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CLASSIFICATION OF GEOMECHANICAL FACTORS THAT CREATE RISKS IN MINES

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КЛАСИФІКАЦІЯ ГЕОМЕХАНІЧНИХ ФАКТОРІВ, ЯКІ СТВОРЮЮТЬ РИЗИКИ В ГІРНИЧИХ ВИРОБКАХ ШАХТ

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КЛАССИФИКАЦИЯ ГЕОМЕХАНИЧЕСКИХ ФАКТОРОВ, СОЗДАЮЩИХ РИСКИ В ГОРНЫХ ВЫРАБОТКАХ ШАХТ

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Summary. The subject of research presented in the article is geomechanical processes that create risks in the underground mining of minerals for the extraction of solid minerals. The aim of the work is to analyze the geomechanical factors that create risks in the construction and operation of underground workings in complex mining and geological conditions, development and classification according to the degree of impact on the safety of mining. In the paper, the methodological approach is used, which is recommended recommended by regulations widely used in a number of highly developed countries, in particular, the British standard "OHSAS 18001", which implements the current risk assessment and continuous correction of actions in accordance with the Schuhart - Deming PDCA cycle, as well as national standard DSTU IEC / ISO 31010: 2013 developed on the analysis of the european experience. Based on our own experience, a number of the most well-known geomechanical factors that create risks during the construction and operation of mine workings have been identified. Among them: depth of mining, geometric parameters of underground working, rock pressure, physical and mechanical properties of rocks, service life of underground working, type of support, hydrogeological structure of the massif, susceptibility to dynamic and gas-dynamic phenomena, stress-strain state of the massif, etc. These factors were classified according to the degree of risk. The factors are indicated, which require constant monitoring and development of special measures and their implementation in the production process in a limited period of time. The factors are separately highlighted, which affect the safety and economic performance of mining enterprises, but belong to the categories of "moderate" or "insignificant", and therefore require periodic monitoring and evaluation with further development of planned measures to eliminate or reduce them. Purpose of the work is to improve safety of miners. This technique is universal. It can be used to assess the operational reliability of engineering facilities under the significant influence of unstable factors of natural origin.

Keywords: mine, mining, geomechanical processes, risk factors, classification by degree of risk, safety advisories

Introduction. Occupational safety remains a painful issue for miners. For example, in Ukraine, despite the fact that a number of important legal documents were modernized over the past two decades to reduce accidents, almost 50 miners were died in coal mines in the last 5 years. In the world practice, a risk-oriented approach is used since the middle of the last century to ensure the functioning of high-risk facilities. The first full-scale practical application of the risk-oriented approach was received in 1949 in the US military industry in the form of the so-called FMEA (Failure Mode and Effects Analysis) analysis. [1]. At the end of the last century, the concept of risk-oriented approach was reflected in the regulations of advanced countries. One of the best standards in the field of labor protection is the British standard "OHSAS (Occupational Health and Safety Management Systems Specifications) 18001", which implements the current risk assessment and continuous

correction of actions in accordance with the PDCA cycle (Plan, Do, Check, Act - plan, execute, check, act) Schuhart - Deming.

In Ukraine, the corresponding changes in the legal framework began after 2000. The Law "On High-Risk Facilities" was adopted [2], for the practical implementation of which a methodology for determining risks and acceptable levels for declaring high-risk objects has been developed [3]. Based on the analysis of European experience, the basic national standard DSTU IEC / ISO 31010: 2013 was developed and approved. "Risk management. Methods of general risk assessment " [4].

Unfortunately, the promotion of a risk-oriented approach in the mining industry is extremely slow. The main reason for this is the lack of a clear grouping of negative natural, man-made and production processes and their classification according to the degree of impact on the safety of the production environment. This is especially true for risks associated with factors of geomechanical safety in mine workings, which is determined by awareness of the state of the production environment and properties of the rock mass, controllability and predictability of thermo-gas dynamics of the environment and geomechanical processes associated with the interaction of the rock massif with excavation cavities, mine support lining and security structures. The problems are exacerbated by the intensification and concentration of mining production, with increased depth of operations and deterioration of geological conditions of mines. The purpose of the work is: to perform the classification of geomechanical factors that create risks in the construction and operation of underground workings in difficult mining and geological conditions.

