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A geological classification of rock mass quality and blast ability for intermediate spaced formations

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Abstract*—Success in the excavation of geological formations is commonly known as being very important in asserting stability. Furthermore, when the subjected geological formation is rocky and the use of explosives is required, the demands of successful blasting are multiplied. The present paper proposes the Blast ability Quality System (BQS), for organizing the classification of geological formations, using the change of the Blast ability Index (BI) in relation to the rock mass quality. The BQS combines the blast ability and the quality of rock masses with intermediate spaced (0,1-1m). The Blast-ability Quality System (BQS) can be an easy and widely - used tool as it is a quick evaluator for blast ability and rock mass quality at one time. Taking into consideration the research calculations and the parameters of BQS, what has been at question in this paper is the effect of blast ability in a geological formation with intermediate spaced discontinuities.

***Index Terms*—Blast ability, discontinuities, geological classification, rock mass**

I. INTRODUCTION

The several geological formations, which are affected by numerous stages of disintegration in varying stress conditions, may act in a different manner under specified blast design, explosive characteristics and specified legislative constraints depending on the site specifics.

The present paper improves the "Blast ability Quality System (BQS)" [3] by combining the quality with the blast ability of a rock mass [8], which can be easily used in situ, in order to estimate, easily, the explosion results [13] in relation to excavation methods. The "Blast ability Quality System (BQS)" is a frame table which uses the changes of the Blast ability Index (BI) in relation to the rock mass quality. The geological provision of explosion results and the ability of engineering geologists or engineers to choose quickly the most applicable way of blasting, minimize, in the same time, the percentage of instability problems.

Taking into consideration the blasting to the excavation, the study takes into consideration the cohesive soil and laminated formations which cannot be excavated by mechanical means easily.

II. THEORY

A. *Rock mass quality using RMR classification system*

Rock Mass Rating (RMR) classification system [1], is based on mechanical and structural characteristics of rock mass. The RMR index is calculated;

$$RMR = A1 + A2 + A3 + A4 + A5 + B \quad (1)$$

Where

A1 = rating for the uniaxial compressive strength of the rock material, A2 = ratings for the Rock Quality Destination (RQD [15]), A3= ratings for the spacing of joints, A4 = ratings for the condition of joints, A5 = ratings for the ground water conditions, and B = ratings for the orientation of joints.

From the value of RMR in the actual excavation, the rock support can be estimated by using a special excavation and support table. RMR can be used to crudely estimate the deformation modulus of rock masses, too. Bieniawski [1] strongly emphasizes that a great deal of judgment is used in the application of a rock mass classification system in support design [18].

In the RMR system, there is no input parameter for rock stresses, but stresses up to 25MPa are included in the estimated RMR value. Thus, overstress (rock burst and squeeze) is not included. Whether of how faulty and weakness zones are included, is unclear. No special parameter for such features is used, but some of the parameters included in the system may represent conditions in faults, though the often complicated structure and composition in these features are generally difficult to characterize or classify. Therefore, it is probable that RMR does not work well for many faulty and weak zones. Swelling rock is not included in the RMR system [16].

B. *Geological strength Index*

The Geological Strength Index (GSI) [6] relates to the overall rock mass quality. It is based on an assessment of the lithology, structure and condition of discontinuous surfaces in the geological foundations and is estimated through visual examination of rock mass exposed in crops, surface excavations such as road cuts, tunnel faces or borehole cores. It utilizes two fundamental parameters of the geological process (block size of the mass and discontinuities characteristics); hence it takes into consideration the main

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geological constraints that govern a formation. Additionally, this index is simple to assess in the field.

Referring to Palmstrom [14], block size and discontinuity spacing can be measured by means of the Volumetric Joint Count J_v, or by means of block volume, V_b. Sommez and Ulusay [20] determined block size in the GSI chart by the Structure Rating coefficient (SR) that is related to the J_v coefficient. Cai et al. [2] presented a quantifier by the mean of discontinuity spacing *S* of by the man block volume V_b. The structure was quantified by joint spacing in order to calculate the block volume, and the joint surface condition was quantified by a joint condition factor. The GSI is therefore built on the linkage between descriptive geological terms and measurable earth field parameters such as joint spacing or roughness. So, based on this information, GSI uses the description of rock mass structure – as laminated and sheared, disintegrated, blocky and disturbed, very blocky, blocky and intact of massive – referring to the block size and discontinuity space and the description of surface conditions – or as very poor, poor, fair, good and very good – referring to the joint surface conditions.

