Applications and Limitations of Geotechnical Classification Systems

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ABSTRACT

During the feasibility and preliminary design stages of a project, when not enough detailed information on the rock mass and its stress and hydrologic characteristics is available, the use of a rock mass classification scheme can be of considerable benefit. This can be used as a check-list to ensure that all relevant information has been considered. It is possible that one or more rock mass classification schemes can be used to build up a picture of the composition and characteristics of a rock mass to provide initial estimates of support requirements, and to provide estimates of the strength and deformation properties of the rock mass.

Different classification systems place different emphases on the various parameters, that's why in our tunnel project we use 3 methods RMi, Q, RMR and compares the results.

One of the results of the comprehensive field work to clarify the geological conditions for the tunnelling works was a comprehensive data collection of rock and rockmass descriptions that contains information about lithology, petrology, mineralogy, texture, fabric and on-site evaluated rock and rockmass physical and mechanical properties. For further data processing the above mentioned rock- and rockmass-classifications were used to give comparable assessments for tunnelling conditions and lining requirements.

The paper at hand is an attempt to clarify, which systems of rockmass classification are best-fit to describe the rockmass conditions of the project area. Which were the limitations of each system used and how to improve their applications. The result is displayed in the geological longitudinal sections of the headrace Moglice – Graboves (Devoll Project, Albania). Consequently the paper at hand is an integrated part of the engineering geological contribution in the feasibility report for the client DHP in which GSI and little "q" systems were used as well.

INTRODUCTION

Devoll Hydropower (DHP) is a joint venture company of EVN (Austria) and Statkraft (Norway), which purpose is to develop, plan, construct and operate up to 3 hydropower plants along the middle reaches of Devoll river.

Besides the completion of the unfinished HPP Banje the project comprises at the present stage two new damsites for reservoirs, more than 30 km of waterway tunnels (headrace and tailrace tunnels) and two powerhouses, at least one of them constructed in a large cavern.

The regional geology covering tectonically very complicated geologic units a quite challenging background for the project. It is a fact, that excavating tunnels and caverns is one of the most important cost factor for such a project. That was the reason to start as early as June 2009 with the investigation works. (see picture.1)

In turn **baugeologie.at** started field work in June 2009. The author was part of the team since July 2009. The detailed geological mapping work with focus on engineering aspects was done based on the accordant sheets of the official geological maps of Albania scale 1:50.000. **baugeologie.at** succeeded in detailed mapping of the key areas for dam-sites and tunnel alignements.

One of the results of the comprehensive field work to clarify the geological conditions for the tunneling works was a comprehensive data collection of rock and rockmass descriptions that contains information about lithology, petrology, mineralogy, texture, fabric and on-site evaluated rock and rockmass physical and mechanical properties. For further data processing several rock- and rockmass-classifications exist to give comparable assessments for tunneling conditions and lining requirements.

After getting the results of the classifications performed, which are displayed in the geological longitudinal sections of the headrace Moglice-Graboves conclusions about the application and limitation were made. Consequently the paper at hand is an attempt to clarify, which systems of rockmass classification are best-fit to describe the rockmass conditions of the project area and which the limitations of each system used were and how to improve their applications.

1. THE METHOD

A comprehensive field investigation program has been carried out in the project area, ranging from regional geological mapping, refraction seismic survey to core drillings and test pits. The investigation is mostly concentrated to key areas for the project such as dam sites, power station areas, and critical sections along tunnel alignments.

During the feasibility and preliminary design stages of a project, when not enough detailed information on the rock mass and its stress and hydrologic characteristics is available, the use of a rock mass classification scheme can be of considerable benefit. This can be used as a check-list to ensure that all relevant information has been considered. It is possible that one or more rock mass classification schemes can be used to build up a picture of the composition and characteristics of a rock mass to provide initial estimates of support requirements, and to provide estimates of the strength and deformation properties of the rock mass.

Different classification systems place different emphases on the various parameters, that’s why the author uses 3 methods RMi, Q, RMR and compares the results.

