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NEW METHODICAL APPROACHES TO JUSTIFY SELECTION EXPLOSIVE FOR DESTRUCTION OF SOLID ROCKS

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НОВІ МЕТОДИЧНІ ПІДХОДИ ЩОДО ОБҐРУНТУВАННЯ ВИБОРУ ВИБУХОВОЇ РЕЧОВИНИ ДЛЯ РУЙНУВАННЯ МІЦНИХ ГІРСЬКИХ ПОРІД

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НОВЫЕ МЕТОДИЧЕСКИЕ ПОДХОДЫ ДЛЯ ОБОСНОВАНИЯ ВЫБОРА ВЗРЫВЧАТОГО ВЕЩЕСТВА ДЛЯ РАЗРУШЕНИЯ КРЕПКИХ ГОРНЫХ ПОРОД

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Annotation. The paper formulates relevance, purpose, problem statement, methodology and research results. The article developed a mathematical model to justify selection the type of explosive for destruction of solid rocks. As an alternative, several types of explosives have been selected, namely: that PETN, Grammonit 79/21, Ammonal VA-4 and Anemix 80. The problem is solved using the analytical hierarchy method (AHM). In the process, many criteria, both quantitative and qualitative, were considered, their importance in selecting the type of explosives and their consistency with the opinions of experts. The following indicators were used as criteria: technological, economic, social, environmental by which to evaluate such as the area of the newly formed surface, the size of the average piece, the heat of explosion, but also the economic (the cost of explosives and technology of its use, rational design of the charge of squeezing substances), environmental (the impact of explosives on the natural environment environment) and social (human security in the use of explosives, the complexity of the use of explosives in the destruction of the solid medium). According to the results, priority vectors were obtained for each hierarchy, which contributed to a reasonable approach to selection type of explosives. The established priorities made it possible to carry out a systematic approach to solve the problem, considering not only technological advantages, but also the costs of using various types of explosives. The factors characterizing the costs in the formation of well charges with various types of explosives are also considered. The analysis of results of mathematical modeling showed that PETN has the highest priority, since this substance has a high ability to destroy the solid medium due to the high heat and explosion temperature, but it is also the most costly. Grammonit 79/21 and Ammonal VA-4 have similar priorities. This indicates that they have very similar detonation characteristics and composition of the explosive. Shown the adequacy of chosen model for selection of alternative types of explosives for the destruction of solid rocks of complex structure. At the same time Anemix 80 is by far the most cost-effective and less harmful to the environment because it has the lowest NOx, zero oxygen balance, lowest cost and no additional cost. The use of AHM allows a balanced approach to the selection and justification of the type of explosive, which is very important when designing rational parameters of drilling and blasting operations in the destruction of solid rocks of complex structure in the mines.

Keywords: rock, explosive, analytic hierarchy method.

Introduction. We are aware of new technologies for the destruction of solid rocks, which are based on non-traditional approaches-thermal destruction, the effects of high-energy particles streams, and others. But the explosion to this day has been and remains an effective way to prepare the rock mass for underground mining, both iron and uranium ores.

Carrying out of bearing work at extraction of hands provides enough rock masses for its processing, economic efficiency and environmental safety of mining operations. To solve all these problems is possible only with a thorough justification of the choice of rational parameters of blasting operations, which must consider many factors. The set of necessary measures includes the following aspects: solving the task of the organization of drilling and blasting operations; rational arrangement of charges of explosives in an array of rocks considering structural features; the justification and choice of the type of explosive to be used in the charge of explosives, etc. One of the important aspects is the choice of type of explosives.

The list of explosives that can be used in carrying out subversive works contains more than a dozen names and the reasoned choice of explosives should be made taking into account many factors and criteria: the dust-gas mode of mine, strength of rock mass and huge level of water in rock massif, technological characteristics of explosives: heat of explosion, detonation velocity, critical charge diameter, oxygen balance, and others. It is also necessary to consider the structure of rock and which type of explosives will be used in. Incorrect selection of explosives leads to unsatisfactory results of explosion, namely, reduction of quantity and destruction quality of rock mass.

