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VALIDATION OF PARAMETERS AND DESIGN OF INFORMATION SYSTEM ON THE UNDERGROUND MINING JOB SAFETY WITH TAKING INTO ACCOUNT GEOMECHANICAL FACTORS

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ОБҐРУНТУВАННЯ ПАРАМЕТРІВ І РОЗРОБКА ІНФОРМАЦІЙНОЇ СИСТЕМИ БЕЗПЕКИ ВЕДЕННЯ ПІДЗЕМНИХ ГІРНИЧИХ РОБІТ З УРАХУВАННЯМ ГЕОМЕХАНІЧНИХ ФАКТОРІВ

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ОБОСНОВАНИЕ ПАРАМЕТРОВ И РАЗРАБОТКА ИНФОРМАЦИОННОЙ СИСТЕМЫ БЕЗОПАСНОСТИ ВЕДЕНИЯ ПОДЗЕМНЫХ ГОРНЫХ РАБОТ С УЧЕТОМ ГЕОМЕХАНИЧЕСКИХ ФАКТОРОВ

Abstract. This article is devoted to solution of one of the live scientific tasks: to determine regularities of dangerous geomechanical process occurrence and criteria for assessing risk of their development in the "support-rocks" system, and to validate parameters for the information system which could provide prompt making of decisions on ensuring safety of underground mining jobs with the help of current technologies: network communication, visual control and electronic documenting of data, which are of great importance for the job safety at the mining enterprises. On the basis of mathematical modeling methods, different scenarios of geomechanical process development around the roadways were assessed. The methods and rational parameters were developed for the information system elements functioning on ensuring the underground job safety. An architecture with the validated rational parameters was designed for the information system of the underground job safety, which differs by its methods for prompt predicting and assessing of different scenarios of geomechanical process development, and which includes the following subsystems: a basic client-server subsystem with functions of interaction between the personnel and management of the enterprise; a reference and information subsystem, which supports a decision making process, accumulates data and analyzes technical documentation; a subsystem for analyzing the job safety by geomechanical factors and for assessing of the "support-rocks" system state basing on the risk criteria and mathematical fuzzy logics.

The job safety is improved thanks to the better interaction between the people and their more strict disciplinary responsibility and early decision-making on maintaining the roadways in the trouble-free state. Methodical recommendations were developed on how to use the information system for ensuring the underground job safety with taking into account geomechanical conditions of the rock mass. The recommendations, which include the information system functioning, preparation and deploy ment, and specificity of its application in different mining enterprises, were successfully approved and implemented.

Keywords: underground mining job safety, information system, geomechanical factors.

Today, a share of the coal production and consumption is steadily increasing in the world energy balance. In Ukrainian coal mines, rate of the face advance is also increased; the mines are transferring to the roof bolting and pillar-free technology for supporting the roadways in order to reuse them in future, and all these factors are realized in extremely dangerous conditions. High danger of the coal and other mines is associated with objective geomechanical factors, as the minerals are extracted from the weak and water-saturated rocks at the great depths. Under such conditions, uncontrolled deformation of the rock mass is occurred in the form of sudden rock fall, destruction of the roof supports and blockage of the roadways, accompanied with the traumatism of up to half of the total number of the casualties. Besides, analysis of accidents shows that they are less commonly caused by equipment failure: human factor ranks the first. Therefore, an effective way to reduce accidents and injuries is to predict the geomechanical processes and strictly control observance of the safety rules by personnel with the help of the latest information systems [1-5].

To determine regularities of dangerous geomechanical process occurrence and criteria for assessing risk of their development in the "support-rocks" system and to validate parameters forthe information system which could provide prompt making of decisions on ensuring safety of underground mining jobs with the help of current technologies - network communication, visual control and electronic documenting of data - is the live scientific task, which is of great importance for the job safety in the mining enterprises.