The Rock Mass Rating system (RMR)

The Rock Mass Rating system also called the Geomechanics Classification was first published in 1976 from Bieniawski. The following six parameters are used to classify a rock mass using this system:

1. Uniaxial compressive strength of rock material.

2. Rock Quality Designation (RQD).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

The Rock Mass Rating system gives the ratings for each of the six parameters listed above. These ratings are summed to give a value of *RMR*.

The Rock Tunneling Quality Index (Q)

Barton of the Norwegian Geotechnical Institute proposed a Tunneling Quality Index (Q) for the determination of rock mass characteristics and tunnel support requirements in 1974. The numerical value of the index Q varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined by:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SFR} \qquad (1)$$

where:

RQD is the Rock Quality Designation $$RQD = \frac{\sum Length \cdot of \cdot core \cdot pieces \geq 10}{total \cdot length \cdot of \cdot core \cdot run} \times 100 \qquad (2)$$

J_n is the joint set number
J_r is the joint roughness number
J_a is the joint alteration number
J_w is the joint water reduction factor
SRF is the stress reduction factor

The Rock Mass Index (RMi)

The rock mass index was first presented in 1995 by Palmström A. This index has been developed as a general strength characterization of the structural material that a rock mass represents. The rock mass is a material much more complex in composition, structure, variability than most other structural materials. The presence of various defects (discontinuities) in a rock mass, which tend to reduce the inherent strength of the rock, constitutes the main feature in its behavior. This fact is the main principle of the Rock Mass index (RMi).

The RMi system has some input parameters similar to those of the Q-system. Thus, the joint and the jointing features are almost the same.

The input parameters in a general strength characterization of a rock mass are:

- the size of the blocks delineated by joints, - measured as block volume;
- the strength of the block material, - measured as uniaxial compressive strength;
- the shear strength of the block faces, - measured as friction angle, and
- the size and termination of the joints, - measured as length and continuity.

The main principle in the development of RMi has been focusing on the effects of the defects in a rock mass in reducing the strength of the intact rock. The RMi is thus defined as

$$\text{RMi} = \sigma c \times \text{JP} \quad (3)$$

Where
σc = the uniaxial compressive strength of the intact rock material, and
JP = the jointing parameter. It is a reduction coefficient representing the block size and the condition of its faces represented by their friction properties and the size of the joints.
The value of JP varies from almost 0 for crushed rocks to 1 for intact rock.
Its value is found by combining empirical relations jC (joint conditions) and Vb (block volume) in the following exponential equation derived from strength tests on large jointed samples.

$$\text{JP} = 0.2\sqrt{jC \times V_b^D} \qquad (\text{ D}= 0.37\, jC^{-0.2}) \quad (4)$$

Where

$$\text{jC}= \text{jR} \times \frac{jL}{jA} \qquad (5) \qquad \text{(jR- joint roughness, jL- joint length, jA- joint alteration)}$$

1.1 THE CFASSIFICATION AND THEIR RESULTS

The work for the classification consists in inserting the input parameters collected in the field in the excel spread sheet (see fig.1)

After classifying a selected number outcrops which concern the Moglice- Grabove tunnel area the results will be displayed in the followed tables.(see fig.2 and 3)

