THE CONNECTION BETWEEN ROCK WALL RAVELING AND IN SITU ROCK MASS STRENGTH – A STUDY ON THE INFLUENCING FACTORS

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Abstract

Definition of the stability characteristics through the strength of jointed rock masses is an important and challenging task in rock mechanics. The existing methods of rock mass classification systems use specific factors; therefore, the proper designation of these methods are important for appropriate rock wall design in open pit mining.

Besides joint sets and cleavage, which have a well-known influence on in-situ rock mass strength, this paper focuses on the factors influencing ravelling by means of in situ observations and laboratory tests.

The aim during the research was to identify the most important influencing parameters and to examine the possibility of the introduction of an in situ measurable parameter as an analytical tool.

1. Introduction

When we think of opencast mining, designers should give detailed consideration to the rock mass, with the mining methods employed and tailored to the specific geological conditions found on site. In order to define interactions between the specific geological conditions and the different environmental acting factors the following parameters are used commonly: intact rock strength, rock mass quality indicators such as RQD (Rock Quality Designation), joint distance and groundwater condition, as well as geological survey techniques and analyses based on the in situ morphology and structural characterization of the rock material.

We examined during our observations and laboratory measurements the parameters influencing slope raveling, focusing on limestone rock walls of a chosen quarry. Previous studies focused on the prediction of raveling using empirical design and rock mass classification systems which rely on e experience and judgment of the engineer. It was concluded that “analytical techniques for prediction are non-effective” and “no analytical tools are available for this task” [1].

The aim during the research was to identify the most influential parameters and to examine the possibility of the introduction of an in situ measurable parameter as an analytical tool.

1.1. Study area The selected study area was the quarry of Mexikóvölgy, which produces limestone (Fig. 1)., Blasting is typically used by miners to loosen stone for quarrying. The mine is situated between 300 and 600 m above sea level over an area of 1.23 km^2. The slope faces have an average dip between 75° and 85° at the observed area. The average height of slopes is 14 to 16 m. The elevation of the observed mining area is between 330 m and 345 m.

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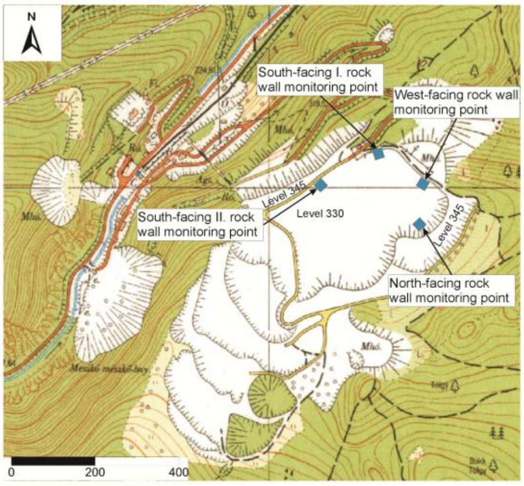

Figure 1. Map overlooking the Mexikóvölgy quarry

1.2. Geology The rock material of the quarry is heavily fractured, grey Triassic limestone with well-developed cleavage and white-yellow calcite veins. The rock material belongs to the Bükkfennsík Limestone Formation. The dolomite content of the formation is minimal, it is represented as a few pelitic dissolution residuals. Clay-red clay cavity fillings are significant. Typical accessory vein minerals are gypsum, calcite, manganese oxides, marcasite, pyrite and iron-oxides.

2. Materials and methods

2.1. Site selection criteria and sampling methods The observation period lasted for two months, starting on 5 March 2012. The observed rock walls were selected according to their cleavage characteristics, the homogenous and heterogeneous properties of the rock material and their orientations. Furthermore, the selected rock walls had to be located at least 50 meters away from blasting operations and should not have been disturbed for at least a year. The collection of the rock fragments was the crucial part during the exploration work.

Since ravelling causes small rock falls, we could use plastic sheets as artificial sampling areas. Six heavy-duty plastic sheets with an area of 6x20 m^2 were used to collect the rock fragments. In accordance with the average 15 m height of slopes and the 5 m length of each sheet parallel with the rock wall, it follows that the area we could sample was 6x75 m^2.

Another aspect was to select monitoring points where the crests of the slopes were clear of rock fragments, because not only the fractured material of the rock walls and the interbedding clay could ravel but also the loose rock previously deposited on the crest of the slopes. Three main monitoring zones were specified on the level of 330 m, underneath of south, north and west-facing rock walls.