Determination of the effectiveness of explosives based on a thorough study of the mechanism of destroying the environment polymineral complex structure that depends on structural and textural characteristics and the physical and mechanical properties of rocks from connection with explosives and detonating explosive properties [1]. Significant factors that influence the choice of explosive type are economic indicators: the cost of explosives, the cost of preparatory and blasting works. In addition, the efficiency of extraction of uranium deposits using the energy of the explosion and the completeness of their extraction from the mountain range should not affect the violation of the integrity of the region's ecosystem. This is explained by the fact that mining enterprises operate in conditions of direct contact with industrial zones, residential agglomerations, natural objects, water and agricultural lands with negative influence on them. [2-5]. Studies in this direction allowed us to obtain new results in the study of the mechanism of explosive destruction of hard environments of a complex structure, which made it possible to improve the existing methods for managing crushing of rocks [6].

Therefore, to solve the problem which is develop mathematical modeling methods justify the choice type of explosive, given its technological, energy and detonation characteristics, properties of rock mass quality crushing economic costs and impact of explosives on the ecological state of the environment is important.

Theoretical results.

Research tasks. Suppose that several alternative variants of the type of explosives that can be used for the destruction of strong rocks of a complex structure are presented. A rational choice of explosive is required based on many criteria that include technological, economic, social and other indicators, considering the benefits and costs associated with their use.

Note that the task is quite complicated. Since it is necessary to take into account not only the technological parameters, such as the area of the newly formed surface, the size of the average piece, the heat of explosion, but also the economic (the cost of explosives and technology of its use, rational design of the charge of squeezing substances), environmental (the impact of explosives on the natural environment environment) and social (human security in the use of explosives, the complexity of the use of explosives in the destruction of the solid medium). These criteria have different nature, scale of measurement, some of them can't be quantified, and sometimes they contradict each other. In addition, a systematic approach to addressing the problem requires considering not only the benefits, but also the costs that arise when using one or another explosive substance.

Results. our types of explosives were taken into consideration, namely: pentaerythrittetranitrate (PETN), Amonal, Gramonite 79/21, Anemix 80. In this case, the possibility of their use for the destruction of such strong rocks was considered: albitite on granites, albitites on mygmatites, gneiss biotite, migmatitis medium-grained, granites pegmatoid.

Detonation characteristics of explosives selected as criteria for expert evaluation in the destruction of rocks of different structures, and for example, PETN are shown in table 1, 2. These data are given in [7, 8] and obtained during the conduct of experimental studies [9, 10].

Table 1 – Types of explosives and their characteristics

Types of explosives	Heat of explosion kcal / kg, (kJ / kg)	Volume of explosion gases, l/kg	Blast tempera-ture, °C	Detonation rate, km / s	Cost, UAH thousand / t
PETN	5756 (2100)	790	4500	7-8	50.0-55.0
Anemix 80	3 231 (770)	1 009	2 060	4.2-5.2	5.0-6.0
Amonal	5200 (1200)	830	3100	4.0-4.5	10.8-12.0
Gramonite 79/21	4300 (1025)	850	2960	4.8	11.2-12.0

In the course of the study, it was assumed that the following factors are the most important for the selection of explosives:

a) the speed of detonation;
b) heat of explosion;
c) the diameter of the middle piece;
d) the degree of shredding;
e) area of the formed surface;
f) the cost of explosives;
g) saving of explosive material;
h) safety when used.

The latter criterion combines the environmental and safety impacts of drilling operations, including the protection of working personnel. In addition, the selected explosive must be suitable for the destruction of the complex structures listed in Table 2.

Table 2 –The dependence of the technological characteristics of explosive such PETN of rocks that collapses

PETN	Lamina-tion	Average height of ribs, $h_{aver.}$, cm	New surface area, S_{new}, cm^2	Diameter of middle piece, $d_{aver.}$	Destruc tion energy	Crushing degree
Gneiss biotite	no	4.00	1235.97	0.70	0.86	5.69
Large-medium-grained migmatitis	Perpen-dicular	4.00	1764.00	0.70	0.61	5.69
	Parallel	4.00	2061.85	0.62	0.52	6.48
Albuminize by mygma-tites	Perpen-dicular	5.00	1069.02	0.80	1.00	6.27
	Parallel	4.00	132.30	0.70	8.07	5.69
Granite pegmatoid	no	4.00	3505.13	0.40	0.30	9.93
Albums on granites	Perpen-dicular	4.00	701.63	0.86	1.52	4.67
	Parallel	4.00	1003.33	0.73	1.06	5.49

To solve the problem, the analytical hierarchy method (AHM) was chosen. The peculiarity of this method is that it allows you to structure the problem, consider both quantitative and qualitative criteria, as well as check consistency of expert opinions.