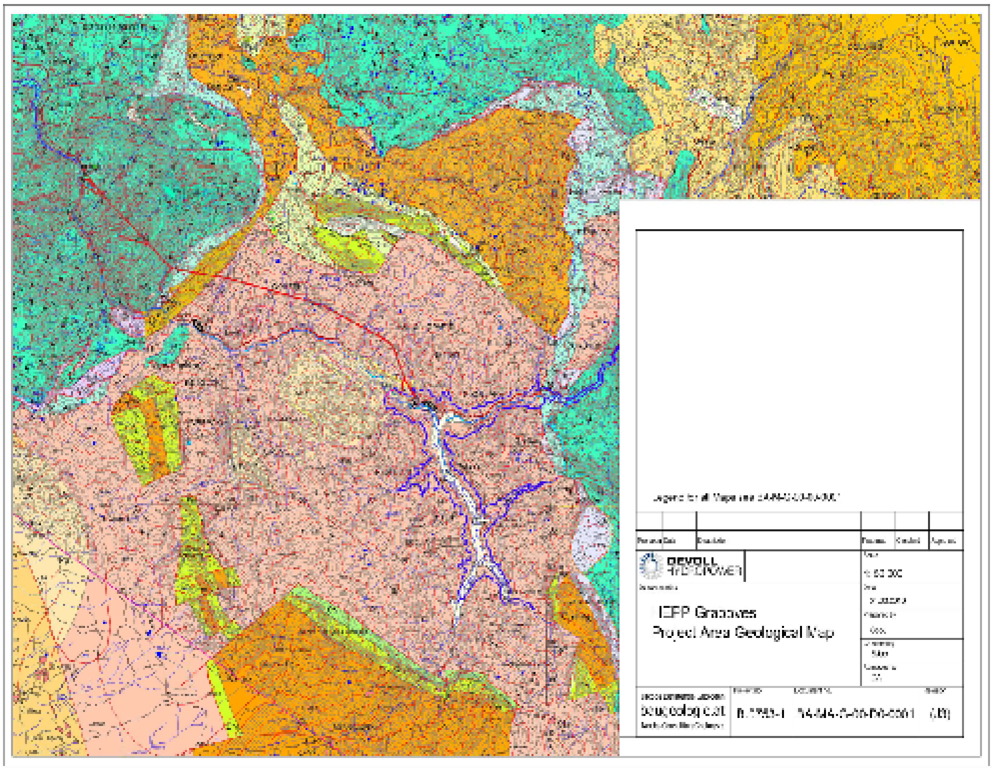
2 APLICATIONS AND LIMITATIONS OF THE USED CLASSIFICATION SYSTEMS

1. The better and comprehensive the description of the rockmass is, and the more of the requested parameters are well defined, the better results are achieved by any classification system.
2. Outcrops with clear lithologic and fabric conditions, that weren't subject to tectonic complications, normally are easiest to describe and allow all parameters to be reckoned as precise as possible. Within the bandwidth of properties of the rockmass entity these outcrops in general represent the more favorable side.
3. In contrary outcrops with complicated lithologic and fabric conditions as well as a multi-stage tectonic history are sometimes difficult to define and hardly to describe according to the requested input parameters of classification systems.
4. Consequently all classification systems will show a broader variation on the "unfavourable side" of the bandwidth.
5. Ideally, all the characteristics (smoothness, waviness, length) included in the joint condition factor of the systems should be measured accurately. Such measurements of the joints would generally be either extremely time-consuming or in most cases, practically impossible to carry out. Only a few joints in the rock mass can be observed