Methodology. The methodical approach recommended in two documents is used in the work. The first is a manual for the identification and assessment of occupational risks in the workplace, developed by experts from the Technical Research Center of Finland (VTT Technical Research Center of Finland). [5]. The second is a guide to occupational safety management systems of the British Institute for Standardization [6]. Both documents are widely implemented in a number of European and American countries, have shown their effectiveness and efficiency.

Results and discussion. The main geomechanical factors that affect the technical condition of mine workings and safety of mining operations include:

- at the stage of construction construction - rock pressure, depth of development, physical and mechanical properties of rocks, the tendency of the rock mass to exhibit dynamic and gas-dynamic phenomena, structural-geological and hydrogeological features of rocks and massif, geometric parameters of development, etc .;

- at the stage of operation, these factors are added by the following factors - service life, type of mine lining and its technical feasibility, rheological properties of rocks, influence of the neighbour excavations and clearing works, character of formation of a stress-strain state around mine working face, etc.

The nature and magnitude of the influence of each of the geomechanical factors on the state of production are different. It can be assessed by using the concept of risk, which is a measure of the safety of production, because it very well combines the probability of damage caused by the danger, and the possible extent of this damage. We emphasize that the purpose of risk assessment is to increase the level of

occupational safety while maintaining economic indicators of production, and the ultimate goal is to use risk management to reduce or eliminate the impact of those hazard factors. By risk assessment we mean the identification of hazards, determining their magnitude and significance. It is necessary to take into account not only adverse events and accidents that occurred earlier, but also dangers that did not cause negative consequences. That is, the risk assessment should identify the hazard before it leads to an emergency or an accident.

For risk assessment which really lead to increased production safety, it is necessary, first of all, to determine the priorities of production safety. The most effective measures are the complete elimination of possible dangers. As such conditions are often impossible to meet, it is necessary to assess the effectiveness of measures and to organize constant monitoring of risks and interaction of workers with the production environment, in our case it is an underground geotechnical system.

As there is too many main geomechanical factors that influence a technical condition and safety of mining operations, it is necessary to rank them by their impact. It is impossible to eliminate all hazards at the same time, so measures to eliminate them should be planned in an order appropriate to the degree of risk. We emphasize that, depending on the type of geomechanical factor, it is necessary to determine the amount of risk in the time period from the moment of direct control to the empirically-determined maximum allowable timespan. Empirical data is given in Table. 1.

Table 1 – Approximately allowable time for determining the magnitude of the risk from the moment of direct control (forecast) of some geomechanical factors

Geomechanical risk factor	**Permissible time for determining risks from the moment of control (forecast)**
Depth of mining development	Until the project work is completed
Geometric parameters of excavation site	
Rock pressure	
Physico-mechanical properties of rocks	
Time lenght of underground excavation site in service use	
Type of excavation site lining fastening	
Structural and geological characteristics of the massif	
Hydrogeological features of the massif	From 1 week to 1 month (depending on the rate of progress of mining operations)
Rheological properties of rocks	
Predisposition to dynamic and gas-dynamic phenomena	
Properties of excavation site lining fastening	From 1 to 3 days (depending on the rate of progress of mining operations)
Impact of adjacent mining operations	
Loss of bearing capacity of excavation site lining fastening	
Stress-strain state of the massif	
Formation of stratifications and cutter breaks in the mine ceiling	1 shift
Risk of dynamic and gas-dynamic phenomena	

There is a quantitative characteristic of a risk determined by the probability of hazardous event and severity of consequences which it causes. The hazardous event could produce effects ample in amount and different by degree of impact. The aftermath itself is the criterion for the size of the risk. If necessary, a total value can be determined by several different effects. For example: the nature of the caused damage (significant, insignificant), the extent of the consequences (how many persons have suffered from some of them, what is the size of the material damage), the periodicity of harmful factor is available or is not available, the duration of harmful factor (short, long) Probability and severity can be assessed by various methods, for example, by добавить using the data from Table. 2 [5].

