SECTION 5. Innovative technologies in science.

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EXACT METHODS OF LINEAR PROGRAMMING FOR CHOOSING ROCK FAILURE CONDITIONS

The article represents the result of exact methods of linear programming choice, determines dominant rock failure conditions, suggests using electrothermal discharge in combination with traditional energy sources in order to reduce rock failure capacity.

Keywords: rock failure, electrothermal discharge, methods of linear programming, rock failure conditions.

Introduction. According to the Directive of the European Parliament and the Board “on the efficiency of energy and energy services end use, and on revocation of the Board’s Directive 93/76/EEC” of April 5, 2006 (2006/32/EU) [1, p. 8], the energy-efficiency increase of rock failure process is an urgent and topical task. In order to implement this directive innovative methods and means, which use combined load of rock mass, are developed. This combined load of rock mass occurs due to joint use of both traditional and alternative energy sources. Under the combined influence of both internal and external loads, potential energy accumulates in a mass. When the critical load values are reached, failure processes begin. Quantitative values of external sources energy potential are considered to be necessary and sufficient when the medium’s internal potential is activated. The use of specified requirements makes it possible to reduce energy consumption of medium failure. Thus, with the help of combined static-dynamic bottomhole load, artificial, additional to the natural, technological cracking occurs. It reduces specific energy output of the bottomhole failure, increases efficiency and enhances performance of work tools and extends their lifespan.

Objective. The objective is to choose and ground the optimum type of external load for rock failure with accordance to the environment conditions and technological potential of rock failure systems. The use of exact methods of systems linear programming in tasks of choosing the external load type for rock failure is introduced for the first time.

Factual statement. At present rock failure process involves using drills, hammers, milling cutters, hydrodynamic machining and electrothermal discharge [2, p. 7 – 8; 3, p. 119 – 142; 4]. Basic conditions for efficient rock failure [5] are:

– x_1 – capability of broken particles forced removal;
– x_2 – efficiency constant when increasing rock strength;
– x_3 – selectivity to rock internal structure change;
– x_4 – possibility of creation of rock failure system adapted to variable rock structures;
– x_5 – possibility of fine dust removal from the failure area;
– x_6 – possibility of using dry dedusting;
– x_7 – use of forced hydrodedusting.

In order to conduct system analysis of failure conditions, table 1, it is suggested to use exact methods of linear programming. Exact methods make it possible to get adequate results when using integral values for availability assessment of a failure condition in every method of rock failure. Iterative methods, as opposed to exact methods, make it possible to get relative values with possibility of error estimation [6, p. 35 – 64].

Table 1

Matrix of initial data for failure conditions assessment in methods under analysis

Rock failure methods	Condition, A							Sum, B
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	
drills, y_1	1	0	0	1	1	1	1	5
milling cutters, y_2	1	0	0	1	1	1	1	5
hammer, y_3	1	0	0	0	0	1	1	3
hydrodynamic machining, y_4	0	0	0	0	1	0	1	2
electrothermal discharge, y_5	0	1	1	1	0	1	0	4

Among exact methods of system analysis of failure conditions the Jordan-Gauss method is marked out. It differs from the existing ones because [7]:

– it provides answers in case of a null determinant;
– the volume of mathematical calculations does not increase even if the quantity of equations increases.

The Jordan-Gauss system analysis method differs from the Gauss method [8] because it uses the rule of rectangle, not a triangular matrix. Using the rule of rectangle makes it possible to reduce time needed for solution and the amount of computer random-access memory used [9, p. 419 – 421]. According to the Jordan-Gauss method, the matrix of initial data is tabulated to the matrix of failure condition calculation, table 2.

Table 2

Tabulated matrix of failure conditions assessment according to the Jordan-Gauss method

1(PE)	0	0	1	1	1	1	5
1	0	0	1	1	1	1	5
1	0	0	0	0	1	1	3

0	0	0	0	1	0	1	2
0	1	1	1	0	1	0	4

where {1, 0, 0, 0, 0} is the main diagonal of the matrix.

In consecutive order, from the first element downward, we choose the permissive element PE, which lies on the main diagonal of the matrix. The permissive element equals one. On the place of permissive element we get 1, and in the column we write zeros. All other elements, including those of the column B, are determined according to the rule of rectangle [9, p. 419 – 421]. In order to do that we choose four numbers, which are situated at the vertexes of the rectangle and always include the permissive element.

The elements of the matrix, table 1: external element EE = CE – (A · B) / PE;
permissive element – PE;
summable element – SE = y_i / PE_i
elements of the matrix – A and B

The calculations of summable and external elements are represented in the table 3.

