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JUSTIFICATION OF THE BASIC ALGORITHMS OF THE MINE SAFETY INFORMATION SYSTEM

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ОБГРУНТУВАННЯ БАЗОВИХ АЛГОРИТМІВ ІНФОРМАЦІЙНОЇ СИСТЕМИ БЕЗПЕКИ ВЕДЕННЯ ГІРНИЧИХ РОБІТ

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ОБОСНОВАНИЕ БАЗОВЫХ АЛГОРИТМОВ ИНФОРМАЦИОННОЙ СИСТЕМЫ БЕЗОПАСНОСТИ ВЕДЕНИЯ ГОРНЫХ РАБОТ

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Annotation. This article is devoted to substantiation of basic algorithms for the information system which could provide prompt making of decisions on ensuring safety of underground mining jobs, which are of great importance for the job safety at the mining enterprises. The information safety system architecture and some basic algorithms was developed. The system 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. Two integral indicators of safety are formed. The first indicator is used 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. To validate the risk criteria 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. 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. Algorithms were tested on example of typical organizational structure of the mines and approved in the production conditions. The results showed that the information system improved rate of the underground mining jobs safety through support of decision-making process at various levels, more detailed data processing on the base of mathematical models and criteria assessing rate of danger for the control object by methods fuzzy logics. "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 Massif" were developed and implemented.

Keywords: underground mining, stress-strain state of rocks, safety information system.

Introduction

In Ukrainian coal mines, rate of the face advance is 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 [1-3]. Therefore, the justification of the basic algorithms of the information system which could provide prompt making of decisions on ensuring safety of underground mining jobs – is the live scientific task, which is of great importance for the job safety in the mining enterprises.

Methods

The methodology for building the information system for mine safety should include methods of operational management of personnel and estimating different scenarios of the geomechanical processes development. The information safety system (ISS) architecture designed as the three main 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.

Results and discussion

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. 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, Figure 1. 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.

A number of basic algorithms have been developed for the personnel management information system, which are designed with the possibility of rapidly increasing the functions of the program complex in cases of its expansion at the request of customers. These libraries serve as a kind of multifunctional designer, which helps to qualitatively and efficiently expand the capabilities of the server and browser parts of the software package. In Table 1 shows a brief description of the functionality of the basic algorithms. The need to implement the possibilities of expanding the project is due to the fact that, as practice has shown, the original software specification is only the basis of the project and cannot always meet the growing demands of customers in the process of software using. As a result, the addition and creation of new system functionality is required. The structural diagram of the developed algorithms is presented in Figure 2.