Table 2 – Criteria for determining the severity of the event

Criterion	Signs of seriousness of consequences
Insignificant	The event causes a short-term illness or health disorder that does not involve the need of medical attention. Possible absence from work for up to three days
Moderate	The event caused significant and lasting consequences. Medical assistance is assumed. It leads to absence from work from 3 days to 30 days
Severe	The event causes permanent and irreversible damage. Provides inpatient treatment and causes absence from work for more than 30 days. For example, serious occupational diseases, permanent disability or death

The probability of an event is influenced by many explicit and implicit factors. The most common of them are: frequency of adverse effect, duration of adverse effect, ability to predict in advance or prevent the influence of adverse effect. It is impossible to give clear instructions on the extent to which events are likely to occur. There are, however, some general instructions for determining the probability of adverse event, for example, using the criteria given in Table. 3 [5].

Table 3 – Criteria for determining the probability of an event

Probability of the event	Signs of the probability of an event
Small	Sometimes and irregularly
Average	From time to time, but irregularly
High	Often and regularly

Absolute accuracy cannot be achieved in determining severity of the consequences nor in the probability of events. Therefore, in determining the levels of risks, their absolute values are not so much important as the differences between different risks in the levels of probability and severity of consequences.

The magnitude of the risk can be determined in different ways. One of the most common is the method regulated by the British standard BS 8800: 2004 [6] and is shown in Table 4.

In the table three levels of severity of consequences and three levels of probability of harm are shown. First the severity of the consequences, caused by the situation, using three different positions in the top row of the table is determined, and then the probability of damage is estimated using the first column. The value of the

found level of risk is at the intersection of the three selected areas. Risk values vary from the minimum value (1 - insignificant risk) to the maximum (5 - unacceptable risk).

Table 4 – The magnitude of risks, according to the standard BS 8800: 2004

Probability	**Effects**		
	insignificant	**moderate**	**serious**
Small	Insignificant risk	Low risk	Moderate risk
Average	Low risk	Moderate risk	Significant risk
High	Moderate risk	Significant risk	Unacceptable risk

The decision on the significance of risks means their delimitation in which small risks are separated. Elimination of all risks is not always possible. Therefore, at the beginning, the risks are identified, for which measures are taken in the first place. Then the measures are extended to other risks, understanding that the goal is to eliminate or minimize the effects of risks.

The approximate limit of the measures can be the difference in the amount of risks (Table 4). If the value of the risk is 1 or 2, it does not involve implementing measures. If the risk values are 3, 4 and 5, the risk should be minimized. The limit of measures is given in Table. 5.

Table 5 – The need for countermeasures

Probability	**Effects:**		
	insignificant	**moderate**	**serious**
Small	Insignificant	Insignificant	Moderate
Average	Insignificant	Moderate	Significant
High	Moderate	Significant	Urgent

The sequence of activities can be determined by using the data in Table. 6.

Table 6 – Significance of risk and decision on the need and sequence of measures

Magnitude of the risk	**Risk mitigation measures**
Insignificant risk	The risk is so small that no action is required
Low risk	Measures are not mandatory, but the situation must be monitored so that the risk is manageable
Moderate risk	Risk mitigation measures are needed, but they can be planned and carried out exactly on schedule. If the risk causes serious consequences, it is necessary to determine the probability of the event more precisely
Significant risk	Risk mitigation measures are mandatory and should be initiated immediately. Work under risk condition must be stopped immediately and cannot be resumed until the risk is reduced.
Unacceptable risk	Risk response measures are mandatory and should be initiated immediately. Work under risk condition must be stopped immediately and cannot be resumed until the risk is eliminated.

