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THE CONCEPT OF RISK-BASED TECHNICAL SOLUTIONS FOR THE PROTECTION OF ORE AND NON-ORE MINE WORKINGS

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Abstract. The subject of the research presented in the article is the fastening and protection of mine workings for the extraction of ore and non-ore minerals for the construction industry. The purpose of the work is the development of the concept of risk-oriented technical and technological solutions for the protection of underground mine workings to dramatically increase the efficiency and safety of extraction of ore and non-ore minerals at deposits of a complex structure. The work uses the well-known mixed method of risk assessment, which assumes that underground mining production is accompanied by three main interrelated indicators: occupational safety of miners, environmental safety, and financial and economic risks. The method involves building a matrix of consequences and probabilities by ranking them. The technical-technological solutions for fastening and protection of workings of iron ore and uranium mines and underground enterprises for the extraction of non-metallic raw materials are analyzed. Their shortcomings are identified and the associated risks of operation and long-term preservation of underground enterprises are assessed. The concept of technical and technological solutions for improving the safety, environmental and economic performance of mines is proposed, which should be the basis of the new regulatory and technical documentation for the protection of workings. In particular, for ore mines, this concerns the transition to new technologies of anchorage, special conditions for lining junctions, introduction of bookmarks in particularly dangerous areas, control and reduction of water inflows. For mines producing non-metallic raw materials, the effectiveness of a complete transition from drilling and blasting technology to a mining machinermed one has been practically. If there are thick seams, it is recommended to work them out in separate layers, leaving a gap between them. It is advisable to divide the zones of geological disturbances into small areas, which are outlined with barrier pillars. Emphasis is placed on the mandatory implementation of comprehensive monitoring of the condition of the roof of the structures and their lining on the active and decommissioned areas. Depending on the degree of risk of collapse in large-scale mine workings and its impact on ground objects, the feasibility of using stowing is determined. Research results can be used to implement measures to improve miners' labor safety, environmental safety, and economic performance of ore and non-ore mines.

Keywords: ore and non-ore mines, lining and protection of workings, complex mining and geological conditions, occupational safety, environmental and economic risks, the concept of risk reduction.

1. Introduction

Complex mining and geological conditions of underground extraction of ore and non-ore minerals, combined with difficulties of an economic nature, significantly increase the degree of risk in production. In such cases, the technological and financial decisions should have a thorough scientific basis. The empirical search for the optimal option for mining operations in today's conditions leads to material losses at best, and emergency situations at worst.

The value of risk factors in the extractive industries is clearly visible from the diagram shown in Fig. 1, which illustrates the main risks – the state of industrial injuries in various industries per 100 000 employees. The average value of this parameter for the national economy of Ukraine as a whole is 33.29. The diagram shows that the mining industry ranks last in Ukraine in terms of labor safety [1].

According to the types of events (according to statistics), the largest number of accidents related to production is caused by sudden collapses in mine workings (up to 70%). The reason for this lies in the not fully understood mechanism of behavior of the "massif – mine working – fastening or protection construction" system.

Negative natural factors that complicate underground mineral extraction play a significant role. These include, first of all, the growth of rock pressure and water inflows, the complex structure of deposits and the presence of geological disturbances. These factors and their consequences are illustrated in Fig. 2 and Fig. 3.