The rock mass type is a controlling factor in the assessment of the earth excavation method, as it is closely related to the number of discontinuity sets and reflects the rock mass structure. The Geological Strength Index, in its original form, was not scale dependent, thus the block size is not directly related to the rock mass type. Nevertheless, each rock type has a broad correlation to the rock block size, i.e., a rock mass which is characterized as "blocky" has bigger blocks than a rock mass which is characterized as "very blocky" or "disintegrated" , that is, made up of very small rock fragments. This correlation is only informative, however, and it is not applicable on certain rock mass types, e.g., sheared schist, as the spacing of the schistosity planes equates to the discontinuity planes and hence the concept of block volume is not applicable. For this reason, the present classification for the assessment of excavation ability is based on the original GSI charts (version 2000). Hoek and Karzulovic [7] suggested a range of GSI values for different excavation methods. They proposed that rock masses can be dug up when GSI is estimated to be about 40 and the rock mass strength is about 1MPa, while ripping can be used when GSI is estimated to be between 40 and 60 and rock mass strength is about 10MPa. Blasting was the only effective excavation method when GSI is greater than 60 and rock mass strength is more than 15MPa.

C. Blastability index and Rock Mass Classification Systems

The factors that influence blasting results fall into two groups. The first group concerns the intact rock properties, which includes strength, hardness, elasticity, deformability, density of rock, etc. The qualities depend on texture, internal bonds, composition and distribution of minerals in the geological foundation. The second group concerns the discontinuity structure, which includes the orientation, spacing, the extent of discontinuities, and the in-situ block sizes created by a range of long-term geological processes.

The Blastability index (BI) is a quantitative measure of the blastability of a rock mass. It will be most advantageous for the BI to be determined before blasting in order to help with the blast design of an excavation [4]. Without any realistic chance in the short term of a practical analytical solution to define the value of the BI for a given rock mass as a function of material properties, the development of a comprehensive assessment system for quantifying the blastability of geological masses would appear to have great potential [10].

The Blastability index (BI) is used for the description of the ease of blasting and it is also related to rock fragmentation [19] or power factor. When the BI is lower than 8, the ease of blasting is described as "very difficult". When the BI range is between 8 and 13, the ease of blasting is described as "difficult". When the BI range is between 13 and 20, the ease of blasting is described as "moderate". When the BI range is between 20 and 40, the ease of blasting is described as "easy". When the BI is higher than 40, the ease of blasting is described as "very easy". This differentiation in description has an immediate effect on excavation cost which always depends on factors like explosion, vibration, disintegration, powder creation etc. [9].

In our study, the BI is to be calculated by the following formula [11] which is proposed by Lilly, based on rock mass description, joint density [17] and orientation, specific gravity and hardness:

$$BI = 0.5x(RMD + JPS + JPO + SGI + H) \qquad (2)$$

Where,
BI = Blastability Index
RMD (Rock mass Description) = 10 (for Powdery/Friable rock mass), 20 (for Blocky rock mass), 50 (for Totally Massive rockmass)
JPS (Joint Plan Spacing) =10 (for closely spaced discontinuities), 20 (for intermediate spaced discontinuities), 50 (for widely spaced discontinuities)
JPO (Joint Plane Orientation) = 10 (for Horizontal), 20 (for Dip out of the Face), 30 (for Strike Normal to Face), 40 (for Dip into Face)
SGI (Specific Gravity Influence) = 25 x Specific Gravity of rock (t/m^3) – 50
H = Hardness in Mho Scale (1-10)

Considering that blastability index, as it is calculated by Lilly's formula, is based on geological formation description, joint density and orientation, evokes the same parameters that Rock Mass Rating System - RMR is also based on. This classification can be described by Geological Strength Index – GSI, too.

