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MODELLING AS A PART OF GEOMECHANICAL MONITORING OF MINE WORKING

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МОДЕЛЮВАННЯ ЯК СКЛАДОВА ЧАСТИНА ГЕОМЕХАНІЧНОГО МОНІТОРИНГУ ГІРНИЧИХ ВИРОБОК

Purpose. Creating a methodology for geomechanical monitoring of mine workings as automated data-measuring system of continuous monitoring, diagnosis and prognosis of the stress-strain state of border rock massif and support.

Methodology. Complex combination of operations research theory and mechanics of underground constructions, computer and physical modelling, mine instrumental observations.

Findings. The paper substantiates a new method of predicting the geomechanical processes and manifestations, as well as making decisions on ensuring the reliability of developments in their design, implementation and maintenance in the rock massif with undefined properties. The method includes geomechanical monitoring, physical and mathematical modelling, controlled at intervals according to the results of mine observations, and allows quantitative assessment of the reliability of heading at different stages of the operational lifetime and the interaction quality of the method, assets and the environment.

Originality. The scientific novelty of the proposed method consists in managing the reliability of headings as the geotechnical system by adjusting its structure to the changing environment during the operational lifetime.

Practical value. An adequate description of rock pressure manifestations in development headings and reasonable choice of adaptive ways and means to control the reliability of mine workings.

Key words: *mine working, geomechanical monitoring, computer and physical modelling*

Introduction. Nowadays while developing coal deposits under complex geological conditions, adequate stability of development workings during their operational lifetime is not ensured by applied methods and means in the form of arch supports made from a special interchangeable section (SIS) and resin-grouted roof bolts. On the one hand, this stems from the disparity of branch prediction techniques for manifestations of rock pressure in coal mines [1], based on a deterministic, empirical approach to developing the computation models, to changeable and in many respects uncertain environment conditions of construction and maintenance of workings. On the other hand, this is due to the complexity of reproduction of real geomechanical processes in the vicinity of the development heading fixed by frame and roof bolting using the applied methods. These difficulties consist in insufficiently accurate consideration of the properties of inhomogeneous and anisotropic rocks, including rheological ones, in excessive idealization of contact conditions between arch supple support and rigid anchors fixed along the entire length of holes with rocks, in neglecting the nonlinear relationship of stress and strain, in rock softening and loosening at their ultraboundary deformation, as well as in variability of dimensions and configuration of the assessed area within the time period.

Unsolved aspects of the problem. To consider the variability and uncertainty of geological and engineering conditions of coal mining, the methodology of

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forecasting rock pressure manifestation and choosing the ways and means to ensure the stability of the headings must be based not only on improbable a priori information but, above all, on more accurate current and forecast data obtained by geomechanical monitoring based due to the research object complexity on an integrated approach, which includes mathematical and physical modelling and direct measuring of the monitored parameters in mining conditions. Using this information, as well as the optimality principle of indicators which estimate the reliability of the heading, one can obtain a flexible operational solution for the problem situation, i. e. implement the concept of adaptive behaviour of a geotechnical system given in [2]. Thus, when solving the problem, you can switch from a static model of the heading functioning to the dynamic one considering its specific behaviour throughout the operational lifetime.

With this approach, the problem of the inadequacy of the geomechanical models is solved by a skillful combination of physical and computer modelling methods, as well as due to the fact that the computation experiment has the task not to represent accurately the real phenomena, which is actually impossible for such complex objects, but to obtain the results which can be checked by using controlling parameters directly in the mine. These simulation results are used to determine statistical relationships necessary for predicting the manifestations of rock pressure with tolerance probability and making engineering decisions on providing the stability of headings, which ensure minimum risk.

The matter of such an approach to solving the problem of insufficient stability of the headings is not in choosing methods inter-related with specific forms of rock pressure manifestations by rigid or plastic ties, but in continuous advancing to the best solution due to adaptive management, i. e. by adjusting the technology to the environment [2].

The peculiarity of a rigid structure is in the fact that to ensure the equilibrium state of a heading as a geotechnical system, its elements (border rock massif, rock outcrop and support) complement each other over a full range of environmental conditions, whereby the high organization structure is achieved. But such systems are vulnerable to transient conditions of the environment, since they are static and unable to undergo a modification as far as the properties and stress-strain state (SSS) of the rock mass vary.

The opposite type presents the systems formed from a number of homogeneous similar elements featuring interchangeability property and therefore plastic structure of inter-connection with the rock pressure manifestations. The examples of such systems are the headings anchored with metal pliable support made of SVP. By virtue of their similarity the elements of such systems hardly complement each other and do not have a high level of organization, but if environmental conditions are changed they can be adjusted by varying the parameters of support (a number of a special section, the fitting density of the frames, pliability, unit resistance in a pliable operation mode etc.). Geotechnical systems with such ties are poorly organized, but they are able to change their form quickly, i.e. to be plastic, that allows them to survive in the conditions of the probability distribution of their properties.