The method involves several steps.

The first is to build a hierarchy. The hierarchy represents a certain type of system, based on the assumption that the elements of the system can be grouped into a separate set. Elements of each group are influenced by elements of a certain well-defined group and, in turn, affect the elements of another group, but the elements in each group are independent.

After building the hierarchy, go to fillings matrix comparisons. In AHM, the task elements are compared in pairs relative to their performance ("significance" or "intensity") on a common characteristic for them. The obtained even make comparisons array of numbers that describe as a matrix. Comparing a set of constituent problems with each other, get a inverse-symmetric square matrix $a_{ij} = 1/\ a_{ji}$. The pairwise comparison of elements is carried out using subjective expert opinions that are numerically evaluated on the Saati scale (table 3.) [11].

Table 3 – Comparison scale

Value	Relative importance
1	equal importance
3	moderate advantage over one another
5	significant advantage over one another
7	significant advantage over one another
9	very strong advantage over one another
2, 4, 6, 8	relevant intermediate values

After completing the matrices, they are checked for consistency. The coherence of the matrix means its numerical consistency and transitivity. If, in calculating deviations from consistency, they will exceed the permissible limits, then judgments need to be checked again. To determine coherence, the coherence ratio is calculated. To do this, use the following algorithm.

1. Each column of judgments is summed up.

2. The sum of the first column is multiplied by the value of the first component of the normalized priority vector, the sum of the second column on the second component, and so on.

3. The resulting numbers are summed up. Their sum is affected by λ_{max}.

4. Coherence Index (CI) CI = ($\lambda_{max} - n)/(n - 1)$, where n – number of comparable elements.

5. Random coherence (RC): RC = CI / $n_{вип}$, where $n_{вип}$ – the number of random consistency.

Random coherence is a RC for randomly filled matrices. Their values are calculated for matrices of different order, which are selected from table 4.

Table 4 – Values of calculation indices for matrices of different order

Matrix sequence	1	2	3	4	5	6	7	8	9	10
RC	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The magnitude of the RC should be about 10% or less to be acceptable. In some cases, the RC is supposed to be up to 20%, but no more; otherwise judgment must be checked.

For each of the matrices, the local priority vector is calculated. It expresses the relative magnitude, desirability or "value" of each individual object. Mathematically this is the normalized main eigenvector of the matrix. It can be calculated in different ways. In this paper, the following vector of local priorities was used.

Let this matrix be given $A(n, n)$.

1. The component of the own vector of the i-th line is calculated by the following formula:

$$b_i = \sqrt[n]{a_{i1} \times a_{i2} \times a_{i3} \times ... \times a_{in}} \ . \qquad (1)$$

2. After you get the components of your own vector $(b_1, b_2, \ldots b_n)$ for all n lines it is normalized by the following formula:

$$\overline{X} = \overline{(\frac{b_1}{\sum b_i}, \frac{b_2}{\sum b_i}, ... \frac{b_n}{\sum b_i})} = \overline{(x_1, x_2, x_3, ..., x_n)} \qquad (2)$$

Next, the priorities are synthesized, starting with the second level down. Local priorities are multiplied by the priority of the relevant criterion at the highest level and summed for each element according to the criteria that this element affects. It gives a compiled, or global priority of an element, which is then used to weigh the local priorities of the elements that are compared to it as a criterion and located below the level. The procedure continues to the lowest level.

If the priorities for the *k* level are received, then the priorities for the level elements (k + 1) are calculated by the formula:

$$x_j^{k+1} = \sum_{i=1}^{n} x_i^k b_{ij} \, , \tag{3}$$

where x_j^{k+1} – global priority of *j* criterion on (k + 1) level, x_i^k – the global priority of the *i* criterion at *k* level; b_{ij} – the local priority of the *j* criterion on (k + 1) is equal to *i* criterion of the *k* level.

When all priorities for lower-level elements are calculated (that is for alternatives), the decision maker chooses an alternative based on the results obtained.

In order to solve the problem, a hierarchy, shown in fig.1, was constructed.

Let's consider more detailed application of the method.

At the first level, a comparison is made between rocks. Since according to the research conditions the highest priority is to be albite on granites and albitite on mygmatites, the matrix of comparisons will look like in table 5.