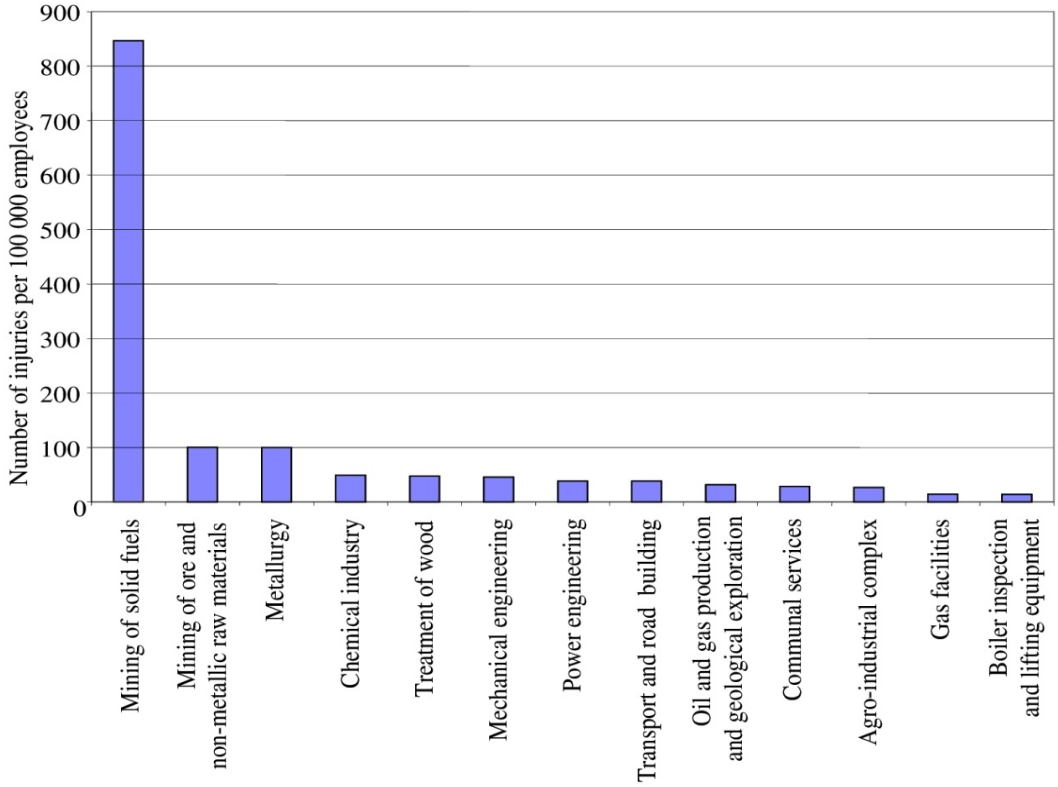


Figure 1 – The level of industrial injuries in Ukraine as of 2019

a) b)

Figure 2 – Operational risks in a gypsum mine: a) – threat of collapse; b) – threat of flooding

Of the underground enterprises that extract ore and non-ore raw materials in Ukraine, the most interesting are the mines of the Kryvyi Rih iron ore basin, the uranium mining enterprises located in the territory of the Kirovohrad region, the mines of the Marhanetsk plant in the Dnipropetrovsk region, and the gypsum and salt mines in the Donbas and Western Ukraine. At the same time, mines for the production of manganese, salt and gypsum do not fall into the category of those operating at great depths, therefore they do not require the development of fundamentally new concepts for the protection of mine workings.

a) b)

a) – collapse of rocks in the workings, b) – subsidence on the earth's surface

Figure 3 – Operational risks on the mine on extraction of iron

Means and methods of protection used in the specified mines in the absence of geological disturbances correspond to the working depth of the productive stratum and the physical and mechanical properties of the rocks. The priority direction of their improvement is to reduce the cost of fastening.

The purpose of this work is to develop the concept of risk-oriented technical solutions for the protection of underground mine workings to dramatically increase the efficiency and safety of mining ore and non-ore minerals at deposits of a complex structure.

2. Methodology

The methodology of risk assessment assumes, with almost one hundred percent probability, that underground mining is accompanied by three main interrelated risks. First, it is the safety of miners. Secondly, it is environmental safety. And, thirdly, there are financial and economic risks. Taking into account such multifactoriality, a mixed method of risk assessment was used in the work to justify technical solutions for fastening and protection of workings. The method involves building a matrix of consequences and probabilities by ranking them in the form of tables.

The general methodology of risk assessment is detailed in the manuscripts [2–12]. In [13], we proposed a matrix of events and corresponding risk calculation tables for coal mines, which fully correspond to the conditions of the entire mining industry. It was according to this scheme that the risks associated with the protection of workings in ore and non-ore mines were assessed.

3. Results and discussion

The most complex deposits in terms of their structure are deposits of iron ore and uranium. The schemes of opening and development of these deposits, as well as the physical and mechanical characteristics of the rock massif, are practically similar. The difference lies in the depth of development, which is greater in iron ore mines.

Both types of deposits are opened by vertical mine shafts secured by cast iron tubing and monolithic concrete or reinforced concrete. Chambers and workings near the mine shafts are fixed with reinforced concrete or monolithic concrete. Regarding strength, materials that meet the requirements of standards, instructions, technical conditions and passports are used to protect the underground mine workings. During the risk assessment, it was established that the designs, technological techniques and safety measures during the operation of the fastening meet the requirements of regulatory documents regarding its use.

