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ROCK MASS BLASTABILITY DEPENDENCE ON ROCK MASS QUALITY

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Abstract

The present paper tries to investigate the influence of rock mass quality characteristics on blasting results. In order to come to some conclusions, blastability and quality of rock mass were put together using the already known classification systems. Taking into account the quantity of blastability index (BI) for every possible structural appearance of the poor rock mass, the relation of discontinuities characteristics and blastability index are investigated. The estimations of the above trial gave arise on a new classification system being called "Blastability Quality System (BQS)", which can be an easily and wide use tool as it is a quickly calculator for blastability index (BI) and rock mass quality.
Key words: *Tunnelling, excavation, explosion, methodology.*

Περίληψη

Η παρούσα εργασία προσπαθεί να εκτιμήσει την επίδραση των χαρακτηριστικών της ποιότητας της βραχομάζας στα αποτελέσματα έκρηξης για την εκσκαφή βραχωδών σχηματισμών. Με σκοπό την εκτίμηση αυτή, η εκρηκτική ικανότητα και η ποιότητα βραχομάζας συνδέονται αξιοποιώντας τα ήδη γνωστά συστήματα ταξινόμησης. Λαμβάνοντας υπόψη την τιμή του Δείκτη Εκρηκτικής Ικανότητας (BI) για κάθε περίπτωση πτωχής ποιότητας βραχομάζας, μπορεί να εκτιμηθεί η σχέση των χαρακτηριστικών των ασυνεχειών και του Δείκτη Εκρηκτικής Ικανότητας (BI). Με αυτά τα στοιχεία δημιουργούμε ένα νέο σύστημα ταξινόμησης που ονομάζεται «Σύστημα Εκρηκτικής Ικανότητας και Ποιότητας Βραχομάζας (BQS)», το οποίο μπορεί να χρησιμοποιηθεί εύκολα και να αποτελέσει εργαλείο για τον συνδυασμό του Δείκτη Εκρηκτικής Ικανότητας (BI) και της ποιότητας της βραχομάζας.
Λέξεις κλειδιά: *Σήραγγες, εκσκαφή, έκρηξη, μεθοδολογία.*

1. Introduction

Many rock mass quality classification systems –RQD (Deere, 1989), Q (Barton et al, 1980), RMR (Bieniawski, 1989), GSI - have been developed for drilling and excavation ability estimation, but not for blasting calculations (Jimeno et al, 1995). The several rock types 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 investigates the influence of rock mass quality characteristics on blasting results. Rock blastability (Kaushik & Phalguni, 2003, Murthy et al, 2003) is quantified using blastability index, which is calculated by geotechnical characteristics. Rock mass quality is also estimating using the already known classification systems. The relation between discontinuities characteristics and blastability index for every possible structural appearance of the poor rock mass is estimating. The above estimations gave arise on a new classification system being called “Blastability Quality System (BQS)”.

The rock mass in study is poor and friable, shared with lack of blockiness due to close spacing of weak schistosity or sheer planes and disintegrated with poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces (Hoek et al, 1998). Although the quality is very poor, a light blast may be needed as the small rock pieces strengthen tight.

2. Connecting blast ability and quality ability.

The laminated and sheared rock mass, with lack of blockiness due to close spacing of week schistosity or sheer 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 & 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 (Scott, 1996) (BI = 0.5 x (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. That means RMD (rock mass description) was standard equal to 10 (powdery / friable rock mass). JPS (joint plan spacing) used equal to 10 for closely spacing, 20 for intermediate spacing and 50 for widely spacing. JPO (joint plane orientation) used 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. 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 was calculated for rock mass with closely spacing discontinuities on table 2. On table 3, blastability index was calculated for rock mass with intermediate spacing discontinuities. On table 4, blastability index was calculated for rock mass with widely spacing discontinuities. The parameters of BI

Table 1 – Specific gravity influence (SGI)

SGI	**specific gravity of rock (t/m3)**
25*specific gravity of rock (t/m3)-50	
-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

calculation are also presented on the above tables, numbering the rock mass types from 1 to 2400.