The monitoring zone beneath the south-facing rock wall was divided into two different locations 100 m from each other. South-facing 1 represented a heavily fissured zone filled with clay. The sampling zone of south-facing 2 represented a fissured rock zone without any clay interbeddings. We used one sheet for each of these monitoring zones. The west-facing zone, called 'sugar hill' by the miners, and the sampling zone beneath the north-facing wall represented the dominant fissure sets perpendicular and nearly parallel to the plane of the rock walls. Some of these fissures are filled with fine-grained rock debris or clay. Table 1 reports the summary statistics of the dry weights of the collected rock material in grams.

Table 1: Summary statistics of the collected rock fragments

Sampling points	***Quantity [pieces]***	***Dry weight [g]***					
		Average	***Median***	***Std. deviation***	***Min***	***Max***	***Sum***
south-facing 1	9	264.85	125.6	306.68	22.27	811.98	2383.64
south-facing 2	10	134.28	120.5	110.64	13.08	315.99	1342.84
west-facing	12	1889.29	689.69	2281.63	23.53	6531.8	22671.4
north-facing	11	4290.88	987.6	7989.55	117.95	27172.9	47199.7
Total	*42*	*1752.32*	*327.64*	*4454.82*	*13.08*	*27172.9*	*73597.6*

2.2. Temperature conditions during the observation period The study area, because of its location, has a subalpine climate. As regards the temperature, the research period enabled us to study the effect of daily freeze-thaw cycles on the rock mass. We measured negative temperatures ten times during the evenings in March and four times in the evenings of April.

Weathering of material and expansion and contraction associated with freeze-thaw cycles are the principle causes of raveling [2]. "Freeze-thaw conditions loosen once solid rock from quarry high walls. Spring generally causes an increase of raveling activity at open cast mines, especially quarries. Diurnal freezing and thawing penetrate to centimetre-to-decimetre scale depths, producing rock debris mainly of pebble size or smaller on rock slopes"[3].

2.3. Precipitation conditions during the observation When measuring started, a dry period had lasted for weeks. There was no rainfall in March, which was unusual as regards this early spring season. In April the total precipitation was 31 mm.

2.4. Orientations of the rock walls The importance of orientation of the observed rock walls arises from the different solar radiation and wind-load exposure. The prevailing wind direction of the area is from the northeast and southwest, according to the direction of the valley the quarry is located in. For the sake of simplification, we took into consideration only the prevailing wind direction and we assumed that the rock wall temperature was determined by air temperature.

2.5. Rock quality designation index (RQD) The Rock Quality Designation index was developed to provide a quantitative estimate of rock mass quality from drill core logs. In 1976, Priest and Hudson found that an estimate of RQD could be obtained from joint spacing measurements made on an exposure by using

$$RQD\ [\%] = 100 \cdot e^{-0,1\lambda}\,(0,1\lambda + 1)$$

where λ is the total joint frequency [joints/m] [4].

During the field works λ was measured only horizontally at approximately 2.0 m height from the toe of the slope. Table 2 shows the average joint frequency of 1.0 m and the calculated RQD.

Table 2. Rock quality classification according to RQD [5]

Sampling points	***Length of the scan line [m]***	$\bar{\lambda}$	***RQD [%]***	***Rock quality classification****
south-facing 1	1.85	26.5	25.8	*Very poor/Poor*
south-facing 2	3	12.33	65.1	*Fair*
west-facing	7	11.4	68	*Fair*
north-facing	6	22.3	35	*Poor*

2.6. Laboratory strength tests We carried out 21 uniaxial compressive tests and 24 indirect or Brazilian tensile strength tests (Table 3). The uniaxial compression tests were complemented with longitudinal deformation measuring in order to determine Young's elastic modulus (also in Table 3). Relevant reference of the ISRM (International Society for Rock Mechanics) contains the regulation of stress tests of the rocks [6,7], thus they are not detailed here.

Table 3. Summary statistics of uniaxial compressive strength tests

Sampling points	***Quantity [pieces]***	***Unaxial compressive strength [MPa]***				
		Average	***Median***	***Std. deviation***	***Min***	***Max***
south-facing 1	5	160.66	168.26	22.24	133.39	187.17
south-facing 2	4	137.33	143.14	28.98	99.18	163.85
west-facing	4	140.95	138.54	17.34	124.41	162.30
north-facing	8	127.01	115.95	22.44	103.37	161.05
Sampling points	***Quantity [pieces]***	***Young modulus [GPa]***				
		Average	***Median***	***Std. deviation***	***Min***	***Max***
south-facing 1	5	43.83	38.57	16.78	24.59	69.37
south-facing 2	4	35.23	34.60	3.06	32.26	39.44
west-facing	4	38.33	38.98	4.07	33.17	42.21
north-facing	8	35.44	36.86	5.13	26.66	40.90
Sampling points	***Quantity [pieces]***	***Brazilian tensile strength [MPa]***				
		Average	***Median***	***Std. deviation***	***Min***	***Max***
south-facing 1	5	7.68	7.98	0.98	6.04	8.61
south-facing 2	5	6.30	6.12	1.40	4.59	8.48
west-facing	5	7.26	8.12	2.12	3.67	9.06
north-facing	9	7.94	7.94	1.90	5.08	10.59