A simple way to visually display the results of the level assessment is a risk profile. The risk profile refers to the cross section of the set of risks. Profiles can be made in different ways, for example, by type of risk according to the number of hazards, or the magnitude of risks, or the relative parts of different types of risks of all identified hazards.

With the help of the risk profile it is possible to determine the priority directions of labor safety development or the most important objects for measures. The longer the profile, the more risk factors it meets. Therefore, measures should be started in places where these hazards are identified.

The significance of the risk can also be determined based on the search for joint risks. Joint risks are those which are characterized by the same hazards and are manifested in different workplaces (areas of the massif, mine workings, etc.).

For example, those are dangers associated with the operation of various machines and mechanisms, the characteristics of the massif, problems related to the method of management, and so on. In general, the significance of general risks is very high, as they affect the operation of the entire geotechnical system, so one measure can increase the security of the entire facility.

In addition to general risks, there are special risks in many work areas or workplaces. Special risks are understood as risks of very high level or risks with special dangers concerning only the controlled object. To determine the significance of special risks and develop measures, additional actions are needed, which are performed with the help of highly qualified specialists.

The purpose of risk assessment is to select the most effective measures to improve working conditions and safety. The idea of risk assessment is to use the amount of identified risk to plan activities. Reducing or eliminating high levels of risk should be a priority in the implementation of measures. Risk management is used to reduce or eliminate risk levels. The purpose of risk management is to prevent harm and minimize damage from harm. In this case the criterion of the effectiveness of measures to reduce risks should be searched for.

The effectiveness of the measure can be assessed according to the following criteria [5]:

- increasing the level of security (the more effective will be the reduction of the highest risks, the more effective the measure will be);
- breadth of impacts (the more risks or the safety of more people are under the action of the measure the more effective it is);
- compliance with the requirements (if the measure will bring the case in line with the law, it should be considered as complied with);
- adding flexibility of work (if due to the measure the flexibility of work has (is) increased, it should be performed, although the impact on occupational safety is small);
- cost-effectiveness (best measures are not necessarily expensive, often with very small improvements or significant results are achieved free of charge).

Measures according to their importance and difficulties are divided into four classes:

- A - easy and important (measures with significant effect, they should be performed immediately);

- B - difficult but important (the measure is more difficult to be implemented than in point A, but it should be done due to its importance. The work, however, must be well planned and more cost-effective way to solve the problem should be found);

- C - easy but not important (the measure is not very important, but is easy to implement. Small improvements must be implemented);

- D - difficult and unimportant (too difficult measures should not be taken if the effect obtained from them is small. The situation, however, should be monitored and, if necessary, a new assessment should be made).

Schematically, this is shown in Fig. 1, borrowed from work [5].