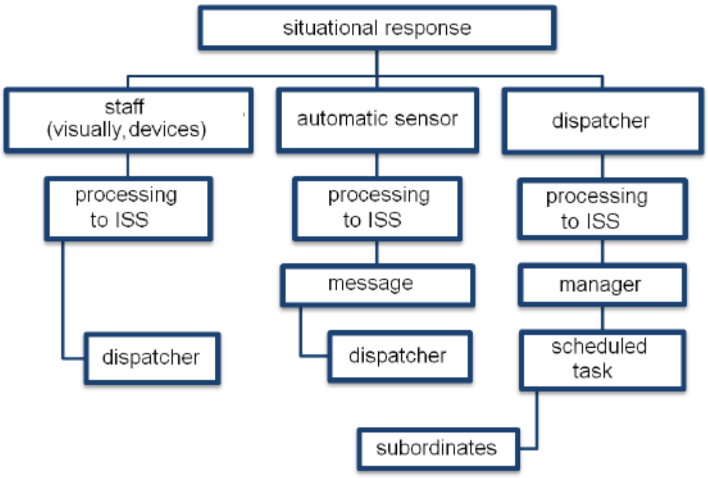
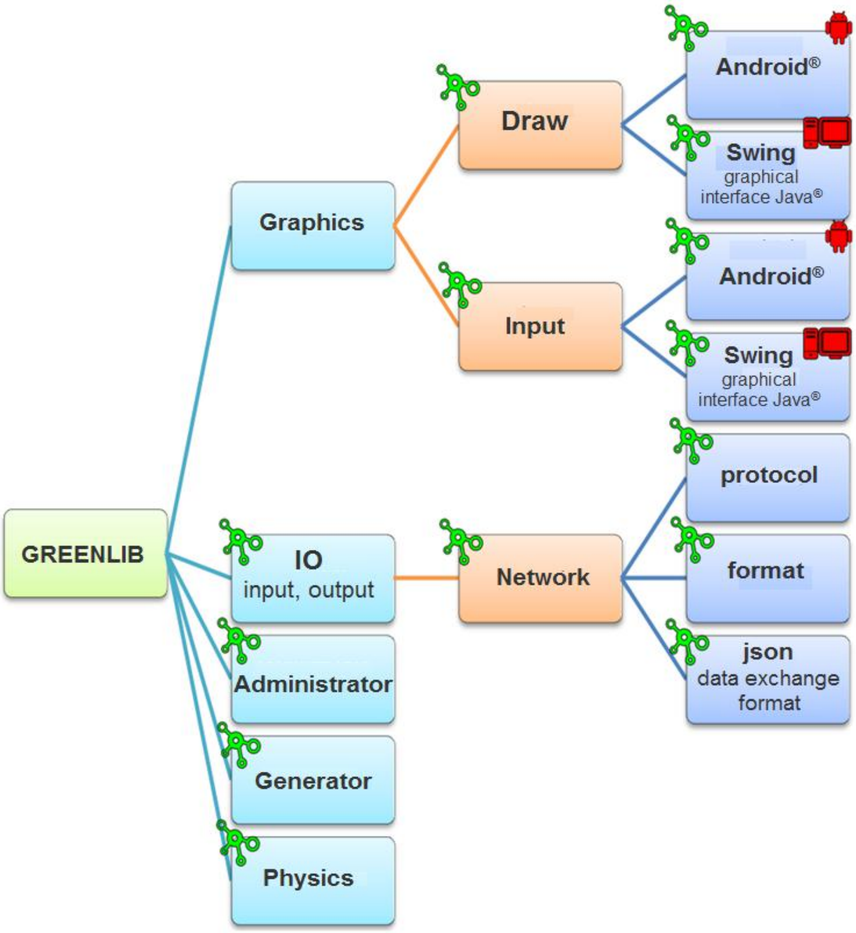


Figure 1 – Responsiveness of the personnel management system to the changed production situation

Table 1 – Brief description of the functionality of the basic algorithms

Module Name	Algorithm Assignment
greenlib.graphics.draw	Common classes and interfaces for graphics output. Provide the ability to modify cross-platform user interface.
greenlib.graphics.draw.android	Platform-specific binding to the *Android*® operating system
greenlib.graphics.draw.swing	Linking to *Java*® *OpenGL*
greenlib.graphics.input	System for recursive handling of mouse or touch screen events (search for components and event delivery to a component)
greenlib.graphics.input.android	Linking *greenlib.graphics.input* to standard *Android*® input
greenlib.graphics.input.swing	Linking *greenlib.graphics.input* to standard input
greenlib.io	Improved serialization system (easy to use and faster than standard)
greenlib.io.network	The system of client-server transmission of byte arrays or buffers over the network. Additionally, a system of extensions is implemented for archiving, encrypting or checking data for integrity.
greenlib.io.network.protocol	Allows to build on top of a simple protocol implemented in *greenlib.io.network*
greenlib.io.network.protocol.format	Implementing the protocol using *greenlib.io.network.protocol* and *serializing greenlib.io*
greenlib.io.network.protocol.json	Implementing the protocol using *greenlib.io.network.protocol* and serializing in *Json*
greenlib.administrator	Monitoring system and console for servers
greenlib.generator	Supporting code to generate source code
greenlib.physics	Mathematical library for working with vectors, matrices and objects



1.

Figure 2 – Library hierarchy for the information subsystem of personnel management: - - module (functionally complete program fragment); - platform-specific code for PC (Windows®, Linux®); - platform-specific code for Android® (tablets, phones, smart-TVs)

In the graphic visualization, two Android® packages (an operating system for smartphones, etc.) for mobile phones and tablets, a swing (library for creating a graphical interface in Java®) - for computers are used. The draw library includes interfaces and functions for drawing on tablets and mobile devices. Drawing is done with the help of triangles and their fill textures. Graphical visualization uses only the browser. The server stores the data, accepts requests and issues responses, and graphical drawing is performed by the browser. Respectively, three graphic libraries and three libraries for entering events from the keyboard and mouse are located in *greenlib.graphics* and belong to the browser part of the project.

