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GEOMECHANICAL MONITORING AT DRILLING AND TUNNELING AS A COMPONENT OF GEOPHYSICAL LOGGING FOR INVESTIGATION OF THE ROCK MASSIF

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ABSTRACT. The new monitoring systems used at drilling and machine boring enable to measure and evaluate the variables like reduced actual penetration rate of drilling and reduced specific energy of disintegration. The notion "reduced" is used for marking the variables purified from the influence of the change of the drilling ability of the tool due to its wear and the influence of the changes of the parameters of drilling. We point out how is it possible to utilise these variables for evaluation of the influence of the scale effect on the strength characteristic of the rock in the rockmass, for mapping and positioning the fracturing zones in the rockmass, and for the estimate of the level of the weakening of the rockmass in dependence to the distance from the fractured zone. In the paper is pointed on the ambiguity of the relation between the strength of the disintegrated rock and the actual penetration rate of drilling. For overcoming this ambiguity the rocks are sorted into the clusters according the prevailing mechanism of its disintegration at drilling or boring by model tools.

1. INTRODUCTION

Geomechanical monitoring, as a component of geophysical logging, can be used for lithological division, determination of quasi homogeneous blocks, cracks and tectonic failures in the rock mass. On the basis of the latest knowledge in this field, it is possible to anticipate its use at acquisition of the data on geotechnical properties of the rock environment from the point of view of so called dimension factor.

New monitoring systems used on the drilling and tunneling machines allow to measure, evaluate and process variables such as so called reduced actual penetration rate of drilling and reduced specific energy of breaking. These variables serve for extension of interpretation options of other variables of geophysical logging applicated for investigation of the rock mass properties.

2. Experimental Results and their Evaluation

The terms such as the reduced actual penetration rate of drilling and reduced specific energy of breaking are used for denomination of variables purified from the effect of the change in drilling ability of the tool caused by its wear and from the effect of changes in drilling parameters, i.e. mainly of axial thrust F, revolutions of the tool and the quality and quantity of drilling fluid Q. This independence is ascertained at the present monitoring systems using mainly software means.

In the paper [Sekula et al. 1992] we have analysed the relation

$$\sigma = \sqrt{2Ew}\,, \tag{1}$$

where

σ – strength of disintegrated rock, Pa

E – Young's modulus, Pa

w – reduced specific energy of breaking, Jm^{-3}.

Further, we have pointed out that at monitoring both under laboratory conditions and under conditions in situ using tools of various diameters, the following experimental relationship is valid

$$\sigma_N = c(w - w_0)^{\alpha}\,, \tag{2}$$

where

$\sigma_N = F_N/S_N$

F_N – normal force on breaking tool, N

S_N – total area of the projection of breaking elements of the tool forced into the rock, m^2

w_0 – constant level of reduced specific energy (so called nonproductive losses of power), Jm^{-3}

α, c – constants.

The difference between formulas (1) and (2) is apparent only, and it follows from interpretation approaches at evaluating the measurements.

It has been shown that the reduced specific energy does not allow to define directly a variable, which would be identical with some strength characteristic of the drilled rock, however, it allows to precise the position of discontinuities in the massif of various types, to determine lithological units or quasi homogeneous blocks, which differ one from another, as a rule, by various levels of reduced specific energy of breaking.

The value of reduced specific energy of breaking responses very sensitively to the diameter of the breaking head at drilling and tunneling. For example, Table 1 gives the data ascertained by us under both laboratory conditions and conditions in situ [Miklúšová 1989] at investigation of breaking of rocks.

