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Blastability Quality System (BQS) for using it, in bedrock excavation

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Abstract. Success in the excavation of foundations is commonly known as being very important in asserting stability. Furthermore, when the subjected formation is rocky and the use of explores is required, the demands of successful blasting are multiplied. The quick and correct estimation of excavation's characteristics may help the design of building structures, increasing their safety. The present paper proposes a new classification system which connects blastability and rock mass quality. This new system primarily concerns poor and friable rock mass, heavily broken with mixture of angular and rounded rock pieces. However, it should concern medium and good quality rock mass. The Blastability Quality System (BQS) can be an easy and widely - used tool as it is a quick calculator for blastability index (BI) and rock mass quality. Taking into account the research calculations and the parameters of BQS, what has been at question in this paper is the effect of BI magnitude on a geological structure.

Keywords: excavation; blast ability; rock mass; quality; classification; explosion; methodology

1. Introduction

Many rock mass quality classification systems -RQD (Deer 1989), Q (Barton *et al*. 1980), RMR (Bieniawski 1989), GSI (Hoek and Brown 1980) - have been developed for excavation ability estimation (Kentli and Topal 2004), but not for blasting calculations. The several structures of rock mass, which are affected by numerous stages of disintegration in varying stress conditions, may be explored in a different manner under specified blast design, explosive characteristics and specified legislative constraints depending on the site specifics.

The present paper is creating a new system connecting the quality and blκastability of rock mass (Jimeno *et al*. 1995), which can be easily used in situ, in order to estimate, quickly, the explosive results (Murthy *et al*. 2003) in addition to excavation methods. The provision of explosive results and the ability to choose quickly, the most applicable way of blasting, minimizes the percentage of probable damage, which may occur on masonries. Taking into account the extent of stability problems on places struck by earthquake, where damage has incurred over the years, has indicated that many reinforced concrete buildings were found to have serious structural deficiencies, especially in their columns and beam - column joints (Tsonos 2010), therefore the use of blasting and explosives needs extra attention.

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The rock mass, in study, is poor and friable, shared with lack of blockiness, due to close spacing of weak schistosity or shear planes, and disintegrated with poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces. Although the quality is very poor, a light blast may be needed as the small rock pieces strengthen tight.

2. Rock mass quality using RMR classification system

Bieniawski (1973, 1974) published the details of a rock mass classification called the Geomechanic Classification or the Rock Mass Rating (RMR) system. Some changes have been made over the years with revisions in 1974, 1975, 1976 and 1989. The 1976 and the 1989 versions of the classification system are mostly used.

RMR = A1 + A2 + A3 + A4 + A5 + B

Where

A1 = rating for the uniaxial compressive strength of the rock material, A2 = ratings for the spacing of joints, 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 also be used to crudely estimate the deformation modulus of rock masses. Bieniawski (1989) strongly emphasizes that a great deal of judgment is used in the application of a rock mass classification system in support design (Romana *et al.* 2013).

In the RMR system, there is no input parameter for rocks stresses, but stresses up to 25MPa are included in the estimated RMR value. Thus, overstressing (rock bursting and squeezing) is not included. Whether of how faults and weakness zones are included, is unclear. No special parameter for such features is applied, 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 and classify. Therefore, it is probable that RMR does not work well for many faults and weak zones. Swelling rock is not included in the RMR system (Palmstrom 2009).

3. Geological strength index

The Geological Strength Index (GSI) was introduced by Hoek *et al*. (1992), Hoek (1994), Hoek *et al*. (1995). This index was subsequently extended for weak rock masses in a series of papers by Hoek *et al*. (1998), Marinos and Hoek (2000). Later, Marinos and Hoek (2001) proposed a chart of the Geological Strength Index for heterogeneous rock masses, such as flysch, which is frequently composed of tectonically disturbed alternations of strong and weak rocks (sandstone and silt stone, respectively). This chart was modified by Marinos *et al*. (2007).

The GSI relates the properties of the intact rock elements/blocks to those of the overall rock mass. It is based on an assessment of the lithology, structure and condition of discontinuous surfaces in the rock mass and is estimated through visual examination of the rock mass exposed in crops, surface excavations such as road cuts, tunnel faces and borehole cores. It utilizes two fundamental parameters of the geological process (block size of the mass and discontinuities characteristics); hence it takes into account the main geological constraints that govern a formation. In addition, the index is simple to assess in the field.

According to Palmstrom (2000), 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 (1999) quantified block size in the GSI chart by the Structure Rating coefficient (SR) that is related to the J_v coefficient. Cai *et al*. (2004) presented a quantifier by the mean 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 field parameters such as joint spacing and roughness. So, based on the above 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 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 rock 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 is not applicable to 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), but specific reference to the block volume is made (Tsiambaos and Saroglou 2010).

Hoek and Karzulovic (2000) 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 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.

4. Excavation of rock mass not applicable to RMR and GSI classification systems

The excavation problem described as followed, during Symbol Mountain’s tunnel excavation, created the of rock mass classification systems’ connection to blastability characteristics.

The excavated rock mass in Moutain Symbol at Strymonas- Kavala’s part of Egnatia Highway in Northern Greece, was consisting of gneiss, amphibolites, marbles and plutonic rock. Generally, according to RMR classification system, the rock mass quality was classified as medium. At the sight of gneiss and plutonic rocks, a formation of chloritic schist appeared, which generated unexpected failure conditions (Chatziangelou *et al*. 2010). The chloritic schist was a hard, massive rock, with a few widely spacing discontinuities, that excavating machines could hardly break. Taking into account the above characteristics, GSI estimation was tried, although schists are not applicable to GSI classification system. This was a trial of observing GSI inapplicability on schists in situ. So, GSI was estimated to be about 75-85, and the need of blasting appeared. That helped excavating works. But just when the chloritic schist cracked and came in touch with the air, the rock mass got rapidly weathered and lost material flow from the walls and the face of excavation. So, explorers needed to be very careful, using light explosion.

The above phenomenon led to the conclusion the chloritic schist rock mass should be described as the fault at the sight of gneiss and plutonic rockmass and not as individual formation. According to this new description, the rock mass is laminated and sheared, with slicken sided discontinuities, with highly weathered surfaces with extremely cohesive clay (chlorite) coatings. Because of the