Usually, the shape of the cross-section of the mine workings is determined in accordance with the physical and mechanical properties and condition of the rocks, the magnitude and direction of the action of the rock pressure, the service life and the adopted design of the fastening. If the mine working is not fixed, it is given a cross-sectional shape that approximates the shape of the vault of natural equilibrium. The characteristics of the main underground workings of ore mines are given in the Table 1.

Table 1 – Characteristics of the main mine workings of ore mines

Product name	Appointment	Form intersection	Fastening type
Vertical trunk	Dissection of the deposit, descent and ascent of people, equipment, materials, ventilation	Round	Monolithic concrete, tubing
Blind trunk	Descent and ascent of people, equipment, materials, from lower horizons	Round, rectangular	Monolithic concrete or wood
Vertical winze	Descent of rock from the upper horizons, movement of people, ventilation	Often rectangular	Wood, long-term – concrete
Inclined trunk	Opening of the deposit, descent and ascent of people, equipment, materials, ventilation, equipped with a conveyor or rail rolling back	Arch, polygonal, less often rectangular	Metal arch, precast reinforced concrete, pulverized concrete
Inclined winze	Descent of rock from upper horizons, movement of people, ventilation	Often rectangular	Tree. Durable concrete
Slope	Transportation of ore from the lower to the overlying horizons at an angle of inclination up to 18^0 is equipped with a belt conveyor	Trapezoidal arches	Arches a special profile of SVP, pulverized concrete
Traveling way	Pipe-cable and cargo-human. Transportation, air supply	Trapezoidal arches	Arches with a special SVP profile or wood
Adit	Transportation in mountainous terrain	Vaulted, rectangular	Ferroconcrete
Cross stroke	Providing access to all or part of the deposit. Serves for moving people, materials, equipment, air supply	Trapezoidal arches	Reinforced concrete or arches. In rocky ones – without lining
Drift	Rollback and ventilation	Trapezoidal arches, crypt-shaped, rectangular or round	Arches from a special profile, wood. In stable rocks – pulverized concrete
Cross-cut	The mine working, crossed with the extension of the	Arch deposit, rectangular	Metal arch, wood

All horizontal and inclined mining workings are carried out with the help of drilling and blasting. The most common means of protecting such products is temporary fastening with reinforced concrete or tubular anchors located on a 1×1 m grid. Pulverized concrete with a thickness of 30-50 mm is used as a permanent fastening. All cavities behind the permanent fastening are covered with non-combustible material.

Cross-cut are used without fastening or pulverized concrete is used. During their construction, some places can be additionally fastened with anchors or combined protection structures. In the case of cracked rocks, a metal arch fastening with a SVP-22 profile is used with a step of 1-2 m and a wooden tightening.

The listed mine workings protection technologies have been tested by years of trouble-free operation and meet the criteria for risk minimization, so they do not require significant improvement. Exceptions are cases of non-compliance with the construction technology anchor, especially anchor reinforced concrete fastening. Over the past few years, we have carried out surveys and expert evaluations of about ten kilometers of workings of various purposes in the mines of the Kryvyi Rih basin. In particular, vertical and inclined trunks, as well as horizontal workings of the Zaporizhzhya iron ore plant, ARSELOR MITTAL KRYVY RIH and SKHID-RUDA enterprises. It was established that in some areas up to 40% of reinforced concrete anchors do not bear the load. The reason lies in the lack of adhesion in the "massif – cement mortar – anchor" system. Long sections fixed with pulverized concrete were also found to be unsatisfactory. The reason is delamination at the contact of concrete with the rock. Therefore, we believe that the concept of risk-oriented technology for the protection of workings should provide for the improvement of the technology of installing reinforced concrete anchors or their replacement with steel-polymer ones. It is mandatory to check the strength of all types of fasteners by the method of non-destructive testing. For this purpose, the equipment and methodical developments of our institute, outlined in [14, 15], are proposed, which must be included in the new technical standards. According to our estimation, such measures will reduce risks by 2.0–2.5 times.