Flexible systems are characterized by a combination of merits of rigid and ductile structures and differ in available control. These geotechnical systems have a high level of organization due to the complementarity of different types of support (framed and anchored ones), and feature high plasticity due to a combination of different designs of the support. Frame and roof bolting support satisfies the principles of flexible system behaviour, which is able to modify its structure as far as external conditions vary not only as a result of combination of the frame and roof bolting support, but also by changing the parameters of each type of support.

The advent of powerful computers and information technologies related to the modern “monitoring” concept opened wide prospects for designing the flexible geotechnical systems. Functioning of the geomechanical monitoring system for the state of development headings should not be limited just to continuous monitoring of the rock massif state and predicting dangerous manifestations of rock pressure, as it is currently performed in the mines which are dangerous due to gas emission and rock bursts. Geomechanical monitoring should be based on computer systems of the operational data processing on the state of border rock massif (e. g. stress, strain, hollowness, strength, etc.) and a support (load-bearing capacity, pliability, etc.). It should provide remote measuring and control in real time, as well as giving the operator continuous information on the state changes of rock massif and a support to allow a purposeful design of the structures which satisfy certain criteria considering the reliability of a heading. Such monitoring systems should include computer patterns of examined rock fragment as their integral part and, if required, physical models of interaction between the support and rock meant for intellectual analysis (diagnostics) of rock pressure manifestations and giving recommendations for managing the reliability of a heading.

Analysis of the recent research. Based on the analysis [3–5] devoted to the numerical computer simulation of geomechanical processes around the headings considering the interaction of the support and the rock, one can outline the following trends in research direction for studying stress and strain state of rock massif in coal mines.

Firstly, while solving geomechanical problems a finite element method (FEM) is most widely used, therewith the applied models are sub-divided according to the type of a problem to be solved (linear or nonlinear, flat or steric) and a method for producing nonlinear solutions. Existing application program packages allow solving spatial problems only in the elastic formulation without considering the interaction of the anchor support and rock massif. For adequate modelling of geomechanical processes calculation methods using SSS are constantly being improved and complicated by taking into account the increasing number of factors. In severe cases to obtain reliable solutions an iterative principle is widely used because iterative methods have proper convergence. Which of the geomechanical parameters should be adjusted in the course of iterations depends on the physical law which establishes the relationship between stress and strain. If a form of the matrix is chosen at the iterations, then methods of variable rigidity are used, but if strain or stress are adjusted, then they use methods of initial strains and stresses. Sometimes it is impossible to find out a relationship between full strain and stress, while the ratio for their increments can be derived. Then the iteration method is used for each load increment (e.g., depending on the distance from the tunnel, or stope) or with time considering creep.

The wide use of computers for solving geomechanical problems and striving to automation of calculations motivates the necessity to pay more attention to the algorithm resistance to various types of errors resulting from non-compliance with the boundary conditions, incorrect discrete sampling of calculated area, rounding of calculations, etc. Due to an increasing number of the PC users who do not have fundamental geomechanical training and are unfamiliar with the numerical methods, there appear new requirements to the programs and modelling algorithms for geomechanical processes, which have to become a part of the geo-mechanical monitoring system headings state in coal mines.

Secondly, a number of tasks for a more detailed reflection of the array structure and features of development of geomechanical processes require steric setting. However, because of rather hard ensuring the adequacy of computer 3D-modelling of geomechanical processes considering the interaction of rocks with a support and a scale of computations, the principle of decomposition of complex problems into more simple occurs to be more perspective considering their hierarchical interdependence (analysis of stress-strain state of the rock mass; the definition of the border zone softening of rocks around the production, analysis of the interaction of the lining to break the rock to determine its parameters), spatial interference (stope, development heading, a separate section of a heading at one distance or another from the stope or heading itself) and the time-base development of geomechanical processes (initial state of massif, formation of a new stress field in the influence zone of the tunnel face, maintaining the heading in static field in time, the impact of temporary bearing pressure of the first face, etc.). At the same time to better reflect the characteristics of the array structure, the geometric object parameters and mechanical properties of rocks, it is possible to use a wide variety of options for FEM, or even a combination of different numerical methods. However, the issue of objective reflection of the matter of processes at the border of conjugated areas examined using different models or different finite difference methods, is still an open question.

Thirdly, an increasing number of works is devoted to detailed examination of the structure of rock massif, record of heterogeneity and anisotropy of rock properties that significantly affect the SSS of rock around the heading and manifestation form of rock pressure. While solving multi-parameter geomechanical problems one should always keep in mind the so-called "curse of dimensionality". Increase in the number of regarded parameters, especially under uncertainty conditions, does not always result in rectification of the computational model, but is usually accompanied by complication of the problem and increasing computation time. The truth criterion in this case can only be the results of mine observations, and while solving the problems lacking major geo-mechanical parameters (e.g. coefficient of horizontal stress, rheological parameters, etc.) one should use the principle of gradual narrowing of the factored space and methods of rational planning of computing experiment (e.g., Latin Square method).

Fourthly, nowadays when modelling geomechanical processes, a growing number of works regard not only plastic and rheological properties of rocks, but their ultimate and transcendent state (with rocks softening and loosening) and the geometric nonlinearity, i.e. a problem with large displacements is formulated. Moreover, one should keep in mind that their result depends on the way of solving the problem, i.e. there is a possibility to obtain a non-unique solution or the result with no physical meaning. In such cases, the load is preset in small intervals and a nonlinear solution is obtained for each individual interval with checking if the equilibrium conditions are satisfied.

