

## COMPUTATIONAL MODEL FOR EVALUATING THE STATE OF GEOMECHANICAL SYSTEMS DURING COMPUTING EXPERIMENTS

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## ФОРМУВАННЯ РОЗРАХУНКОВОЇ МОДЕЛІ ОЦІНКИ СТАНУ ГЕОМЕХАНІЧНИХ СИСТЕМ ПРИ ПРОВЕДЕННІ ОБЧИСЛЮВАЛЬНИХ ЕКСПЕРИМЕНТІВ

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### ABSTRACT

**Purpose.** To create a model allowing integration of the diverse features identified for the rock massif behavior by differentiation of various theories and real phenomena into a single information-analytical flow.

**Methods.** System analysis of computational experiments' results was based on the use of recursive calculation methodology for assessing accuracy of the obtained results with different methods of geometric and physical description applied to individual elements of simulation in the computational domain.

**Findings.** Sample tables were obtained containing the acceptable values of weight characteristics for the various simulated elements in the generalized computational domain. A recursive algorithm for the analysis of the studied objects description' efficiency in the solution of geomechanics problems by grid numerical methods was formulated and implemented as a computational module. The authors created a system for the assessment of the results obtained via computational experiment at the time of full-scale investigation, which provides a comprehensive analysis of changes in the rock massif state during the operation of the selected support system. The conditions of combining the design characteristics of the simulated support elements functioning in a single load-carrying system under dynamic redistribution of forces were obtained.

**Originality.** The resulting generalized model of mine working and elements affecting its condition allows to determine most accurately the nature of changes in the stress-strain state of geotechnological system regardless of the originally a priori specified limitations.

**Practical implications.** The unified approach can be used in the search for the optimal parameters of implementing combined working supports in the area of mining operations and beyond.

**Keywords:** rock pressure, stress-strain state, information and physical structure of the rock massif, heuristic multi-variate model, neural network, cluster

### 1. INTRODUCTION

The development of technologies for underground mining is currently retarded, largely because of impossibility to predict rapidly and accurately the behavior of the massif adjacent to the excavations operating in difficult geological conditions (Toderas, 2014). In fact, such situation is typical for most mines in Ukraine (Dychkovskiy & Bondarenko, 2006; Pavlenko, Salli, Bondarenko,

Dychkovskiy, & Piwniak, 2007). It turns out that the effective maintenance of excavation and high speed of the working face advance, in some cases, are achieved not through the formation of the optimal technological characteristics, but due to excessive protective precautions. Or else, where they do not help, due to additional amount of manual labor, which not only reduces the profitability of production, but also leads to a high accident rate among miners.

## 2. GENERAL SCIENTIFIC PROBLEM

Considering the issues related to the stability of excavation, we are always faced with the need for more accurate determination of rock pressure value, which will affect the working support. Most methods for solving problems of geomechanics consider rock pressure as a constant factor the value of which is defined on the basis of laboratory and field experiments with the material of massif rocks. Such experiments, in general, are based on the theoretical concepts of classical continuum mechanics and fracture mechanics (Fomychov, 2012). However, equating the behavior of rocks under stress to that of a technological material obtained by industrial method is very conventional. Mining rock is not the kind of material with uniform physical characteristics in the whole volume (Lodus, 1986). As a result, the distribution of the rock mass stress cannot be predicted with a great degree of accuracy, using only the fundamental laws of structures stability analysis. Thus, the obtained results are rather conventional and cannot be used for a wide range of combining geological and mining factors.

As of today, there exist a sufficient number of different approaches to modeling the behavior of the rock mass around excavations. Conventionally, these techniques may be divided into several qualitative groups: firstly, changing characteristics of rocks by using additional reducing coefficients; secondly, development of methods for differential description of rocks behavior; thirdly, manipulation with the value of external loads and boundary conditions of the computational domain. These approaches can be used in combination with analytical solutions or numerical methods. However, regardless of the mathematical tools used in problem solving, the above measures can only lead to deterioration of qualitative indicators of the obtained results. In this case, it is natural and logical to expect high margin of permissible error in the research. In some cases, this error may reach 20%. In such circumstances, projecting a preliminary excavation based on optimization of load-bearing structures with an extremely small margin of safety is impossible.