It was also established that the most problematic element is the protection of all connections, especially horizontal and vertical (or inclined) workings. It is in these areas that the greatest number of accidents occur, provoked by various geomechanical factors. First of all, this is the process of weakening the massif due to the formation of rock blocks and stratification of rocks, which under the action of their own weight and mechanical stresses cause collapse in the workings. Therefore, first of all, it is necessary to fix the mouth of all workings that are carried out from the surface. Secondly, all connections of inclined and vertical workings must be fixed regardless of the strength of the rocks. Thirdly, the connections of horizontal mine workings should be fixed in unstable and medium-strength rocks.

A conceptual solution for the safety of work on connections should be the development and implementation at mining enterprises of a mobile temporary protective structure that would prevent accidents during the construction of permanent supports of connection of workings. As an option, the institute's developments for coal mines can be used [16].

Fastening of roadway and main ventilation workings in ore mines must be continuous. In the case of a cross-section of more than 4 m^2, it should be made using metal frames with wooden tightening or completely wooden. In the case of a smaller section, concrete is used.

When carrying out horizontal and inclined workings, themining face must be systematically brought to a safe state by removing pieces of rock that peel off and collapse from the roof and sides of the workings. For an objective assessment of the state of the massif, it is recommended to use non-destructive testing methods [14, 15]. Rocks discovered during inspection should be felled from a safe place with a tool designed for this purpose. In case of impossibility, it should be used one-time explosions in holes.

The lag of the fastening from the mine face should be minimal, but such that it takes into account the effect of the shock wave from drilling and blasting. In the case of suspension of works for a long time on the constructed site, permanent fastening is installed tightly to the face.

One of the problems that arise during underground mining of ore is the formation of cave on the surface on the earth's surface [14]. In order to prevent environmental risks during the development of deposits in areas adjacent to settlements and industrial facilities, as well as to reduce the loss of valuable raw materials, it is necessary to switch to the use of systems with the stowing of workings. Currently, this is economically justified in the case of uranium raw material extraction. The use of development systems with such a tab is connected, first of all, with an increase in the depth of development and the value of mined ores. However, the world's leading experience and calculations of the risks of environmental consequences require the transition to this technology of all enterprises. At the same time, a number of production tasks aimed at increasing the efficiency and safety of mining operations are solved. This is the complete extraction of reserves, the preservation of the earth's surface under objects of various purposes, the competi-tiveness of raw materials on domestic and world markets.

The main features of systems with a hardenable stowing are the formation of massif of low strength (1-3 MPa). This is determined, in most cases, by favorable mining and geological conditions, and a smaller volume of construction works.

Classification of the stowing, its purpose and conditions of use in uranium mines are given in Table 2.

Table 2 – Solid stowing classification for uranium mines

Strength category	Purpose	Conditions of use
Low strength (0.2-1.2 MPa)	Creation of lateral fastening for the walls of the structures	Flat roof without additional load
Strong (1.2-2.5 MPa)	Limiting the limits of influence of the created space	Additional load within the vault
Very strong (≥2.5 MPa)	Division of massif into safe spans	Additional load of rocks to the earth's surface

It was established that the stability of exposures in blocks can be preserved when forming a bookmark with differentiated strength, namely:

- in the slabs of the first stage, the strength of the stowing should be: 3 MPa for drifts and 5 MPa for cross-cuts;
- in the cleaning slabs of the second and third stages, it is stowing to use a low-strength – 1.2 MPa;
- in cleaning slabs with two artificial outcrops, voids can be filled with loose, hydraulic and combined stowing.

The use of systems with a stowing will make it possible to extract ores under rivers, reservoirs and the residential sector. At the same time, ore processing is ensured without disturbing the rock massif. However, this requires the use of a high-quality backfill with a compressive strength of at least 7-8 MPa. It should be noted that at the present time, some uranium mines are using hardening pads, which are prepared mainly from grains of slag, sand and water and have a strength of no more than 1.0-1.5 MPa.

The vast majority of deposits of non-mineral raw materials (sandstone, limestone, gypsum, anhydrite and dolomite) are developed by the open method. Only thick seams of high-quality raw materials are developed underground. Mining is carried out leaving columnar or banded pillars. Stoing of used underground space, with the exception of some cases, is unprofitable. Therefore, the design of such a development system requires a safety factor of elements of the geomechanical system not lower than 3. This should ensure long-term stability of underground workings – theoretically an infinitely long period of time. In practice, a significant decrease in long-term stability is observed, caused by a number of unfavorable factors.