Table 5 – The matrix of comparisons of rock types

Indicators	Albums on granites	Albuminize by mygmatites	Gneiss biotite	Middle-grained migmatitis	Granite pegmatoid
Albums on granites	1	1	5	5	5
Albuminize by mygmatites	1	1	5	5	5
Gneiss biotite	0,2	0,2	1	1	1
Middle-grained migmatitis	0,2	0,2	1	1	1
Granite pegmatoid	0,2	0,2	1	1	1

After calculations yielded the following priorities:

Albums on granites	0.384615
Albuminize by mygmatites	0.384615
Gneiss biotite	0.076923
Middle-grained migmatitis	0.076923
Granite pegmatoid	0.076923

The next step is to compare the criteria. Given the expert opinion was built the matrix of comparisons **(**table 6).

According to results of test, matrix is matched (0.04) and considering previous level of hierarchy, following values of global priorities of criteria are obtained:

Detonation rate – 0.2058;
heat of explosion – 0.1915;
diameter of the middle piece – 0.1669;
the degree of shredding – 0.1455;
area of the formed surface – 0.1287;
cost – 0.0753;

saving of explosive material – 0.0499;
safety at use – 0.036142166.

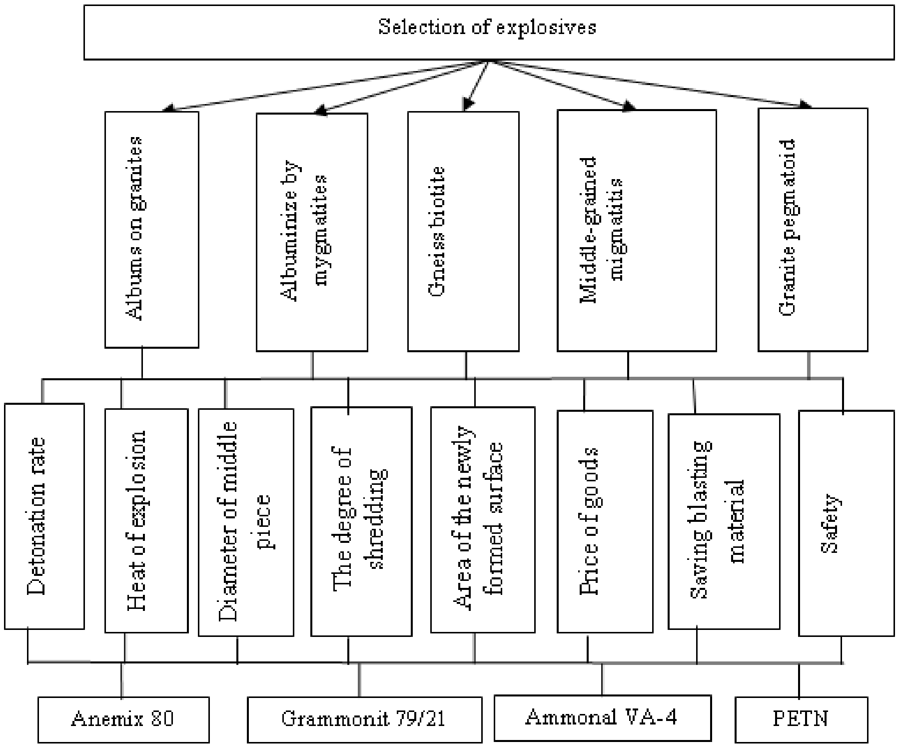

Figure 1 – Hierarchy of selecting an explosive

Table 6 – Comparison of criteria for selection of explosives

Indicators	Detonation rate	Heat of explosion	Diameter of middle piece	Degree of shredding	Area of the formed surface	Cost	Saving of explosive material	Safety at use
Detonation rate	1	1	1	2	2	3	4	4
Heat of explosion	1	1	2	2	1	3	3	3
Diameter of middle piece	1	0,5	1	1	2	3	3	4
Degree of shredding	0,5	0,5	1	1	1	3	4	4
Area of formed surface	0,5	1	0,5	1	1	2	3	3
Cost	0,33	0,33	0,33	0,33	0,50	1	2	5
Saving of explosive material	0,25	0,33	0,33	0,25	0,33	0,5	1	2
Safety at use	0,25	0,33	0,25	0,25	0,33	0,2	0,5	1

Subsequently, matrixes of comparisons of alternatives for each of these criteria were formed. An example of comparisons matrix with respect to the "cost" criterion, the calculated vector of local priorities and RC is shown in table 7.