Furthermore, during exploitation of modern mines, the number of potential threats only grows. There are manifestations of rock pressure which are new, inexplicable from the viewpoint of the existing hypotheses, for example, sudden ejections of mining rock into the cavity development, unaccompanied by any noticeable increase of deformation of the circuit excavation just before the accident (Dudukalov, 2003; Letov, 2004). In some cases, excavations which are conducted in similar geological conditions and protected in the same manner, behave differently (Latyshev, Matveev, Martushov, & Eremizin, 2011). For example, support of one excavation almost does not have any load, whereas the rack frame support, in another generation, can be pressed to a depth of 300 mm (Fomychov, 2012).

Such differences in manifestation of rock pressure are difficult to generalize, and therefore they try to find a scientific hypothesis for each case that would satisfy the kind of the effect observed in natural conditions. In fact, the massif as an object of study is simplified to a state of primitive model in which it can be described in terms of

classical concepts of continuum mechanics. To make it easy, a complicatedly structured object under continuous or intermittent exposure to a variety of physical processes, is attempted to be squeezed into one, adopted as a basic, scientific hypothesis.

## 3. FORMULATION OF THE PROBLEM

So, summing up all the above, it turns out that geomechanics has a unique, from the perspective of physical properties, object of study. It analyzes the object's behavior ultimately relying on the theories of materials' behavior accepted in classical mechanics. In other words, the results received in the course of the research cannot be interpreted beyond the context of these ideas, and thus they do not allow to describe the massif fully within a unified system of stress-strain state. Therefore, from our point of view, it is high time to create such a model of geotechnical system behavior, using which it would be possible to describe all the diversity of properties and processes occurring in it.

Thus, we need to create a primary model which allows to integrate all the variety of identified features characterising the massif behavior by differentiating miscellaneous theories and real phenomena into a single information-analytical flow. Here we do not aim at creating a fundamentally new theory of materials or the theory of strength, the goal is to form a certain scientific platform which will enable to display functional relationships of various scientific hypotheses using the principles of openness and parallelism. Relevant indicators would form a highly accurate information model of the medium with significant nonlinear characteristics.

In essence, this model represents a philosophical doctrine which makes it possible to transform ideas about the state of the infinitely small volume of the massif in respect to the features of the medium embodying it. The main objective in the development of such a theory is accumulation of all the available knowledge within a single formal philosophical law of shaping the image of a real object in the form of intricately coherent information structure (Fig. 1). Using this method, it is possible to create sets of variables in the form of an array of tables, each element of which is associated with one chosen volume of the geomechanical model. This model of massif behavior is meant to be used together with the grid numerical methods.

The proposed approach is the result of careful consideration and a great amount of research into stress-strain state of the geotechnical system "working support – rock mass". This brought about understanding of the need for a coherent description of the properties and processes taking place in the massif. The studies involved analyzing the results of field observations and computational experiments. A significant experience in creating and improving adequacy of design models built on the basis of the finite elements method has been accumulated. The processed data and their comparison with available developments of other research groups allowed to conclude that there is no universal theory of the massif behavior which could faithfully represent all the diversity of the observed phenomena. Consequently, it was pivotal to develop a theoretical basis for the simulation experiment parameters of the computational domain elements.