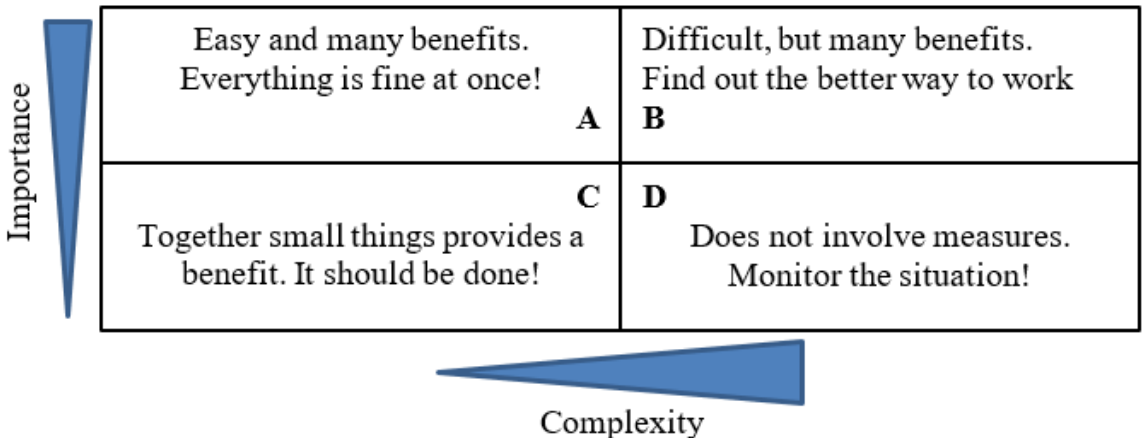

Figure 1 – Assessment of the importance and complexity of the measures [5]

By using modern methods of risk assessment in production, categories and criteria for their assessment, as well as our own experience in the field of observation, study and monitoring of geomechanical processes occurring in the underground geotechnical system for extraction of solid minerals, the classification of geomechanical factors was proposed with taking into account operation of underground workings in difficult mining and geological conditions (Table 7).

Conclusions. Thus, the following well-known geomechanical factors that create risks during the construction and operation of mine workings can be identified as the most significant: dynamic manifestations of rock pressure in the form of rock shocks, gas-dynamic phenomena in coal mines, loss of bearing capacity of mine lining which can be "instantaneous", and also formation of stratifications and cutter breaks in the mine mine roof leading to both single, and to mass collapses of a mine roof. The validity of technical parameters, passports and technology of fastening construction in all underground workings is also essential.

These factors require constant monitoring and, if detected, the development of special measures and implementation in the production process during a limited period of time.

All other geomechanical factors undoubtedly affect the safety and economic performance of mining enterprises, but belong to the categories of "moderate" or

"insignificant", so they need only periodic monitoring and evaluation with further development of planned measures to eliminate or reduce them.

Table 7 - Classification of the main geomechanical factors according to risk criteria

Geomechanical risk factor	Seriousness of factor influence	Probability occurrence of the event	The magnitude of risks, acc. to BS 8800:2004	The necessity for applying of measures
Depth of mining operation	Moderate	Likely	Moderate	Moderate
Geometric parameters of excavation site	Insignificant	Small	Insignificant	Insignificant
Rock pressure	Moderate	Likely	Moderate	Moderate
Physicomechanical properties of rocks	Moderate	Likely	Moderate	Moderate
Time length of underground excavation site in service use	Moderate	Likely	Moderate	Moderate
Type of excavation site lining fastening	Moderate	Small	Small	Insignificant
Structural and geological characteristics of the massif	Insignificant	Small	Insignificant	Insignificant
Hydrogeological features of the massif	Moderate	Small	Small	Insignificant
Rheological properties of rocks	Insignificant	Small	Insignificant	Insignificant
Predisposition to dynamic and gas-dynamic phenomena	Serious	Likely	Significant	Significant
Properties of excavation site lining fastening	Serious	Small / Likely	Moderate / Significant	Moderate / Significant
Impact of adjacent mining operations	Insignificant / Moderate	Small	Insignificant / Small	Insignificant
Loss of bearing capacity of excavation site lining fastening	Serious	Likely	Significant	Significant
Stress-strain state of the massif	Moderate	Likely	Moderate	Moderate
Formation of stratifications and cutter breaks in the mine ceiling	Serious	Likely	Moderate	Significant
Risk of dynamic and gas-dynamic phenomena	Serious	High	Unacceptable	Urgent