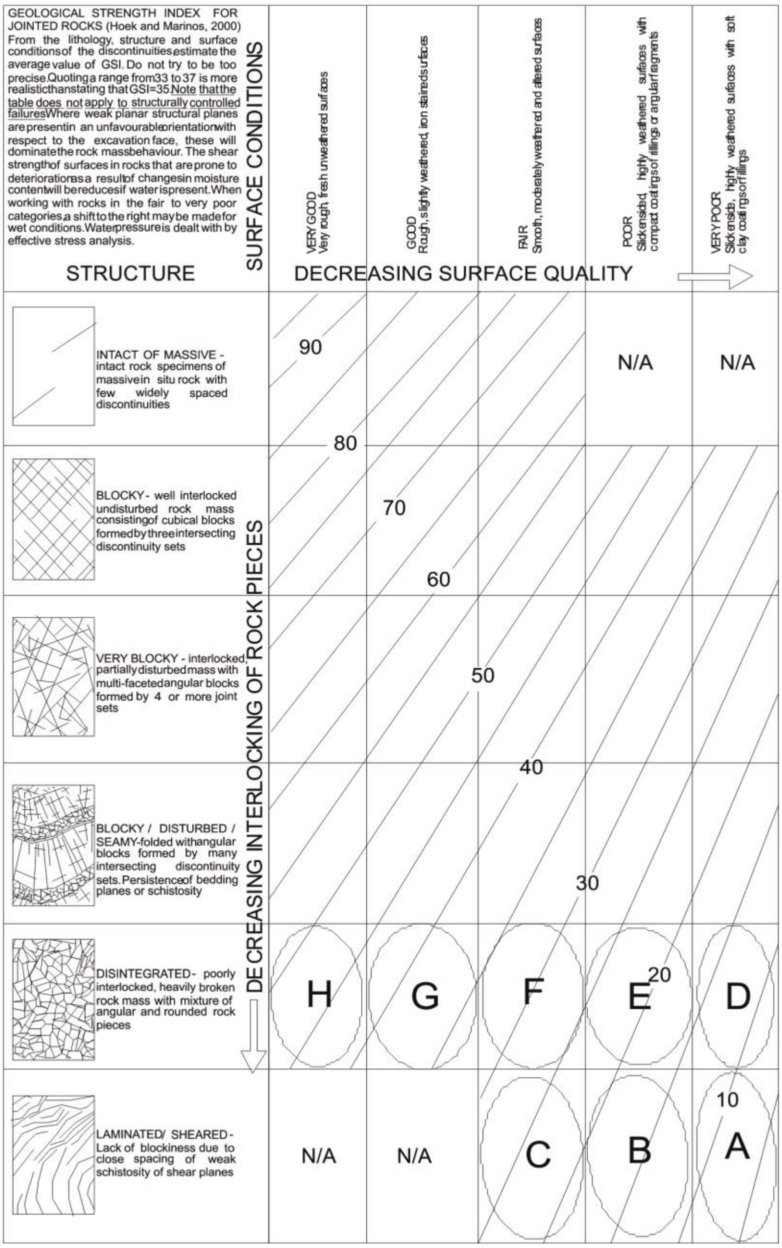


Fig. 1 Eight part division of GSI diagram

above description and taking into account that the clay softens in contact with the air, a GSI between 5 and 10 was estimated. So, using this way of thinking, blasting is an effective excavation method for rocks of very low GSI values, too.

5. Blastability index concerning 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 rock texture, internal bonds, composition and distribution of minerals in the rock. 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 coefficient of Blastability index (BI) is a quantitative measure of the blastability of a rock mass. It will be most advantageous for the coefficient BI to be determined before blasting in order to help with the blast design of an excavation. Without any realistic chance in the short term of a practical analytical solution to define the value of BI for a given rock mass as a function of material properties, the development of a comprehensive assessment system for quantifying the blastability of rock masses would appear to have great potential (Latham and Lu 1999).

Blastability index (BI) is used for the description of the ease of blasting and it is also related to rock fragmentation (Singh and Sinha 2012) and power factor. When the BI is lower ~~to~~ 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., (Kaushik and Phalguni 2003).

In our study, BI is to be calculated by the following formula (Lilly 1986), based on rock mass description, joint density and orientation, specific gravity and hardness:

BI = 0.5×(RMD+JPS+JPO+SGI+H)

Where,

BI = Blastability Index

RMD (Rockmass Description) = 10, for Powdery/Friable rockmass
= 20, for Blocky rockmass
= 50, for Totally Massive rockmass

JPS (Joint Plan Spacing) = 10, for Closely Spacing (<0.1m)
= 20, for Intermediate (0.1-1.0m)
= 50, for Widely Spacing (>1.0m)

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×Specific Gravity of rock (t/m^3) – 50

H = Hardness in Mho Scale (1-10)

Considering that blastability index based on rock mass description, joint density and

Table 1 Specific gravity influence (SGI)

SGI 25*specific gravity of rock (t/m^3)-50	specific gravity of rock (t/m^3)
-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

orientation, evokes the same parameters that Rock Mass Rating System - RMR (Bieniawski 1989) is also based on.

Also, the above classification can be described by Geological Strength Index - GSI (Marinos and Hoek 2000).

6. Connecting blastability and quality ability.

The laminated and sheared rock mass, with lack of blockiness due to close spacing of week schistosity or shear planes and disintegrated rock mass, with poorly interlocked, heavily broken rock with mixture of angular and rounded rock pieces, which are described by the lower part of GSI diagram (Hoek 1983, Hoek and Brown 1997, Marinos and Hoek 2000), has been divided into eight parts (Fig. 1); A- GSI about 0-12, B- GSI about 12-23, C- GSI about 22-23, D- GSI 7-17, E- GSI about 18-28, F- GSI about 16-36, G- GSI 35-43, H - GSI 42-50.

Taking into account the parameters of Blastability Index BI=0.5×(RMD+JPS+JPO+SGI+H) (Lilly 1986), the Blastability Index (BI) was calculated for every possible combination of the above parameters, which refers to powdery/friable rock mass. This means that RMD (rock mass description) was equal to 10 (powdery / friable rock mass). JPS (joint plan spacing) was equal to 10 for closely spaced, 20 for intermediate spaced and 50 for widely spaced. 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

Table 2 BI calculations for closely spaced discontinuities

A/A	RMD	JPS	JPO	SGI	H	BI	A/A	RMD	JPS	JPO	SGI	H	BI
001-20	10	10	10	from -22.5 to 25	1	4.25-28	401-420	10	10	30	from -22.5 to 25	1	14.25-38
21-40	10	10	10	from -22.5 to 25	2	4.75-2.5	421-440	10	10	30	from -22.5 to 25	2	14.75-38.5
41-60	10	10	10	from -22.5 to 25	3	5.25-29	441-460	10	10	30	from -22.5 to 25	3	15.25-39
61-80	10	10	10	from -22.5 to 25	4	5.75-29.5	461-480	10	10	30	from -22.5 to 25	4	15.75-39.5
81-100	10	10	10	from -22.5 to 25	5	6.25-30	481-500	10	10	30	from -22.5 to 25	5	16.25-40
101-120	10	10	10	from -22.5 to 25	6	6,75-30.5	501-520	10	10	30	from -22.5 to 25	6	16.75-40.5
121-140	10	10	10	from -22.5 to 25	7	7.25-31	521-540	10	10	30	from -22.5 to 25	7	17.25-41
141-160	10	10	10	from -22.5 to 25	8	7.75-31.5	541-560	10	10	30	from -22.5 to 25	8	17.75-41.5
161-180	10	10	10	from -22.5 to 25	9	8.25-32	561-580	10	10	30	from -22.5 to 25	9	18.25-42
181-200	10	10	10	from -22.5 to 25	10	8.75-32.5	581-600	10	10	30	from -22.5 to 25	10	18.75-42.5
201-220	10	10	20	from -22.5 to 25	1	9.25-33	601-620	10	10	40	from -22.5 to 25	1	19.25-43
221-240	10	10	20	from -22.5 to 25	2	9.75-33.5	621-640	10	10	40	from -22.5 to 25	2	19.75-43.5
241-260	10	10	20	from -22.5 to 25	3	10.25-34	641-660	10	10	40	from -22.5 to 25	3	20.25-44
261-280	10	10	20	from -22.5 to 25	4	10.75-34.5	661-680	10	10	40	from -22.5 to 25	4	20.75-44.5
281-300	10	10	20	from -22.5 to 25	5	11.25-35	681-700	10	10	40	from -22.5 to 25	5	21.25-45
301-320	10	10	20	from -22.5 to 25	6	11.75-35.5	701-720	10	10	40	from -22.5 to 25	6	21.75-45.5
321-340	10	10	20	from -22.5 to 25	7	12.25-36	721-740	10	10	40	from -22.5 to 25	7	22.25-46
341-360	10	10	20	from -22.5 to 25	8	12.75-36.5	741-760	10	10	40	from -22.5 to 25	8	22.75-46.5
361-380	10	10	20	from -22.5 to 25	9	13.25-37	761-780	10	10	40	from -22.5 to 25	9	23.25-47
381-400	10	10	20	from -22.5 to 25	10	13.75-37.5	781-800	10	10	40	from -22.5 to 25	10	23.75-47.5