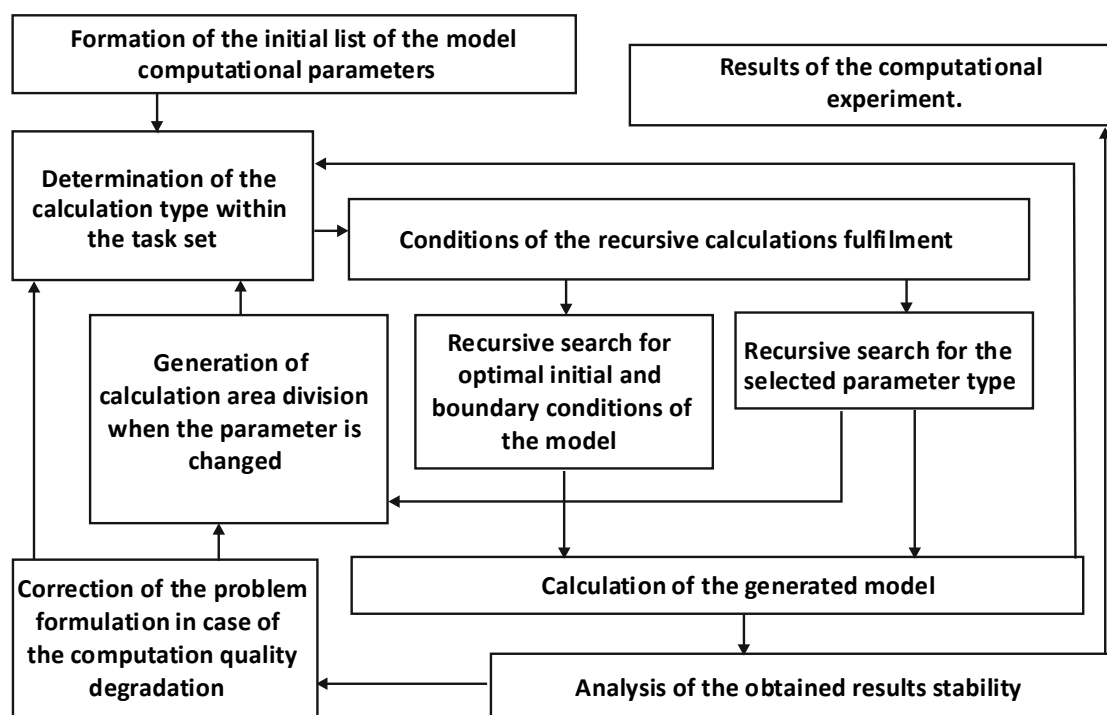


Figure 1. Generalized algorithm for implementation of multi-parameter model in calculation of the geotechnical system

#### 4. PRINCIPLES AND EXAMPLES OF THE RESEARCH

The present research is grounded on the formation of principles and technologies of building a data reporting system in the form of heuristic multidimensional model representing information and physical structure of the massif. Let us dwell in more detail on the meaning of the proposed concept. We regard information and physical structure as a well-defined duplex list of physical properties and information elements used in modeling of the object (Fig. 2). In other words, physical characteristics of the area under study are described parametrically or functionally as a synthetic element of generalized regularities generated within the heuristic and multidimensional model.

Heuristic method is based on logic, common sense and experience, which yield new substantive information. This method is used when it is impossible to apply formal methods of research. In our case, such approach makes it possible to produce coherent information structure in conditions of a partial description of the real massif components using elements of continuous prediction of the resultant state of the interacting information fields. To put it simply, using this approach, and having specific values of physical characteristics distributed in the massif, it is possible to build a continuous multidimensional function of the massif behavior.

What is the multidimensional model? In order to get the initial design parameters of the model, it is necessary to obtain their values, the combination of which will provide the most accurate description of a real object behavior. Thus it is important to define these indicators on the basis of the conventional system implying differentiation of information components of various physical natures. These components provide the description of: the material behavior in the elastic state; the theory of transition into the transcendent state; characteristics of jointing; water

inflow pattern; heterogeneity of the material; the effect of chemical reactions; rock layers; tectonic stresses; major structural failures. We call each of the above components "information and geotechnical field". These fields constitute the core of the proposed model. Essentially, information and geotechnical field is a set of data presented as constants and functional relationships which characterize the degree of the selected theory effect in the whole computational domain.