We assume that the results given in Tab. 1 are in correspondence with so called dimension effect of the rock mass [Krúpa et al. 1993]. The value of indentation hardness measured on the same rock decreases with the increasing area of the indented indentor. The highest values of the indentation hardness have been measured by

TABLE 1. Values of reduced specific energy of breaking for various diameters of the breaking head

diameter of breaking head, m	0,046	0,05–0,08	0,28	2,7	3,3	5,5
w, MJm^{-3}	200 – 10000	100 – 1000	50 – 300	20 – 300	10 – 200	5 – 30

TABLE 2. The classified experimental stand results with large dispersion of measured values. Impregnated bits, $d = 46\,\mathrm{mm}$, 6–8 channels, synthetic diamonds SDA-50, 200–250 pieces per carat. Drilling conditions: $F = 10{,}000\,\mathrm{N}$, $n = 16.7\,\mathrm{s}^{-1}$

Sample No.	Rock – locality	σ_m, MPa	v, mh^{-1}
27–1	olivine, slightly glassy	1 746	13.21
27–2	diabase – Kolín	1 766	9.00
27–3		2 423	10.23
27–4		2 462	4.68
28–1	biotite quartz – Vrančice	2 021	4.25
28–2		2 335	3.85
28–3	Alexander mine	2 557	3.85
28–4		3 149	3.06
28–5		3 512	2.81
28–6		4 000	3.71
28–7		4 120	4.39
29–1	granite–the Jerseníky Mts.	2 295	6.44
30–1		2 019	8.3
30–2	granite – Hnilec	3 151	5.75
30–3		3 508	10.06
31–1	greisen – Hnilec	2 368	6.3
31–2		3 563	13.09
32–1	quartz diorite to	3 100	8.51
32–2	granodiorite – Požáry	3 700	10.95

the microhardness tester, and the lowest ones at the test according to Baron, where the area of the indented indentor is $10\,\mathrm{mm}^2$. We assume that the resistance against breaking decreases with increasing size of the breaking tool in a similar way as at indentation tests, therefore the values of specific energy of breaking decrease with increasing diameter of the breaking tool.

In relationship between specific energy of breaking and the strength characteristic of the rock we have not specified in detail the strength intentionally, i.e. we have not used the particular method used at investigation of this strength.

At analyzing the value of the reduced actual penetration rate of drilling, we oriented towards the value of the reduced indentation hardness obtained using the standardized method, which is usually used in geological prospection. The actual penetration rate of drilling correlates very well with the indentation hardness of drilled rocks.

TABLE 3. The classified stand experimental data at drilling by impregnated tools $d = 46\,\mathrm{mm}$, 6–8 channels, 300–400 HV, 200–250 pieces per carat

Class $i = 1, 2, 3$	Rock – tool	Rock – locality	σ_m, MPa	v, mh^{-1}
	1–1	sandstone – Řeka	1344	24.39
	1–2		1269	20.00
	1–3		1432	18.52
	2–1	sandstone – Čergov	2183	15.63
1	2–2		2317	15.87
	3–1	sandstone – Boskovická Bříza	3245	12.19
	4–1	andesite – Ruskov	4211	9.80
	4–2		5050	12.99
	4–3		5339	11.36
	5–1	quartzite – Řevnice u Prahy	5552	9.62
	6–1	light shales – Zlaté Hory	842	14.71
	6–2		2050	11.36
	7–1	dark shales – Zlaté Hory	1429	11.76
	7–2		1800	10.42
2	9–1	corneo–muscovite quartzite	5641	4.33
	9–2	Zlaté Hory – Kozlín	5641	5.32
	9–3		5690	5.49
	11–1	granite porphyry – Cínovec	4777	4.03
	12–1	porphyrite – Litohlavy	7112	3.25
	14–1	diabase – Hnilec	987	7.46
	14–2		989	7.19
	14–3		1609	6.17
3	15–1	migmatite – Jesenie	1063	7.25
	16–1	olivine gabbro – Staré Ransko	3277	3.50
	16–2		3659	3.31
	17–1	keratophyre – Horní Benešov	7779	1.94

Let us analyze the results, which have been obtained at laboratory investigation of impregnated bits of the 46 mm diameter. It has been shown, during investigation of relationship between the values of the actual penetration rate of drilling and the values of reduced indentation hardness, that some rocks had large dispersion of values. Rocks with distinct grain texture belong to this group. This texture was of such a nature that at least one group of grains were considerably larger than dimensions of breaking elements – the diamond grains of impregnated tools. These results are given in Table 2. The other results obtained using impregnated tools are given in Table 3, and they are classified into three classes.