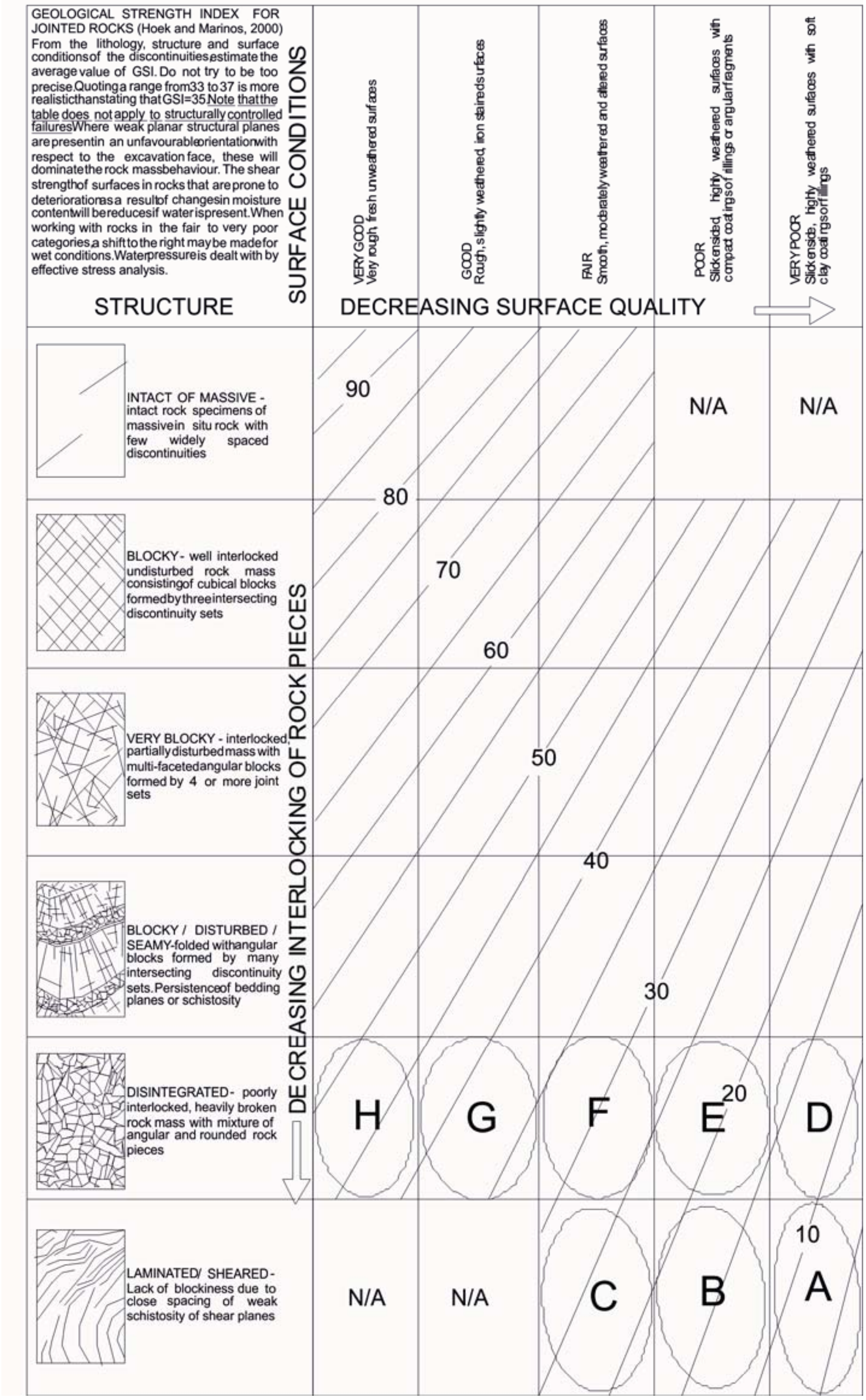


Figure 1 – Eight part division of GSI diagram

At next stage, the above rock structures were grouped according to RMR range and GSI parts, taking into account 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 different types of rock mass are also numbered from 1 to 2400 and they 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 is appeared for the above grouped rock masses in addition to GSI parts. On the same tables RMR range is equivalent to GSI parts.

Table 2 – BI calculations for closely spacing 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	4,75-28,5	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

Finally, three useful diagrams of composite rock mass quality and range of Blastability Index (BI) aroused from the above estimations (Fig. 2-4). Figure 2 refers to rock mass with closing spacing discontinuities. The above rock planes may strike parallel or perpendicular to tunnel axis. The rock foundations, which strike parallel to tunnel axis, may be extremely soft of 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 case. Taking into account 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 tunnel axis, may consist only of gradient discontinuities, when the tunnel drives with dip direction, or consist of gradient and perpendicular discontinuities, when the tunnel 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 (Hoek, E., 1994) and RMR range.