On the basis of mathematical modeling methods, different scenarios of geomechanical process development around the roadways were estimated. The task of reducing accidents and injuries in the mining enterprises was solved with the help of designed information system of safety (ISS), one of the basic functions of which is an opportunity to quickly predict and assess various scenarios of geomechanical process development. The geotechnical system "support-rocks" is considered as a control object. To assess its state, the ISS applies mathematical models of the rock mass, which combine methods of continuum mechanics (finite element method) with the theory of boundary and out-of-bounds states of the rocks (method of initial stresses). The data on structural and geological characteristics of the rock mass and physical-mechanical properties of rocks are taken into account.

It is proposed to use the local situational geomechanical models in the information system of safety, which include parameters (in accordance with the passport of supports)of one of the possible ways of the roadway supporting and the most likely estimated rock mass behavior under increasing load on the control object. In case of increasing convergence of the roadway contour and rock destruction recorded by devices of objective control, this approach makes it possible to quickly validate the required organizational and technical measures and to create conditions for the timely warning of personnel about the emergency danger.

To validate the risk criteria used by the ISS for assessing the job safety with taking into account geomechanical factors, typical scenarios of distribution of zones with inelastic deformation and stress changes in the rock mass are identified (Fig. 1).

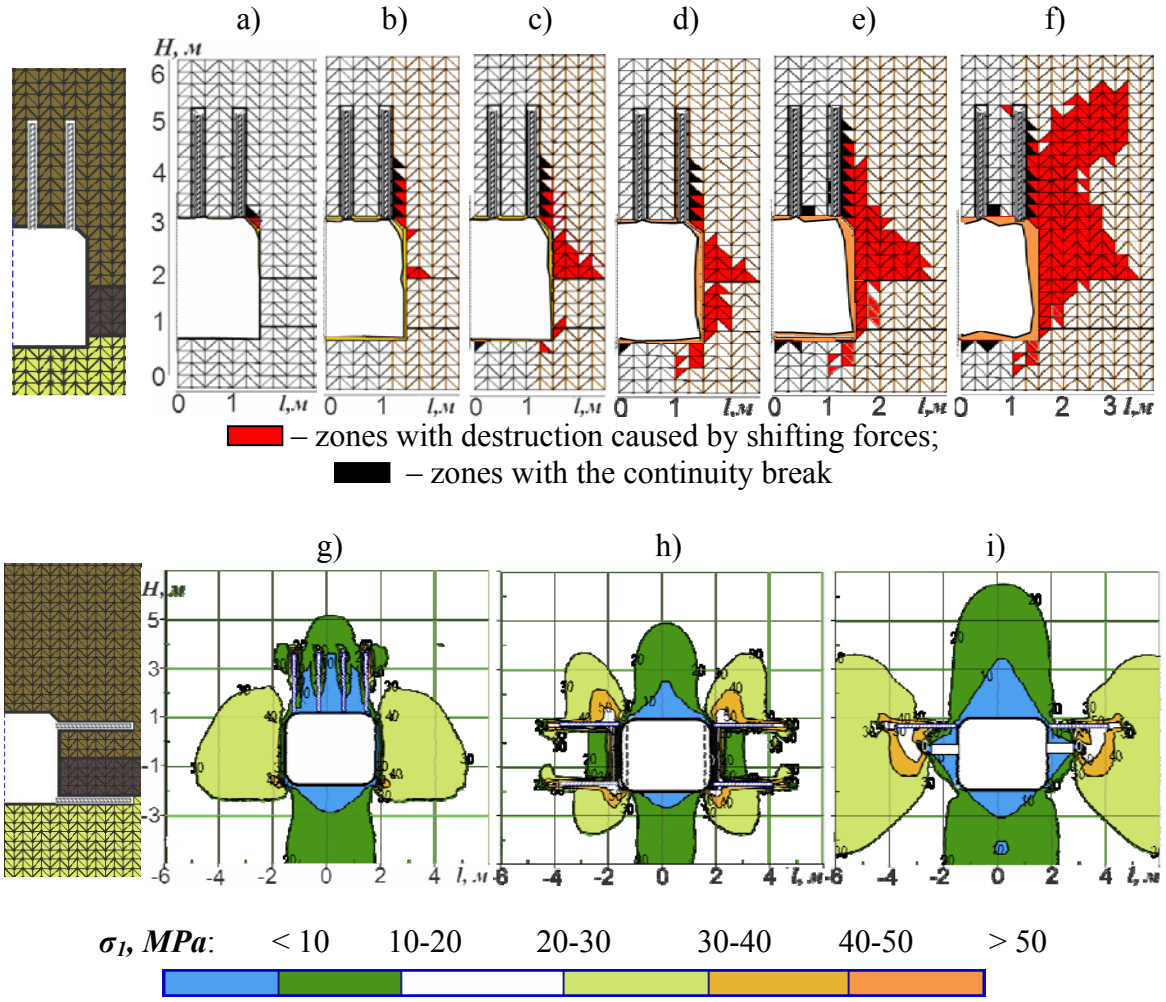

Figure 1 - Scenarios of inelastic deformation zone behavior in the rock mass around the roadway supported by the roof bolting at increasing depth of the mining jobs (a - 250 m, b - 500 m; c - 750 m; d - 1000 m; e - 1250 m; f - 1500 m) and changes of maximal stresses at different methods of the roof supporting (g-i)