Thus, despite a large number of used geomechanical models, it should be noted that their basis is made of classical-empirical methods of solid mechanics, and the variety of tasks suggests the universality of the FEM and application perspectiveness of this method to solve geomechanics problems within the geomechanical monitoring system. However, methods of computer simulation face serious obstacles when studying the mechanism of interaction between the frame support and anchors with border rocks and determination of their common bearing capacity in a single geotechnical system depending on the control action.

In this case, the computer model can be amplified with methods of physical modelling [6], based on the similarity theory, dimension theory, and allowing displaying in certain scale a structure and physical-mechanical properties of border massif interacting with the support.

Objectives of the article. The aim of this study was to develop new methodological approaches which ensure the prognosis adequacy for rock pressure manifestation within geomechanical monitoring system through a combination of computer and physical modelling.

Computer modelling. Background experience in providing the stability of development headings using the above approach allowed developing a methodology of solving the problem, whose algorithm for visual presentation of some steps is shown in Fig. 1–4.

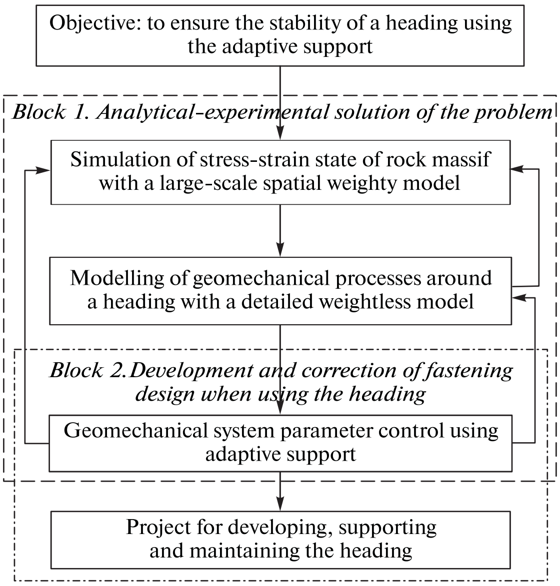

Fig. 1. Solution scheme for the problem on providing the stability of a heading using an adaptive support

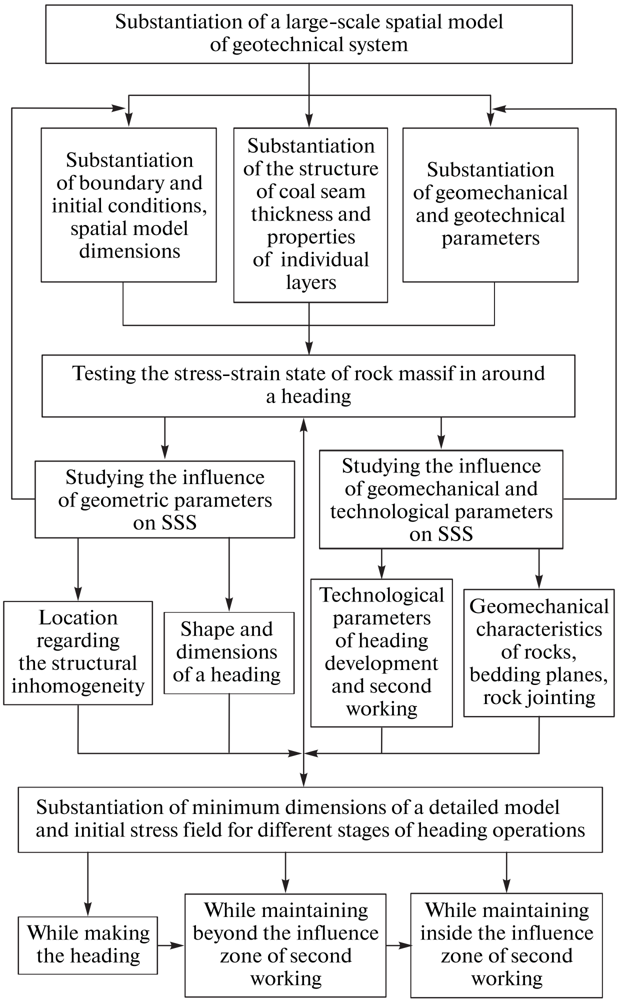

Fig. 2. Scheme of choosing a research model of geomechanical processes around a single heading

The general structural and logical scheme for solving the problem is shown in Fig. 1; it comprises two blocks. Block 1, which includes analytical and experimental research methods, aims to study SSS of rock massif with a large-scale spatial model and simulation modelling of geomechanical processes around the heading with the detailed weightless model for assessing the border state of rocks and determining the shifts of rock circuit in the heading. Block 2 is aimed to develop a project supporting the heading at its developing and adjusting the project during the operation of the heading in changeable conditions by controlling the parameters of geotechnical system using an adaptive support.