Figure 3 refers to rock mass with intermediating spacing discontinuities (Deere, D.U. and Deere, D.W. 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 tunnel axis when excavation drives against dip direction, rock mass may strike perpendicular to tunnel axis when excavation drives with dip direction, and rock mass may strike parallel to tunnel axis. Where rock mass strikes perpendicular to tunnel 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 perpendicular to tunnel axis, and excavation drives with dip direction, the blastability index was calculated between 24 and 52. Where rock foundation strikes parallel to tunnel axis, the rock mass may be medium hard, or extremely soft to soft. The blastability index was calculated between 14 and 46 for the first case and between 19 and 44 for the second case. Taking into account the surface conditions and the structure of the rock mass, we can estimate GSI and RMR range.

Table 3 – BI calculations for intermediating spacing 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

Figure 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 tunnel axis, when excavation drives against dip direction, gradient discontinuities with strike perpendicular to tunnel axis, when excavation drives with dip direction, or strike parallel to tunnel axis. The blastability index was calculated between 24 and 54 when the discontinuities are horizontal or gradient with strike perpendicular to tunnel axis, when excavation drives against dip direction. The blastability index was calculated between 39 and 64 when strike is perpendicular to tunnel axis, when excavation drives with dip direction. The blastability index was calculated between 34 and 59 when strike is parallel to tunnel 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 tunnel axis, when excavation drives against dip direction. The blastability index was calculated between 41 and 66 where strike is perpendicular to tunnel 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 tunnel axis, when excavation drives against dip direction. The blastability index was calculated between 42 and 67 where strike is perpendicular to tunnel 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.

Table 4 – BI calculations for widely spacing 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
1981-2000	10	50	20	FROM -22,5 TO 25	10	33,75-57,5	2381-2400	10	50	40	FROM -22,5 TO 25	10	43,75-67,5

3. Blastability Index (BI) related to structural geology

Taking into account the calculations of BI for every possible quality of the rock mass, a diagram which connects the structural description, the hardness of rock mass and BI (Fig.5) can be easily resulted, where; rock mass quality 1 refers to closely spacing discontinuities (Priest &Hudson, 1976), horizontal formations, and gradient formations where the excavation drives against dip direction. Rock mass quality 2 refers to intermediate spacing discontinuities and horizontal formations. Rock mass quality 3 refers to closely spacing discontinuities and gradient formations, where excavation drives with dip direction. Rock mass quality 4 refers to intermediate spacing discontinuities and gradient formations. Rock mass quality 5 refers to widely spacing discontinuities, horizontal formations, and soft gradient rock mass, where excavation drives against dip direction. Rock mass quality 6 refers to widely spacing discontinuities and gradient formations (except soft gradient rock mass where excavation drives against dip direction).

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

GSI (part)	A/A: 001-80 RMR	A/A: 81-140 RMR	A/A: 141-200 RMR	A/A: 201-280 RMR	A/A: 281-340 RMR	A/A: 341-400 RMR	A/A: 401-480 RMR	A/A: 481-540 RMR	A/A: 541-600 RMR	A/A: 601-680 RMR	A/A: 681-740 RMR	A/A: 741-800 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 RMR	A/A: 881-940 RMR	A/A: 941-1000 RMR	A/A: 1001-1080 RMR	A/A: 1081-1140 RMR	A/A: 1141-1200 RMR	A/A: 1201-1280 RMR	A/A: 1281-1340 RMR	A/A: 1341-1400 RMR	A/A: 1401-1480 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 RMR	A/A: 1541-1600 RMR	A/A: 1601-1680 RMR	A/A: 1681-1740 RMR	A/A: 1741-1800 RMR	A/A: 1801-1880 RMR	A/A: 1881-1940 RMR	A/A: 1941-2000 RMR	A/A: 2001-2080 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 RMR	A/A: 2141-2200 RMR	A/A: 2201-2280 RMR	A/A: 2281-2340 RMR	A/A: 2341-2400 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

