A PROBABILITY APPROACH TO ANALYSING AND ASSESSING SOME NATURAL AND TECHNOGENIC FACTORS AND THEIR INFLUENCE ON THE RISK LEVEL IN SELECTING AN OPTIMAL MINING TECHNOLOGY SOLUTION

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ABSTRACT

The stability number N', calculated on the basis of the Stability Graph Method developed in 1981, has been widely used in selecting the mining technology. The indices determining the stability number N' have a random character so that its calculation is suggested to be performed by applying simulation based on the Monte-Carlo method. The hydraulic radius S is considered as a random variable along with N'. The procedure demands the introduction of limiting conditions resulting from the structure of the mining method and extraction technology. This approach requires analysis and assessment of alternative solutions, each characterised by a certain risk level. Criteria for the final selection of optimal technology are the technical and economic indices and, in particular, production costs, damage caused by losses and ore contamination, safety costs, accident prevention costs. The procedure thus presented allows to select a strategy based on a reasonable risk in taking the final solution.

In working steeply inclined ore deposits, the orebody thickness and physico-mechanical properties of the ore and wallrock are some of the strictest limiting conditions for determining the mining method to be applied in the stope. The most favourable conditions for mining and the highest technical and economic indices, respectively, can be achieved for stable ores and wall rocks and orebody thickness of over 5 m. Preconditions are created for high intensity of mining operations with low ore contamination, which is typical of sublevel blasting stoping with caving mining methods. With decreasing the degree of stability of the wallrock, the application of open stoping methods becomes impossible. Then the proportion of sublevel caving methods rises significantly. By degree of mining intensity these methods are not less effective than the open stoping methods but their major drawback is ore contamination since most of the ore is drawn while in contact with caved rock.

Transition zones exist where it is difficult to determine with certainty the expediency of applying one of the two mining methods mentioned above. The degree of stability of the wallrock can be evaluated by different criteria and approaches but the stability number N' is a sufficiently representative index judging by its wide application in practice. The stability number N' allows to assess the varying geometry of the stope and, mostly, its length L_s and width B_s . Then, besides the economic indices of prime cost, damage caused by losses and ore contamination, we can use the stope dimensions and especially those structural components related to the use of highly productive mechanisation for drilling holes, their charging, loading and ore delivery. From this point of view, the

tendency to increase the height of the sublevel is obvious. A volume extracted at one time is directly proportional to the sublevel height. That means higher mining intensity and rate of development of mining operations.

The categorization of the ore and wallrock into mediumstable to unstable leads to considerable changes in the tendency mentioned above. When working medium-thick (2-5 m) orebodies, splitting (mining in splits) is applied, the split height depending on the mining and rock pressure control methods. Practice has shown that in working thick ore deposits (5-15 m), top slicing, mostly horizontal slicing is used. In those two cases, viz. splitting or cut-and-fill, either ascending or descending order of mining is used. The choice of ascending or descending order of mining has a decisive role on the nature of mining technology. The separate variants differ with respect to both mining intensity and ore guality, particularly concerning losses and contamination. As a natural property, the stability of ore and wallrock has the greatest effect on the mining method. The ascending order of mining requires a preliminary assessment of the stope back stability of the exploitation split, i.e. it (the stability) is a limiting condition for using ascending order of mining. If this condition is not satisfied, then the extraction should be carried out by dividing the orebody into slices with the necessary use of hardening fill. The other alternative, i.e. descending order of mining, is more versatile. It allows to cut both splits and slices using hydraulic and hardening fill. An essential drawback of that method is the lower mining intensity due to the large volume of support operations. In this case, the choice of ascending order as a more productive technology should be related to the stability number N' which appears to be the most appropriate parameter for stability assessment of the extraction workings.

Following the results from previous studies, it was found that the relationship N' = f(S) exists where S is the hydraulic radius of the open stope mined. On the other hand, $S = \frac{a.b}{2.(a+b)}$,

where a and b are two mutually perpendicular dimensions of the open stope. Then, if the dimension corresponding to the stope length is L, and b is the dimension corresponding to the horizontal thickness of the orebody is M (M = B_s), we can determine the degree of stability of the stope back in relation to the selected stope length Ls and orebody thickness (the slice width, respectively) B_s . In other words, $L_s = a$; $B_s = M = b$. The orebody thickness should be taken as a random variable. Therefore, the hydraulic radius S will also be a random variable. The approach to presenting the stability number N as a random variable was discussed in Mihaylov, G., Trapov, G. (2001). Nevertheless, the choice of an engineering solution there is based on the fixed value of variable S. The identification of S as a random variable provides for a more detailed analysis of possible solutions. This is of particular significance for transition zones where the task of selecting a mining technology in relation to the stable state has no single answer. The procedure proposed evaluates both the random character of the natural factors and the risk level in the final selection of the mining technology for the particular natural and mining conditions.