With the help of method of mathematical modeling, the geomechanical situational models were calculated, which assumed use of different types of supports, increase of load on the "support-rocks" system, and changing conditions of the rocks bedding and water intrusion. The methods are developed, and parameters are validated for functioning of the information system elements on ensuring safety of the underground mining jobs [6, 7, 8].

The methodology for building the information system of safety was further developed, and now it uses different methods for the prompt predicting and estimating different scenarios of the geomechanical processes development. The ISS architecture consists of three subsystems. The first is a basic client-server subsystem, which, with the help of network technologies and mobile communication, provides functions of interaction between the personnel and management of the enterprise. The second is a reference and information subsystem, which supports a decision-making process

through the data accumulation and storage, information presentation as requested and automatic analysis of needed normative and technical documentation.

The third subsystem assesses rate of the job safety by geomechanical factors and with the help of mathematical models. This is a system for supporting the decision-making with elements of expert knowledge, which accumulates and analyzes knowledge (for example, typical mining and geological conditions or standard scenarios of the rock massive behavior) and has algorithms for assessing state of the "support-rocks" system on the basis of danger criteria and mathematical fuzzy logics.

Organization of personnel management assumes that the text description of the tasks, time for their accomplishment, explanatory images, additional requirements and instructions and on-line information concerning monitoring of the current task accomplishment are transmitted to and recorded by the electronic media (Fig. 2). The subsystem of personal management has a warning function for rapid response to the occurrence and development of events caused, in the first turn, by geomechanical factors (Fig. 3). This function helps to make appropriate decisions during essentially shorter period of time. Labor safety is improved thanks to better interaction between the people and their more strict disciplinary responsibility.