Table 3

Calculation of summable and external elements of the first stage

Element	x_1	x_2	x_3	x_4	x_5	x_6	x_7	B
SE	1/1=1	0/1=0	0/1=0	1/1=1	1/1=1	1/1=1	1/1=1	5/1=5
EE	1-(1·1/1)=0	0-(0·1/1)=0	0-(0·1/1)=0	1-(1·1/1)=0	1-(1·1/1)=0	1-(1·1/1)=0	1-(1·1/1)=0	5-(5·1/1)=0
	1-(1·1/1)=0	0-(0·1/1)=0	0-(0·1/1)=0	0-(1·1/1)=-1	0-(1·1/1)=-1	1-(1·1/1)=0	1-(1·1/1)=0	3-(5·1/1)=-2
	0-(1·0/1)=0	0-(0·0/1)=0	0-(0·0/1)=0	0-(1·0/1)=0	1-(1·0/1)=0	0-(1·0/1)=0	1-(1·0/1)=0	2-(5·0/1)=2
	0-(1·0/1)=0	1-(0·0/1)=1	1-(0·0/1)=1	1-(1·0/1)=1	0-(1·0/1)=0	1-(1·0/1)=0	0-(1·0/1)=0	4-(5·0/1)=4

As a result of calculations, the table 4 is formed:

Table 4

Table of the second stage calculations according to the Jordan-Gauss method

x_1	x_2	x_3	x_4	x_5	x_6	x_7	B
1	0	0	1	1	1	1	5
0	0	0	0	0	0	0	0
0	0	0	-1	-1	0	0	-2
0	0	0	0	1	0	1	2
0	1	1	1	0	1	0	4

As the second permissive element equals zero, the rows of the matrix change places, table 5.

Table 5

The third stage of calculations according to the Jordan-Gauss method

x_1	x_2	x_3	x_4	x_5	x_6	x_7	B
1	0	0	1	1	1	1	5
0	1	1	1	0	1	0	4
0	0	0	-1	-1	0	0	-2
0	0	0	0	1	0	1	2
0	0	0	0	0	0	0	0

On the place of permissive element we get 1, and in the column we write zeros. All other elements, including those of the column B, are determined according to the rule of rectangle [9, p. 419 – 421]. In order to do that we choose four numbers, which are situated at the vertexes of the rectangle and always include the permissive element PE. The third stage calculations of summable and external elements are represented in the table 6.

Table 6

The third stage calculations of summable and external elements

X_1	X_2	X_3	X_4	X_5	X_6	X_7	B
1-(0·0/1)=1	0-(1·0/1)=0	0-(1·0/1)=0	1-(1·0/1)=1	1-(0·0/1)=1	1-(1·0/1)=1	1-(0·0/1)=1	5-(4·0/1)=5
0/1=0	1/1=1	1/1=1	1/1=1	0/1=0	1/1=1	0/1=0	4/1=4
0-(0·0/1)=0	0-(1·0/1)=0	0-(1·0/1)=0	-1-(1·0/1)=-1	-1-(0·0/1)=-1	0-(1·0/1)=0	0-(0·0/1)=0	-2-(4·0/1)=-2
0-(0·0/1)=0	0-(1·0/1)=0	0-(1·0/1)=0	0-(1·0/1)=0	1-(0·0/1)=1	0-(1·0/1)=0	1-(0·0/1)=1	2-(4·0/1)=2
0-(0·0/1)=0	0-(1·0/1)=0	0-(1·0/1)=0	0-(1·0/1)=0	0-(0·0/1)=0	0-(1·0/1)=0	0-(0·0/1)=0	0-(4·0/1)=0

The results of the calculations are tabulated to the table 7.

Table 7

Results of the third stage calculations according to the Jordan-Gauss method

Rock failure method	x_1	x_2	x_3	x_4	x_5	x_6	x_7	B
cutting (y_1)	1	0	0	1	1	1	1	5
milling cutters (y_2)	0	1	1	1	0	1	0	4
percussion (y_3)	0	0	0	-1	-1	0	0	-2
hydro (y_4)	0	0	0	0	1	0	1	2
electrothermal (y_5)	0	0	0	0	0	0	0	0

The analytical definition of rock failure initial conditions:

$$x_i = B - EE_{(i+1)j} + EE_{(i+2)j} + \ldots + EE_{(i+(n-1))j}\,, \qquad (1)$$

where *i* – the number of conditions, r. u.;
j – the number of methods, r. u.

The initial conditions of rock failure conditions with specific method:

$x_1 = 5 - x_4 + x_5 + x_6 + x_7$,
$x_2 = 4 - x_3 + x_4 + x_6$,
$x_3 = -2 + x_4 - x_5$,
$x_4 = 2 - x_5 + x_7$,
$x_5 = 0$.

Variables x_5, x_6, x_7 are taken as free variables that determine other variables [9]. Variables x_5, x_6, x_7, according to the method, equal zero, variables $x_1 = 5$, $x_2 = 4$. There are no negative values among basic variables. Thus, given solution is reference, it has dominant meaning.

According to the Jordan-Gauss method, conditions x_1 and x_2 are determined as dominant ones. According to these conditions we choose and ground rock failure conditions for using drills, milling cutters and electrothermal discharge. Using technical data from "Chrome" catalogues [10], we determine that efficiency of electrothermal discharge failure method is up to 1.5 times higher than efficiency of failure methods that involve cutting or using milling cutters. That is why the method of electrothermal discharge is chosen to be the optimum method for rock failure.

Conclusions and recommended practice

1. The exact method of linear programming is grounded and used in tasks of external load type choice for rock failure.
2. The Jordan-Gauss method is proven to be optimum for choosing external load types for rock failure.
3. According to the Jordan-Gauss method, it is determined that dominant conditions for rock failure are broken particles forced removal and efficiency constant in case of rock strength increase.
4. The method of electrothermal discharge is chosen to be optimum for combination with traditional rock failure methods.

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