The matter of the problem consists in:

- predicting rock shifts in the heading considering the interaction with adaptive support, which allows measuring rock shifts in any direction radially with required accuracy;
- predicting a state of an arbitrary cross-section of the heading fixed with a metal arch support of special section by calculating the arch for strength and stability taking into account the active arch thrust, sealing and strengthening the crashed rock in around a single heading;
- predicting a critical ratio area of geomechanical and mining parameters of the “massif-support” system which requires special measures to ensure the stability of the heading including the operation of the heading.

Let us study the individual stages of the problem solving in detail. The first phase is objected to simulate SSS of the massif in order to stipulate the size and initial stress field of the detailed model aimed to simulate geomechanical processes in around the heading. The structure of this stage (Fig. 2) includes three sub-tasks targeted to substantiate collectively a geomechanical model for studying processes of deformation and destruction of rock massif around the heading adequate to real conditions. The objectives of the first phase are extremely important since the accuracy and reliability of the results regarding the forecast of the heading state depends on the thoroughness of examining the calculation schemes, boundary and initial conditions, behaviour of individual elements of the geomechanical system. These tasks are interrelated with the common goal, which consists in determining the initial stressed state of rock massif in around the heading. The first task is to substantiate a large-scale spatial model of rock massif and covers:

- substantiation of boundary and initial conditions, determination of spatial model dimensions considering inter-influencing headings and second working;
- substantiation of the structure of coal seam thickness and properties of individual layers;
- substantiation of geomechanical and geotechnical parameters (heading depth, development techniques, support type, method of protecting the heading, method of rock pressure control in a longwall, heading location regarding the coal layer etc.).

The second task has been testing the stress-strain state of rock massif in around the heading through

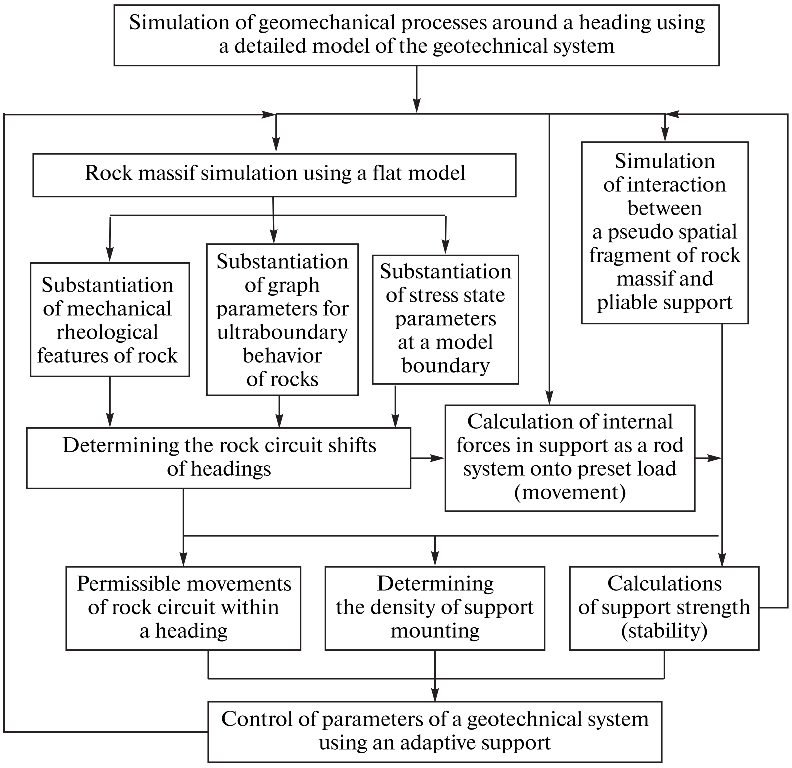

Fig. 3. Scheme of simulating with a detailed model and determining the parameters of support