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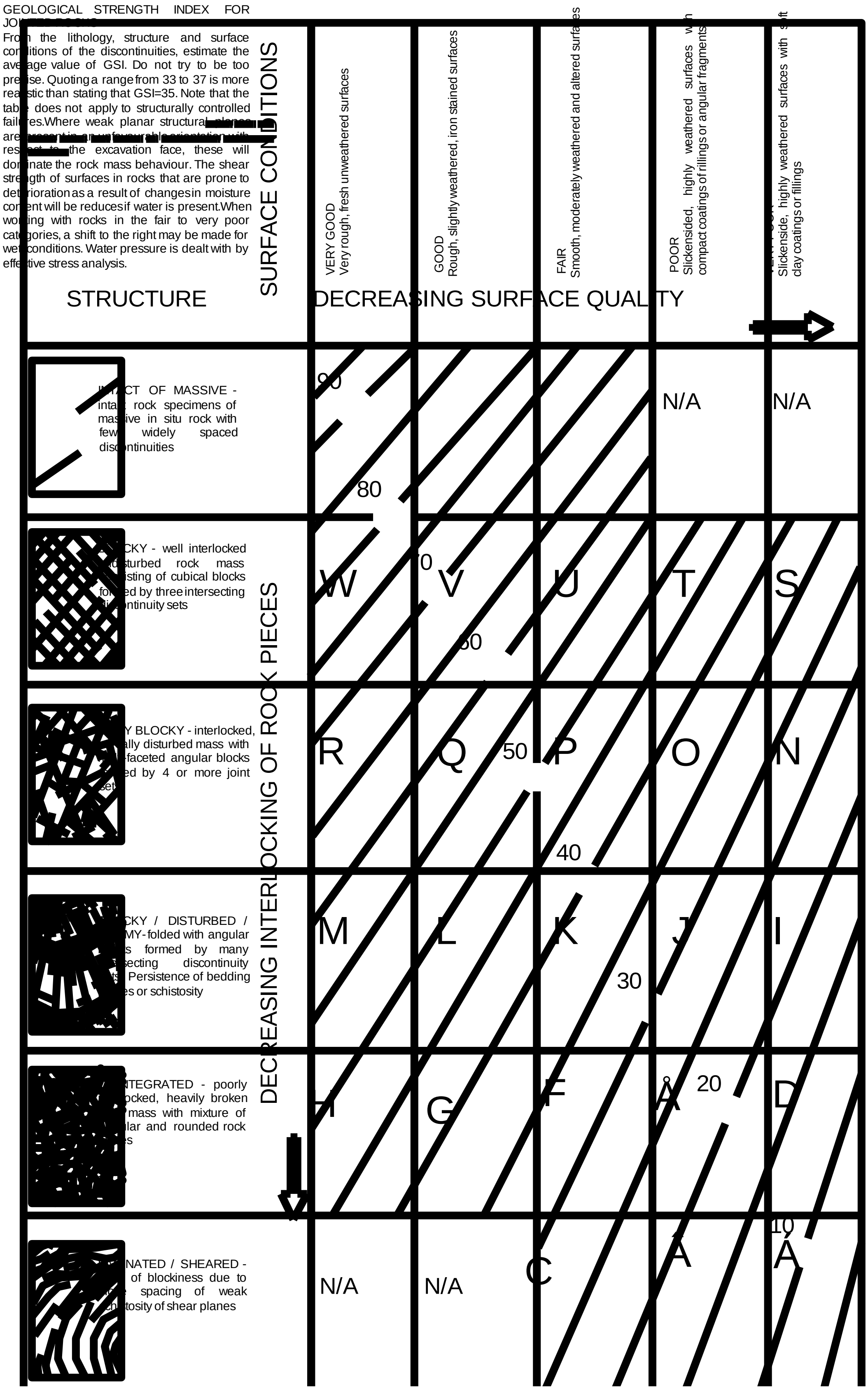

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III. RESULTS

A. *Combining blastability with quality*

The laminated and sheared rock mass, with lack of blockiness, due to intermediate spaced discontinuities of week schistosity or shear planes and disintegrated rock mass, with poorly interlocked, heavily broken rock with mixture of angular or rounded rock pieces, which are described by the lower part of GSI diagram, has been divided into eight parts (Fig.1); A, B, C, D, E, F, G, H. The disturbed, seamy and very blocky rock mass, folded with angular blocks formed by many intersecting discontinuity sets with bedding planes or schistosity, in addition to interlocked, partially disturbed mass with multi-faceted angular blocks formed by four or more joint sets, which are described by the middle part of GSI diagram, has been divided into ten parts (Fig.1); I, J, K, L, M, N, O, P, Q, R. The well interlocked undisturbed blocky rock mass, which consists of cubical blocks formed by three intersecting discontinuity sets, that is, described by this part of GSI diagram, has been divided into five parts (Fig. 1); S, T, U, V and W.