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Анотація. Предмет досліджень - геомеханічні процеси, що відбуваються в масиві гірських порід і підземних гірничих виробках шахт з видобутку твердих корисних копалин. Метою роботи є аналіз геомеханічних факторів, які створюють ризики при спорудженні і експлуатації підземних виробок в складних гірничо-геологічних умовах, та їх класифікація за ступенем впливу на безпеку гірничого виробництва. В роботі використано методичний підхід, що рекомендований нормативними документами, які широко використовуються в ряді високорозвинутих країн світу, зокрема, британський стандарт «OHSAS 18001» (Occupational Health and Safety Management Systems Specifications), в якому реалізовано поточне оцінювання ризику та постійна корекція дій у відповідності з циклом PDCA (Plan, Do, Check, Act) Шухарта – Демінга, а також розроблений на основі аналізу європейського досвіду національний стандарт ДСТУ IEC/ISO 31010:2013 «Керування ризиком. Методи загального оцінювання ризику». На підставі власного досвіду виділено ряд найбільш відомих геомеханічних факторів, що створюють ризики під час спорудження і експлуатації гірничих виробок. Серед них: глибина розробки, геометричні параметри виробки,

гірський тиск, фізико-механічні властивості порід, термін експлуатації виробки, тип кріплення, гідрогеологічна будова масиву, схильність до динамічних і газодинамічних явищ, напружено-деформований стан масиву тощо. Виконано класифікацію цих факторів за ступнем ризику. Вказані фактори, що потребують постійного моніторингу та розробки спеціальних заходів і втілення їх у виробничий процес в обмежений проміжок часу. Окремо виділено фактори, які впливають на безпеку і економічні показники роботи гірничодобувних підприємств, але відносяться до категорій «помірних» або «незначних», тому потребують періодичного контролю та оцінки з подальшою розробкою планових заходів по їх усуненню або зменшенню. Робота спрямована на підвищення безпеки праці шахтарів. Наведена методика має універсальний характер. Вона може бути застосована для оцінки експлуатаційної надійності інженерних об'єктів при значному впливі нестабільних факторів природного походження.

Ключові слова: шахта, гірничі виробки, геомеханічні процеси, фактори ризиків, класифікація за ступенем ризику, рекомендації з безпеки

Аннотация. Предмет исследований, изложенных в статье, это геомеханические процессы, происходящие в массиве горных пород и подземных горных выработках шахт по добыче твердых полезных ископаемых. Целью работы является анализ геомеханических факторов, создающих риски при сооружении и эксплуатации подземных выработок в сложных горно-геологических условиях, и их классификация по степени воздействия на безопасность горного производства. В работе использован методический подход, рекомендованный нормативными документами, широко используемыми в ряде высокоразвитых стран мира, в частности, британский стандарт «OHSAS 18001» (Occupational Health and Safety Management Systems Specifications), в котором реализована текущая оценка риска и постоянная коррекция действий в соответствии с циклом PDCA (Plan, Do, Check, Act) Шухарта – Деминга, а также разработанный на основе анализа европейского опыта национальный стандарт ДСТУ IEC/ISO 31010:2013 «Управление риском. Методы всеобщего оценивания риска». На основании собственного опыта выделен ряд наиболее известных геомеханических факторов, создающих риск при сооружении и эксплуатации горных выработок. Среди них: глубина разработки, геометрические параметры выработки, горное давление, физико-механические свойства пород, срок эксплуатации выработки, тип крепи, гидрогеологическое строение массива, склонность к динамическим и газодинамическим явлениям, напряженно-деформированное состояние массива и т.д. Выполнена классификация этих факторов по степени риска. Указанные факторы требуют постоянного мониторинга и разработки специальных мероприятий и воплощения их в производственный процесс в ограниченный промежуток времени. Отдельно выделены факторы, влияющие на безопасность и экономические показатели работы горнодобывающих предприятий, но относятся к категориям «умеренных» или «незначительных», поэтому требуют периодического контроля и оценки с последующей разработкой плановых мер по их устранению или уменьшению. Работа направлена на повышение безопасности труда шахтеров. Приведенная методика имеет универсальный характер. Она может быть применена для оценки эксплуатационной надежности инженерных объектов при значительном влиянии нестабильных факторов природного происхождения.

Ключевые слова: шахта, горные выработки, геомеханические процессы, факторы рисков, классификация по степени риска, рекомендации по безопасности.

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