Libraries *greenlib.io* ... (I/O) are designed to transfer data over the network and store data on the server, *greenlib.administrator* – to assist in debugging and monitoring the server. Using the *greenlib.generator* library, part of the *greenlib.io* code was generated, which reduced the number of potential errors and accelerated development.

The auxiliary library *greenlib.physics* was used for mathematical calculations in *greenlib.graphics.draw*. All libraries are written in Java®, as an example is presented part of the developed mathematical module *greenlib.physics*.The subsystem for assessing the safety level of mining operations by geomechanical factors evaluates the parameters 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:

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

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:

$$R_\Sigma = k_1^v \sum_{i=1}^{m_1} R(E_r)_i + k_2^v \sum_{i=1}^{m_2} R(E_s)_i + k_3^v \sum_{i=1}^{m_3} R(E_g) + k_4^v \sum_{i=1}^{m_4} R(K_r)_i + k_5^v \sum_{i=1}^{m_5} R(K_g)_i, \quad (2)$$

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.

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 (an example is shown in Figure 3). 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.

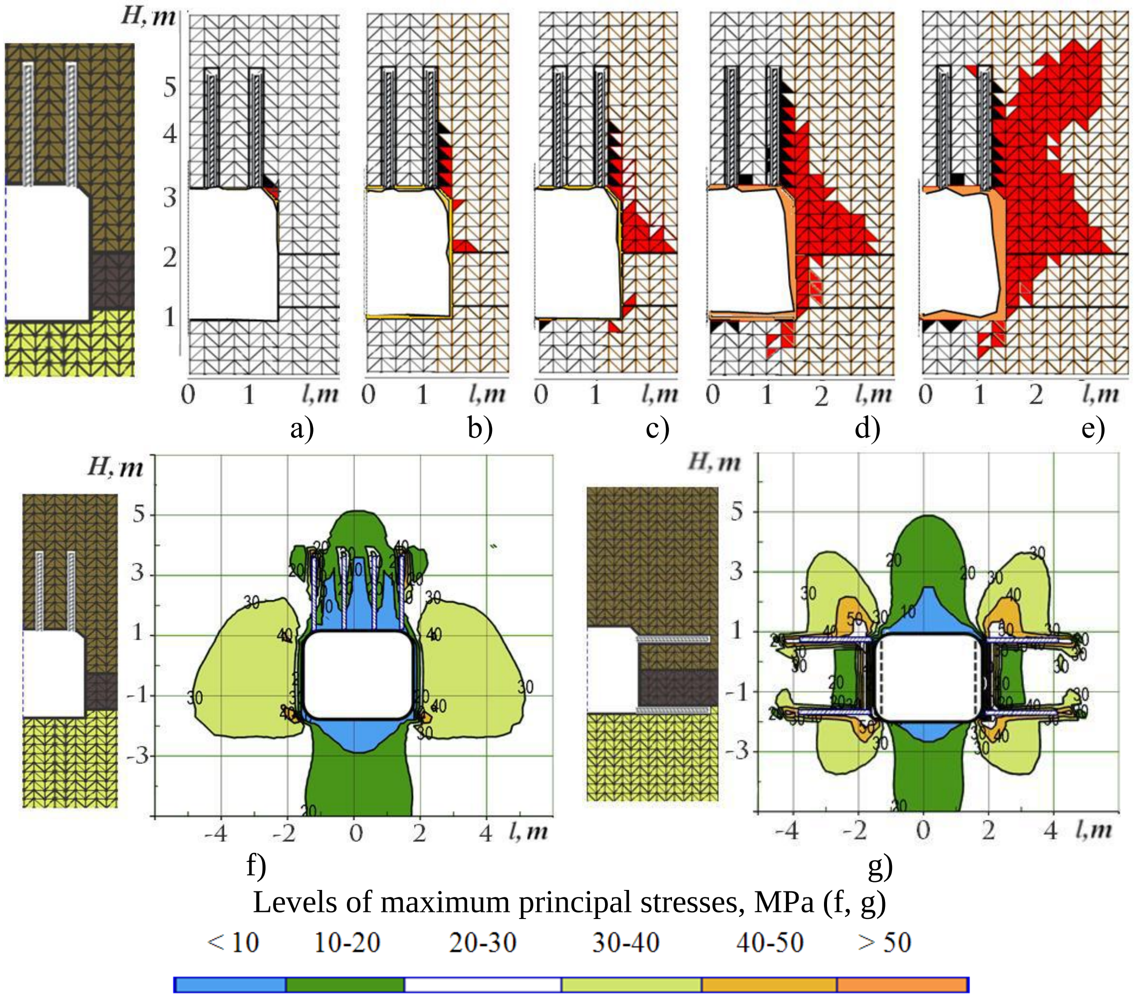


Figure 3 – Scenarios of inelastic deformation zone behavior in the rock massif around the roadway supported by the roof bolting at increasing depth of the mining jobs (a - 250 m, b - 500 m; c - 750 m; d - 1250 m; e - 1500 m) and changes of maximal stresses at different methods of the roof supporting (f, g); ▬ – zones with destruction caused by shifting forces (a-e); ▬ – zones with the continuity break (a-e)

Algorithms were 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 levels 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, SHES "Kryvyi Rih National University" of Ministry of Education and Science of Ukraine and by other mining companies.

Conclusions

1. 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. 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. Two integral indicators of safety are formed. 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 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. The information safety system architecture and some basic algorithms were developed. The system 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.

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 Massif" 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 обґрунтуванню базових алгоритмів інформаційної системи забезпечення оперативного прийняття керуючих рішень для безпечного ведення підземних гірничих робіт, що має важливе значення для охорони праці на гірничодобувних підприємствах. Розроблені архітектура інформаційної системи безпеки та ряд базових алгоритмів. Система 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. Сформовані два інтегральних індексу безпеки. Перший показник використаний для контролю виходу об'єкта управління в аварійний режим і визначення фактора, що потребує термінового втручання, а другий – для загальної оцінки його поточного стану. Для обґрунтування критеріїв оцінки небезпеки ведення гірничих