Taking into consideration the parameters of Blastability Index BI=0.5x (RMD+JPS+JPO+SGI+H) [11], the Blastability Index (BI) was calculated for every possible combination of these parameters. This means that RMD (rock mass description) was equal to 10 for powdery / friable rock mass and 20 for blocky rock mass.

TABLE 1. Specific gravity influence (SGI)

SGI *25*specific gravity of rock (t/m3)-50*	specific gravity of rock (t/m3)
-22.5	1.1
-20	1.2
-17.5	1.3
-15	1.4
-12.5	1.5
-10	1.6
-7.5	1.7
-5	1.8
-2.5	1.9
0	2
2.5	2.1
5	2.2
7.5	2.3
10	2.4
12.5	2.5
15	2.6
17.5	2.7
20	2.8
22.5	2.9
25	3

As the present study concerns intermediate spaced discontinuities, JPS (joint plan spacing) was equal to 20. JPO (joint plane orientation) was equal to 10 for horizontal discontinuities, 20 for declined discontinuities where the excavation drives against dip direction, 30 for declined discontinuities with strike parallel to face, 40 for declined discontinuities where the excavation drives with dip direction and SGI (specific gravity influence) was calculated using specific gravity of rocks (t/m^3) from 1-3 (table 1). 1600 different rock mass combinations were estimated and the BI was calculated for every rock mass type.

At next stage, we regrouped these rock structures referring to RMR range and GSI parts, taking into consideration rock mass hardness and discontinuities orientation. The range of BI was also calculated. GSI range was calculated for every rock mass type with a specific RMR. The rock structures are numbered from 1 to 1600 and they were banded together according to RMR range, too.

Finally, a useful diagram of composite rock mass quality and range of the Blastability Index (BI) aroused from these estimations (Fig. 2). The rock mass may consist of horizontal or gradient discontinuities with strike perpendicular to tunnel axis or strike parallel to tunnel axis. In case there are only horizontal discontinuities, the blastability index was calculated between 24 and 54 for disintegrated and laminated rock mass and between 29 and 57 for blocky rock mass. In case the discontinuities are inclined and the strike of formation is parallel to tunnel axis, the blastability index was calculated between 31 and 62 for disintegrated and laminated rock mass and between 39 and 67 for blocky rock mass. In case of gradient discontinuities and rock mass may strike perpendicular to excavation axis when excavation drives against dip direction, the blastability index was calculated between 24 and 61 for disintegrated and laminated rock mass and between 31 and 62 for blocky rock mass. In case of gradient discontinuities and rock mass may strike perpendicular to excavation axis when excavation drives with dip direction, the blastability index was calculated between 36 and 67 for disintegrated and laminated rock mass and between 44 and 72 for blocky rock mass. All in all, according to the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range. According to the estimated BI values, blasting is characterized of a relative easiness, according to rock mass quality and hardness. A detailed evaluation of blastability index for every rock mass structure type is given on figure 2, so as the rock mass is classified according to GSI and RMR systems, the exact BI range may be estimated. The relation between blastability index and powder factor led to the conclusion, the optimal design and explosive parameters may safely be calculated.

B. *Blastability Quality System (BQS)*

Blastability Quality System (BQS) is a very useful approach as it includes the most useful characteristics of rock mass, which are easily estimated and used in situ. In addition to it is easily and wide use, it is a quick calculator for the BI and rock mass quality, which make our choice of excavation, blast and support measures quicker.