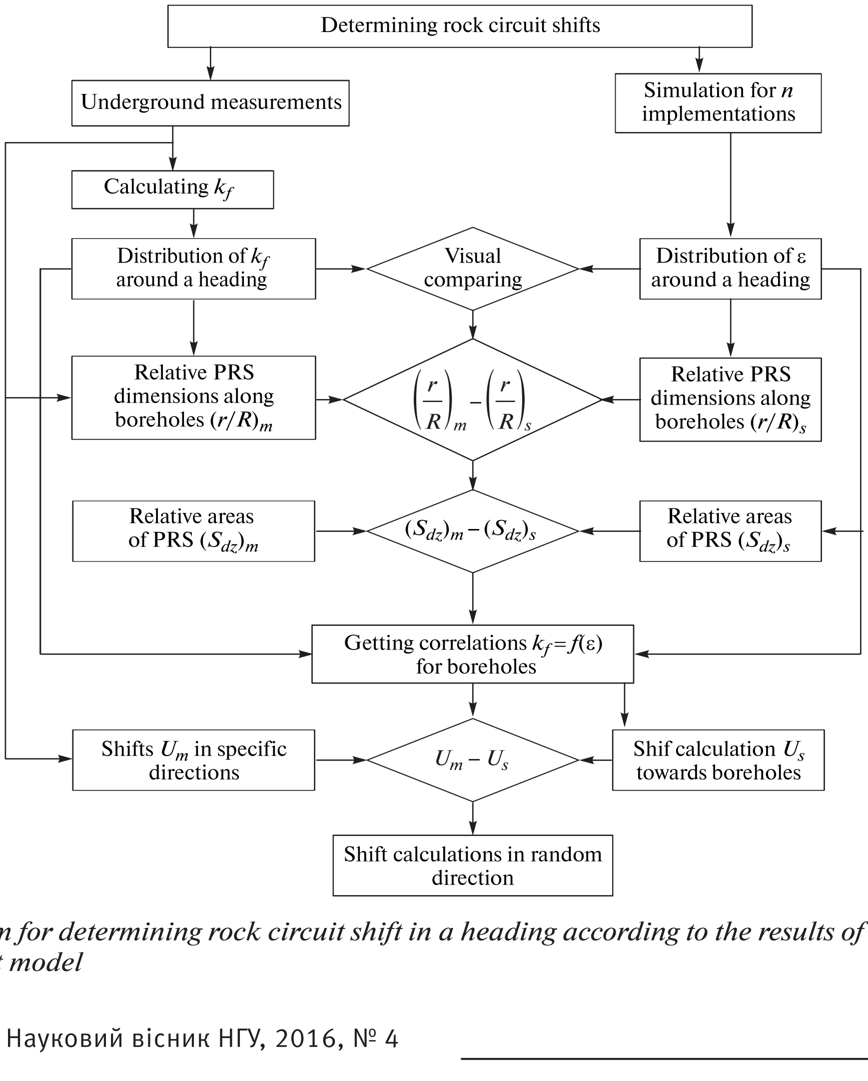

Fig. 4. Algorithm for determining rock circuit shift in a heading according to the results of imitating simulation on a flat model

complex test calculations to study the effect of space geometry parameters (heading location regarding the structural inhomogeneities, adjacent mines and second workings, the shape and size of headings, inclination of the heading etc.) on SSS as well as that of geomechanical parameters (thickness of the individual layers, rock inclination, stratification and rock junction, mechanical characteristics of rocks and planes of their softening etc.) and technological parameters (e.g. the form of a face, rock destruction methods, type of support, a roof type according its ability to collapse and hang over the open area). This task requires a large number of test calculations to establish the main factors influencing the SSS of rocks in around the heading. It involves making changes to the original model, so this stage supposes to have feedback with the objectives of the first phase.

The third objective of the first stage consists in substantiation of the detailed model and initial stress field in different periods of heading operations starting with its developing to maintaining it in an influence zone of second working. It involves reflection of a temporary logical sequence of geomechanical processes formation when solving the problem of heading sustainability: nucleation of an inelastic deformation zone in a changeable stress field caused by building a heading; further development of the destruction zone beyond the influence zone of second working in the stationary stress field, however, with changeable rock strength due to their intrinsic rheological properties; sharp changes in rock pressure manifestations influenced by second workings, which is implemented in an alternating stress field caused by periodical shift processes, collapse of rocks and hanging over the open area.

As it can be seen from the first phase structure (Fig. 2), all tasks and subtasks are interconnected by logical ties and relationships occurring in a real object. The procedure of test calculations consists in making any changes into the geomechanical model based on the analysis of the results obtained during the previous SSS test calculations. The final result of the first phase is a geomechanical model with such initial stress field where the main features of the deformation of the simulated rock massif around the development heading can be displayed.

The second phase structure given in Fig. 3 suggests two possibilities of modelling options for geomechanical processes around the heading using a detailed model being a part of a large-scale spatial model:

- modelling of geomechanical processes using a flat model, which allows reproducing the original rheological and mechanical properties of rocks in more detail, to record a diagram of ultraboundary behaviour of rocks in the zone of their destruction, and substantiating more accurately the parameters of the initial stress state at a model boundary followed by calculation of the internal forces in support units as a rod system for preset load (movement);
- simulation of direct interaction of a pseudo spatial fragment of rock massif and frame support implemented in the form of a rod system having pliability and interconnected with rocks in separate units described with special finite elements with unilateral elastic ties of given rigidity considering the tangential rock movements and their friction with the contour of support.

While determining rock circuit movements in the heading for eliminating the uncertainty in presetting the initial stress field and rock properties based on the known manifestations of rock pressure in the heading, the inverse problem is solved, whose algorithm is given in Fig. 4. The implementation of the proposed method consists in the following operations:

- multiple solution of the main geomechanical task through FEM on evaluation of possible manifestations of rock pressure W_s with known χ and unknown beforehand ξ conditions for different types of solution for $x \in X(W_s = f(\chi, x, \xi))$;
- determining the actual indices W_m rock pressure manifestations in certain conditions according to the pictures of distribution of interstitial cavity index k_f using instrumental observations;
- assessing the parameter parts ξ by comparing the simulation results W_s with observations in a mine W_m for choosing the decision $x = x^*$, when calculated parameters to the maximum extent meet actual data;
- determining x^* for the solution sought which is characterized by the found set of parameters χ and ξ, correlations with similar natural values, which are used for current predicting of rick movements and support load till the next control point.