Table 3 BI calculations for intermediately spaced discontinuities

A/A	RMD	JPS	JPO	SGI	H	BI	A/A	RMD	JPS	JPO	SGI	H	BI
801-820	10	20	10	from -22.5 to 25	1	9.25-33	1201-1220	10	20	30	from -22.5 to 25	1	19.25-43
821-839	10	20	10	from -22.5 to 25	2	9.75-33.5	1221-1239	10	20	30	from -22.5 to 25	2	19.75-43.5
841-860	10	20	10	from -22.5 to 25	3	10.25-34	1241-1260	10	20	30	from -22.5 to 25	3	20.25-44
861-880	10	20	10	from -22.5 to 25	4	10.75-34.5	1261-1280	10	20	30	from -22.5 to 25	4	20.75-44.5
881-900	10	20	10	from -22.5 to 25	5	11.25-35	1281-1300	10	20	30	from -22.5 to 25	5	21.25-45
901-920	10	20	10	from -22.5 to 25	6	11.75-35.5	1301-1320	10	20	30	from -22.5 to 25	6	21.75-45.5
921-940	10	20	10	from -22.5 to 25	7	12.25-36	1321-1340	10	20	30	from -22.5 to 25	7	22.25-46
941-960	10	20	10	from -22.5 to 25	8	12.75-36.5	1341-1360	10	20	30	from -22.5 to 25	8	22.75-46.5
961-980	10	20	10	from -22.5 to 25	9	13.25-37	1361-1380	10	20	30	from -22.5 to 25	9	23.25-47
981-1000	10	20	10	from -22.5 to 25	10	13.75-37.5	1381-1400	10	20	30	from -22.5 to 25	10	23.75-47.5
1001-1020	10	20	20	from -22.5 to 25	1	14.25-38	1401-1420	10	20	40	from -22.5 to 25	1	24.25-48
1021-1039	10	20	20	from -22.5 to 25	2	14.75-38.5	1421-1439	10	20	40	from -22.5 to 25	2	24.75-48.5
1041-1060	10	20	20	from -22.5 to 25	3	15.25-39	1441-1460	10	20	40	from -22.5 to 25	3	25.25-49
1061-1080	10	20	20	from -22.5 to 25	4	15.75-39.5	1461-1480	10	20	40	from -22.5 to 25	4	25.75-49.5
1081-1100	10	20	20	from -22.5 to 25	5	16.25-40	1481-1500	10	20	40	from -22.5 to 25	5	26.25-50
1101-1120	10	20	20	from -22.5 to 25	6	16.75-40.5	1501-1520	10	20	40	from -22.5 to 25	6	26.75-50.5
1121-1140	10	20	20	from -22.5 to 25	7	17.25-41	1521-1540	10	20	40	from -22.5 to 25	7	27.25-51
1141-1160	10	20	20	from -22.5 to 25	8	17.75-41.5	1541-1560	10	20	40	from -22.5 to 25	8	27.75-51.5
1161-1180	10	20	20	from -22.5 to 25	9	18.25-42	1561-1580	10	20	40	from -22.5 to 25	9	28.25-52
1181-1200	10	20	20	from -22.5 to 25	10	18.75-42.5	1581-1600	10	20	40	from -22.5 to 25	10	28.75-52.5

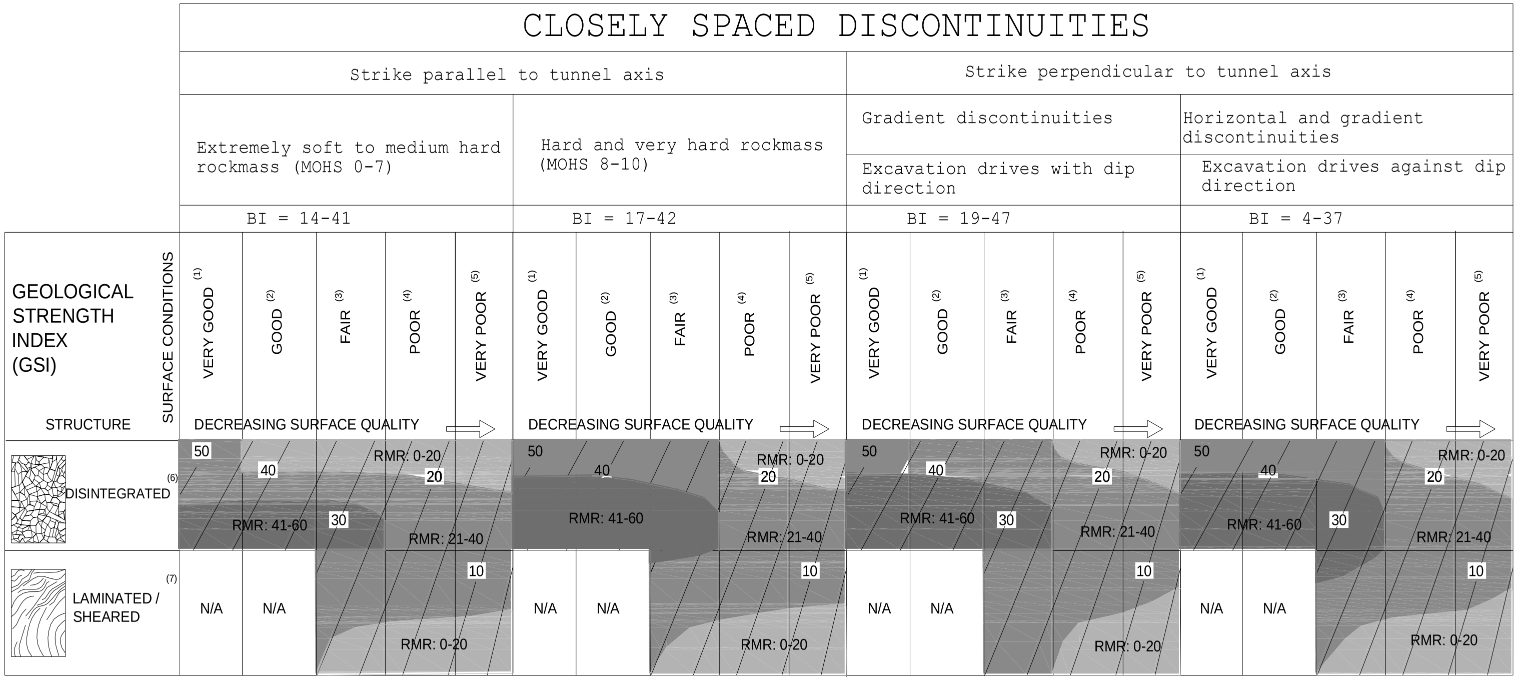
face, 40 for declined discontinuities where the excavation drives with dip direction and SGI (specific gravity influence) was calculated using specific gravity of rocks (t/m^3) from 1-3 (Table 1). 2400 different rock mass combinations were estimated (Tables 2, 3, 4).