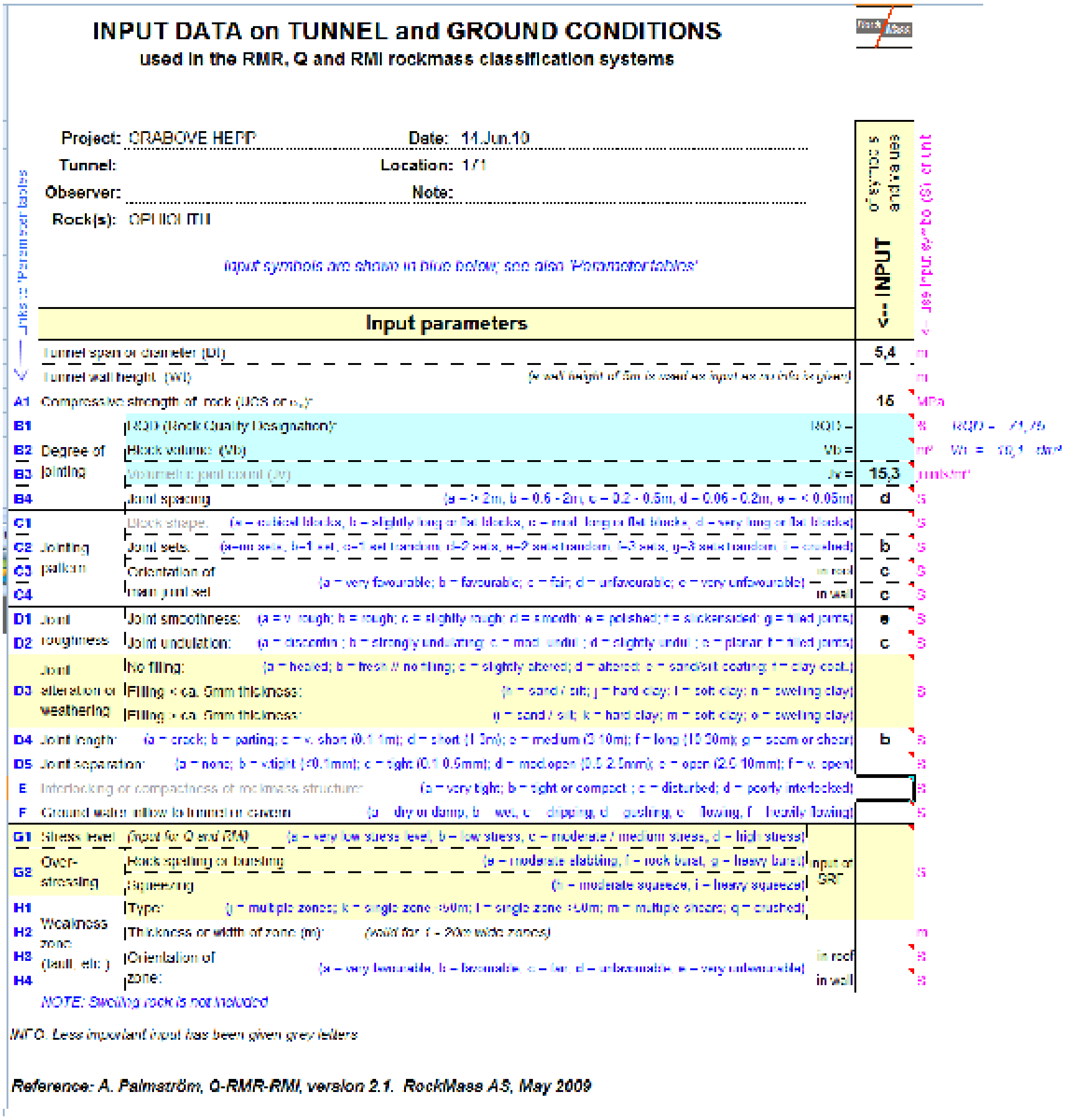
and measured and extrapolations have to be made. This may result in a difering of the real quality of the rockmass.

6. Where the rock mass characterization is carried out *before* construction, uncertainties are introduced from the *interpolations* made between more or less known conditions at the surface and from various forms of *extrapolations* carried out from these (known) conditions to areas with unknown information. Except for wrong interpretations, improved characterization of the rock mass by RMi will generally increase the quality of the geological input data to be applied in evaluation, assessments or calculations. This will in turn lead to better designs
7. RQD is applied in the main classification systems as an input parameter for the block size or the jointing density. RQD is one-dimensional; therefore it is strongly directional. This was stressed among others by Bjerrum (1965). Therefore, Hudson and Priest (1983) and several other authors recommend carrying out core drillings in three directions to obtain reliable results. This is, however, an expensive solution to obtain information on the jointing.
8. Scanlines are a good solution for not selecting the better outcrops while maping.
9. The most important thing in having good results from classification systems is the experience and knowledge of the engineer at site.

Tables and Figures



Picture 1 *Geology along the tunnel layout*



INPUT DATA on TUNNEL and GROUND CONDITIONS

used in the RMR, Q and RMi rockmass classification systems

Project: GRABOVE HEPP Date: 11.Jun.10

Tunnel: Location: 1/1

Observer: Note:

Rock(s): OPHIOLITH

input symbols are shown in blue below; see also 'Parameter tables'

<--- links to 'Parameter tables'