It should be noted that x, χ and ξ are not numbers in a general case, but vectors, being put under limits narrowing down the factor space. If the number of possible solutions constituting a set X is not big, then its determining is possible using simple exhaustive search. With a great number of factors x^* searching by simple exhaustion becomes really impossible, so it is reasonable to use a direct exhaustion method, when desired solution is found by continuous narrowing down of the factor space.

Simulation results are presented as a picture of relative deformation distribution and shapes of plastic range of stress (PRS) due to which one can define their dimensions in specific directions and the area; moreover, a form of rock pressure manifestation is diagnosed. The given summation of calculated data is compared with mine observation results objecting to choose such a solution when compared rock pressure manifestations could be mostly similar. Above all, matching condition should include a qualitative analogue of kinetics of movement of destruction front of a group of intermediate state of elements which they have when the destruction zone is being formed and the PRS form at certain distance z from the face of the heading. The development mechanism of geomechanical processes is visually assessed through a display. It allows immediately throwing aside from the record those solutions, which do not match natural data dramatically and gives an opportunity to put initial multitude of choices to the limited number whose further analysis is done using the quantitative criteria.

The first quantitative criterion is relation of equality of destruction zone dimensions to the radius of the heading *(r/R)* in certain directions for one and the same point of time. It allows additionally putting aside the solutions x, which do not match mine measurements on SSS configuration and being restricted to an analysis of a small number of calculation choices. The final choice of the required option is based on the idea that mine measurements will match better that loading scheme and group of parameters whose algebraic sum of deviations for measured and calculated parameters with the relative area of the destruction zone is zero, i.e.

$$\sum_t [(S_{dz})_m - (S_{dz})_s] = 0, \qquad (1)$$

where $(S_{dz})_s$ and $(S_{dz})_m$ are relative areas of the destruction zone consequently according to the results of simulation and geomechanical control.

Occurrence of uncertain factors which influence $(S_{dz})_s$, changes this problem from being purely mathematical into the problem of choosing the solution in uncertain conditions considered in a theory of operation investigation. Herewith, a man, who has a number of methods available used depending on the type of uncertainty (stochastic, nonstohastic), makes a decision. In our case, when probability distribution of unknown factors basically exists, but it cannot be obtained by a decision making moment, it is reasonable to apply an adaptive control algorithm. On the ground of matching the results of mine measurements with simulation data at moment t_1 we set in advance some characteristics of random factors and values of control parameters supposing preliminarily they are not accurate and not optimum. As far as information is accumulated at moments t_2, t_3 the characteristics of uncertain factors are changing, so that matching of mining and calculated data will increase rather than reduce.

Nonconformity problem of calculated movements is solved by matching the simulation results with onsite measurements and obtaining stochastic dependences between relative softening ε_{dz} deformations and interstitial cavity index k_f in specific directions (along and across bedding, at 45° to stratification lines) and for different types of rock. While accumulating data, the relationship between the above values is specified. Within the intervals of measurements the obtained dependences are used to predict variation limits for k_f index with preset reliability in all elements of massif involved into a deformation process. Knowing a general distribution picture for interstitial cavity index $k_f = f(x, y, z, t)$ for rocks around the heading by PRS depth integrating, you define total opening of cracks along the set direction numerically equal to the displacement of the point in the circuit. The integration having been done in several directions, a new position of rock outcrop is developed being a result of rock deformations in around the heading.

According to simulation results a new heading contour, which corresponds constant distance from a face to a longwall, is built for each calculation choice, or the heading lifetime t and certain stake; the section area S_w is defined due to the circuit changed. Calculation results for each moment of time t are used to correct conditions of interaction between the frame support and rocks.

The initial section area of the heading S_{w0} being known, dimensionless parameter $k_w = S'_w/S_w$ is calculated, i.e. relative change of the horizontal section area of the heading used for assessing the heading stability and its operational suitability for further production (reliability), including the personnel and transport movement factor, ventilating efficiency for mine field site etc.

First of all, a suitability test for the heading section firstly, is performed to meet safety requirements (e.g., concerning the permissible value of horizontal vertical pliability of a support, minimum permissible free clearance for a man's safety walk and moving of transport, maximum permissible value of floor heaving in a heading in relation to preservation of mine railroad etc.).

Testing the support state in the heading at the second stage of simulation is conducted not only by determining the density of support frames setting according to [1], but regarding the boundary states as well, when reaching them it stops meeting the preset operational requirements. It should be noted, that supports in the heading are under the same calculation rules as metal structures based on construction norms and standards which cover two groups of boundary states: concerning a bearing ability loss and concerning suitability to normal operation.

The calculation regarding the first group of boundary states is conducted on the preset loads considering the calculated resistance of the material and is intended to prevent the destruction and loss of stability of constructions. The calculation regarding the second group of boundary states is done on standard loads considering regulatory standard material resistance and has a purpose to prevent excessive deformations and support displacements. This design boundary state of support should be selected depending on the nature of rock pressure manifestations and the role of the heading in the operation of mine.