Blastability index for rock mass with closely spaced discontinuities was calculated on Table 2. Blastability index for rock mass with intermediate spaced discontinuities was calculated on Table 3. Blastability index for rock mass with widely spacing discontinuities was calculated on Table 4. The parameters of BI calculation are also presented on these tables, numbering the rock mass types from 1 to 2400. At next stage, we regrouped the above rock structures according to RMR range and GSI parts, taking into consideration rock mass hardness, discontinuities spacing and orientation, also calculating the range of BI (Tables 5, 6, 7, 8, 9, 10, 11, 12). GSI range was calculated for every rock mass type with a specific RMR on Tables 5,6,7,8. The rock structures are also numbered from 1 to 2400 and they were banded together according to RMR range. On the same tables GSI parts are equivalent to RMR range. Actually, 90000 rock mass types were investigated. On the Tables 9, 10, 11, 12 blastability index for the above grouped rock structures appears in addition to GSI parts. On the same tables RMR range is equivalent to GSI parts.

Finally, three useful diagrams of composite rock mass quality and range of Blastability Index (BI) aroused from the above estimations (Fig. 2-4). Fig. 2 refers to rock mass with closely spaced discontinuities. The above rock structure may strike parallel or perpendicular to excavation axis. The rock foundations, which strike parallel to excavation axis, may be extremely soft and medium hard or hard and very hard. The blastability index was calculated between 14 and 41 for the first case and between 17 and 42 for the second one. Taking into consideration the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range. Furthermore, the rock foundations, which strike perpendicular to excavation axis, may consist only of gradient discontinuities, when the excavation drives with dip direction, or consist of gradient and perpendicular discontinuities, when the excavation drives against dip direction. The blastability index was calculated between 19 and 47 for the first case and between 4 and 37 for the second case. Taking into account the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range.

Fig. 3 refers to rock mass with intermediately spaced discontinuities (Deere and Deere 1988). The rock mass may consist of horizontal or gradient discontinuities. In case there are only horizontal discontinuities, rock mass may be extremely soft to soft or medium hard to very hard. The blastability index was calculated between 9 and 34 for the first case and between 11 and 37 for the second case. In case of gradient discontinuities, rock mass may strike perpendicular to excavation axis when excavation drives against dip direction, rock mass may strike perpendicular to excavation axis when excavation drives with dip direction, and rock mass may strike parallel to excavation axis. Where rock mass strikes are parallel to excavation axis, when excavation drives against dip direction, rock mass may be extremely soft to medium hard or hard and very hard. The blastability index was calculated between 14 and 46 for the first case and between 17 and 47 for the second case. Where rock mass strikes are perpendicular to excavation axis, and excavation drives with dip direction, the blastability index was calculated between 24 and 52. Where rock foundation strikes parallel to excavation axis, the rock mass may be extremely soft to soft. The blastability index was calculated between 19 and 44. Taking into account the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range.

Fig. 4 refers to rock mass with widely spacing discontinuities. The rock mass may be extremely soft to soft, medium hard to hard, or hard and very hard. In case the rock mass is extremely soft to soft the discontinuities may be horizontal or gradient with strike perpendicular to excavation axis,



(1) Very rough, fresh unweathered surfaces

(2) Rough, slightly weathered, iron stained surfaces

(3) Smooth, moderately weathered and altered surfaces

(4) Slickensided, highly weathered surfaces with compact coatings of rillings or angular fragments