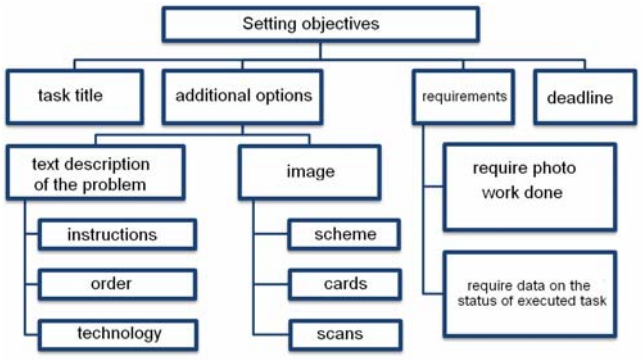

Figure 2 – Setting of production task

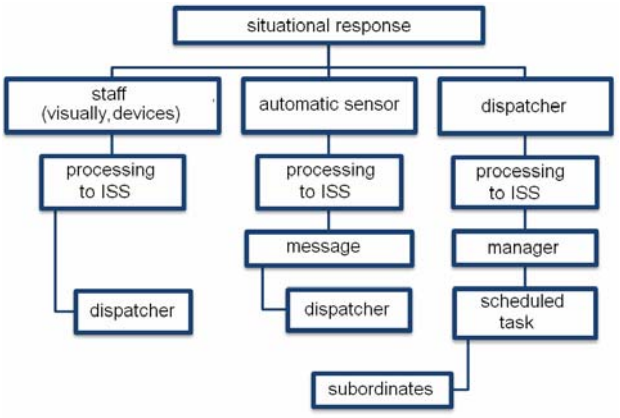

Figure 3 - Responsiveness of the personnel management system to the changed production situation

In assessing parameters for geomechanical monitoring of the "support-rocks" system, it is proposed to combine factors of expected technical risks for the system to lose its stability by way of integrating the probability estimates of informative parameters of the rock mass and roadway state. Two integrated indices of safety were formed for each group of parameters consisting of m indicators (standardized or normalized in the range from 0 to 1).

The first indicator R_{max} reflects level of maximum technical risk and is determined by the value or rate of change of the monitoring parameter, which characterizes the most unacceptable state of the control object by choosing a maximum value from the calculated functions of the risk value distribution:

$$R_{\max} = \begin{cases} R(E_r) = kr_1 R(E_r^1) + kr_2 R(E_r^2) + ... + kr_{m_1} R(E_r^{m_1}) \\ R(E_s) = ks_1 R(E_s^1) + ks_2 R(E_s^2) + ... + ks_{m_2} R(E_s^{m_2}) \\ R(E_g) = kg_1 R(E_g^1) + kg_2 R(E_g^2) + ... + kg_{m_3} R(E_g^{m_3}) \\ R(K_r) = kr_1 R(K_r^1) + kr_2 R(K_r^2) + ... + kr_{m_4} R(K_r^{m_4}) \\ R(K_g) = kg_1 R(K_g^1) + kg_2 R(K_g^2) + ... + kg_{m_5} R(K_g^{m_5}) \end{cases},$$

where m_1, m_2, m_3 are the number of risk factors, which affect stability of the roof (E_r factor), walls (E_s factor) and floor (E_g factor) of the roadways, respectively; m_4, m_5 are the number of risk factors, which can cause sudden failure of the roof (K_r factor) and sudden raising of the floor (K_g factor); $R(E_r)$, $R(E_s)$, $R(E_g)$, $R(K_r)$, $R(K_g)$ are potential risk factors of emergency caused by the factors of E type (volume of inelastic deformation zones, displacement of roadway contour, etc.) and K type (changed displacement rate, stress, volume of zones with continuity break, etc.); K_r, K_s, K_g are normalized weighting factors, which can cause potential risk for specific factors in the group.

The second indicator R_Σ reflects an integrated technical risk of the "support-rocks" system destruction, which is determined by sum of all of the risks:

$$R_\Sigma = k_1^v \sum_{i=1}^{m_1} R(E_r)_i + k_2^v \sum_{i=1}^{m_2} R(E_s)_i + k_3^v \sum_{i=1}^{m_3} R(E_g) + k_4^v \sum_{i=1}^{m_4} R(K_r)_i + k_5^v \sum_{i=1}^{m_5} R(K_g)_i ,$$

where k_1^v, k_2^v, k_3^v, k_4^v, k_5^v are normalized weighting factors of influence of each factor group, $k_1^v + k_2^v + k_3^v + k_4^v + k_5^v = 1$.

The first indicator is used by the ISS to control entering of the control object to the emergency mode and to determine a factor, which requires urgent interruption, and the second indicator is used for the total assessment of the object current state.

