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Modern Mathematical Forecast Methods of Maintenance and Support Conditions for Mining Tunnel

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The research focuses on mathematical methods of mining pressure forecast to develop rational support patterns for mining tunnels and to ensure safety of mining operations. The purpose of research is to develop the methodology of applying advanced calculation methods and software solutions based on neural networks to reduce dispersion of factors influencing stability of mining tunnels, as well as to define rational parameters of mining tunnel support. The authors review the algorithm of geomechanical process examination, which is divided into several stages. First of all, it is proposed to use cluster analysis to examine location conditions of man-made outcrops, which allows to divide all the diversity of existing conditions for mining tunnel construction. Cluster analysis first allows to reduce the dispersion of factors that influence the stability of mining tunnels in various clusters, and then to determine rational parameters of tunnel support in each cluster. After the problem of cluster analysis is solved, it is proposed to use software programs that allow to study geomechanical processes in each cluster. At this stage, both standard methods (normative techniques, numerical modelling, analogies use, etc.) and the most advanced methods – neural networks – can be applied. Described algorithm of solving geomechanical problems, which utilizes advanced numerical methods and a software package based on neural networks, ensures an individual approach to estimation of mining pressure under varying conditions of man-made outcrop location in the rock mass.

Key words: geomechanics; mining pressure; border rock mass; rock stressing; cluster analysis; plastic range of stress; neural networks

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Introduction. Additional pressure of the rock mass on underground man-made outcrops is one of the main reasons behind accidents in the mines. To control characteristic manifestations of mining pressure, specific knowledge on continuum and loose material mechanics is needed, as well as estimation of elements of various development technologies, special methods and means of natural tests, correct interpretation of examinations in time and space [2].

Problem statement. Increasing depth of excavation and worsening mining, geological and engineering conditions require more reliable methods to forecast mining pressure both to develop rational support patterns for mining tunnels and to ensure safety of mining operations. More frequent utilization of anchors, as compared to frame support, implies a more accurate forecast of geomechanical processes occurring around the mining tunnel. Existing normative techniques of forecast are not always able to reflect all the diversity of factors that impact rock pressure manifestations.

Applied mathematical methods of modeling allow to take into account a wide range of various factors, which influence rock pressure manifestations around mining tunnels [7]. However, in most cases these methods require adjustment or adaptation of the program to specific conditions of the mining plant, which in its own turn complicates their utilization. Application of mathematical methods is also held back by significant heterogeneity of the rock mass in different areas.

Methodology. Estimation of stress-strain state (SSS) of the border mass around the cavity of any shape does not present any difficulties with the use of specialized mathematical software and modern computing equipment. The greatest difficulty after SSS estimation lies in finding the plastic range of stress (PRS), or fracture range, around the cavity of given shape, which determines rock pressure. This range serves as a basis for the development of mining tunnel support parameters. The difficulty of defining the main factor of rock fracturing, different stressing conditions in the rock mass and during strength tests, scale effect and natural variations of physical and mechanical properties in different areas of the rock mass can sometimes invalidate sophisticated mathematical estimations of SSS.

Here we come to a contradiction: methods of material resistance and construction mechanics can only estimate the carrying power of mining tunnel's support with satisfactory degree of precision, when the value and character of its stressing are known. As it is impossible to estimate exact stressing of the support and its character during rock pressure manifestation and to perform an accurate engineering calculation of mining constructions, it leads to either unjustified overestimation of the model's reliability and overconsumption of support materials, or to the destruction of support structure, which is often accompanied by human losses.

Due to uncertainty and impossibility of precise stress estimation, solution of such problems does not always start with strength calculations. First of all, conditions of mining tunnel construction should be specified using mathematical methods, and then more specific engineering solutions should be developed.

Such approach is used in economic systems. Turbulence of external environment in modern economics does not allow to solve economic problems explicitly, as one does with engineering tasks. Here economic parameters get influenced by too many factors. Back at the beginning of the last century, mathematicians developed methods (econometric analysis) that helped to identify critical influence of external environment on a given economic indicator [8]. IT development drastically simplified complex mathematical calculations, which made mathematical tools available for a wide range of researchers.

Application of correlation and regression analysis, construction of paired and multiple linear models in the examination of geomechanical processes can be encountered in most dissertations and scientific research in the mining field. These methods have always been confined to specific conditions of the tests; although it should be noted that in some cases these methods allow to use simple mathematical dependencies to model complex processes in the rock mass.

The most difficult and demanding process is examination itself, which utilizes more advanced calculation methods and software products. In current case, the first stage involves cluster analysis of location conditions of man-made outcrops, which allows to divide all the diversity of existing conditions for mining tunnel construction. The second and subsequent stages suggest application of software programs, which allow to identify a dependency between nature factors and tunnel support parameters (such dependency can be identified using both simple correlation models and advanced neural networks). Suggested method first of all allows to reduce dispersion of factors, influencing stability of mining tunnels in various clusters, and then to determine rational parameters of tunnel support in each cluster.