(5) Slickenside, highly weathered surfaces with soft clay coatings or fillings

(6) Poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces

(7) Lack of blockiness due to close spacing of weak schistosity of shear planes

Fig. 2 BQS for closely spaced discontinuities

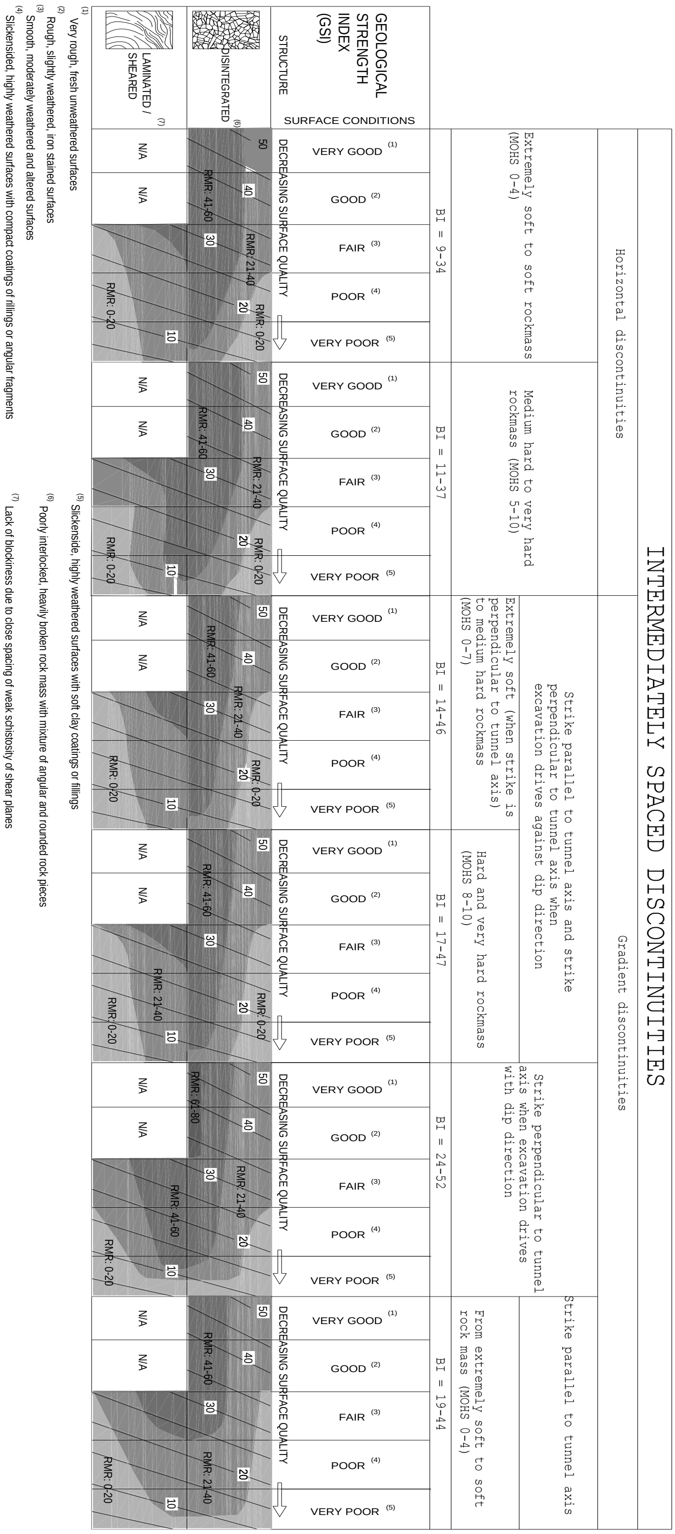


Fig. 3 BQS for intermediately spaced discontinuities

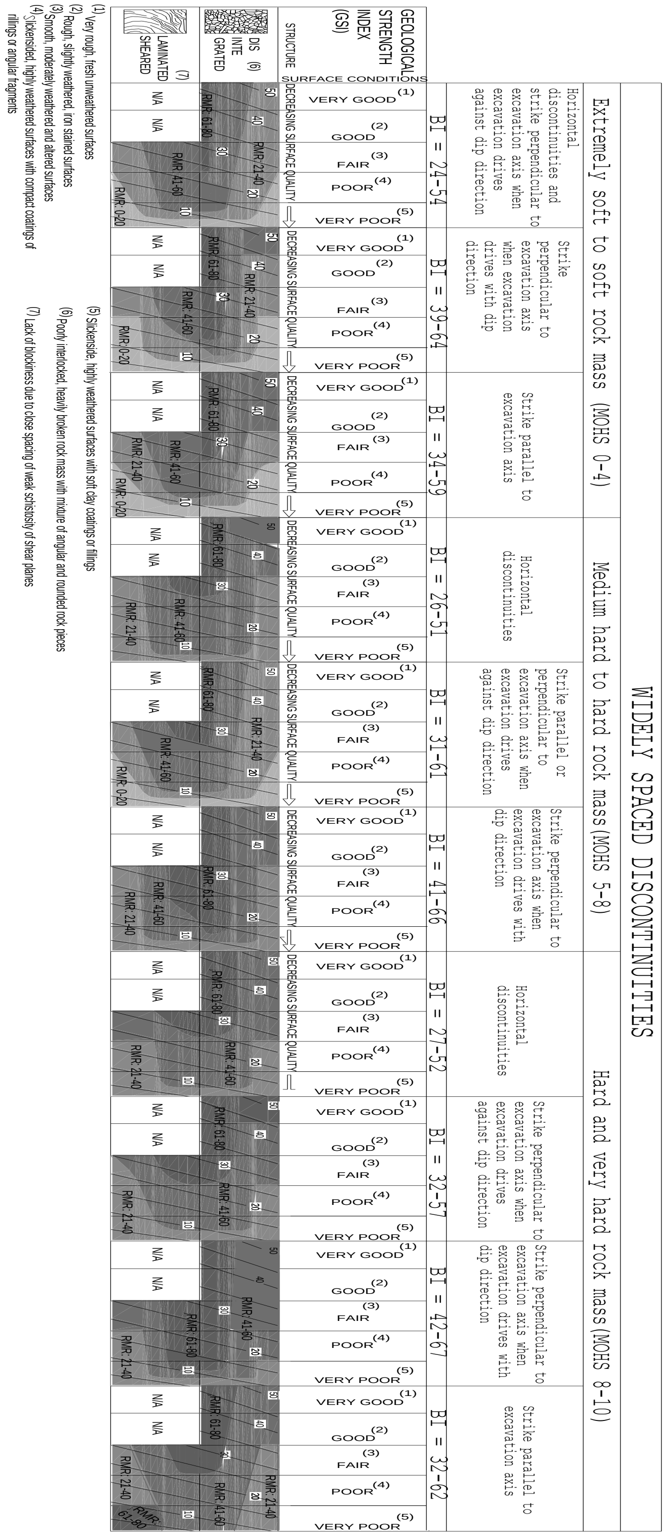


Fig. 4 BQS for widely spaced discontinuities

Table 4 BI calculations for widely spaced discontinuities

A/A	RMD	JPS	JPO	SGI	H	BI	A/A	RMD	JPS	JPO	SGI	H	BI
1601-1620	10	50	10	from -22,5 to 25	1	24,25-48	2001-2020	10	50	30	from -22,5 to 25	1	34,25-58
1621-1640	10	50	10	from -22,5 to 25	2	24,75-48,5	2021-2040	10	50	30	from -22,5 to 25	2	34,75-58,5
1641-1660	10	50	10	from -22,5 to 25	3	25,25-49	2041-2060	10	50	30	from -22,5 to 25	3	35,25-59
1661-1680	10	50	10	from -22,5 to 25	4	25,75-49,5	2061-2080	10	50	30	from -22,5 to 25	4	35,75-59,5
1681-1700	10	50	10	from -22,5 to 25	5	26,25-50	2081-2100	10	50	30	from -22,5 to 25	5	36,25-60
1701-1720	10	50	10	from -22,5 to 25	6	26,75-50,5	2101-2120	10	50	30	from -22,5 to 25	6	36,75-60,5
1721-1740	10	50	10	from -22,5 to 25	7	27,25-51	2121-2140	10	50	30	from -22,5 to 25	7	37,25-61
1741-1760	10	50	10	from -22,5 to 25	8	27,75-51,5	2141-2160	10	50	30	from -22,5 to 25	8	37,75-61,5
1761-1780	10	50	10	from -22,5 to 25	9	28,25-52	2161-2180	10	50	30	from -22,5 to 25	9	38,25-62
1781-1800	10	50	10	from -22,5 to 25	10	28,75-52,5	2181-2200	10	50	30	from -22,5 to 25	10	38,75-62,5
1801-1820	10	50	20	from -22,5 to 25	1	29,25-53	2201-2220	10	50	40	from -22,5 to 25	1	39,25-63
1821-1840	10	50	20	from -22,5 to 25	2	29,75-53,5	2221-2240	10	50	40	from -22,5 to 25	2	39,75-63,5
1841-1860	10	50	20	from -22,5 to 25	3	30,25-54	2241-2260	10	50	40	from -22,5 to 25	3	40,25-64
1861-1880	10	50	20	from -22,5 to 25	4	30,75-54,5	2261-2280	10	50	40	from -22,5 to 25	4	40,75-64,5
1881-1900	10	50	20	from -22,5 to 25	5	31,25-55	2281-2300	10	50	40	from -22,5 to 25	5	41,25-65
1901-1920	10	50	20	from -22,5 to 25	6	31,75-55,5	2301-2320	10	50	40	from -22,5 to 25	6	41,75-65,5
1921-1940	10	50	20	from -22,5 to 25	7	32,25-56	2321-2340	10	50	40	from -22,5 to 25	7	42,25-66
1941-1960	10	50	20	from -22,5 to 25	8	32,75-56,5	2341-2360	10	50	40	from -22,5 to 25	8	42,75-66,5
1961-1980	10	50	20	from -22,5 to 25	9	33,25-57	2361-2380	10	50	40	from -22,5 to 25	9	43,25-67

