Correlation relationship between drilling bit endurance and the most important parameters of the rock mass

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Abstract: The paper presents the possibility of correlation relationships between the drilling bit endurance and the most important parameters of a rock mass. The correlation relationships were determined between the drilling bit endurance and the rock strength, separately for all examined rocks. The endurance of the drilling bit is monitored in a wider area, with the rock strength coefficient from 23–160 MPa (f = 2.3–16). The drilling was carried out using hammer drill RK-28, where the borehole diameter was 32 mm. The analysis of the obtained data identified a graphical and analytical dependence between the drilling bit endurance and the most important parameters of rock mass. The graphic dependence is shown on diagrams 1, 2, 3 and 4, while the analytical dependence is shown in equations 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10.

Key words: drilling, rock mass, correlation

INTRODUCTION

Operating elements of drilling tools and machines in contact with rocks are exposed not only to mechanical stress but to the friction between the surfaces of operating elements and rocks. The same applies to percussive rotary drilling bits, rotary drilling heads, toothed roller for deep rotary drilling etc. When the friction between surfaces is intensified, particles are swept away from the bit, operating element, and thus cause the change in the shape and dimensions of the operating element.

Drilling bit endurance depends on several main natural factors, where the most eminent are: abrasive characteristics, rock mass strength, elasticity, crushing resistance, quartz and other hard material content in the rock, rock mass weight level and others. In addition to natural characteristics, drilling bit endurance is also affected by technical factors including the steel quality of the drilling bit, the shape and geometry of the bore-crown, reinforcement and technological solution, and the quality of the joint between hard alloy and the crown matrix, as well as by the disciplined main-

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tenance of the crown and the drilling bit shank head.

All these factors, both separately and collectively, affect the drilling bit endurance. Such research works enable one to determine how many linear meters could be drilled by a drilling bit before it becomes useless.

Table 1 presents the total bore length that a single drilling bit can achieve. From a scientific and practical viewpoint, it is of great interest to find out the correlation between the drilling bit's useful life and one of the mechanical rock parameters. To this effect, the analysis was made in relation to:

- Rock mass strength coefficient,
- Elasticity module,
- Strength coefficient determined by a crushing method and the rock mass quality index *RQD* established by Dir method.

Testing conditions

Rock mass and ore in the Kopaonik region were examined. Rocks and ores of different strength, and with a compression strength ranging from 23–160 MPa (f = 2.3–16), were examined. For such rock masses, the following main mechanical properties were also examined:

- Compression strength *R*p, on the basis of which (f) is determined according to Protodjakonov;
- Elasticity module (E);
- Crushability coefficient (f_1);
- Quality index of the rock mass according to Dir.

The obtained results of examining 17 different rock types are shown in Table 1.

Blast holes were always drilled by means of a hammer drill (RK 28) and the same type of drilling bit (manufacturer Sandvik Coromant, length 1.6 m, diameter of the bore-crown blade 32 mm, with the constant air pressure of 0.6 MPa).

Analysis of the obtained results

The obtained results enable an analysis of the correlation between each single parameter of the rock mass and the drilling bit endurance, as well as that the drilling bit endurance is expressed through all of the examined rock mass' mechanical characteristics. The software adapted to PC operations was used with this purpose in mind.

Correlation Relationship Between the Drilling Bit Endurance and the Rock Mass Strength Coefficient

Using the data about the length that a drilling bit can drill before it becomes useless, and the data about the rock mass strength coefficient (Table 1), it was possible to define their relationships analytically and graphically. The relationship between these two characteristics is graphically shown in Figure 1. We can see in the Figure that the regularity in behavior concerning their relationships has the correct development in rocks of medium hardness and hard rocks, for $f > 5$, and can be expressed with the equation:

$$L_f = 238{,}54 - 7{,}8\,f - 0{,}18\,f^2 \qquad (1)$$

Table 1. Overview of Rock mass parameters (*f*, *E*, f_d and *RQD*) and drilling bit endurance achieved in each examined rock mass

Rock type code	1	2	3	1	5	6
Rock mass strength coefficient (*f*)	3.1	4.0	6.7	3.2	5.7	4.3
Elasticity module *E*/(MPa × 10)	25.0	33.9	60.1	29.6	35.5	62.1
Crushability coefficient (f_d)	2.1	3.4	8.6	4.2	4.9	5.6
Quality index (*RQD*)	37.0	64.0	58.0	41.0	68.0	83.0
Optimum angle of sharpening αopt for achieving the maximum drilling speed	110.0	105.0	110.0	100.0	105.0	90.0
Total meters drilled (m)	186.6	203.8	186.0	325.0	153.0	211.2

Table 1. Overview of Rock mass parameters (*f*, *E*, f_d and RQD) and drilling bit endurance achieved in each examined rock mass; continuation of Table 1

