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New methodical approaches to justify selection explosive for destruction of solid rocks

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Abstract. The article developed a mathematical model to justify selection the type of explosive for destruction of solid rocks. 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, etc. 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 results of mathematical modeling showed the adequacy of chosen model for selection of alternative types of explosives for the destruction of solid rocks of complex structure.

1 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

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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.

2 Theoretical results

2.1 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.

2.2 Results

Four 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 temperature, °C	Detonation rate, km/s	Cost, UAH thousand/t
PETN	5756 (2100)	790	4500	7-8	50.0-55.0
Anemix 80	3231 (770)	1009	2060	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

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

PETN	Lamination	Average height of ribs $h_{\text{aver.}}$, cm	New surface area, S_{new}, cm^2	Diameter of middle piece, d_{aver}, cm	Destruction energy, J/cm^2	Crushing degree, $K_{\text{cr}}=h_{\text{aver}}/d_{\text{aver}}$
Gneiss biotite	No	4.00	1235.97	0.70	0.86	5.69
Large-medium-grained migmatitis	Perpendicular	4.00	1764.00	0.70	0.61	5.69
	Parallel	4.00	2061.85	0.62	0.52	6.48
Albuminize by mygmatites	Perpendicular	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
Albuminize by granites	Perpendicular	4.00	701.63	0.86	1.52	4.67
	Parallel	4.00	1003.33	0.73	1.06	5.49

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

1) the speed of detonation;
2) heat of explosion;
3) the diameter of the middle piece;
4) the degree of shredding;
5) area of the formed surface;
6) the cost of explosives;
7) saving of explosive material;
8) 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.

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 $\lambda_{\max}$.
4. Coherence Index (CI) $CI = (\lambda_{\max} - n)/(n - 1)$, where n – number of comparable elements.
5. Random coherence (RC): $RC = CI / n_{\text{ran.}}$, where $n_{\text{ran.}}$ – 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:

$$b_i = \sqrt[n]{a_{i1} \times a_{i2} \times a_{i3} \times \ldots \times a_{in}} \;. \tag{1}$$

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

$$\overline{X} = \overline{\left(\frac{b_1}{\sum b_i}, \frac{b_2}{\sum b_i}, \ldots \frac{b_n}{\sum b_i}\right)} = \overline{(x_1, x_2, x_3, \ldots, x_n)} \tag{2}$$

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 Figure 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.

After calculations yielded the following priorities (Table 6).

The next step is to compare the criteria. Given the expert opinion was built the matrix of comparisons (Table 7).

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.

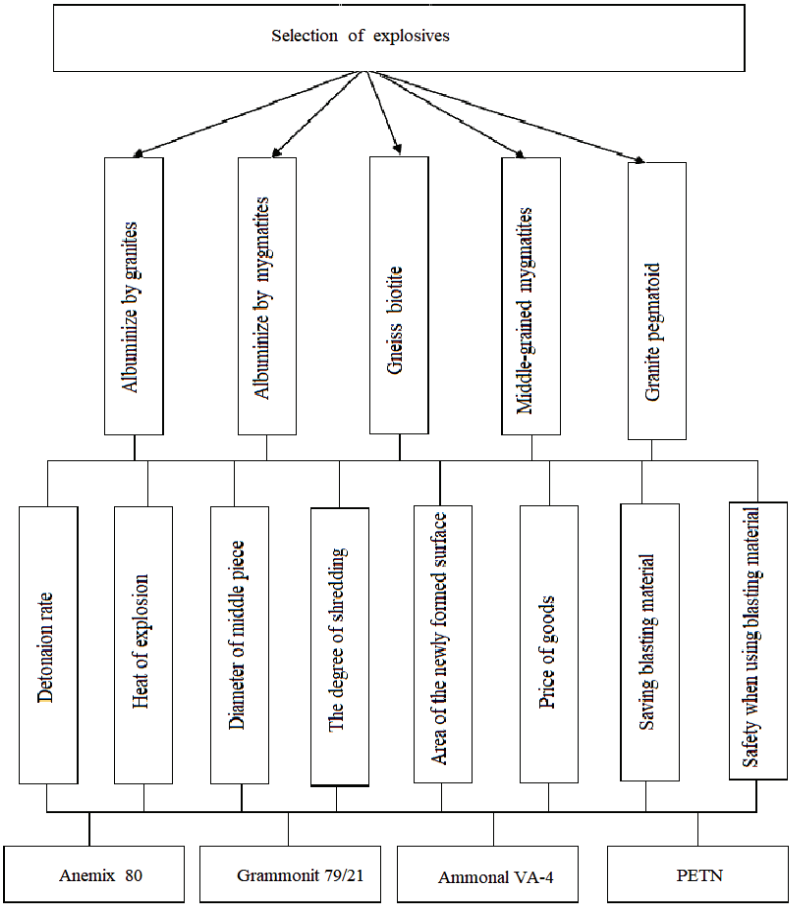

Fig. 1. Hierarchy of selecting an explosive.

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 8.

Table 5. The matrix of comparisons of rock types.

Rock	Albums on granites	Albuminize by mygmatites	Gneiss biotite	Middle-grained migmatitis	Granite pegmatoid
Albuminize by 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 migmatites	0.2	0.2	1	1	1
Granite pegmatoid	0.2	0.2	1	1	1

Table 6. The results of the calculations of the main priorities.

Number	Rock	Priorities
1	Albums on granites	0.384615
2	Albuminize by mygmatites	0.384615
3	Gneiss biotite	0.076923
4	Middle-grained migmatitis	0.076923
5	Granite pegmatoid	0.076923

Table 7. 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

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 8. 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 9.

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.

Table 9. 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	Grammonit 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 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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