Let us look for correlations of the relationship between the actual penetration rate of drilling and the reduced indentation hardness for each class of rocks in the form of

$$V = A_i \sigma_m^{\alpha_i} , \tag{3}$$

where

A_i , α_i – correlation coefficients, $i = 1, 2, 3$

σ_m – indentation hardness.

The relationships between the inverse value of the actual penetration rate of drilling v^{-1} and the indentation hardness σ_m is illustrated in Fig. 1, using both experimental and calculated data.

We have selected this method of processing in order to discriminate better the results in individual classes. The "v^{-1}" variable has the nature of the resistance to drilling, and can serve, in the sense of our definition, as the reduced breaking characteristic of rocks in relation to diamond impregnated tools.

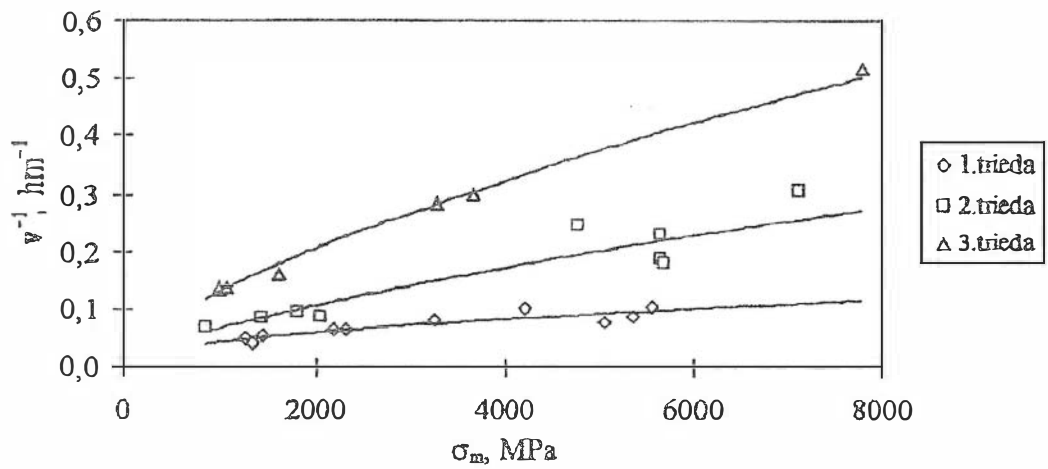

FIG. 1. The relationship between the inverse value of the actual penetration rate of drilling and the indentation hardness at drilling by impregnated tools

The values of the constants of the correlation dependence (3) A_i and α_i, as well as the values of the correlation coefficient r_i for the experimental data in Table 3 are given in Table 4.

As we can see, the values of the constants α_i are in the class 2 and class 3 similar, and differ from the values in class 1. The corresponding values of the constants A_i, which we want to characterize differences of rocks as to the penetration rate of drilling, do not show the expected trend. Therefore the results were processed in such a way, that instead if individual different values of the constants α_i, we have

TABLE 4. The values of the constants of correlation dependence (3) for impregnated tools

class, $i = 1, 2, 3$	α_i	A_i	r_i
1	−0.41441	395.101	0.8489
2	−0.68606	1 713.448	0.9555
3	−0.64781	663.662	0.9952

TABLE 5. The values of the constants of new correlation functions

class, $i = 1, 2, 3$	α_i	A_i	r_i
1	−0.6	1 654.6	0.826 1
2	−0.6	893.72	0.965 0
3	−0.6	468.73	0.991 9
1	−0.7	3 438.37	0.873 7
2	−0.7	1 861.39	0.953 3
3	−0.7	956.53	0.985 8
1	−0.8	7 245.06	0.802 7
2	−0.8	3 830.16	0.921 1
3	−0.8	1 941.36	0.966 7

substituted gradually in the sequence the constant values for α_i, which were the same for all classes, namely −0.6, −0.7 and −0.8. We have got new correlation functions, for which we have calculated new values of the constants A_i, as well as new values of the correlation coefficients r_i, which are given in Table 5.