In choosing an optimal engineering solution, the assessment criterion should take into account the income (I), expenditures (E) and risk level (R). These three parameters can be expressed as values thus making it possible to determine the anticipated average (average statistical) "profit" Q as a difference between the anticipated average income and expenditures:

$$Q=(1-R).I-R.E=I-R(I+E).$$
 (1)

The anticipated income (I) is usually higher when operating under higher risk conditions. For example, income as a result of operating larger stopes, decreasing investments for protection measures, etc.

The expenditures (E) are financial means to redeem losses, eliminate consequences of inflicted damage and safety costs (investments in protection measures, training of personnel for adequate response to an undesired event, etc.).

The risk level (R) is the probability for an undesired event to happen. Here the following sequence for its determination is adopted. Two variables are considered - N' (stability number) and S (hydraulic radius).

Factors (RQD, J_n , J_r , J_a , A, B, C) on which N' depends, have a probability character with certain probability laws of distribution.



Figure 1

As was already mentioned, the hydraulic radius is obtained by the formula $S = \frac{a.b}{2.(a+b)}$, where *a* μ *b* are the two mutually perpendicular dimensions of the open stope. The value of variable *a* is usually assumed to be within [40*m*; 100*m*]. For the particular simulation of the model we assumed *a*=60*m*. The values of variable *b* depend largely on the natural factor, i.e. the thickness of the ore vein being mined. Its consideration as a random variable taking values in the interval [2; 5] or [5; 15] is of particular interest. Then the hydraulic radius is also a random variable taking values in the intervals [0.97; 2.31] or [2.31; 6.00] and obeying certain probability laws.

The two random variables N' and S, considered jointly, present a two-dimensional random variable X=(N'; S). The Monte-Carlo method has been applied in this paper and as a result, after taking into account the laws of distribution of N' and S, we have obtained a set of values for X. This is the empirical law of distribution of that random variable. Now it becomes easy to find the risk level in adopting a strategy for operation corresponding to each zone in Fig. 1 (zone no.1 – STABLE ZONE; no.2 – UNSUPPORTED TRANSITION ZONE; no.3 – STABLE WITH SUPPORT; no. 4 – SUPPORTED TRANSITION ZONE; no.5 – CAVED ZONE).

The values assumed for variables I and E as well as the values obtained for R and Q for a case corresponding to operation under competent rock conditions, are presented in Tables 1 and 2. They comply with the two probability laws (in the two intervals) of change in the hydraulic radius. The boundary risk values are given in the fourth row of the tables which are calculated by (1) of the condition Q=I-R(I+E)=0, i.e.

 $R_l = \frac{D}{D+E}$. These numbers allow to assess the maximum

risk for which the anticipated average "profit" will be positive applying the respective strategy.

Table 1						
Zone	1	2	3	4	5	
1	60	65	70	62	55	
E	40	48	50	40	35	
R/	0,6	0,58	0,58	0,61	0,61	
R	0,05	0,95	1,00	1,00	1,00	
Q	55	-42,4	-50	-40	-35	

Table 2

Zone	1	2	3	4	5
1	65	65	70	60	55
E	40	50	55	40	38
R/	0,62	0,57	0,56	0,60	0,59
R	0,08	0,94	0,98	1,00	1,00
Q	55,8	-43,1	-52,5	-40	-38

The analysis of the results obtained on the average "profit" shows definitely that the only winning strategy is no. 1. With all others the anticipated average profit will have a negative sign, i.e. when adopting any of those strategies, the anticipated average "profit" will actually be a loss in the average statistical sense. This is due primarily to the high risk level in adopting strategies corresponding to zones 2 - 5 for the two ranges of change in the hydraulic radius.

The values of variables I and E as well as the values obtained for R and Q for a case corresponding to operation under conditions of weak rock are presented in Tables 3 and 4. They correspond to the two probability laws (in the two intervals) of change in the hydraulic radius.

Table	3
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Zone	1	2	3	4	5
1	60	65	70	62	55
E	40	48	50	40	35
R	0,54	0,53	0,94	1,00	1,00
Q	6,00	5,11	-42,8	-40	-35

Table 4						
Zone	1	2	3	4	5	
	65	65	70	60	55	
E	40	50	55	40	38	
R	0,919	0,553	0,548	0,980	1,0	
Q	-31,50	1,405	1,5	-38	-38	

The analysis of the results obtained on the anticipated average "profit" for a change in the hydraulic radius by the first probability law (Table 3) does not show definitely which strategy, i.e. no. 1 or no. 2, should be preferred. If the aim is to operate at a lower risk level, strategy 2 should be chosen. The risk level will be 0.53, i.e. it will have a minimum value. Provided a strategy is chosen that will lead to a maximum anticipated average profit, then strategy 1 should be chosen since in that case the anticipated average profit will have the highest value, i.e. will be equal to 6.00 units.

When changing the hydraulic radius by the second probability law (Table 4), the anticipated average profit will be positive only with strategies 2 and 3. The best choice in this case should be the third strategy where the risk level is considerably lower (0.548) and the anticipated average profit (1.5 units) is a little higher.

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