The main unfavorable factors that reduce the stability of mining workings are obvious and hidden geological disturbances in the rock massif, the imperfection of the mining technology and the presence of water pressure horizons in the roof of the workings.

It is impossible to prevent these natural phenomena without studying the mechanism of their occurrence. The results of our long-term research on a number of non-ore deposits have shown that the development of negative processes in the geomechanical system is not spontaneous, but can last for quite a long period of time [18]. This conclusion is confirmed by other researchers [19]. Fig. 4 illustrates the consequences of these processes.

In particular, it was established that outside the influence of geological disturbances, the development of deformations in the layered roof of the chamber occured in four stages:

- formation of a base crack in the lower layer (3–10 years);
- the formation of a system of cracks with the release of rock blocks (3–5 years);
- collapse of individual rock blocks of the lower layer and detachment of a deeper layer (1–3 years);
- successive destruction of rock layers until the formation of a dome of natural balance above the camera (up to 1 year).

a) b)

a) – collapse of the roof of the chamber, b) - surface collapse by the excavated space

Figure 4 – Consequences of negative geomechanical processes in underground gypsum mining

In the case of geological disturbances, deformations develop without prior formation of cracks in the roof of the chamber. The main condition for the intensification of the process of destruction of the roof of the chamber is a significant decrease in thickness or complete absence of the main roof. At the same time, we have the following three stages of the process:

- local collapse of the immediate roof of the chamber (5–20 years);
- gradual expansion of the opening in the roof with filling of the chamber with rock (up to 1 year);
- the formation of a funnel on the earth's surface (up to 1 year).

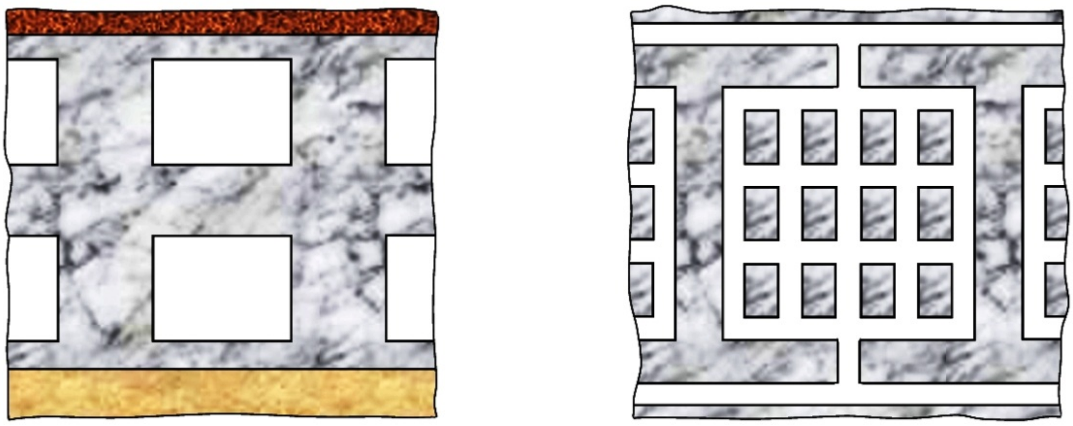
A decrease in stability also occurs when the massif is wetted. For example, the average strength of argillite at a moisture content of 2 % is 53 MPa, and at moisture content of 4 % it is 15 MPa. An increase in the moisture content of gypsum to 2 % reduces the uniaxial compressive strength by 2.0–2.5 times.

Of the operational risks in non-ore mines, the most dangerous in terms of its consequences is the combined destruction of the wholes and the collapse of the roof of the chambers. A much rarer, but catastrophic in its consequences, phenomenon is the destruction of pillars. This can cause a powerful collapse of the entire mine site due to the "domino effect". The combination of karst formation with the presence of an aquifer is also very dangerous for the stability of underground chambers.

The analysis of accidents shows that the primary measures to ensure the stability of mining operations should be aimed at preventing the destruction of wholes and roof collapses. This can be achieved by optimizing the parameters of the development system, changing the mining technology or fixing the roof. For example, for the chamber-column system, the choice of pillars in the form of a parallelepiped with a ratio of the length of the pillar to its width from 2.5 to 3.5 is the most widely used. This form is technological, but it is not optimal from the point of view of geomechanics when using the drilling and blasting method. As the authors' research showed, taking into account the unevenness of the contour and the near-contour zone disturbed by cracks, the depth of the weakened zone is about 1 m. From this it follows that, with an optimal shape, a pillar with a given cross-sectional area should have a minimum perimeter length. The optimization criterion is the ratio of the area S_n, which fully perceives the rock pressure, to the total area S_0. Therefore, the cylinder-shaped rear sight is optimal, which allows to obtain the maximum value of the S_n/S_0 ratio.