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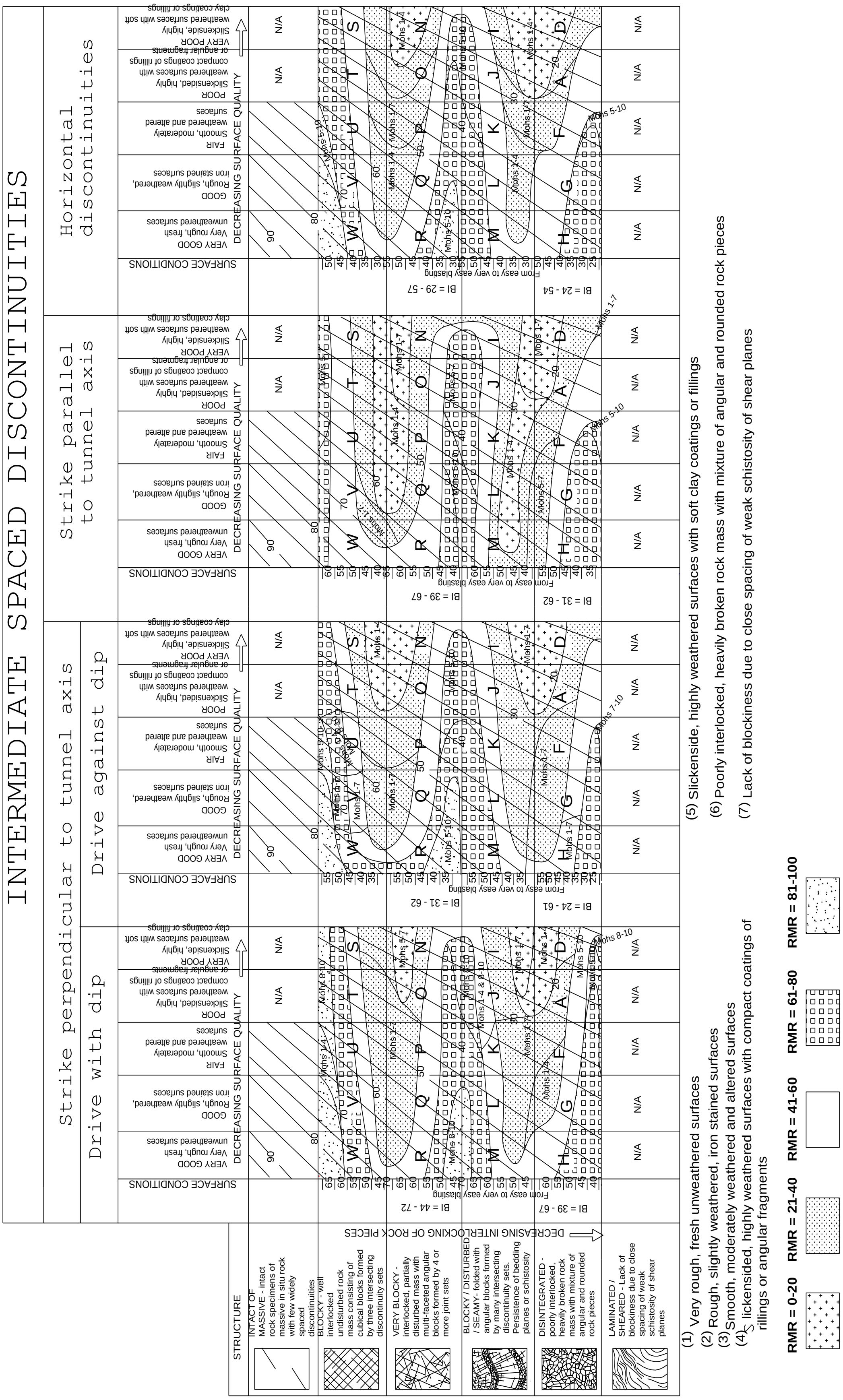

Fig.2. BQS for intermediate spaced discontinuities

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The BQ system (Fig. 2) combines rock mass classification systems RMR and GSI, structural data and the Blastability Index [5]. The long excavated and tunnelling practice establishes the strong relation of the classification systems RMR and GSI. Also, the estimations of RMR and GSI for every possible rock mass type support this opinion. The RMR and GSI results were combined so as they can be estimated graphically.

There are two ways of BQS application;

a) The first way of BQS application requires that we have already classified the rock mass according to RMR classification system. At the first stage of the application, the orientation of discontinuities is distinguished. At second stage, we can relate the structure to the surface conditions in order to estimate an area of the Geological Strength Index (GSI) using the gradient lines. At third stage, we define the right area of RMR taking into consideration the structure and surface conditions in addition to the area of the Geological Strength Index (GSI). Sometimes, we may use rock mass hardness (Mohs scale) [12] in order to estimate the exact area of RMR and GSI. Having completed this classification, the BI range can easily be determined at the left hand side of the diagram.

b) The second way of BQS application does not requires the previous classification according RMR system. At the first stage of the application, the orientation of discontinuities is distinguished. At second stage, we can relate the structure to the surface condition in order to estimate; 1) an area of the Geological Strength Index (GSI) using the gradient lines and 2) an area of RMR. Taking into account that an excavated face is not usually homogenous, we may estimate two or three RMR areas of different rock mass qualities. Having completed this classification, the BI range can easily be determined at the left hand side of the diagram.