The more fields of such kind are used in the analysis of the model, the higher its multidimensionality and wider the set of factors affecting the adequacy of modeling. Mutual influence of information and geotechnical fields can manifest in different ways. For each pair of interacting fields, it is necessary to define a separate system of relations in terms of abstract logic, physics, and mathematical implementation. As a result, we have a balance of the joint impact on the qualitative and quantitative characteristics of each element of the computational domain. At the same time, the proposed model of the massif description is a completely open platform that can be expanded by the introduction of new information and geotechnical fields which describe the previously discussed hypothesis and field phenomena. In addition, since such platform is distinguished by a high rate of modularity, it does not require any fundamental transformations, if the internal structure of a certain information and geotechnical field changes due to modifications in provisions of a specific scientific theory.

To control the state of the proposed massif model, we can use a variety of analytical and numerical methods, with the help of which a system of mathematical expressions transforms into the logical framework of the simulated space including information and geotechnical fields. It is possible to create such framework using technology of building neural networks.

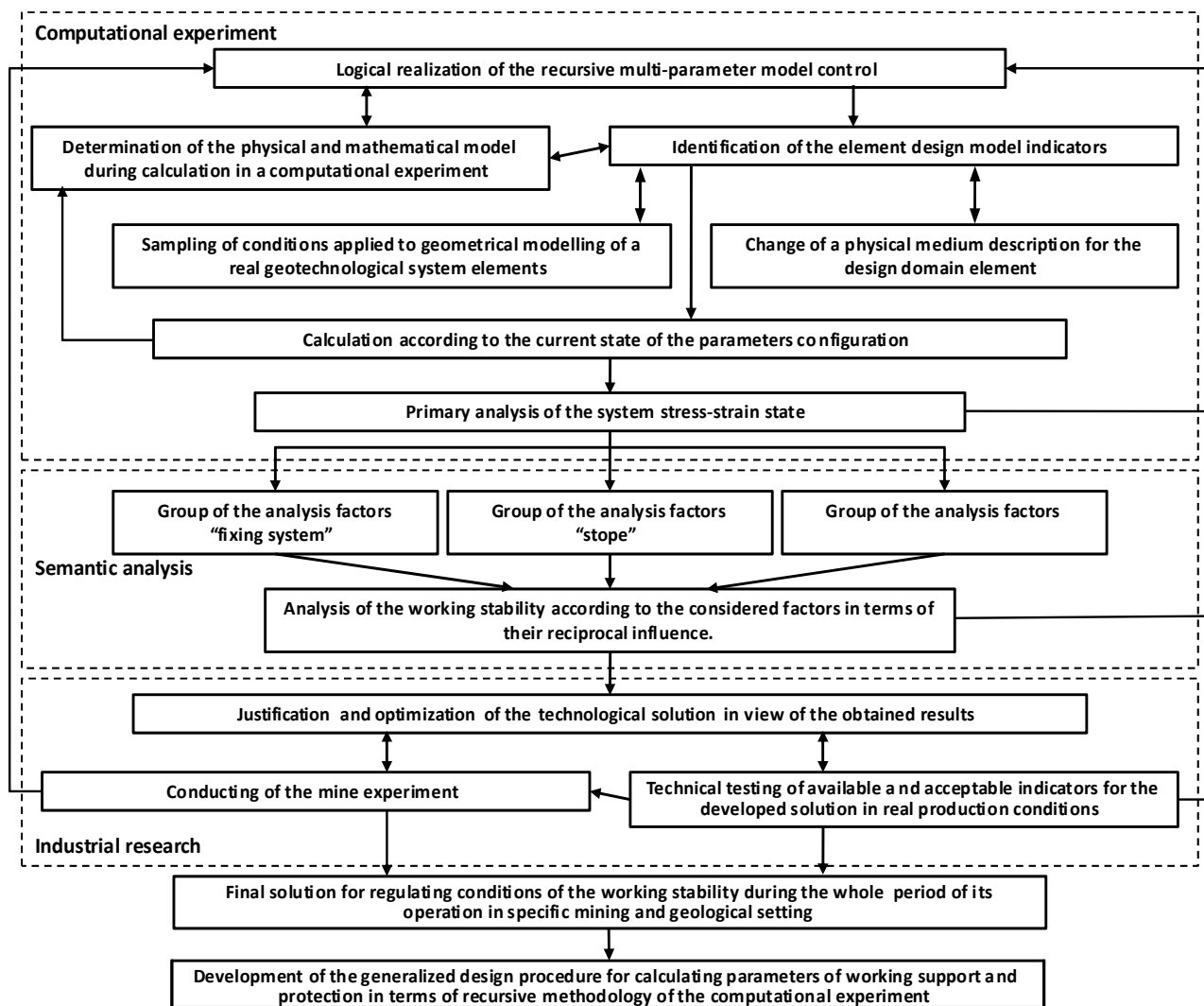


Figure 2. Structural and logical schematic for the research into optimization of geotechnical system technological parameters

The produced neural network is formed and trained on the basis of the maximum allowable states of the real massif as described by the model. Thus, the analysis allows to predict heterogeneous physical nature of the studied volume of a geomechanical system (Fig. 3).

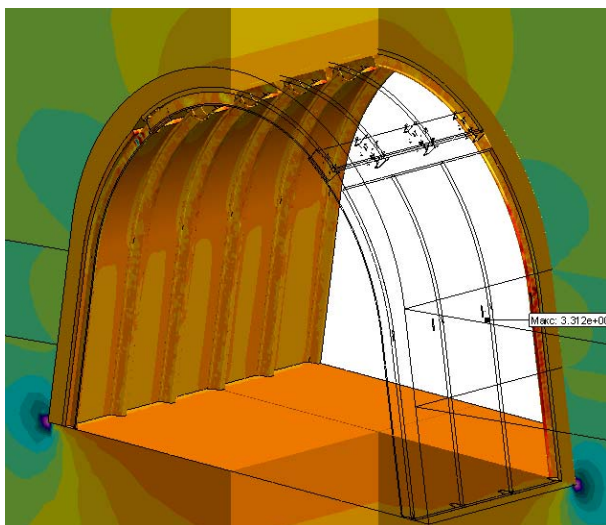