When working out a fastening of high capacity, the ratio of the height of the pillar to its width increases. It was established that with a ratio of more than 1.5, tensile stresses occur in the central part. Since the tensile strength is much lower than the compressive strength, this accelerates the process of its destruction. Accordingly, durability also decreases. Therefore, it is advisable to divide the layer into floors with a protective layer between them (Fig. 5a).

When performing mining operations in a karst zone, the probability of premature destruction of the elements of the chamber-column system increases significantly. In such cases, it is proposed to divide the mine field into separate blocks of small sizes with barrier pillars along the contour (Fig. 5b).

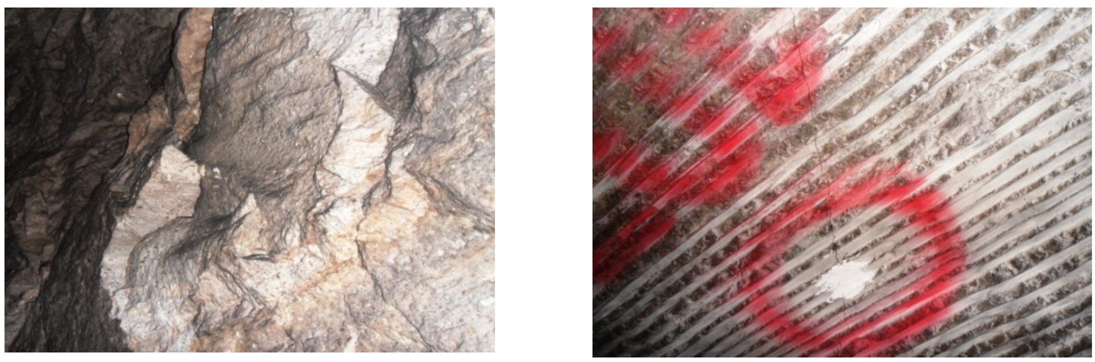


a) b)

a) – division of the seam into levels, b) – barrier safety around danger zone

Figure 5 – Ensuring long-term stability of workings in a gypsum mine

Increasing the stability of products without changing the parameters of the chamber-column system can be achieved by changing the mining technology. Replacing the drilling and blasting technology with the combine technology significantly improves the condition of the near-contour zone (Fig. 6).



a) b)

a) – drilling and blasting technology, b) – driving with the help of a heading machine

Figure 6 – Working surface for various options of breaking

4. Conclusions

Underpinning the presented concept of risk-oriented technical solutions for the protection of underground workings in complex mining and technical conditions of extraction of solid minerals, we point out the need to improve the existing regulatory and technical documentation, which concerns the protection of mining workings.

The following should be provided for in the documents relating to the protection of workings in ore mines:

- to improve the technology of installing reinforced concrete anchors or replacing them with steel-polymer anchors with mandatory control of the quality of lining by the method of non-destructive testing;

- to secure the mouth of all workings leading from the surface (the length of the fixed section is determined by the project or passport of securing the work), as well as all junctions of inclined and vertical workings, regardless of the strength of the rocks;

- it is necessary to fix the junctions of horizontal workings in unstable and medium-strength rocks;

- to development and implementation of a mobile temporary protection construction structure at mining enterprises. This will prevent accidents during the construction of permanent lining of junction of workings;

- in order to prevent environmental risks during the development of deposits in areas adjacent to populated areas and industrial facilities, as well as to reduce the loss of valuable raw materials, it is to use development systems with the stowing of workings. Also develop and implement high-quality stowing with a com-pressive strength of at least 7-8 MPa for the purpose of mining ore under rivers, reservoirs and the residential sector;

- as a mandatory element, periodic hardware control of the strength of all types of fasteners, as well as the surrounding rocks of unsecured areas to detect hidden punctures and peeling.