When calculating the support regarding the boundary state, one should distinguish between the boundary status of a separate section and construction as a whole. Considering the work of a metal pliable support for the whole lifetime of a heading (from its construction to destruction), it is possible to identify a number of qualitatively different stages of its operation: a rigid (elastic) one, rigid-plastic, pliable ones, formation of plastic hinges in the individual sections, and finally, the destruction of the support. Moments of the support transition from one stage to another correspond to the boundary states of this or that element (section) of the construction. Quantitatively, they are characterized by maximum values of internal forces (bending moments, transversal and longitudinal forces) which a separate cross-section is able to accept on one or another stage of work; moreover, maximum values of internal forces are linked by certain correlation whose form is determined by the load value, movements of heading circuit, rigidity of backfill material, occurrence of cavities behind the support, a type of special section, types of pliable units, occurrence of anchors and other factors (often unknown).

Since the support works with rocks in the mode of inter-influencing deformations, that is in direct contact with the rock outcrop, the occurrence of boundary conditions (plastic hinges) in one or even more sections does not result in exhausting the operational ability of the support and it partly maintains its operational ability, but with rather low values of probable uptime. So, there comes a change in the rigidity of a support as a structural unit by eliminating one tie and including the others. Therefore, consequently, interaction conditions between support and bearing rocks change, i. e., the calculation scheme changes as well. Thus, adequate assessment of operational ability of a support on boundary states considering the influence of the plastic hinges can be given only by the sequential calculation, based on consideration of all the periods of the lifetime of the heading, i. e. all working stages of the support under changing load.

Conclusions. Presented principles of imitating simulations of rock pressure manifestations and calculation of support in the heading allow choosing parameters of active control methods for stability of rock outcrops in uncertain conditions on the basis of more reliable information. This combination of control of the massif state and the support, as well as of the imitating simulation, in fact, represents a new methodology for current prediction of multiparameter geomechanical processes and phenomena while developing and maintaining the headings being the basis of geomechanical monitoring.

Physical modelling. Since boundary rock massif being the main load-carrying element of geotechnical system is deformed under conditions of interaction with the surrounding rocks, i. e., in the mode of specified deformation, and reducing of bearing ability of rocks below the strength limit does not mean the disruption of the normal operation of the heading, the computer simulation of geomechanical processes using detailed models are conducted using theory methods of ultraboundary deformation. In this regard at the stage of studying the parameters of diagrams of ultraboundary behaviour of rocks (Fig. 3), including the interaction with a support at its thrust, or anchors, you must know the original strength and deformation properties of rocks and their changing with the development of geomechanical processes.

Typically, properties of extremely tense rocks are studied on small samples by testing them using a hard test machines or triaxial compression machines. Tests on rigid press machines are usually performed for uniaxial compression, and the accuracy of the parameters is low and depends on the rigidity of the loading system, the contact conditions between the sample and pressing plates, absolute and relative dimensions of the sample. Tests in triaxial compression machines implement volumetric stress state matching the load which rocks undergo in massif. The so-called Karman scheme ($\sigma1 > \sigma2 = \sigma3$) is the most common which corresponds to the stress state of rock massif not affected by a heading (generalized compression). The results of such tests are used to make the rock strength passport. The testing of samples in triaxial compression machines by kind of generalized tension or the so-called Becker's scheme is rather rare, although within the boundary area of rock massif there occurs three-dimensional stress state that is close to this scheme. However, these methods require special equipment and are very labour intensive because of the complexity of sample preparation. In addition, results obtained by all above methods on small samples are very different from the properties of natural rocks due to large-scale effect and do not regard the interaction of rocks with a support.

Around the heading in stress concentration area, which defines geomechanical processes, one-sided-component stressed state of rocks ($\sigma1 > \sigma2 > \sigma3$) is generally implemented, which is reproduced in the special machines for three-dimensional loading. Such machines are unique, they allow getting any stress state of rocks, but do not eliminate the drawbacks relating to the small sample testing technology.

On the other hand, there is a method of physical modelling on equivalent materials, based on theories of similarity and dimension which allows reproducing the actual process of mineral excavation at a preset depth of its bedding, but without giving mechanical characteristics of rock massif around mine working considering interaction of rocks with a support.

The paper presents a set of methodological and technical solutions to overcome the drawbacks inherent to the methods of direct rock sample testing, and to develop a method of physical modelling to be included into general geomechanical monitoring system based on a new approach to process simulation for joint deformation of rocks and support in a single load-bearing system.

The proposed solutions are based primarily on the experience of creating small-scale research models of geomechanical processes on the rock equivalent materials considering interaction between rock and support [6]. The matter of the new approach of physical modelling is not in strong reproduction of a support design, and simulation of its impact on the massif and in observing the thermodynamic similitude for a stress-strain diagram of the "support-massif" system and rock strength passport (unloaded and softening, compacted with active thrust, held together by injection or anchors, etc.). This approach allows implementing virtually any stress state and various types of structural building of a rock massif. It gives an opportunity to explore regular patterns of changes of the model properties of rock massif at all stages of deformation up to ultraboundary and find geomechanical and technological parameters whose values are important to solve a particular practical problem.