7	8	9	10	11	12	13	14	15	16	17
5.6	15.9	4.8	2.3	2.7	2.3	3.0	12.7	10.4	8.4	12.0
47.9	96.1	73.0	61.0	17.4	47.0	19.9	94.1	65.6	51.4	81.0
3.6	16.8	4.6	3.4	3.2	2.8	2.5	12.4	9.2	7.4	14.2
87.0	65.0	47.0	49.0	43.0	45.0	39.0	79.0	72.0	64.0	68.0
105.0	110.0	90.0	90.0	110.0	90.0	100.0	110.0	105.0	105.0	110.0
229.1	66.4	100.6	127.0	219.8	294.2	313.2	118.0	135.6	152.2	120.2

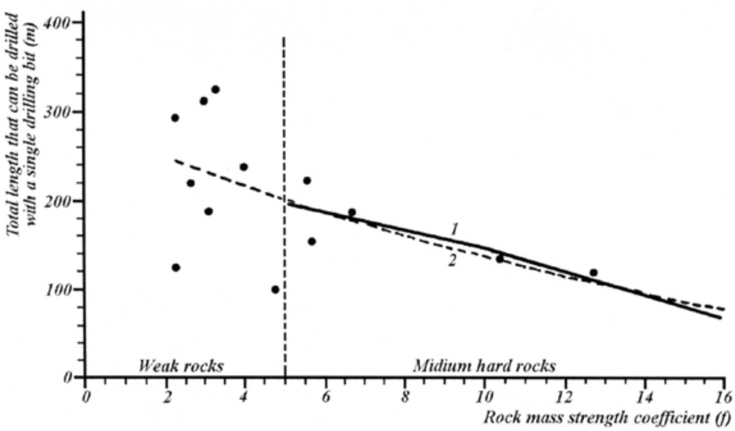

Figure 1. Correlation between the rock mass elasticity module and the total length that can be drilled by a single drilling bit with an optimum sharpening angle. 1. Curve for medium hard and hard rocks; 2. Curve for all examined rocks.

However, with regard to weak rocks ($f < 5$), such regularity cannot be guaranteed considering the great attenuation of results. The final analytical expression of this dependence is given in the equation below:

$$L_f\,(\text{general}) = 279{,}96 - 17{,}47\,f + 0{,}29\,f^2 \quad (2)$$

Correlation Relationship Between the Drilling Bit Endurance and the Elasticity Module

The correlation relationship between the elasticity module and the drilling bit endurance was established in the same way as in the previous case. The data shown in Table 1 enabled making a diagram of this relationship and thereby obtaining a visualisation of the phenomenon's behaviour. Also, it is possible to define this phenomenon analytically on the basis of the available data.

Based on the mathematical analysis of the available data, the following correlation relationship was obtained:

- For medium hard and hard rocks:

$$L_e = -158{,}27 + 15{,}22\,E - 0{,}205\,E^2 + 7{,}58 \cdot 10^{-4}\,E^3 \quad (3)$$

- For all other examined rocks:

$$L_e = 223{,}62 + 3 \cdot 10\,E - 0{,}10\,E^2 + 5{,}2 \cdot 10^{-4}\,E^3 \quad (4)$$

Correlation Relationship Between the Drilling Bit Endurance and the Strength Coefficient Determined by Crushing Method

In the same way that it was done in the previous two examples, in this case the correlation relationship between the drilling bit endurance and the strength coefficient was also determined via the crushing method. A diagram of relationship between these two parameters is shown in Figure 3. While the analytical dependence between the drilling bit endurance and the strength coefficient was defined with the crushing method, such a relationship for medium hard and hard rocks was given as follows:

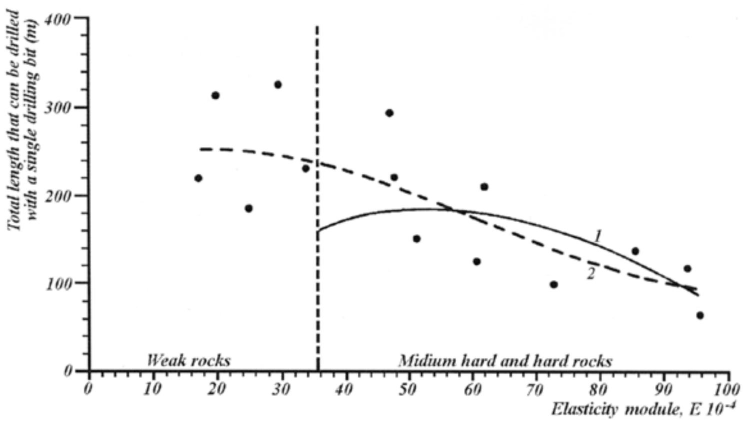

Figure 2. Correlation between the rock mass strength coefficient and the total length that can be drilled by the drilling bit with an optimum blade angle. 1. Curve for medium hard and hard rocks; 2. Curve for all examined rocks.