For mines for the extraction of non-ore raw materials are appropriate:

- complete transition from drilling and blasting to combine mining technology;
- floor-by-story mining system or leaving barrier pillars on thick seams;
- implementation of continuous monitoring of the condition of the roof of the products and their fastening in the finished areas. Or stowing, depending on the degree of risk of collapse and its impact on ground objects (especially in zones of geological disturbances);
- provision of measures to eliminate or significantly reduce water inflows.

REFERENCES

1. State Service of Ukraine on Labor Issues (2020), (12/01/2021) available at: https://dsp.gov.ua/category/diyalnist/travmatyzm-statystyka-prychyny/ (Accessed 12 January 2021).

2. Morgan, J.L., Colombo, D. and Meloni, F. (2019), "InSAR tools for risk assessment over mine assets", Proc. of the first Int. conf. on mining geomechanical risk, Perth, Australia, 2019, pp. 159-170. https://doi.org/10.36487/ACG_rep/1905_06_Morgan

3. Tubis, A., Werbi'nska-Wojciechowska, S. and Wroblewski, A. (2020), "Risk assessment methods in mining industry - a systematic review", Applied Sciences, vol.10, issue 15, 5172, https://doi.org/10.3390/app10155172

4. Karra, V.K. (2005), "Analysis of non-fatal and fatal injury rates for mine operator and contractor employees and the in-fluence of work location", Journal of Safety Research, vol. 36, issue 5, pp. 413-421. https://doi.org/10.1016/j.jsr.2005.08.002

5. Lenné, M.G., Salmon, P.M., Liu, Ch.C., and Trotter, M. (2012), "A systems approach to accident causation in mining: an application of the HFACS method", Accident Analysis & Prevention, vol. 48, pp.111-117. https://doi.org/10.1016/j.aap.2011.05.026

6. Maiti, J., and Bhattacherjee, A. (1999), "Evaluation of risk of occupational injuries among underground coal mine work-ers through multinomial logit analysis", Journal of Safety Research, vol. 30, issue 2, pp. 93-101. https://doi.org/10.1016/S0022-4375(99)00003-1

7. Pivniak, H.H., Tabachenko, M.M., Dychkovskyi, R.O. and Falshtynskyi, V.S. (2015), Keruvannia ryzykamy v hirnychodobuvnii diialnosti [Risk management in mining activities], National Mining University, Dnipropetrovsk, Ukraine.

8. Volodchenkova, N. (2018), "Identification and evaluation of professional risk at the enterprise by method of operation safety and efficiency", Scientific Works of NUFT, vol. 24, issue 4, pp. 139-145. https://doi.org/10.24263/2225-2924-2018-24-4-16

9. Bochkovskyi, A., Sapozhnikova, N., and Kurska, T. (2022), "Improvement of methodological provision of the process of professional risk assessment in civil security management systems of enterprises", Development and Security, vol.12, no 6, pp.166-179. https://doi.org/10.33445/sds.2022.12.6.14

10. Kruzhilko,O, Maystrenko, V., Polukarov, O. (2020), "Improvement of the approach to hazard identification and indus-trial risk management, taking into account the requirements of current legal and regulatory acts", Archives of Materials Science and Engineering, vol. 105, issue 2, pp. 65-79. https://doi.org/10.5604/01.3001.0014.5763

11. Domínguez, C.R., Martínez, I.V., Piñón Peña, P.M. and Rodríguez Ochoa, A. (2019), "Analysis and evaluation of risks in underground mining using the decision matrix risk-assessment (DMRA) technique, in Guanajuato, Mexico", Journal of Sus-tainable Mining, vol. 18, issue 1, pp. 52-59. https://doi.org/10.1016/j.jsm.2019.01.001

12. Skipochka, S., Palamarchuk, T., Prokhorets, L. and Sergiienko, V. (2020), "The development of the risk-oriented ap-proach to increase the efficiency", Transactions of Kremenchuk Mykhailo Ostrohradskyi National Universiti, issue 4(123), pp. 71-77. https://doi.org/10.30929/1995-0519.2020.4.71-77

13. Skipochka, S, Palamarchuk, T and Prokhorets L (2022), "The concept of risk-based technical solutions for the protec-tion of coal mine workings", Proceedings V International Conference "Essays of mining science and practice", Dnipro, Ukraine, 9-11 November.

14. Skipochka, S., Palamarchuk, T. and Sergienko, V. (2018), Geomechanical monitoring for underground mining mineral deposits. Innovative development of resource-saving technologies for mining. Multi-authored monograph, Sofia: Publishing House "St. Ivan Rilski", pp. 147-167.