<-- INPUT

Input parameters

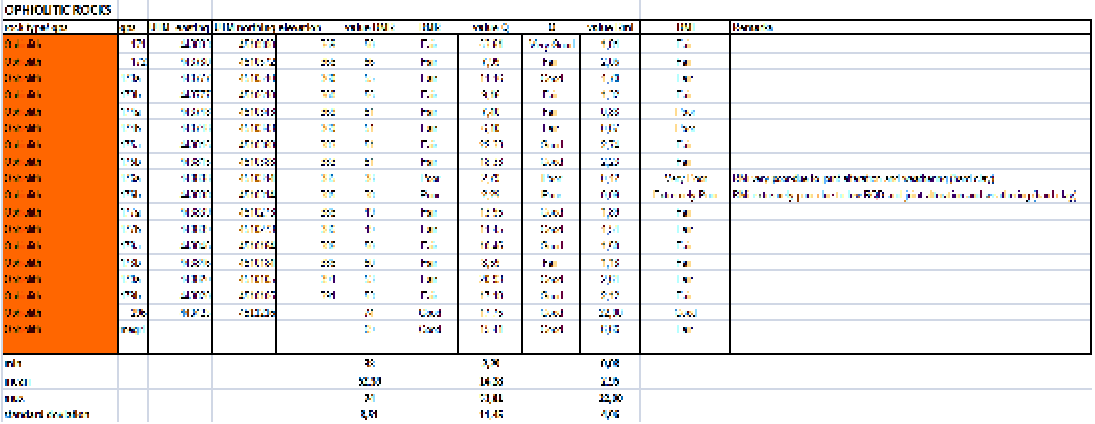
	Tunnel span or diameter (Dt)			5,4	m
	Tunnel wall height (Wt)		(a wall height of 5m is used as input as no info is given)		m
A1	Compressive strength of rock (UCS or σ_c)			15	MPa
B1	Degree of jointing	RQD (Rock Quality Designation)	RQD =		% RQD = 71,75
B2		Block volume (Vb)	Vb =		m³ Vb = 10,1 dm³
B3		Volumetric joint count (Jv)	Jv =	15,3	joints/m³
B4		Joint spacing	(a = > 2m, b = 0.6 - 2m, c = 0.2 - 0.6m, d = 0.06 - 0.2m, e = < 0.06m)	d	S
C1	Jointing pattern	Block shape:	(a = cubical blocks, b = slightly long or flat blocks, c = mod. long or flat blocks, d = very long or flat blocks)		S
C2		Joint sets:	(a=no sets, b=1 set, c=1 set random, d=2 sets, e=2 sets random, f=3 sets, g=3 sets random, i = crushed)	b	S
C3		Orientation of main joint set	(a = very favourable; b = favourable; c = fair; d = unfavourable; e = very unfavourable) in roof	c	S
C4			in wall	c	S
D1	Joint roughness	Joint smoothness:	(a = v. rough; b = rough; c = slightly rough; d = smooth; e = polished; f = slickensided; g = filled joints)	e	S
D2		Joint undulation:	(a = discontin.; b = strongly undulating; c = mod. undul.; d = slightly undul.; e = planar; f = filled joints)	c	S
D3	Joint alteration or weathering	No filling:	(a = healed; b = fresh // no filling; c = slightly altered; d = altered; e = sand/silt coating; f = clay coat.)		S
		Filling < ca. 5mm thickness:	(h = sand / silt; j = hard clay; l = soft clay; n = swelling clay)		
		Filling > ca. 5mm thickness:	(i = sand / silt; k = hard clay; m = soft clay; o = swelling clay)		
D4	Joint length:		(a = crack; b = parting; c = v. short (0.1-1m); d = short (1-3m); e = medium (3-10m); f = long (10-30m); g = seam or shear)	b	S
D5	Joint separation:		(a = none; b = v.tight (<0.1mm); c = tight (0.1-0.5mm); d = mod.open (0.5-2.5mm); e = open (2.5-10mm); f = v. open)		S
E	Interlocking or compactness of rockmass structure:		(a = very tight; b = tight or compact; c = disturbed; d = poorly interlocked)		S
F	Ground water inflow to tunnel or cavern		(a = dry or damp; b = wet; c = dripping; d = gushing; e = flowing; f = heavily flowing)		S
G1	Stress level (input for Q and RMi)		(a = very low stress level; b = low stress; c = moderate / medium stress; d = high stress)		
G2	Over-stressing	Rock spalling or bursting	(e = moderate slabbing; f = rock burst; g = heavy burst) input or SRF		S
		Squeezing	(h = moderate squeeze; i = heavy squeeze)		
H1	Weakness zone (fault, etc.)	Type:	(j = multiple zones; k = single zone >50m; l = single zone <50m; m = multiple shears; q = crushed)		
H2		Thickness or width of zone (m):	(valid for 1 - 20m wide zones)		m
H3		Orientation of zone:	(a = very favourable; b = favourable; c = fair; d = unfavourable; e = very unfavourable) in roof		S
H4			in wall		S