Unlike classification problems, cluster analysis does not require apriori suggestions about the dataset, does not put constraints on the display of examined objects, allows to analyze indicators of various data types (interval data, frequencies, binary data). At the same time it should be understood that variables need to be measured using comparable scales.

Cluster analysis allows to decrease the amount of data needed for modelling [5]. The objectives of cluster analysis can be grouped into the following categories: development of typology or classification; examination of useful conceptual schemes of object categorization; presentation of hypotheses based on research data; verification of the suggestion that types, identified with different means of cluster analysis, are adequately reflected in the examined data. Generally, practical application of cluster analysis provides a complex solution to one or several of the mentioned problems.

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The size of cluster can be estimated either using cluster diameter, or mean square deviation of cluster objects. The object belongs to the cluster if the distance from the object to the center of the cluster is less than cluster radius. If this condition is met for two or more clusters, the object is disputable. Ambiguity of this problem can be eliminated by an expert or an analyst.

Cluster analysis relies on two main suggestions: 1) identified characteristics of the object must allow division of a certain group of objects into clusters; 2) correct choice of the scale or necessary measuring units, reflecting object's characteristics (in some cases use of standardized values is required).

After the problem of cluster analysis is solved, a software program must be activated, which allows to examine geomechanical processes in each cluster. In this case we either come to standard methods applied in the mining industry (normative techniques, numerical modelling, analogies use, etc.), or to the most advanced and currently widely spread method – neural networks (NN) [6].

A wide range of problems solved by NN up to this day does not permit to develop universal powerful networks, instead compelling researchers to create specialized NNs, functioning according to different algorithms. Despite significant distinctions, different NN types share several common features.

At the foundation of every NN lie relatively simple and generic elements, which imitate the functioning of neurons in the human brain [1]. A neuron is understood as an artificial cell, an elemental part of NN. Each neuron, being an analogue of neural cells in the brain that can get excited, is characterized by its current state. It owns a group of one-dimensional input links, connected to the exits of other neurons, as well as an axon – an output connection, which sends a signal (of excitation or inhibition) to the synapses of other neurons. Thus, common features, characteristic for all NNs, include parallel processing of all incoming signals, which is achieved by the accumulation of a huge number of neurons into specific layers and organized merging of neurons from different layers.

The number of layers and neurons in each layer can be random, but in fact it is limited by technical characteristics of the computer (memory, CPU frequency, etc.). The more sophisticated the NN, the greater the problem it can solve. Current level of IT development (powerful equipment and software support) allows to solve difficult tasks with multiple input parameters. Selection of NN structure is performed with a regard towards the specifics and complexity of the problem. Today there already are optimal configurations for certain types of tasks.

The process of rational NN functioning, i.e. actions that it can perform, depends on the stability of synaptic connections; therefore, after the researcher has decided on a certain NN structure, relevant for a particular problem, he has to estimate rational values of all variable weight coefficients (some synaptic connections can be constant).

This important stage is called initial NN learning, and the correctness of its implementation defines the adequacy of future solutions obtained with the network. Apart from the quality of weight choice, another important factor is the time allocated for the learning of the system. As a rule, these two parameters are inversely related, and they are selected basing on a compromise and researcher's previous experience.

Proposed algorithm of solving geomechanical tasks, using advanced numerical methods and specialized applied software packages, will allow to use an individual approach to the problems of rock pressure under changing location conditions of man-made outcrops in the rock mass and thus ensure development of rational parameters of mining tunnel support.

Discussion. To exemplify complicated estimation of plastic range of stress in a fractured rock mass, an arch-shaped mining tunnel was selected. Stress calculations in the proximity of a mining tunnel were performed using the method of boundary integral equations [3].

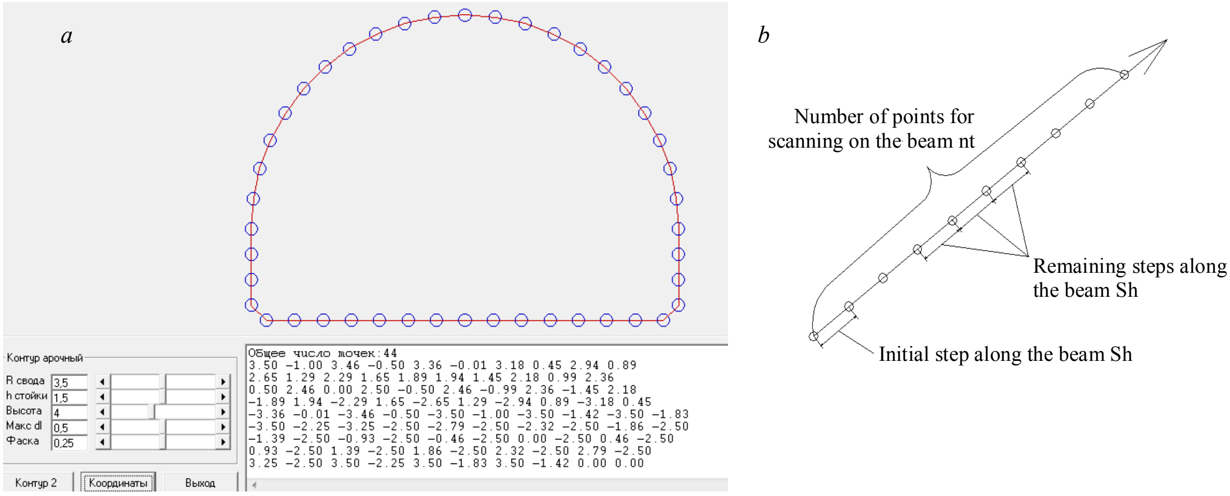

Fig.1. Calculation schemes: *a* – a scheme of beam identification on the tunnel contour; *b* – a scheme of the beam for rock mass scanning

Check points are evenly spaced along the beam, the distance set according to the required level of precision and the shape of the tunnel cross-sections (Fig. 1).