when excavation drives against dip direction, gradient discontinuities with strike perpendicular to excavation axis, when excavation drives with dip direction, or strike parallel to excavation axis. The blastability index was calculated between 24 and 54 when the discontinuities are horizontal or gradient with strike perpendicular to excavation axis, when excavation drives against dip direction. The blastability index was calculated between 39 and 64 when strike is perpendicular to excavation axis, when excavation drives with dip direction. The blastability index was calculated between 34 and 59 when strike is parallel to excavation axis. Concerning medium hard to hard rock mass, the blastability index was calculated between 26 and 51 where the discontinuities are horizontal. The blastability index was calculated between 31 and 61 where strike is perpendicular to excavation axis, when excavation drives against dip direction. The blastability index was calculated between 41 and 66 where strike is perpendicular to excavation axis, when excavation drives with dip direction. Concerning hard and very hard rock mass, the blastability index was calculated between 27 and 52 where the discontinuities are horizontal. The blastability index was calculated between 32 and 57 where strike is perpendicular to excavation axis, when excavation drives against dip direction. The blastability index was calculated between 42 and 67 where strike is perpendicular to excavation axis, when excavation drives with dip direction. The blastability index was calculated between 32 and 62 where strike is parallel to tunnel axis. Taking into account the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range.

7. 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 its easily and wide use, it is a quick calculator for BI and rock mass quality, which make our choice of excavation, blast and support measures quicker.

The BQ system (Figs. 2-4) combines rock mass classification systems RMR and GSI, structural data, hardness of rock mass, and BI (Hino 1959).

At the first stage, the spacing of discontinuities is distinguished. At second stage, the orientation of discontinuities in addition to the hardness of rock mass is described. Having completed the above classification, the BI range can easily be determined. Looking a rock structure, we can easily distinguish discontinuities in spacing and orientation (Priest and Hudson 1976). Also, we can estimate rock mass hardness using a Schmidt Hammer.

At the final stage we can relate the structure to the surface conditions in order to estimate Geological Strength Index (GSI) and Rock Mass Rating (RMR).

Taking into account the GSI and RMR estimations, we can come up with appropriate excavated technique and support measures, according to Bieniawski (1989), Hoek and Marinos (2000).

8. Application of BQS at the Asprovalta-Strymona's part of Egnatia Highway

The excavations during the construction of Asprovalta - Strymona's part of Egnatia Highway in Northern Greece were very difficult because of rock mass quality. Rock mass consisted of weathered and cracked gneiss with pegmatitic veins, or cracked marbles. There was no cohesion of rock mass pieces, and they formed potential sliding wedges. When the face area of disintegrated wedges had been uncovered, the sliding happened suddenly (Christaras *et al*. 2001). Although the

Table 5 RMR estimations for different types of rock mass with specific GSI range

GSI (PART)	A/A: 001-80	A/A: 81-140	A/A: 141-200	A/A: 201-280	A/A: 281-340	A/A: 341-400	A/A: 401-480	A/A: 481-540	A/A: 541-600	A/A: 601-680	A/A: 681-740	A/A: 741-800
	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR
0-12 (A)	008-28	009-29	010-30	003-28	004-29	005-30	001-28	002-29	003-30	011-33	0012-34	13-35
012-23 (B)	012-32	13-33	14-34	007-32	008-33	009-34	005-32	006-33	007-34	15-37	16-38	17-39
22-32 (C)	21-40	22-41	23-42	16-40	17-41	18-42	14-40	15-41	16-42	24-45	25-46	26-47
007-17 (D)	14-33	15-34	16-35	009-33	010-34	011-35	007-33	008-34	009-35	17-38	18-39	19-40
018-28 (E)	18-37	19-38	20-39	13-37	14-38	15-39	011-37	012-38	13-39	21-42	22-43	23-44
16-36 (F)	27-45	28-46	29-47	22-45	23-46	24-47	20-45	21-46	22-47	30-50	31-51	32-52
35-43 (G)	26-44	27-45	28-46	21-44	22-45	23-46	19-44	20-45	21-46	29-49	30-50	31-51
42-50 (H)	29-47	30-48	31-39	24-47	25-48	26-49	22-47	23-48	24-49	32-52	33-53	34-54

Table 6 RMR estimations for different types of rock mass with specific GSI range

GSI (PART)	A/A: 801-880	A/A: 881-940	A/A: 941-1000	A/A: 1001-1080	A/A: 1081-1140	A/A: 1141-1200	A/A: 1201-1280	A/A: 1281-1340	A/A: 1341-1400	A/A: 1401-1480
	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR
0-12 (A)	011-36	012-38	013-37	006-36	007-38	008-39	004-36	005-38	006-39	14-41
012-23 (B)	015-39	16-41	17-42	010-40	011-40	012-41	008-39	009-40	010-41	18-44
22-32 (C)	22-47	23-48	24-49	17-47	18-48	019-49	015-60	16-48	17-49	25-52
007-17 (D)	012-41	13-42	14-43	007-40	008-41	009-43	006-36	006-41	007-42	15-45
018-28 (E)	16-44	17-45	18-46	011-44	012-45	13-46	010-40	010-45	011-46	19-49
16-36 (F)	23-52	24-53	25-54	18-52	019-53	20-54	16-48	017-53	018-54	26-57
35-43 (G)	29-56	30-57	31-58	24-56	25-57	26-58	22-52	23-57	24-58	32-61
42-50 (H)	34-58	32-59	33-60	26-58	26-59	28-60	24-54	24-59	25-60	34-63

Table 7 RMR estimations for different types of rock mass with specific GSI range

GSI (PART)	A/A: 1481-1540	A/A: 1541-1600	A/A: 1601-1680	A/A: 1681-1740	A/A: 1741-1800	A/A: 1801-1880	A/A: 1881-1940	A/A: 1941-2000	A/A: 2001-2080
	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR	RMR
0-12 (A)	15-42	16-43	13-43	20-58	28-58	008-43	15-58	23-58	006-43
012-23 (B)	17-45	20-46	15-45	22-60	30-60	011-45	17-60	25-60	008-45
22-32 (C)	26-53	27-54	29-30, 33-42, 44-45,49-50	36-37, 40-57, 59-62,64-65	42-43, 46-55, 57-58,62-63	24-25, 28-42,44-45	31-32, 35-57, 59-62,64-65	39-40, 43-57, 59-60,64-65	22-23, 26-45,49-50
007-17 (D)	16-46	18-47	13-45	20-58	28-58	008-45	15-58	23-58	006-45
018-28 (E)	20-50	21-51	16-60	23-60	31-60	011-60	18-60	26-60	009-60
16-36 (F)	27-58	28-59	29-57, 59-62,64-65	36-37, 40-57, 59-62,64-65	44-45, 48-57, 59-60,64-65	30-69, 65-68,70-71	31-32, 35-57, 59-62,64-65	34-40, 43-57, 59-60,64-65	22-62,64-65
35-43 (G)	33-62	34-63	33-71	40-71	48-66,68-71	28-71	35-57	43-66,68-71	26-71
42-50 (H)	35-64	36-65	37-65, 67-70,72-73	44-45, 48-65, 67-70,72-73	52-53, 56-65, 67-68,72-73	32-45, 67-70,72-73	39-40, 43-65, 67-70,72-73	47-48, 51-65, 67-68,72-73	30-70,72-73