Table 6. Qualified characteristics of discontinuity sets of 1st application

Strength of intact rock material	100-250 Mpa		
RQD	75-90%		
	Set 1	**Set 2**	**Set 3**
Spacing of discontinuities	1m	50cm-1,5m	20-70cm
Discontinuity length	9m	16m	13m
Seperation	<0,1mm	None	None
Roughness	Rough	Rough	Rough
Infilling	Soft filling <5mm	None	None
Weathering	Highly weathered	Slightly weathered	Slightly weathered
Groundwater	Damp	Damp	Damp
Effect of discontinuity strike and dip orientation	Fair	Unfavorable	Fair

Taking into consideration the GSI and RMR estimations, we can come up with appropriate excavation technique and support measures, [1], [6], [21]. The ease of excavation, excavatability has been related with RMR and for the whole range of rock mass types. Although excavatability assessment includes also blasting ability, the already known literature does not estimate the blastability index at once. The ease of estimating the blastability index quickly is very useful in order to determine the required energy for fragmentation, the powder factor and explosive properties. Since the information required can be obtained from exploration drilling or from existing bench faces, it can be used in both the planning and production phases of projects requiring rock blasting. When coupled with computerized fragmentation models, the blastability index can provide an excellent mean to experiment on the Visual Display Unit screen with a variety of blast designs, thereby avoiding expensive mistakes or miscalculations in the field.

IV. DISCUSSION

A. *Case studies of BQS application*

Two application examples are described further down which refer to Norhtern Greece.

The first example is a part of Polimilos tunnel excavation works at Northern Greece. Looking at the rock mass example on figure 4, three discontinuity sets are observed. The qualitative characteristics of the discontinuity sets are shown on table 6.

According to the qualitative characteristics of discontinuity sets, the Rock Mass Rating (RMR) is calculated 67.5 for Set 1, 63 for Set 2, 70 for Set 3. That means the rock mass quality is good (II). The calculation of Rock Mass Rating, when the effect of discontinuity strike and dip orientation is not concerned (RMR_{bas}), is calculated 72.5 for Set 1, 75 for Set 2, 75 for Set 3. That means the rock mass quality is good (II). Taking into consideration the rock mass quality and the characteristics which influence rock mass stability, the rock mass is classified according to Blastability Quality System (BQS). So, the stability is determined by three discontinuity sets, the unfavorable effect of discontinuity strike to dip orientation (strike perpendicular to tunnel axis and drive against dip direction) and the soft clayey coating of discontinuous surfaces because of high erosion. The estimated area of BQS is shown on figure 3. The BQS area is referred to blocky rock mass, well interlocked undisturbed, which consists of cubical block formed by three intersecting discontinuity sets, with very poor surface conditions, where the stability may be affected by discontinuities with strike perpendicular to tunnel axis (drive against dip). According to this classification, GSI is estimated between 35 and 40, and taking into account that RMR is 61-80, Blastability Index (BI) is estimated between 54 and 62 (very easy blasting).