At comparing the correlation coefficients r_i in Table 4 and in Table 5, we can see that they are not very different. When comparing the values of the constants A_i in Table 5 we can see that at the transition from class 1 of rocks to higher classes they are decreasing. The values A_i processed in this way characterized the differences in the drillability of the rocks in particular classes.

During drilling the samples of drilling debris were taken. Morphology of the grain surfaces of some rocks were studied using scanning electron microscope (Fig.2a, Fig.2b, Fig.2c).

3. DISCUSSION OF RESULTS

Separating some results from the overall set of rocks, which are given in Tab. 2 and classification of the other results obtained by impregnated tools (Tab. 3, Fig. 1) is not unambiguous.

Methodic steps, which allow to point out the differences between individual classes of rocks, which we managed to create on the basis of the obtained experiments, appear to of og great importance at looking for the following functional relations

$$v^{-1} = f(\sigma_m) \qquad \text{or} \qquad v = f\left(\frac{1}{\sigma_m}\right).$$

We have succeeded in numerical expression of the differences between drillability of rocks (see Tab. 5).

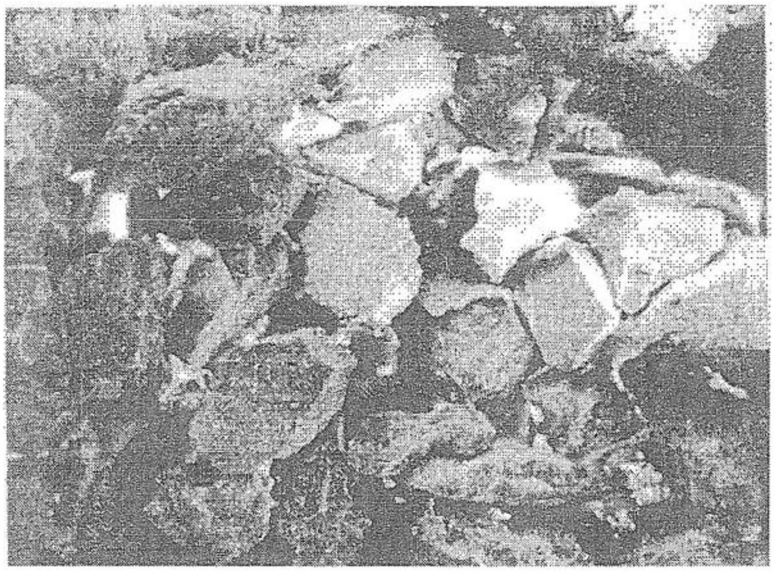

FIG. 2a. Microscope images of the andesite grains from the Ruskov locality, fraction under 40 mm, magn. 400×

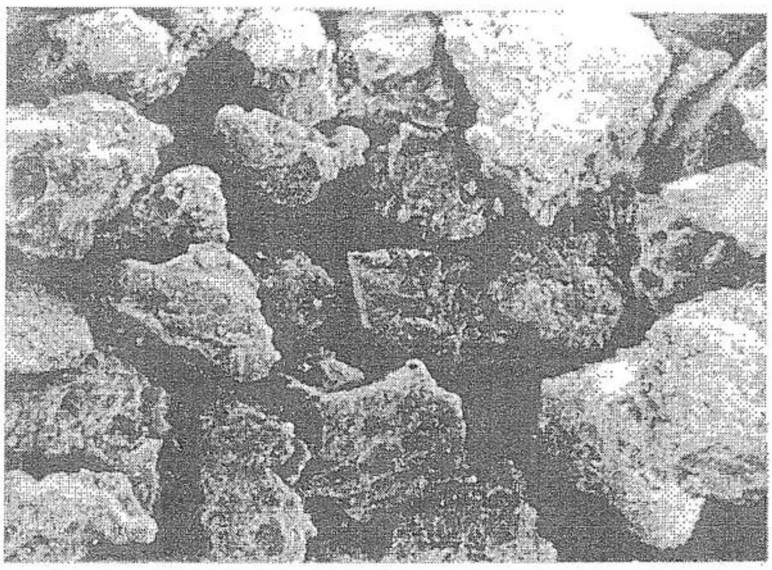

FIG. 2b. Microscope images of the diabase grains from the Hnilec locality, fraction under 40 mm, magn. 400×

