.7	38.0	ST	–
8	564-2c	23.7	20.3	8.0	12.4	13.6	ST	19.5	29.4	ST	18.3	22.6	ST	–
9	295-1.2	17.0	17.0	7.5	10.4	23.9	ST	26.1	55.1	ST	9.7	60.6	ST	–
10	235-165	20.5	15.5	4.2	6.3	19.6	ST	28.6	45.3	ST	6.3	38.0	ST	–
11	115-8	11.9	10.5	5.3	8.7	11.1	ST	19.9	29.5	ST	8.5	31.7	ST	–
12	105-1	13.6	13.6	3.5	9.2	19.6	ST	20.4	34.1	ST	9.4	39.9	ST	–
13	344-8	10.3	10.3	13.0	9.8	13.9	ST	23.1	44.9	ST	9.2	38.1	ST	–
14	344A-1.2	32.7	14.7	17.0	8.8	20.1	ST	13.4	55.2	CT	7.8	57.0	ST	–
15	344A-4.5	39.1	23.1	15.0	9.8	18.7	ST	38.0	40.3	CT	9.2	35.5	ST	–
Novokostiantynivska underground mine														
1	329-3(1-2o)	35.2	35.2	6.4	11.2	20.9	ST	25.1	43.5	ST	21.6	50.3	ST	–
2	310-1	23.7	24.5	2.6	8.0	11.7	ST	17.6	21.4	ST	18.1	25.4	ST	–
3	235-4	30.7	14.0	2.2	8.5	12.9	ST	19.2	23.9	ST	18.5	27.2	ST	–
4	235-2	24.7	23.4	3.6	5.3	12.9	ST	21.9	22.4	ST	14.2	27.9	ST	–
5	310-2	20.5	20.5	2.1	6.1	11.7	ST	21.0	23.4	ST	15.1	24.8	ST	–
6	341-6	20.5	20.5	1.5	17.2	17.6	ST	27.9	37.4	ST	18.3	28.9	ST	–
7	341-7	24.7	24.7	1.0	12.0	22.0	ST	28.0	49.2	ST	23.9	38.0	ST	–
8	341-5	44.5	44.5	2.2	17.5	20.5	ST	29.9	40.9	ST	26.7	50.0	ST	–
9	329-2	43.7	43.7	4.1	12.1	12.4	ST	22.3	22.7	ST	18.9	27.0	ST	–
10	329-1	40.1	40.1	2.7	9.8	11.5	ST	21.9	22.6	ST	13.9	25.8	ST	–

Note: IS – instable; ST – stable

Based on the accumulated production experience, the observations conducted and a thorough analysis of the actual state of cavities, new and adjusted current dependences have been obtained that more accurately consider the impact of both determined factors and those unprovisioned in the current Instruction for determining the safety and stability parameters of rooms. It is proposed to additionally comprehensively consider the degree of fracturing and strength of the rock mass, the presence of tectonic disturbances in it, as well as the slope angle of outcrops and their contour restraint conditions. At the same time, for the first time, the paper presents numerical values of the factor that considers the rock mass strength depending on the degree of its fracturing for conditions of the SE "SkhidGZK" underground mines.

Calculations of the outcrop stability in the mined-out rooms, when considering their actual lifetime, demonstrate that the obtained parameters fully correspond to the actual stability of the rooms in the blocks of all underground mines. Thus, the advanced methodology for determining the safety and stability parameters of room mining systems in the SE "SkhidGZK" underground mines provides higher accuracy when determining the design parameters of rooms in the stoping blocks and greater reliability of predictive stability of both individual outcrops and rooms in general. The implementation of advanced methodology will enhance the safety of mining operations.

Based on the performed research and advanced methodology, a new instruction has been developed, approved as a new regulatory document, to determine the safety and stability parameters of room systems with backfilling in the course of mining uranium ores in the SE "SkhidGZK" underground mines.

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Удосконалення методики визначення параметрів камерних систем при видобутку уранових руд в умовах шахт ДП "СхідГЗК", Україна

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Мета. Метою даної роботи є удосконалення методики визначення безпечних та стійких параметрів камерних систем розробки із закладкою виробленого простору при видобутку уранових руд в умовах шахт Державного підприємства "Східний гірничо-збагачувальний комбінат" (ДП "СхідГЗК").

Методика. У роботі був використаний аналітичний метод досліджень, який включав аналіз попередніх відповідних інструкцій та звітів науково-дослідних робіт, що виконувались на ДП "СхідГЗК", літературних джерел з даної тематики, а також аналіз робочої геолого-маркшейдерської документації, яка відображає моніторинг напружено-деформованого стану гірського масиву навколо утворених порожнин та фактичний стан відпрацьованих блоків на усіх шахтах комбінату.

Результати. На підставі виконаних досліджень розроблена нова інструкція для визначення безпечних та стійких параметрів камерних систем із закладкою при видобутку уранових руд в умовах шахт ДП "СхідГЗК". Виконані згідно розробленої нової інструкції розрахунки стійкості відслонень у відпрацьованих камерах з урахуванням фактичного часу їх існування показали, що отримані параметри повністю відповідають фактичній стійкості камер у блоках усіх шахт. Це свідчить про те, що нова інструкція є більш досконалою у порівнянні з чинною інструкцією та її впровадження сприятиме підвищенню безпеки робіт.

Наукова новизна. Зростання глибини видобування уранових руд на шахтах ДП "СхідГЗК" і збільшення часу існування відпрацьованих камер потребують періодичного коригування методики визначення їх безпечних та стійких параметрів. На підставі накопиченого виробничого досвіду, проведених спостережень та в результаті ретельного аналізу фактичного стану порожнин були отримані нові та скориговані відомі залежності, які більш точно враховують вплив як відомих факторів, так й тих, що не були враховані в чинній інструкції з визначення безпечних та стійких параметрів камер.

Практична значимість. Удосконалена методика визначення безпечних та стійких параметрів камерних систем у порівнянні з методикою, яка застосовується у чинній на шахтах комбінату інструкції, забезпечує вищу точність при визначенні проєктних параметрів камер в очисних блоках і більшу достовірність прогнозної стійкості як окремих відслонень, так і камер у цілому.

Ключові слова: *уранові руди, камерна система розробки із закладкою, геометричні параметри, стійкість, безпека*