Loading of the rock mass is created by the infinitely remote stress, expressed in shares of γH (where γ – specific weight of the rock, *H* – depth of the mining tunnel). Strength characteristics of the rocks are defined layer by layer: cohesion – in shares of γH, tensile strength – in shares of γH, tangent of internal friction angle. In case there are weak planes, their strength characteristics and the fracture angle are also identified.

Solution of this problem in the elastic range provided stress values in the proximity of the mining tunnel, estimated from the initial stressed state of the rock mass, the shape and size of the mining tunnel.

Subsequently an assumed plastic range of stress was mapped around the tunnel. Under the assumed plastic range of stress one understands an area, where stress values, obtained by solving the elasticity problem, do not satisfy strength criteria [11, 12]. Two conditions have been chosen for transition of the boundary rock mass into unstable state: tension stress and Mohr-Coulomb criterion. According to the mentioned conditions, the tunnel is considered to be unstable if at least one of the conditions fails.

The basic example included PRS estimation under $\sigma_t/\gamma H = 0.5$ (where σ_t – tensile stress of the rock), which led to the formation of a fracture zone around the mining tunnel (0.4-0.8 m). The fracture zone in this case evenly repeats the contour of the tunnel (Fig.2, *a*).

The second case focused on the same rock mass, but with fractures studied in works [4, 9, 10], spaced at 1 m from one another. Strength characteristics of the rock mass were divided by 2 regardless of the fractures (Fig.2, *b*). This led to a formation of a greater fracture zone around the modelled tunnel (1.0-1.3 m), the zone still evenly repeated the contour.

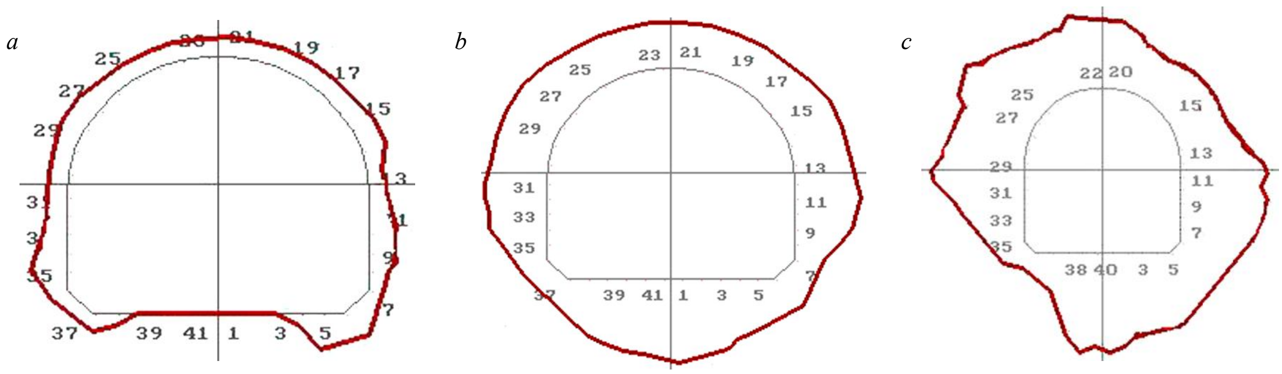

Fig.2. Sizes of plastic ranges of stress

Conditions of the third case included three systems of fractures taking into account reduced strength characteristics in the fracture planes (Fig.2, *c*). In the latter case, the most objective result is elastic solution to the problem in the proximity of the mining tunnel. Subsequently, comparison of results obtained with various methods of the strength theory leads to different results of PRS estimation and tunnel support stress. In this case authors can recommend researchers to specify, which criterion has been used to estimate the plastic range of stress and which specifics of this criterion are characteristic for the given mining plant.

Conclusion. Solution of geomechanical problems of man-made outcrops stability is always associated with the complexity of strength estimations for the boundary rocks and the variability of this parameter due to natural or man-induced factors. All this leads to a significant increase in the margin of safety in mining tunnel support systems.

Advanced numerical methods (finite element method, method of boundary integral equations) provide an acceptable level of precision in the calculation of additional stresses in the rock mass around the mining tunnel, but they cannot take into account all the diversity of rock properties.

Methods of cluster analysis and neural networks, applied in a combination with advanced numerical methods, can ensure better consideration of all the numerous mining, geological and engineering conditions around the mining tunnel and by this provide more rational ways of maintaining its stability.

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