Table 8 RMR estimations for different types of rock mass with specific GSI range

GSI (PART)	A/A: 2081-2140	A/A: 2141-2200	A/A: 2201-2280	A/A: 2281-2340	A/A: 2341-2400
	RMR	RMR	RMR	RMR	RMR
0-12 (A)	13-58	45-46,49-68,72-73	16-33	23-61	31-63
012-23 (B)	15-60	23-60	20-50	25-65	33-65
22-32 (C)	29-30,33-62,64-65	37-38,41-60,64-65	32-50,52-55	39-70	47-65,67-70
007-17 (D)	13-58	21-58	16-50	23-63	31-63
018-28 (E)	16-60	24-60	19-65	26-65	34-65
16-36 (F)	29-33,34-62,64-65	37-38,41-60,64-65	32-70	39-70	47-65,67-70
35-43 (G)	33-71	41-66,68-71	36-76	43-76	51-76
42-50 (H)	37-38,41-70,72-73	42-46,49-68,72-73	40-78	47-78	55,-73,75-78

Table 9 GSI estimations for different types of rock mass with specific RMR range

RMR	A/A: 001-80	A/A: 81-140	A/A: 141-200	A/A: 201-280	A/A: 281-340	A/A: 341-400	A/A: 401-480	A/A: 481-540	A/A: 541-600	A/A: 601-680	A/A: 681-740	A/A: 741-800
	BI: 4-29	BI: 6-31	BI: 7-32	BI: 9-34	BI: 11-36	BI: 12-37	BI: 14-39	BI: 16-41	BI: 17-42	BI: 19-44	BI: 21-46	BI: 22-47
	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)
0-20	ABDE	ABDE	ABDE	ABCDE	ABCDE	ABCDE	ABCDEFG	ABCDEFG	ABCDE	ABD	ABD	ABD
21-40	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH
41-60	FGH	CFGH	CFGH	FGH	FGH	CFGH	FGH	FGH	CFGH	CEFGH	CEFGH	CEFGH
61-80												
81-100												

Table 10 GSI estimations for different types of rock mass with specific RMR range

RMR	A/A: 801-880	A/A: 881-940	A/A: 941-1000	A/A: 1001-1080	A/A: 1081-1140	A/A: 1141-1200	A/A: 1201-1280	A/A: 1281-1340
	BI:9-34	BI:11-36	BI:12-37	BI:14-39	BI:16-41	BI:17-42	BI:19-44	BI:21-46
	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)
0-20	ABCDE	ABDE	ABDE	ABCDEF	ABCDEF	ABCDE(F)	ABCDEF	ABCDEF
21-40	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH
41-60	C(D)EFGH	(B)CDEFGH	BCDEFGH	CEFGH	C(D)EFGH	(B)CDEFGH	CGH	C(D)EFGH
61-80								
81-100								

Table 11 GSI estimations for different types of rock mass with specific RMR range

RMR	A/A: 1341-1400	A/A: 1401-1480	A/A: 1481-1540	A/A: 1541-1600	A/A: 1601-1680	A/A: 1681-1740	A/A: 1741-1800	A/A: 1801-1880
	BI:22-47	BI:24-49	BI:26-51	BI:27-52	BI:24-49	BI:26-51	BI:27-52	BI:29-54
	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)
0-20	ABCDEF	ABDE	ABD(E)	A(B)D	ABDE			ABDE
21-40	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEF	ABDE	ABCDEFGH
41-60	CDEFGH	(A)BCDEFGH	ABCDEFGH	ABCDEFGH	BCDEFGH	ABCDEFGH	ABCDEFGH	ABCDEFGH
61-80		(G)H	GH	GH	FGH	CFGH	CFGH	FGH
81-100								

Table 12 GSI estimations for different types of rock mass with specific RMR range

RMR	A/A: 1881-1940	A/A: 1941-2000	A/A: 2001-2080	A/A: 2081-2140	A/A: 2141-2200	A/A: 2201-2280	A/A: 2281-2340	A/A: 2341-2400
	BI:31-56	BI:32-57	BI:34-59	BI:36-61	BI:37-62	BI:39-64	BI:41-66	BI:42-67
	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)	GSI (PART)
0-20	ABDE		ABDE	ABDE		A(B)DE		
21-40	ABCDEFGH	AB(C)DEF	ABCDEFG	ABCDEFGH	BCDEF	ABCDEFG	ABCDEF	ABD
41-60	ABCDEFGH	ABCDEFG	ABCDEFGH	ABCDEFGH	ABCDEFGH	BCDEFGH	ABCDEFGH	ABCDEFGH
61-80	CFGH	(CF)GH	FGH	CFGH	ACFGH	EFGH	BCDEFGH	ABCDEFGH
81-100								

Fig. 5 Weathered and disintegrated rock mass quality at Asprovalta - Strymona's part of Egnatia Highway at Northern Greece

Fig. 6 Chloritic schist rock mass during tunneling of Symbol Mountain at Strymonas-Kavala's part of Egnatia Highway at Northern Greece

use of blasting was needed, the explosion had to be very careful, so that no accident took place. Looking at the rock mass example on Fig. 5, the spacing discontinuities easily distinguished and characterized "closely". Using the Fig. 2, the orientation of discontinuities may be determined. Looking again Fig. 5, strike is parallel to tunnel axis. When the strike formation is parallel to the tunnel axis, the average hardness of minerals needs to be determined. So, as the rock mass is very weathered, the hardness is to be extremely soft to medium hard. Looking the Fig. 2, BI is estimated 14-41. That means blasting is moderate to easy. Furthermore, looking the lower part of the same figure, we combine the structure or rock mass, which is disintegrated with the surface conditions, which are poor, estimating RMR 0-20 (as rock mass is disintegrated to blocky and not laminated) and GSI 20-25.

According to estimated values of RMR and GSI, the excavation was divided in two parts – upper and lower part - keeping a standard excavated step smaller than 1,5 m. Support measures were applied during the excavation and shotcrete, 15-20 mm thick, was also applied very quickly after the blasting. Rock bolts of 5-6 m length, whose distance was 1-1,5 m, were put on the roof and on the walls. Also, wire mess covered the roof and the walls. Finally, an invert was excavated at the base to the tunnel.