In this case, ratio of coherence is 0.09, estimates are consistent. Priorities of alternatives for this criterion are distributed as follows: Anemix 80 - 0.618024; Grammonit 79/21 - 173577; Ammonal VA-4 - 173577; PETN - 0.034822.

As you can see, according to the "Cost" criterion, Anemix 80 significantly exceeds all criteria, Grammonit 79/21 and Ammonal VA-4 have a significant advantage over PETN. PETN loses on this criterion all other alternatives, and therefore it has the smallest local priority.

Table 7 – Comparison of alternatives by the criterion "Cost"

Cost	Anemix 80	Grammonit 79/21	Ammonal VA-4	PETN
Anemix 80	1	5	5	9
Grammonit 79/21	0,2	1	1	7
Ammonal VA-4	0,2	1	1	7
PETN	0.111111	0.142857	0.142857	1

The results of calculations of global alternatives priorities are shown in table 8.

Table 8 – Calculation of global priorities

Third Level Criteria	Global Priorities for Third Level Criteria x_i^k	Local priorities for alternatives to b_{ij} criterion			
		Anemix - 80	Gram-monit 79/21	Ammonal VA-4	PETN
Detonation rate	0.21	0.16	0.23	0.12	0.49
Heat of explosion	0.19	0.09	0.16	0.25	0.50
Diameter of middle piece	0.17	0.49	0.25	0.17	0.09
Degree of shredding	0.14	0.06	0.17	0.27	0.50
Area of formed surface	0.13	0.06	0.12	0.26	0.56
Cost	0.07	0.63	0.17	0.17	0.03
Saving of explosive material	0.05	0.63	0.18	0.12	0.07
Safety at use	0.04	0.55	0.25	0.16	0.04
Global Alternatives Priorities $x_j^{k+1} = \sum_{i=1}^{n} x_i^k b_{ij}$		0.25	0.19	0.20	0.36

The analysis of results shows that PETN has the highest priority, since this substance has a high ability to destroy the solid medium due to the high heat and explosion temperature, but it is also the most costly. Grammonit 79/21 and Ammonal VA-4 have similar priorities. This indicates that they have very similar detonation characteristics and composition of the explosive. At the moment, Anemix is the most preferable in terms of costs and less harmful to the environment, since it has the lowest level of emissions of harmful gases, the zero oxygen balance, the lowest cost and its use does not require additional costs.

The solution to task of multi-criteria choice of explosive determines the advantage of PETN, the second place by priority is Anemix.

Conclusions.

1 A mathematical model for justifying selection type of explosives for the destruction of strong rocks has been developed.

2. Mathematical modeling was performed for the solution of the problem using AHM.

3. In the process of solving the problem, the main criteria for the selection of a rational type of explosives are defined. The obtained priority vectors for each hierarchy, which contributed to a reasonable approach to the choice of type of explosives.

4. Priorities were established for which a systematic approach was carried out to solve the problem, considering not only technological advantages, but also the costs of using various types of explosives.

5. The results of mathematical modeling have shown the adequacy of the developed model for the selection of alternative types of explosives for the destruction of solid rocks of complex structure.

6. The use of AHM allows a balanced approach to the selection and justification of the type of explosive, which is very important when designing rational parameters of drilling and blasting operations in the destruction of solid rocks of complex structure in the mines.