The information system of the mining job safety was synthesized and tested with taking into account geomechanical factors. The designed subsystems were integrated into the information system of the mining jobs safety with the help of information management methods, which are available for the authorized users. The remote divisions of the enterprise were covered by the client software arranged on the mobile devices connected to the local and global networks. The interaction with the system was organized via the GUI.

The basic software-and-hardware complex is developed, which includes personnel management system based on the network technologies, stationary and mobile communication tools and algorithms for warning about occurrence of dangerous geomechanical factors. The complex was tested on example of typical organizational structure of the mines and approved in the production conditions. The results showed that the ISS improved rate of the underground mining jobs safety through: the integration of geomechanical data obtained from various measurements and information sources into one information field; support of decision-making process at various lev-

els and provision of up-to-date information; organizational adaptation to the management structures; more detailed data processing on the base of mathematical models; criteria assessing rate of danger for the control object by methods fuzzy logics; personnel interaction via stationary and mobile interfaces.

"The Methodical Recommendations on How to Use the Information System for Ensuring the Underground Mining Jobs Safety on the Basis of Geomechanical State of the Rock Mass" were developed including the ISS functioning, preparation and deployment and specificity of its application in different mining enterprises. The Methodical Recommendations were successfully tested and implemented in the Institute of Safety and Ecology in the Mining and Metallurgical Industry, SHEI "Kryvyi Rih National University" of Ministry of Education and Science of Ukraine and by other mining companies.

Introduction of the designed ISS into the production lines provides high economic efficiency thanks to the reduced rate of injuries and forced outages as it: provides prompt information about the rock mass state and indications of dangerous situations in the roadways, which is obtained after processing data from various sources (personnel, control sensors, control systems); improves staff safety and efficacy of existing emergency systems due to the increased number of the controlled processes and better quality of their control; provides more strict labor discipline and minimizes costs thanks to the improved coherence between different infrastructural divisions of the enterprise and better production control with the help of electronic documenting of the tasks and performed jobs.

Conclusions.

1. The analysis shows that totally up to half of all accidents and accidents are caused by geomechanical factors, which occurring the form of uncontrolled deformation of the rock mass, destruction of the roof supports and blockage of the roadways. The second reason is the human factor. It is shown that one of the ways to reduce number of accidents and injuries is to ensure more strict labor discipline of employees and to prevent scenarios of negative geomechanical processes with the help of the state-of-the art information systems.

2. To validate the risk criteria used by the ISS for assessing the job safety with taking into account geomechanical factors, the typical scenarios of distribution of zones with inelastic deformation and stress changes in the rock mass are identified. Two integral indicators of safety are formed for assessing parameters of the current geomechanical monitoring of the "support-rocks" system. The first indicator determines the maximum level of technical risk and is defined by maximal values selected from the functions of the groups related to the risk of losing stability of the roadway roof, walls and floor. The second indicator reflects an integrated geotechnical risk for the system to lose its stability and is determined by the values and rate of monitoring parameters changing. The first indicator is used by the ISS to control entering of the control object to the emergency mode and to determine a factor, which requires urgent interruption, and the second indicator is used for the total assessment of the object current state.

3. An architecture with the validated rational parameters was designed for the new information system of underground job safety, which differs by its methods for prompt predicting and assessing of different scenarios of geomechanical process development, and which includes the following subsystems: a basic client-server subsystem with functions of interaction between the personnel and management of the enterprise; a reference and information subsystem, which supports a decision making process, accumulates data and analyzes technical documentation; a subsystem for analyzing the job safety by geomechanical factors and for assessing of the "support-rocks" system state basing on the risk criteria and mathematical fuzzy logics. The job safety is improved thanks to the better interaction between the people and their more strict disciplinary responsibility and early decision-making on maintaining the roadways in the trouble-free state.

4. “The Methodical Recommendations on How to Use the Information System for Ensuring the Underground Mining Jobs Safety on the Basis of Geomechanical State of the Rock Mass” were developed including the ISS functioning, preparation and deployment and specificity of its application in different mining enterprises.