$$L_f = 176{,}97 + 2{,}81\, f_d - 0{,}55\, f^2 \quad (5)$$

- And for the whole locality:

$$L_f\,(\text{general}) = 277{,}11 - 17{,}49\, f - 0{,}35\, f^2 \quad (6)$$

Correlation Relationship Between the Drilling Bit Endurance and the Rock Quality Index *RQD* According to Dir

As it was done in previous cases, in this case the correlation between the drilling bit endurance and the rock quality index according to DIR was determined. A diagram of the relationship between these two parameters is shown in Figure 4. While the analytical dependence between the drilling bit endurance and the rock quality index was determined according to Dir, the cor-

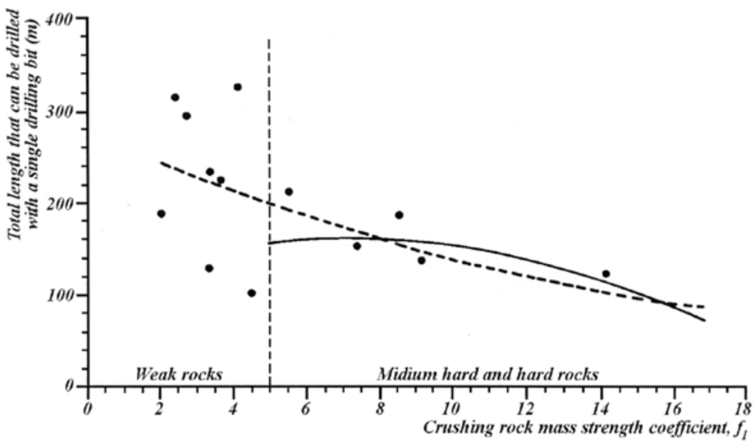

Figure 3. Correlation between the crushing rock coefficient (f_1) and the total length that can be drilled by the drilling bit with the optimum sharpening angle. 1. Curve for medium hard and hard rocks; 2. Curve for all examined rocks.

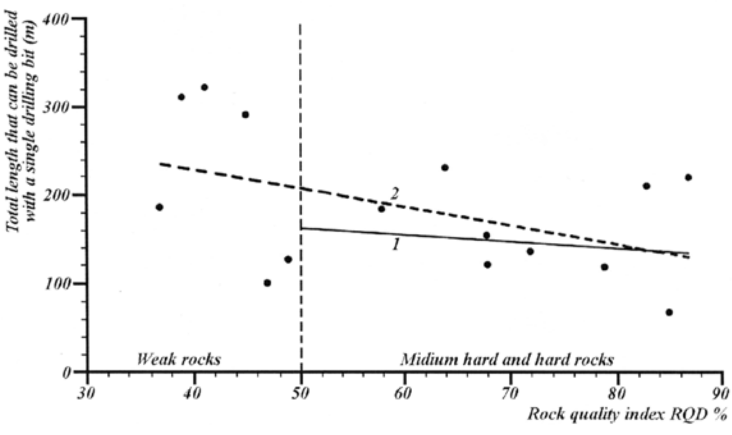

Figure 4. Correlation between the drilling bit endurance and the rock quality index according to DIR (*RQD*) 1. Curve for medium hard and hard rocks; 2. Curve for all examined rocks.

relation curve for medium hard and hard rocks was defined as follows:

$$L = 205,44 - 0,844 \ (RQD) \quad (7)$$

Correlation curve for all other examined rocks is defined as follows:

$$L = 313,30 - 2,103 \ (RQD) \quad (8)$$

Defining a correlation relationship between working environment parameters (f, E, f_1, RQD) and the drilling bit endurance

Using the linear regressive analysis, it was possible to define an equation of the correlation between the drilling bit endurance and a group of mechanical and structural characteristics of the rock mass for all examined parameters of a working environment and the drilling bit endurance.

Interdependence analysis was performed separately for medium hard and hard rocks and separately for examined rock masses. Based on such an analysis, the correlation interdependences were established as follows:

- For medium hard and hard rocks:

$$L = 166,09 - 24,93 \ f \ + 1,21 \cdot 10^{-4} E + \\ + 4,48 f + 1,28 (RQD) \quad (9)$$

- For all examined rock masses:

$$L = 286,0 - 13,45 \ f \ + 1,96 \cdot 10^{-4} E + \\ + 8,91 f_1 + 0,56 \ (RQD) \quad (10)$$

Conclusions

The obtained results and their analysis has shown that it is possible to define the interdependencies, not only between one parameter of the rock mass and the drilling bit endurance, but also among a large number of various parameters, and to obtain high-level correlation relationships.

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