Figure 3. Intermediate result of modeling the node of workings frame support yielding

Overlapping and multidimensional coherence of information and geotechnical fields can lead to flattening of the analyzed features graphs (because of the high rate of the massif homogeneity) and to creating the resulting picture with fluctuations significant in size and localized in a certain point in space. As a result, we obtain a discretely associated image of the massif in the form of a set of clusters combined in space and time. Departing from this image, we can carry out numerical calculation of geotechnical models with unique factors affecting mechanical characteristics typical for classical geomechanics. Thus, on the basis of the abstract method of analysis of available ideas about the nature of the studied object, we can form the informational array of specified physical indicators that subsequently most adequately describes the actual structure of the massif. However, from the viewpoint of formalization, the proposed model of the massif description is sufficiently amorphous and does not have a strictly constructed evidence base, but, as already mentioned, it can be considered appropriate in terms of completeness of ideas about the development of the massif state near the opening.

In order to develop the described techniques of the massif state representation, it is necessary to go through the following stages: firstly, to determine the generalized



properties of information and geotechnical field as an object which is modeling the physical medium or process; secondly, to form techniques for physical properties transformation into the information blocks processed within the model frames; thirdly, to develop basic operations underlying organization of interaction of information and geotechnical fields; Fourthly, to develop the requirements for the management of physical and mathematical platform of forming the resultant heterogeneous structure of the massif model.