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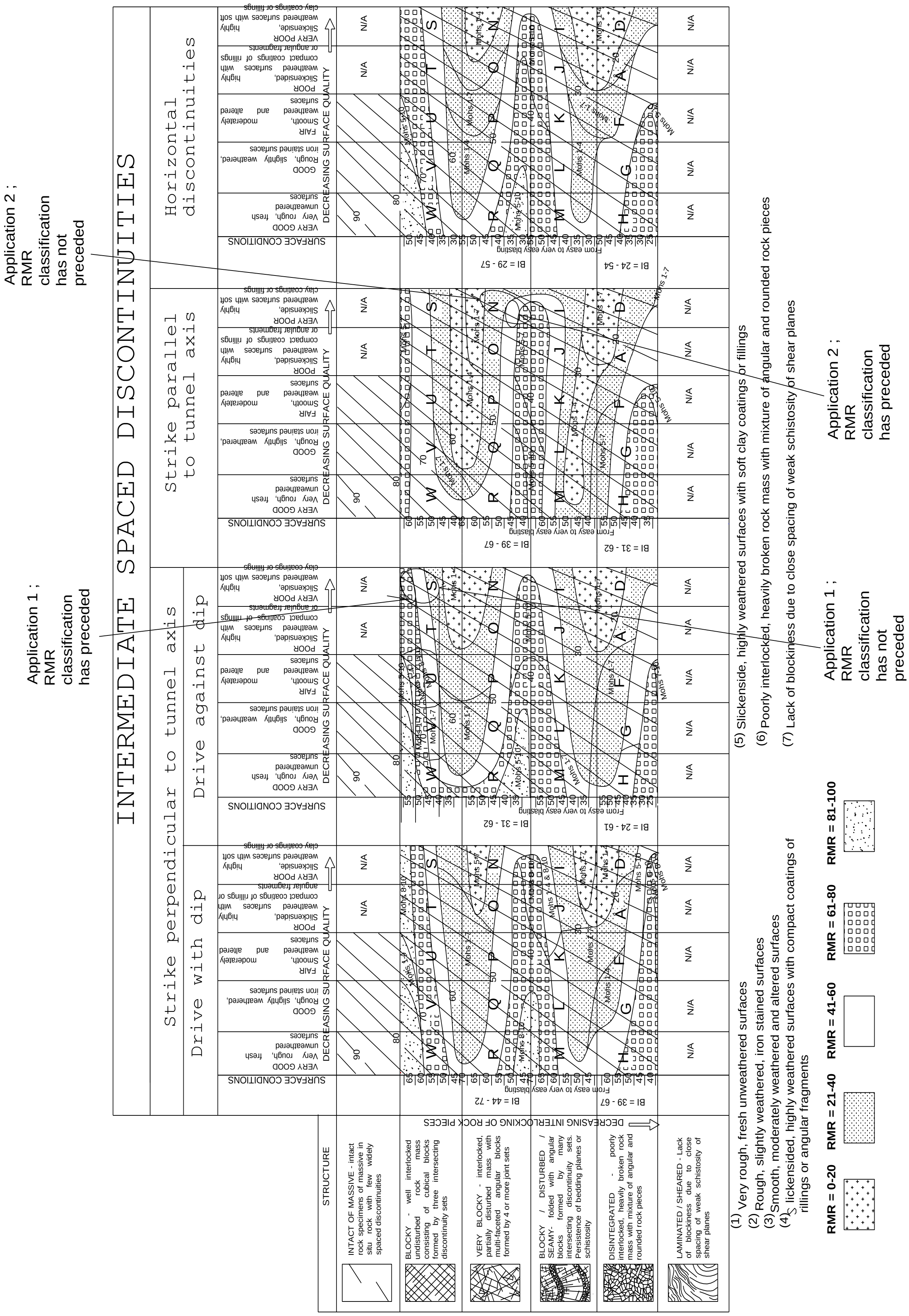

Fig.3. Areas of estimation during application of the BQS for intermediated spaced discontinuities

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On the other hand, BQS does not require the previous classification according RMR system; the stability is determined by the discontinuity set of unfavorable effect of strike to dip orientation (strike perpendicular to tunnel axis and drive against dip direction). Also, the rock mass is blocky, well interlocked undisturbed, and consists of cubical block formed by three intersecting discontinuity sets, with very poor surface conditions. Referring to this description, the BQS area is estimated on figure 3; GSI is estimated to be between 30 and 40, RMR is 21-80, Blastability Index (BI) is estimated between 43 and 62 (very easy blasting).

Combining the two ways of BQS application, the quality of rock mass is good, although there may be places where the quality is getting worse (poor and medium quality – IV and III). Also, GSI is between 35 and 40, but there may be places where it falls to 30. Anyway, the blasting is very easy, Blastability Index (BI) is between 54 and 62 and somewhere may fall to 43.

The second example concerns the excavation of the entrance of a drainage tunnel at Northern Greece. Looking at rock mass example on figure 5, four discontinuity sets are observed. The qualitative characteristics of the discontinuity sets are shown on table 7.