15. Skipochka, S., Krukovskyi, O., Serhiienko, V. and Krasovskyi, I. (2019), Non-destructive testing of rock bolt fastening as an element of monitoring the state of mine workings, Mining of Mineral Deposits, 2019, 13(1), 16-23, https://doi.org/10.33271/mining13.01.016

16. Skipochka, S., Mukhin, A. and Chervatuk. V. (2002), Geomehanika ohranyi vyiemochnyih shtrekov v neustoychivyih porodah [A geomechanics of guard of hollow drifts is in unsteady breeds], Dnepropetrovsk, NGAU.

17. Lapshyn, O. Ye., Lapshyn, O. O. and Khudyk, M. (2020), "The tragic consequences of the collapse of the earth's sur-face within the mining allotment of Ordzhonikidze mine", E3S WebConferences ICSF 2020, Kryvyi Rih, Ukraine, May 20-22, 2020, https://doi.org/10.1051/e3sconf/202016603003

18. Sergienko, V.N, Amelin, V.A., Vasiljev, B.V., Vojtovich, T.G. and Amelina, L.V. (2013), "To the estimate of long-term stability off the roof coal in tunnels of gypsum mines in zones with geological disturbances", Geo-Technical Mechanics, no. 110, pp. 139-148.

19. Wang, S., Lv, W., Liu, Z. and Zheng, H. (2022), "Lagging collapse mechanism of gypsum-mined gob with rock creep", Geotechnical and Geological Engineering, issue 40, pp. 2489-2499. https://doi.org/10.1007/s10706-021-02040-2

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КОНЦЕПЦІЯ РИЗИК-ОРІЄНТОВАНИХ ТЕХНІЧНИХ РІШЕНЬ З ОХОРОНИ ВИРОБОК РУДНИХ І НЕРУДНИХ ШАХТ

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Анотація. Предметом досліджень, викладених в статті, є кріплення та охорона гірничих виробок шахт з видобутку руди і нерудних копалин для будівельної індустрії. Метою роботи є розробка концепції ризик-орієнтованих техніко-технологічних рішень з охорони підземних гірничих виробок для кардинального підвищення ефективності та безпеки видобутку рудних і нерудних копалин на родовищах складної структури. Використано відомий змішаний метод оцінки ризиків, який припускає, що підземне гірничодобувне виробництво супроводжується трьома основними, пов'язаними між собою, показниками: безпекою праці шахтарів, екологічною безпекою і фінансово-економічними ризиками. Метод передбачає побудову матриці наслідків і ймовірностей шляхом їх ранжування. Проаналізовані техніко-технологічні рішення з підтримання та охорони виробок залізорудних і уранових шахт та підземних підприємств з видобутку нерудної сировини. Виявлено їх недоліки та виконано оцінку, пов'язаних з цим ризиків функціонування і багаторічної консервації підземних підприємств. Запропоновано концепцію техніко-технологічних рішень для підвищення безпеки, екологічних і економічних показників роботи шахт, які мають бути покладені в основу нової нормативно-технічної документації з охорони виробок. Зокрема, для рудних шахт це стосується переходу на нові технології анкерного кріплення, особливих умов кріплення сполучень, впровадження закладки в особливо небезпечних зонах, контролю і зменшення водоприпливів. Для шахт з видобутку нерудної сировини практично підтверджено ефективність повного переходу від буро-вибухової на комбайнову технологію. При наявності пластів великої потужності рекомендовано їх відпрацювання окремими поверхами з залишенням цілика між ними. Зони геологічних порушень доцільно поділити на невеликі ділянки, які оконтурюють бар'єрними целиками. Наголошується на обов'язковість впровадження на діючих і відпрацьованих ділянках комплексного моніторингу стану покрівлі виробок та їх кріплення. В залежності від ступеню ризику обвалення в виробках великого об'єму та його впливу на наземні об'єкти визначають доцільність виконання закладних робіт. Результати досліджень можуть бути використані для реалізації заходів по підвищенню безпеки праці шахтарів, екологічної безпеки та економічних показників роботи рудних і нерудних шахт.

Ключові слова: рудні та нерудні шахти, підтримання та охорона виробок, складні гірничо-геологічні умови, безпека праці, екологічні та економічні ризики, концепція зменшення ризиків.