## 5. CONCLUSIONS

The proposed heuristic multidimensional model of the massif information and physical structure enables to significantly improve the quality and accuracy of calculations results using the grid of numerical methods for solving problems of geomechanics. This model allows to obtain a non-linear picture of rock massif state which takes into account a wide spectrum of physical constants and phenomena, whose influence on the material per volume unit can change its mechanical properties and the current temporal state.

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## ABSTRACT (IN UKRAINIAN)

**Мета.** Створити модель, що дозволяє інтегрувати все різноманіття виявлених особливостей поведінки гірського масиву шляхом диференціації різних теорій і реальних явищ у єдиний інформаційно-аналітичний потік.

**Методика.** Системний аналіз результатів обчислювальних експериментів, що побудований на застосуванні рекурсивної методики оцінки розрахункової точності одержуваних результатів при різних методах геометричного й фізичного опису окремих елементів моделювання у розрахунковій області.

**Результати.** Отримано типові таблиці, що містять припустимі величини вагових характеристик для різних елементів, які моделюються в узагальненій розрахунковій області. Сформульовано й реалізовано у вигляді розрахункового модуля рекурсивний алгоритм аналізу ефективності опису досліджуваних об'єктів при рішенні завдань геомеханіки сітковими чисельними методами. Створено систему оцінки одержуваних результатів обчислювального експерименту при проведенні натурних досліджень, яка забезпечує комплексний аналіз зміни стану породного масиву в ході експлуатації обраної системи кріплення. Отримано умови сполучення розрахункових характеристик елементів кріплення, які моделюються й функціонують у єдиній вантажонесучій системі при динамічному перерозподілі зусиль.

**Наукова новизна.** Одержана узагальнена модель гірничої виробки й елементів, що впливають на її стан, гранично точно дозволяє визначати картину зміни напружено-деформованого стану геотехнологічної системи незалежно від початкових апріорі заданих обмежень.

**Практична значимість.** Забезпечується можливість застосування уніфікованого підходу в пошуку оптимальних показників застосування комбінованих кріплень гірничих виробок, які знаходяться поза зоною й у зоні дії очисних робіт.

**Ключові слова:** гірський тиск, напружено-деформований стан, інформаційно-фізична структура гірського масиву, евристична багатомірна модель, нейронна мережа, кластер

## ABSTRACT (IN RUSSIAN)

**Цель.** Создать модель, позволяющую интегрировать все многообразие выявленных особенностей поведения горного массива путем дифференциации различных теорий и реальных явлений в единый информационно-аналитический поток.

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**Методика.** Системный анализ результатов вычислительных экспериментов, построенный на применении рекурсивной методики оценки расчетной точности получаемых результатов при различных методах геометрического и физического описания отдельных элементов моделирования в расчетной области.

**Результаты.** Получены типовые таблицы, содержащие допустимые величины весовых характеристик для различных моделируемых элементов в обобщенной расчетной области. Сформулирован и реализован в виде расчетного модуля рекурсивный алгоритм анализа эффективности описания исследуемых объектов при решении задач геомеханики сеточными численными методами. Создана система оценки получаемых результатов вычислительного эксперимента при проведении натурных исследований обеспечивающая комплексный анализ изменения состояния породного массива в ходе эксплуатации выбранной системы крепления. Получены условия совмещения расчетных характеристик моделируемых элементов крепи функционирующих в единой грузонесущей системе при динамическом перераспределении усилий.

**Научная новизна.** Полученная обобщенная модель горной выработки и элементов, влияющих на ее состояние, предельно точно позволяет определять картину изменения напряженно-деформированного состояния геотехнологической системы независимо от первоначально априори заданных ограничений.

**Практическая значимость.** Обеспечивается возможность применения унифицированного подхода в поиске оптимальных показателей применения комбинированных крепей горных выработок находящихся вне зоны и в зоне действия очистных работ.

**Ключевые слова:** горное давление, напряженно-деформированное состояние, информационно-физическая структура горного массива, эвристическая многомерная модель, нейронная сеть, кластер

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