робіт з урахуванням геомеханічних факторів визначені типові сценарії поширення зон непружних деформацій і змін напружень в породному масиві. Методом математичного моделювання розраховані ситуаційні геомеханічні моделі, які передбачають застосування різних засобів кріплення, збільшення навантаження на систему «кріплення-масив», зміну умов залягання і обводнення порід. Алгоритми були протестовані на прикладі типової організаційної структури управління шахтою та апробований на виробництві. Встановлено, що інформаційна система підвищує рівень безпеки ведення підземних гірничих робіт за рахунок підтримки прийняття рішень на різних рівнях, поглибленої обробки даних на базі математичних моделей і критеріальної оцінки ступеня небезпеки об'єкта управління методами нечіткої логіки. Розроблені та впроваджені «Методичні рекомендації з використання інформаційної системи забезпечення безпеки ведення підземних гірничих робіт з урахуванням геомеханічного стану породного масиву».

Ключові слова: підземні гірничі роботи, напружено-деформований стан гірських порід, інформаційна система безпеки.

Аннотация. Статья посвящена обоснованию базовых алгоритмов информационной системы обеспечения оперативного принятия управляющих решений для безопасного ведения подземных горных работ, что имеет важное значение для охраны труда на горнодобывающих предприятиях. Разработаны архитектура информационной системы безопасности и ряд базовых алгоритмов. Система отличается методами оперативного прогнозирования и оценки сценариев развития геомеханических процессов и включает: базовую клиент-серверную подсистему, которая осуществляет 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. Сформированы два интегральных индекса безопасности. Первый показатель использован для контроля выхода объекта управления в аварийный режим и определения фактора, который требует срочного вмешательства, а второй – для общей оценки его текущего состояния. Для обоснования критериев оценки опасности ведения горных работ с учетом геомеханических факторов определены типовые сценарии распространения зон неупругих деформаций и изменений напряжений в породном массиве. Методом математического моделирования рассчитаны ситуационные геомеханические модели, предусматривающие применение различных средств крепления, увеличение нагрузки на систему «крепь-массив», изменение условий залегания и обводнения пород. Алгоритмы были протестированы на примере типовой организационной структуры управления шахтой и апробированы на производстве. Установлено, что информационная система повышает уровень безопасности ведения подземных горных работ за счет поддержки принятия решений на разных уровнях, углубленной обработки данных на базе математических моделей и критериальной оценки степени опасности объекта управления методами нечеткой логики. Разработаны и внедрены «Методические рекомендации по использованию информационной системы обеспечения безопасности ведения подземных горных работ с учетом геомеханического состояния породного массива».

Ключевые слова: подземные горные работы, напряженно-деформированное состояние горных пород, информационная система безопасности.

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