9. Application of BQS on the chloritic schist of the Stymonas - Kavala's part of Egnatia Highway

The BQ system was also applied on the excavation of chloritic schist during the tunneling of Stymonas - Kavala's part of Egnatia Highway. According to the rock mass example on figure 6, rock mass is intermediate spacing. Using the figure 3, the orientation of discontinuities may be determined. According to Fig. 6, there are horizontal discontinuities. At next stage, rock mass hardness needs to be determined. So, as the rock mass is quickly weathered and loosen, it is extremely soft to soft rock mass. Looking at figure 3, BI is estimated 9-34. That means blasting may be very difficult and needs careful explosion. Furthermore, looking at the lower part of the same figure, we combine the structure of rock mass, which is laminated and sheared, with the surface conditions, which are very poor, because of slicken sided discontinuities with highly weathered surfaces with soft clay (chlorite) coatings, estimating RMR 0-20 (as rock mass is sheared and no way disintegrated) and GSI 5-10.

According to the estimated values of RMR and GSI, the excavation was divided in several parts; one part was covered by shotcrete, 15-20 mm thick, before the excavation of the other part be completed using the technique of Sprayed Concrete Lined Tunneling (Thomas *et al*. 2004) keeping a standard excavated step smaller than 1,5 m. Rock bolts of 5-6 m length, whose distance was 1-1,5 m, were put on the roof and on the walls. Fiber glass of 12m length was placed on the face (Tsonos and Stylianides 2002). Also, wire mess covered the roof and the walls. Finally, an invert was excavated at the base to the tunnel.

10. Application of BQS at the Athens Olympic Wresting Hall's foundation

The bedrock of Athens Olympic Wresting Hall consists of extremely cohesive conglomerate. Although the geological formation looks like soil and is disintegrated when scratched by nail, it could not be excavated with digger, ripper or even hammer. Hence blasting was used to help the excavation (Fig. 8). The rock pieces get much tighter because of the presence of solid clay.

According to the rock mass example of Fig. 7, rock mass has widely spaced discontinuities. Also, the rock mass, which is in contact with the air, can be scratched by nail. That means, according to MOHS Scale (Mohs 1812), rock mass is extremely soft to soft (Szymanski and Szymanski 1989). Using the Fig. 4 and taking into consideration the fact that the open excavation took place downwards, the strike is parallel to excavation axis and BI is estimated 34-59. Blasting is characterized as "easy" and "very easy". Actually, blasting was very easy and problems or sudden failures did not occur; the excavation was completed very quickly. Furthermore, looking at the lower part of Fig. 4, we combine the structure of rock mass, which looks as disintegrated, with the surface conditions, which are poor as they are filled with compact coating (solid clay) or angular fragments (rock pieces of conglomerate), estimating RMR 0-20 (as rock mass is far away from being characterized as" laminated and sheared rock mass" but it is prone to be "blocky and disturbed rock mass" - Fig. 1) and GSI 20-25.

11. Blastability Index (BI) related to structural geology

Taking into account the calculations of BI for every possible structural appearance of the

Fig. 7 Very cohesive conglomerate formation as Olympic Wresting Hall foundation

Fig. 8 Olympic Wresting Hall Explosion

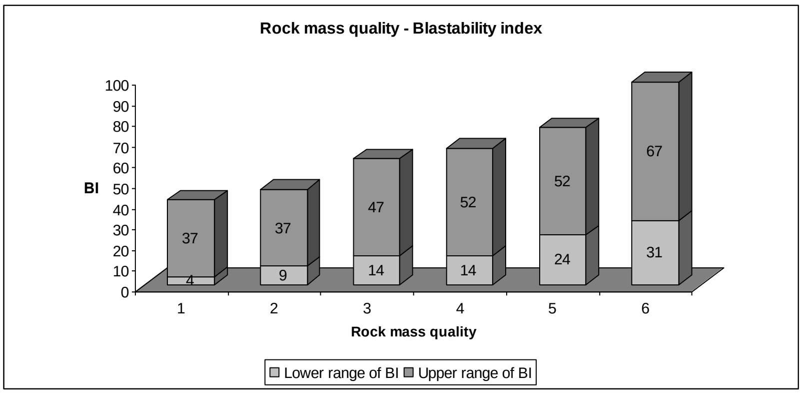


Fig. 9 Rock mass quality versus to BI

rockmass, we can easily prepare a diagram which connects the structural description, the hardness of rockmass and BI (Fig. 9), where rock mass quality 1 refers to closely spaced discontinuities, horizontal formations, and gradient formations where the excavation drives against dip direction. Rock mass quality 2 refers to intermediate spaced discontinuities and horizontal formations. Rock mass quality 3 refers to closely spaced discontinuities and gradient formations, where excavation drives with dip direction. Rock mass quality 4 refers to intermediate spaced discontinuities and gradient formations. Rock mass quality 5 refers to widely spaced discontinuities, horizontal formations, and soft gradient rock mass, where excavation drives against dip direction. Rock mass quality 6 refers to widely spaced discontinuities and gradient formations (except soft gradient structures where excavation drives against dip direction).

Looking at the above diagram, we can easily conclude that as the spacing of discontinuities gets bigger, the BI in horizontal formations is lower than in gradient formations.

The BI is higher where the excavation drives with dip direction and it is lower where the excavation drives against dip direction.

12. Conclusions

The present paper relies on practical experience in structural and infrastructure constructions, adding newly investigated data to existing knowledge. The already known rock mass quality classification systems on structural excavations, RMR and GSI, could not be applied on a lot of rock mass cases. RMR does not work well for many faulty, weak zones and swelling rock, in the same way that GSI is not applicable on sheared schist rock masses. Also, blasting has been effectively applied for rocks exhibiting GSI values greater than 60 and rock mass strengths of more than 15MPa.

The combination of the excavation methods which are proposed by the above classification systems with the excavation methods which were finally used in Central and Northern Greece constructions, adds new knowledge to RMR and GSI classification systems applicability; So, GSI classification system can be applied on massive rock mass of schists or conglomerate, and blasting is also applicable and helps the excavation, although the above masses are weathered in condact with air.

All the above observations result in the use of a new system called "Blastability Quality System (BQS)" as a tool which (at present) for poor and friable rock structures, shared, with lack of blockiness due to close spacing of weak schistosity or sheer planes and disintegrated with poorly interlocked, heavily broken, with mixture of angular and rounded rock pieces. It connects rock mass quality, discontinuities orientation, rock mass hardness and blastability index (BI). It can be easily used during the excavations, in order to estimate rock mass quality and the range of BI very quickly and to describe the ease of rock mass blasting as

- "very difficult", when the BI range is lower to 8,
- "difficult", when the BI range is between 8 and 13,
- "moderate", when the BI range is between 13 and 20,
- "easy" when the BI range is between 20 and 40 and
- "Very easy", when the BI range is higher than 40.

This is a great help for deciding on explosions and support measures, adding to the already known methodology. Examples of BQ-System applicability are on cracked and weathered rock mass of Asprovalta - Strymona's part of Egnatia Highway, on chloritic schist during the excavations of Stymonas - Kavala's part of Egnatia Highway, and on cohesive conglomerates of Athens Oympic Wresting Hall's foundation.

All in all, according to the calculations of the BI for every possible structure of rock mass, the wider the space of discontinuities is, the bigger the BI is. Also, the BI in horizontal formations is lower than that in gradient formations. Finally, the BI is higher in rock masses where the excavation drives with dip direction than those where the excavation drives against dip direction.

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