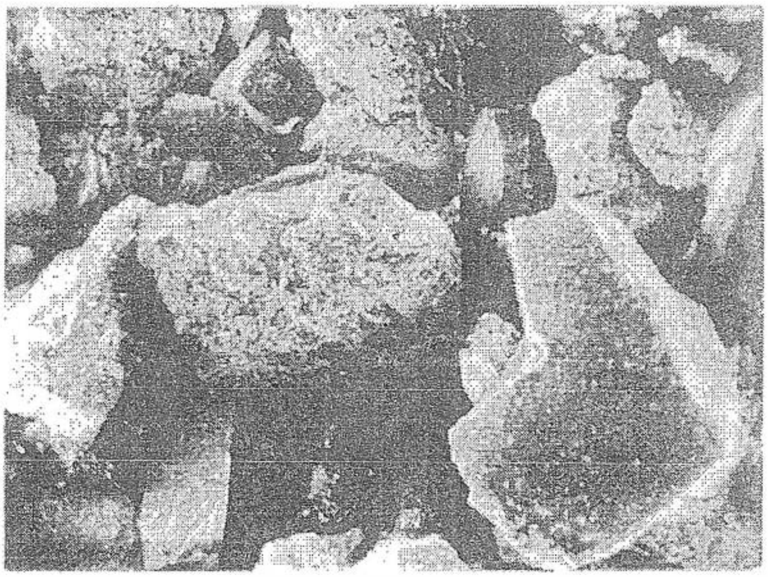

FIG. 2c. Microscope images of the granite grains from the Hnilec locality, fraction under 40 mm magn. 1000×

Fig. 2 also gives a certain explanation of such classification. Fig. 2a shows the magnified image of the andesite debris from the Ruskov locality. We can see that breaking take place quite easily for this rock, smooth plane of cleavages witness about it. On the other hand, in Fig. 2b, where debris of diabase from the Hnilec locality are displayed, very complicated surfaces are visible, which are the evidence that the breaking process of this rock is more difficult, at high energy demands. Therefore we have classified andesite in Tab. 3 and in Fig. 1 into class 1, and diabase into class 3. The debris of granite from the Hnilec locality is depicted in Fig. 2c. In this figure, both the andesite grains from Fig. 2a and the diabase grains from Fig. 2b are present. Probably the penetration rate of drilling in this rock is then dependent on which proportion the mechanisms of brittle fracturing, which are typical for andesite, or the mechanisms of complicated propagation of cracks as it is at rocks of the diabase type, take place. This is probably the reason why a great dispersion of the values of the actual penetration rate of drilling has been recorded at drilling in this rock by impregnated tools.

Howarth and Rowlands [Howarth, Rowlands 1987] pointed out some other reasons affecting the values of the actual penetration rate of drilling using the selected type of tool, associated mainly with the texture of rocks. It is important the process of breaking at drilling is to be studied in dependence on the size of breaking elements and on the size of mineral grains, from which the rock is composed. Of the size of breaking elements is much larger than the average size of the mineral grains of the rock, the effect, which has been observed at breaking granite from the Hnilec locality, will not affect the results of drilling significantly.

The method presented in this paper is the basis for classification of rocks from the point of view of their drillability.

4. Conclusion

The utilization of monitoring data at drilling or tunneling in the rock mass can significantly extend the interpretation data bases of the data obtained by geophysical methods, or by other methods used at investigation of the rock mass. In addition, these data allow to study the dimension factor directly in situ, which is very difficult to study using other methods. The presented methods of study give very important additional information, which are necessary for solution of the stability problems in underground mining workings and engineering works.

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