NOTE: Swelling rock is not included

INFO: Less important input has been given grey letters

Reference: A. Palmström, Q-RMR-RMi, version 2.1. RockMass AS, May 2009

Figure 1. *Spread sheet for RMR, Q, RMi rock mass classification*



OPHIOLITIC ROCKS

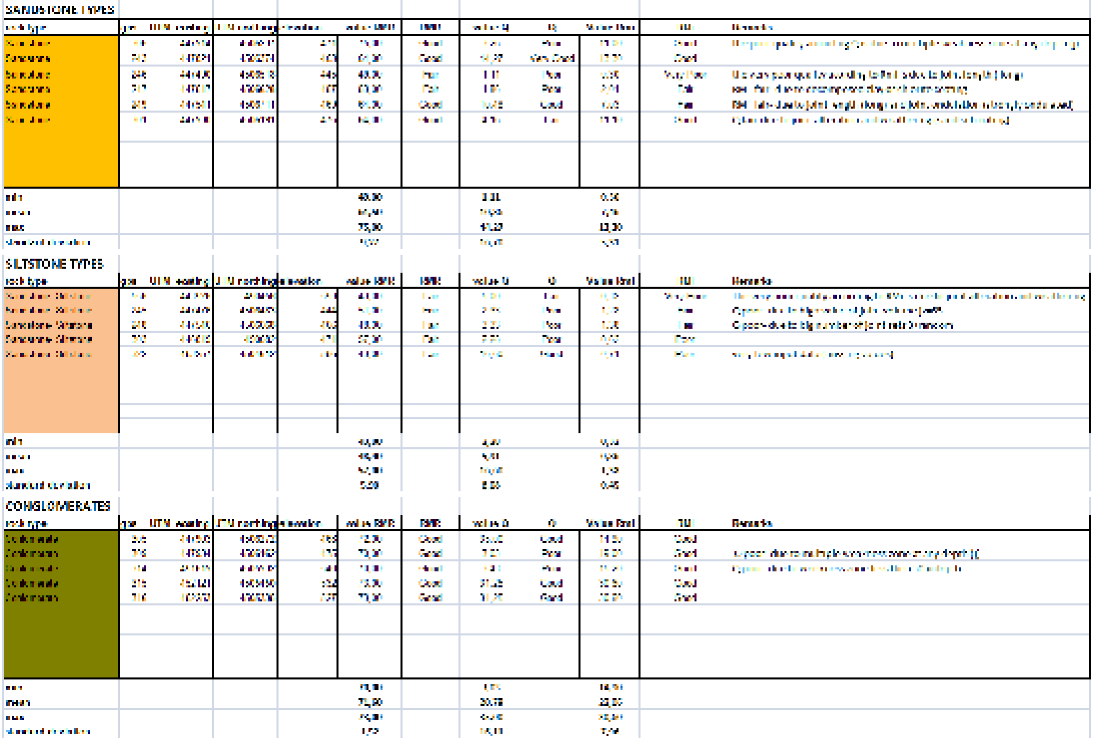
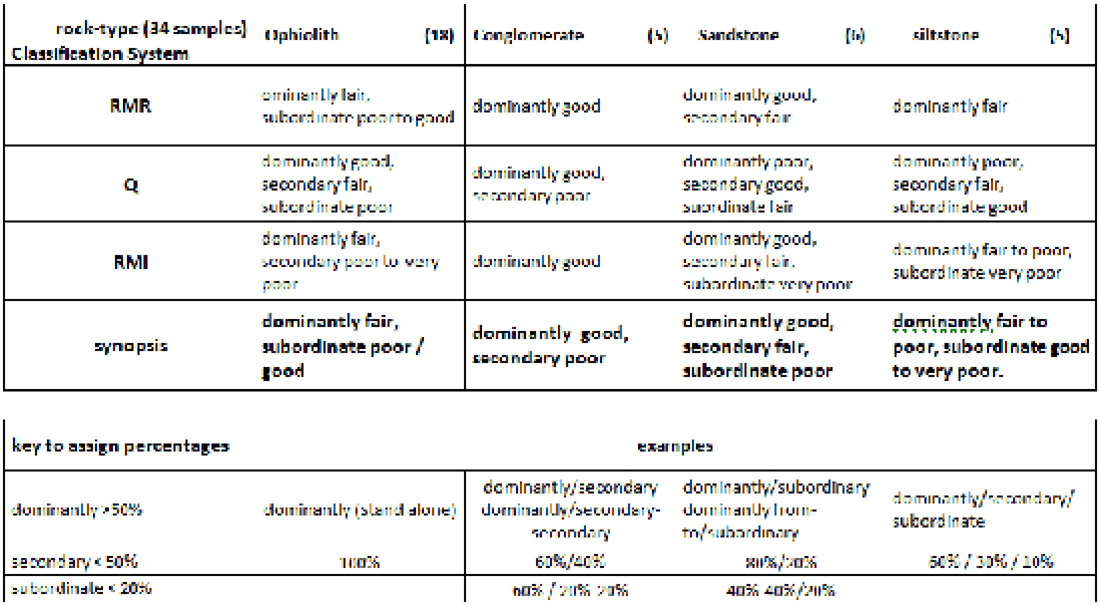