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Анотація. У статті сформульована актуальність, мета, постановка задачі, методологія і результати досліджень. Розроблено математичну модель для обґрунтування вибору типу вибухової речовини для руйнування твердих гірських порід. В якості альтернативи було вибрано декілька типів вибухових речовин, а саме: ТЕН, Грамоніт 79/21, Амонал ВА-4 і Анемікс 80. Завдання вирішено з використанням методу аналітичної ієрархії (МАІ). При цьому враховувалися багато критерієв, як кількісні, так і якісні, їх важливість при вибору типу вибухових речовин і їх відповідність думок експертів. В якості критеріїв використовувалися наступні показники: технологічні, економічні, соціальні, екологічні, за допомогою яких можна оцінювати такі, як площа новоствореної поверхні, розмір середнього куску, теплоту вибуху, а також економічні (вартість вибухової речовини), технологія його використання, (раціональна конструкція заряду вибухової речовини), екологічна (вплив вибухових речовин на навколишнє середовище) і соціальна (безпека людини при використанні вибухових речовин для руйнування гірських порід). Згідно з результатами було отримано вектори пріоритетів для кожної ієрархії, що сприяло обґрунтованому підходу до вибору типу ВР. Встановлені пріоритети дозволили здійснити системний підхід до вирішення проблеми з урахуванням не тільки технологічних переваг, але і витрат на використання різних видів вибухових речовин. Також розглянуто фактори, що характеризують витрати при формуванні свердловинних зарядів з різними типами вибухових речовин. Аналіз результатів математичного моделювання показав, що ТЕН має найвищий пріоритет, оскільки ця речовина має високу здатність до руйнування твердого середовища через високу теплоту вибуху, але також є найбільш дорогим. Грамоніт 79/21 і Амонал ВА-4 мають схожі пріоритети стосовно детонаційних властивостей і складу вибухової речовини. Показано адекватність обраної моделі для вибору альтернативних типів вибухових речовин для руйнування твердих порід складної структури. У той же час Анемікс 80 є найбільш економічно вигідним і менш шкідливим для навколишнього середовища, оскільки має найменшу кількість шкідливих газів, нульовий кисневий баланс, найменшу вартість і ніяких додаткових витрат при його застосуванні. Використання методу аналітичної ієрархії (МАІ) дозволяє зважено підійти до вибору і обґрунтуванню типу ВР, оскільки має велике значення при проектуванні раціональних параметрів буропідривних робіт при руйнуванні міцних гірських порід складної будови на копальнях.

Ключові слова: гірська порода, вибухова речовина, метод аналітичної ієрархії.

Аннотация. В статье сформулирована актуальность, цель, постановка задачи, методология и результаты исследований. Разработана математическая модель для обоснования выбора типа взрывчатого вещества для разрушения твердых горных пород. В качестве альтернативы было выбрано несколько типов взрывчатых веществ, а именно: ТЭН, Граммонит 79/21, Аммонал ВА-4 и Анемикс 80. Задача решается с использованием метода аналитической иерархии (МАИ). При этом учитывались многие критерии, как количественные, так и качественные, их важность при выборе типа взрывчатых веществ и их соответствие мнениям экспертов. В качестве критериев использовались следующие показатели: технологические, экономические, социальные, экологические, с помощью которых можно оценивать такие, как площадь вновь сформированной поверхности, размер среднего куска, теплота взрыва, а также экономические (стоимость взрывчатых веществ). и технология его использования,(рациональная конструкция заряда ВВ), экологическая (воздействие взрывчатых веществ на окружающую среду) и социальная (безопасность человека при использовании взрывчатых веществ для горных пород). Согласно результатам, векторы приоритетов были получены для каждой иерархии, что способствовало обоснованному подходу к выбору типа ВВ. Установленные приоритеты позволили осуществить системный подход к решению проблемы с учетом не только технологических преимуществ, но и затрат на использование различных видов взрывчатых веществ. Также рассматриваются факторы, характеризующие затраты при формировании скважинных зарядов с различными типами взрывчатых веществ. Анализ результатов математического моделирования показал, что ТЭН имеет наивысший приоритет, поскольку это вещество обладает высокой способностью к разрушению твердой среды из-за высокой температуры взрыва, но также является наиболее дорогостоящим. Граммонит 79/21 и Аммонал ВА-4 имеют схожие приоритеты. Это указывает на то, что они имеют очень похожие детонационные характеристики и состав взрывчатого вещества. Показана адекватность выбранной модели для подбора альтернативных типов взрывчатых веществ для разрушения твердых пород сложной структуры. В то же время Анемикс 80 является наиболее экономически выгодным и менее вредным для окружающей среды, поскольку имеет наименьшее количество вредных газов, нулевой кислородный баланс, наименьшую стоимость и никаких дополнительных затрат при его применении. Использование МАИ позволяет взвешенно подходить к выбору и обоснованию типа взрывчатого вещества, что очень важно при проектировании рациональных параметров буровзрывных работ при разрушении твердых пород сложной структуры в шахтах.

Ключевые слова: горная порода, взрывчатое вещество, метод аналитической иерархии.

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