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Анотація. Стаття присвячена вирішенню актуального наукового завдання встановлення закономірностей і критеріїв оцінки небезпеки розвитку геомеханічних процесів в системі «кріплення-масив», а також обґрунтування параметрів інформаційної системи забезпечення оперативного прийняття керуючих рішень для безпечного ведення підземних гірничих робіт з використанням сучасних технологій: мережного зв'язку, візуального контролю і електронного документування даних, що має важливе значення для охорони праці на гірничодобувних підприємствах.

На базі методів математичного моделювання виконано оцінку сценаріїв розвитку геомеханічних процесів навколо гірничих виробок. Розроблено методи і обґрунтовані параметри функціонування елементів інформаційної системи з безпеки ведення підземних гірничих робіт. Розроблена архітектура і обґрунтовані параметри нової інформаційної системи безпеки ведення підземних гірничих робіт, яка відрізняється методами оперативного прогнозування і оцінки сценаріїв розвитку геомеханічних процесів та включає: базову клієнт-серверну підсистему, що забезпечує функції взаємодії та управління персоналом на підприємстві; довідково-інформаційну підсистему підтримки прийняття рішень, яка здійснює накопичення даних і аналіз технічної документації; підсистему аналізу рівня безпеки гірничих робіт за геомеханічними факторами, яка оцінює стан системи «кріплення-масив» на основі критеріїв небезпеки та математичного апарату нечіткої логіки. Безпека праці підвищується за рахунок покращення взаємодії і дисциплінарної відповідальності персоналу, а також прийняття завчасних рішень з підтримання гірничих виробок в безаварійному стані.

Розроблені, затверджені та впроваджені «Методичні рекомендації з використання інформаційної системи забезпечення безпеки ведення підземних гірничих робіт з урахуванням геомеханічного стану породного масиву», що включають основи функціонування, підготовки і розгортання інформаційної системи, а також особливості її застосування на гірничорудних підприємствах.

Ключові слова: безпека ведення підземних гірничих робіт, інформаційна система, геомеханічні фактори.

Аннотация. Статья посвящена решению актуальной научной задачи установления закономерностей и критериев оценки опасности развития геомеханических процессов в системе «крепь-массив», а также обоснования параметров информационной системы обеспечения оперативного принятия управляющих решений для безопасного ведения подземных горных работ с использованием современных технологий: сетевой связи, визуального контроля и электронного документирования данных, что имеет важное значение для охраны труда на горнодобывающих предприятиях.

На базе методов математического моделирования выполнена оценка сценариев развития геомеханических процессов вокруг горных выработок. Разработаны методы и обоснованы параметры функционирования элементов информационной системы безопасности ведения подземных горных работ. Разработана архитектура и обоснованы параметры новой информационной системы безопасности ведения подземных горных работ, которая отличается методами оперативного прогнозирования и оценки сценариев развития геомеханических процессов и включает: базовую клиент-серверную подсистему, которая обеспечивает функции взаимодействия и управления персоналом на предприятии; справочно-информационную подсистему поддержки принятия решений, которая осуществляет накопление данных и анализ технической документации; подсистему анализа уровня безопасности горных работ по геомеханическим факторам, которая оценивает состояние системы «крепь-массив» на основе критериев опасности и математического аппарата нечеткой логики. Безопасность труда повышается за счет улучшения взаимодействия и дисциплинарной ответственности персонала, а также принятия заблаговременных решений по поддержанию горных выработок в безаварийном состоянии.

Разработаны, утверждены и внедрены «Методические рекомендации по использованию информационной системы обеспечения безопасности ведения подземных горных работ с учетом геомеханического состояния породного массива», которые включают основы функционирования, подготовки и развертывания информационной системы, а также особенности ее применения на горнорудных предприятиях.

Ключевые слова: безопасность ведения подземных горных работ, информационная система, геомеханические факторы.

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