Figure 2. *Resuling values from classification*



rock-type (34 samples) Classification System	Ophiolith (18)	Conglomerate (5)	Sandstone (6)	siltstone (5)
RMR	ominantly fair, subordinate poor to good	dominantly good	dominantly good, secondary fair	dominantly fair
Q	dominantly good, secondary fair, subordinate poor	dominantly good, secondary poor	dominantly poor, secondary good, subordinate fair	dominantly poor, secondary fair, subordinate good
RMI	dominantly fair, secondary poor to very poor	dominantly good	dominantly good, secondary fair, subordinate very poor	dominantly fair to poor, subordinate very poor
synopsis	**dominantly fair, subordinate poor / good**	**dominantly good, secondary poor**	**dominantly good, secondary fair, subordinate poor**	**dominantly fair to poor, subordinate good to very poor.**

key to assign percentages		**examples**		
dominantly >50%	dominantly (stand alone)	dominantly/secondary dominantly/secondary-secondary	dominantly/subordinary dominantly from-to/subordinary	dominantly/secondary/subordinate
secondary < 50%	100%	60%/40%	80%/20%	50% / 30% / 10%
subordinate < 20%		60% / 20% 20%	40% 40%/20%	

Figure 3 *Classified Rock mass quality*

CONCLUSION

After classifying a selected number outcrops which concern the Moglice- Grabove tunnel area the results are displayed in tables.

The use of three classification systems give a better check of the estimates made. Even if there are similarities between the three systems, the differences in their structures cause that the commonly used correlations between them can lead to errors.

As noticed from the results all the three systems work best in jointed rock in which the degree of jointing is the input parameter with the strongest influence on stability. This can be easily seen in the similar results of each classification in the jointed ophiolith rock.

Thus from a limited amount of input parameters (example in the siltstones), it is possible to find crude estimates of the RMR, Q and RMi values. Obviously, better and more accurate results will be found when the input values of all parameters are known and used.

There have turned up some difficulties when the input parameter of Jv, the volumetric joint count is estimated from the formula. These difficulties are caused from inaccuracy in the measurement and limits of the formula.

$$J_V = \sum \left(\frac{1}{S_i} \right) \frac{N_V}{5} \quad (6)$$

Where S_i is the joint spacing in meters for the actual joint set

N_v is the number of random joints in the observed area.

There may be difficulties too when the block size is estimated from RQD because of limits to characterize massive rock and highly jointed rock.

Another limit is that they do not work well for many faults and weak zones.

REFERENCES

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