Such kinds of problems at physical modelling are the most difficult, because it is required to ensure maximum compliance to field conditions for a particular object in these models. As quantitative characteristics of the main affecting factors are uncertain and may vary within certain limits, design schemes for models should provide opportunities to reproduce these factors in the models in concerned limits as well. Through this approach it is possible to get the closest approximation to the real geomechanical processes and provide massive scale testing, realized by repeating certain experiments and necessary for introduction of statistical variability indicators.

With such simulation for transition from parameters obtained under laboratory conditions to the nature they must be strictly complied with the criteria of similarity, while regarding controlled deformation mode of massif beyond strength limits, unit stiffness of the press should be higher than stiffness of a tested sample. The latter condition is fulfilled by reducing the rigidity of the model made of low-strength material rather than by increasing the rigidity of the press. With this, decrease in a labour-intensity of simulation and obtaining the mathematical dependence of the mechanical indices of rock massif deformation (including the descending branches of the diagram) on the control of process parameters is achieved through the application of mathematical methods of experiment planning.

This approach to physical modelling was implemented in Donbass State Technical University (Lisichansk, Ukraine) in recent years and its results were displayed in a number of published papers [2, 7, 8]. The list of proposed methodical solutions and developed techniques is given below:

- equivalent materials with parameters which provide following the criteria of mechanical similitude for strength and strain properties of rock massif and rock strength passport, as well as methods for operative selection of material content, equivalent to mine rocks using the theory of experiments planning;
- devices and tools for simulation of frame support, anchors of various types, and relays which allow determining forces, movements, stress and strains in a whole range of scale modelling with sufficient accuracy;
- an automated control system for loading the models which involves electromechanical mechanisms and transformers which allow implementing various kinds of stress state of a rock massif model [8]. Management for the system is performed through the computer by using a specialized software allowing to reproduce random diagrams of deformation of a rock massif model, both static and in time in the mode of preset deformations;
- a set of mathematical models for describing the behaviour of monolith, crumbling and plugged massifs at their interaction with a framed and anchored support including softening of rocks, depending on controlled technological parameters for on-line calculating required values within common system of on-line geomechanical monitoring [2].

Research conclusions. In this manner, the proposed method of physical modelling suits naturally a common system of geomonitoring in the form of its mathematical models or as a tool testing adequacy of computer programs. This approach allows increasing prediction accuracy for rock pressure manifestations in the headings and to substantiate the recommendations on control of heading stability in changeable and uncertain conditions on the basis of using adaptive methods and means.

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Мета. Створення методології геомеханічного моніторингу гірничих виробок як автоматизованої інформаційно-вимірювальної системи безперервного контролю, діагностики та прогнозу напружено-деформованого стану приконтурного масиву й кріплення.

Методика. Комплексне поєднання теорії дослідження операцій, механіки підземних споруд, комп’ютерного та фізичного моделювання, шахтних інструментальних спостережень.

Результати. У роботі обґрунтована нова методологія прогнозування геомеханічних процесів і проявів, та прийняття рішень щодо забезпечення надійності виробок при їх проектуванні, проведенні та підтриманні в породному масиві з невизначеними властивостями. Методологія поєднує геомеханічний контроль, фізичне й математичне моделювання, що періодично контролюється за результатами шахтних спостережень, і дозволяє кількісно оцінювати надійність виробки на різних етапах життєвого циклу та якість взаємодії способу, засобів і середовища.

Наукова новизна. Наукова новизна запропонованої в роботі методології полягає в управлінні надійністю виробки як геотехнічної системи шляхом адаптації її структури до мінливого середовища протягом усього життєвого циклу.

Практична значимість. Адекватне описання проявів гірського тиску в підготовчих виробках і обґрунтований вибір адаптивних способів і засобів управління надійністю гірничих виробок.

Ключові слова: *гірнича виробка, геомеханічний моніторинг, комп’ютерне та фізичне моделювання*

Цель. Создание методологии геомеханического мониторинга горных выработок как автоматизированной информационно-измерительной системы непрерывного контроля, диагностики и прогноза напряженно-деформированного состояния приконтурного массива и крепи.

Методика. Комплексное сочетание теории исследования операций, механики подземных сооружений, компьютерного и физического моделирования, шахтных инструментальных наблюдений.

Результаты. В работе обоснована новая методология прогнозирования геомеханических процессов и проявлений, а также принятия решений по обеспечению надежности выработок при их проектировании, проведении и поддержании в породном массиве с неопределенными свойствами. Методология включает в себя геомеханический контроль, физическое и математическое моделирование, периодически контролируемое по результатам шахтных наблюдений, и позволяет количественно оценивать надежность выработки на различных этапах жизненного цикла и качество взаимодействия способа, средств и среды.

Научная новизна. Научная новизна предложенной в работе методологии заключается в управлении надежностью выработки как геотехнической системы путем адаптации ее структуры к изменчивой среде в течение всего жизненного цикла.

Практическая значимость. Адекватное описание проявлений горного давления в подготовительных выработках и обоснованный выбор адаптивных способов и средств управления надежностью горных выработок.

Ключевые слова: *горная выработка, геомеханический мониторинг, компьютерное и физическое моделирование*

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