3. Results and discussion

3.1. Comparison of fallen weight trends with rock mass quality indicator and intact rock strength parameters We found that the characterising RQD based on the relations using total joint frequency is not consistent with the amount of crumbled rock fragments. The basis for this observation is that, although we took heavily jointed rock mass into consideration, the faults, fissure sets and joints directionality are unfavourable for the rock falling.

The trend of the amount of crumbled rock fragments shows a relatively weak relationship with the characterising uniaxial compressive strength as well as with the Young's elastic modulus. We observed that fractures influenced the strength parameters measured in the laboratory, due to sigmoidal tension gashes present in the structure of rock samples. This phenomenon can be explained by the influence of the volume of a specimen on this mechanical behaviour, the so-called size effect. The trend of the amount of crumbled rock fragments shows a relationship with the tendency of tensile strength. This result may refer to the presence of veinlets and microfissure sets, although more testing is required to confirm the correlation.

3.2. Stereographic projections of the structural elements in the observation area Stereograms were made by plotting measurements of the fault planes, striae and systematic joint sets at the areas of the four monitoring points (Fig. 2). It can be concluded that the results fitted the characterising Neogene stress field of the mountain rim. The cleavage dipping to north-northeast forms steep fissures with smooth surfaces, frequently filled with calcite. This system is traceable over a long distance, and the planes were often transformed to faults [8].

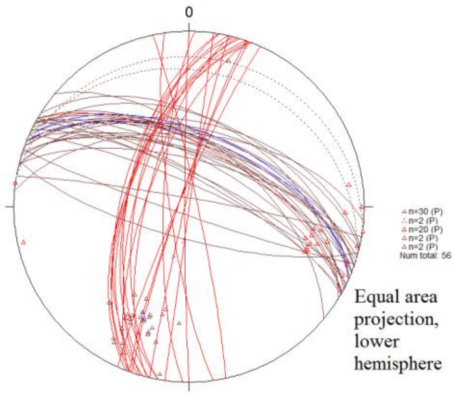

Figure 2. Stereoplot of structural orientation data from south-facing 2 monitoring point

3.3. Comparison of fallen weight trends To compare the different weight populations, we used the Kruskal-Wallis test as a multiple-sample comparison. It tests whether the sample medians are significantly different. Since the P-value = 0.000159, less than 0.05, there is a statistically significant difference amongst the medians at the 95.0% confidence level, therefore statistically there is no connection between the four weight populations. As a consequence, these statistically different weight trends could be connected to different environmental, e.g. climatic, acting factors.

We used linear regression analysis to find connections between weight populations and the populations of climatic factors. We calculated with weight populations as the dependent variables, while temperature differences, precipitation values and maximal wind speed values were used as independent variables. Temperature differences mean the absolute values of the differences between the maximum and minimum temperatures of the observation periods.

The R-Squared statistic indicates a relatively strong relationship between the variables of south-facing 1 weight population and precipitation, a moderately strong relationship for south-facing 2 and west-facing weight populations and precipitation, and a relatively weak relationship for north-facing weight population and precipitation.

P-values in the ANOVA tables show a statistically significant relationship between south-facing 1 weight population and precipitation and between west-facing weight population and precipitation.

4. Conclusion

The aim of the research was to identify factors that influence the raveling of rock blocks and fragments at steep rock walls of a strong rock mass with disturbed structure. We carried out our observations in a limestone quarry near Miskolc, Hungary. Directivity of cleavage and foliation shown with stereographic projections, joint sets of the rock walls, laboratory strength parameters, daily temperature fluctuations, precipitation and maximal daily wind velocity were taken into account during the research of factors influencing the amount of ravelling.

To sum up, it can be concluded that if the directivity of cleavage and joint sets correspond and the cleavage dipping is less than the angle of the rock slope, more significant weights of rock fragments could be observed on the sheets. There were not enough data to find connections between poor rock quality according to RQD and the weight populations of the crumbled rock fragments; further measurements are needed. Diurnal freeze/thaw cycles, precipitation and significant wind pressure have an influence on the amount of the raveled rock fragments.

It is important to emphasize that the mass data of rock fragments collected by the sheets should be taken into account as trends, not as specific values. If we would like to adopt this trend as a factor which involves the influencing factors mentioned above, then further measurements are needed.

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