Table 7. Qualified characteristics of discontinuity sets of 2nd application

Strength of intact rock material	70 Mpa			
RQD	50-75%			
	Set 1	**Set 2**	**Set 3**	**Set 4**
Spacing of discontinuities	10 -50cm	20-50cm	>2m	20-60cm
Discontinuity length	3-10m	4m	>20m	3-10m
Separation	>5mm	>5mm	None	None
Roughness	Rough	Rough	Very rough	Very rough
Infilling	Soft filling >5mm	Soft filling >5mm	None	None
Weathering	Slightly weathered	Slightly weathered	Unweathered	Slightly weathered
Groundwater	Damp	Damp	Completely dry	Completely dry
Effect of discontinuity strike and dip orientation	Very unfavorable	Fair	Fair	Very favorable

According to the qualitative characteristics of discontinuity sets, the Rock Mass Rating (RMR) is calculated 43 for Set 1, 54 for Set 2, 80 for Set 3 and 73 for Set 4. Looking at figure 5, the soft filling and the vertical surfaces are the most important characteristics of the rock mass which may cause sliding. So, the discontinuity sets 1 and 2 may influence the stability badly and minimize rock mass quality. Because of this reason, the rock mass is characterized as medium (III), where RMR is between 40 and 60. The calculation of Rock Mass Rating, when the effect of discontinuity strike and dip orientation (RMR_{bas}) is not concerned, is calculated 55 for Set 1, 59 for Set 2, 85 for Set 3 and73 for Set 4. For the same already mentioned reasons, he rock mass quality is also characterized as medium (III). Taking into consideration the rock mass quality and the characteristics which influence rock mass stability, the rock mass is classified according to Blastability Quality System (BQS). So, the stability is determined by four discontinuity sets, the very unfavorable effect of discontinuity strike to dip orientation (strike parallel to tunnel axis and dip between 45^o and 90^o) and the soft thick filling between discontinous surfaces. The estimated area of BQS is shown on figure 3. The BQS area is referred to very blocky rock mass, interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets, with very poor surface conditions, where the stability may be affected by discontinuities with strike parallel to tunnel axis. According to this classification, GSI is estimated to be between 20 and 30, and taking into account that RMR is 41-60, Blastability Index (BI) is estimated to be between 43 and 49 (very easy blasting).

Fig. 4. A face of tunnel excavation at Polimilos Part of Egnatia Highway at Northern Greece

On the other hand, BQS does not require the previous classification according RMR system; the stability is determined by the discontinuity set 1 of very unfavorable effect of strike to dip orientation (strike parallel to tunnel axis). Also, the rock mass is very blocky, interlocked partially disturbed with multi-faceted angular blocks formed by 4 or more joint sets, with very poor surface conditions. Referring to this description, the BQS area is estimated on figure 3; GSI is estimated to be between 20 and 30, RMR is 0-80, Blastability Index (BI) is estimated between 39 and 60 (easy and very easy blasting).

Combining the two ways of BQS application, the quality of rock mass is medium, although there may be places where the quality is getting worse (poor and very poor quality – IV and V). Also, GSI is between 20 and 30. Anyway, the blasting is very easy, Blastability Index (BI) is between 43 and 49 and somewhere may fall to 39.

V. CONCLUSIONS

The present paper improves the effectiveness of the "Blastability Quality System (BQS)" for intermediate spaced

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discontinuities combining the quality with blast ability of rock mass, which can be easily used in situ, for estimating, quickly, the explosion results, in relation to the excavation methods. “Blastability Quality System (BQS)” is a tool which combines rock mass quality with discontinuities orientation and rock mass hardness with the blastability index (BI). It can be easily used during excavation process, in order to describe, quantitatively, the rock mass blasting and calculate the BI.

Fig. 5. Rock mass at entrance of a drainage tunnel at Northern Greece

This is a great help for deciding on explosions and support measures, in addition to the already known methods. Two examples of the new system are described using the two ways of BQS application. Referring to the first way of application, the rock mass has already classified according to RMR classification system and the estimation is taking into consideration BQS application. Referring to the second way of BQS application, RMR and GSI in addition to Blastability Index are estimated using BQS. The two applications are combined and the engineers can form a collective opinion of rock mass behavior, and decide the most relevant excavation technique and support measures.

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