Looking at the above diagram, we can easily conclude that

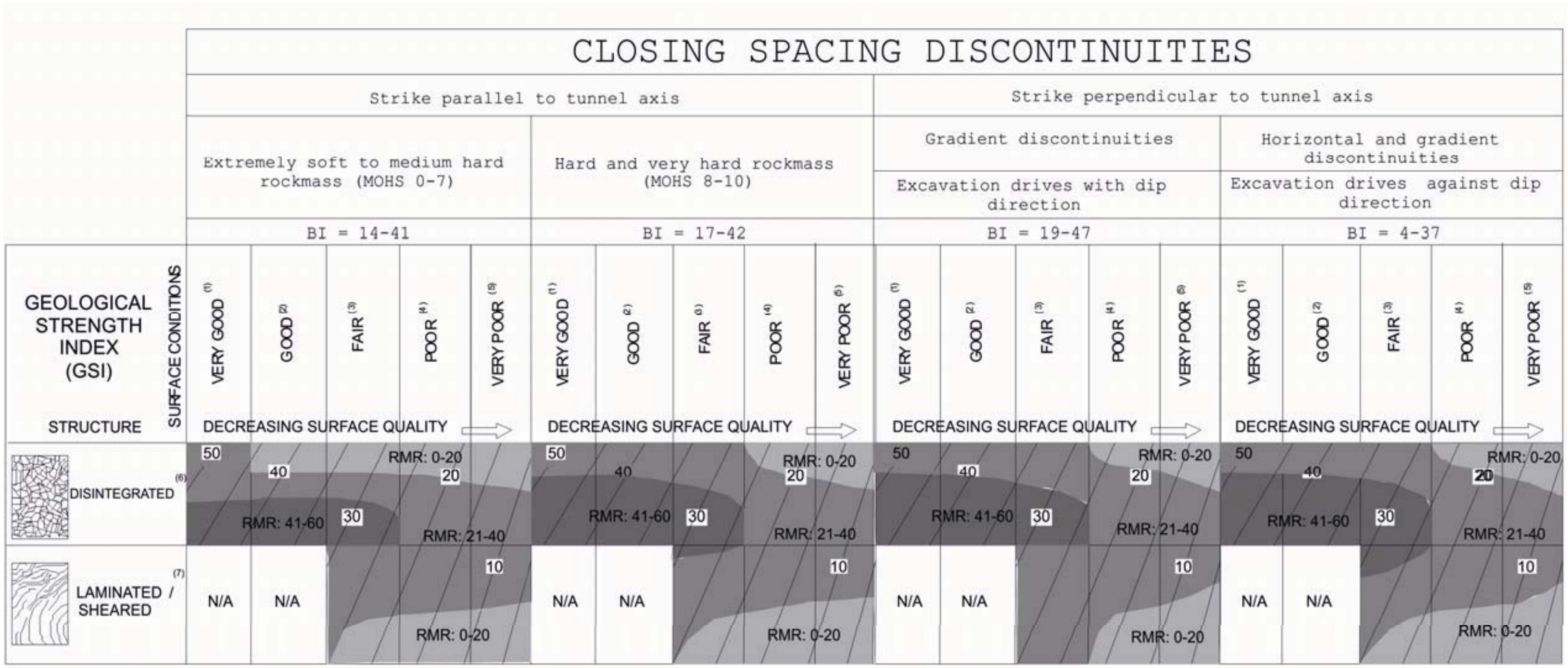
- The wider the space of discontinuities is, the bigger the BI is.
- The BI is lower to horizontal formations than to gradient formations.
- The BI is higher where the excavation drives with dip direction than where it drives against dip direction.

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

RMR	A/A: 001-80 BI: 4-29 GSI (part)	A/A: 81-140 BI: 6-31 GSI (part)	A/A: 141-200 BI: 7-32 GSI (part)	A/A: 201-280 BI: 9-34 GSI (part)	A/A: 281-340 BI: 11-36 GSI (part)	A/A: 341-400 BI: 12-37 GSI (part)	A/A: 401-480 BI: 14-39 GSI (part)	A/A: 481-540 BI: 16-41 GSI (part)	A/A: 541-600 BI: 17-42 GSI (part)	A/A: 601-680 BI: 19-44 GSI (part)	A/A: 681-740 BI: 21-46 GSI (part)	A/A: 741-800 BI: 22-47 GSI (part)
0-20	ABDE	ABDE	ABDE	ABCDE	ABCDE	ABCDE	ABCDE FG	ABCDE FG	ABCDE	ABD	ABD	ABD
21-40	ABCDEF GH	ABCDEF GH	ABCDEF GH	ABCDEF GH	ABCDE FGH	ABCDE FGH	ABCDE FGH	ABCDE FGH	ABCDE FGH	ABCDE FGH	ABCDE FGH	ABCDE FGH
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 BI:9-34 GSI (part)	A/A: 881-940 BI:11-36 GSI (part)	A/A: 941-1000 BI:12-37 GSI (part)	A/A: 1001-1080 BI:14-39 GSI (part)	A/A: 1081-1140 BI:16-41 GSI (part)	A/A: 1141-1200 BI:17-42 GSI (part)	A/A: 1201-1280 BI:19-44 GSI (part)	A/A: 1281-1340 BI:21-46 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								



(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

Figure 2 – BQS for closing spacing discontinuities

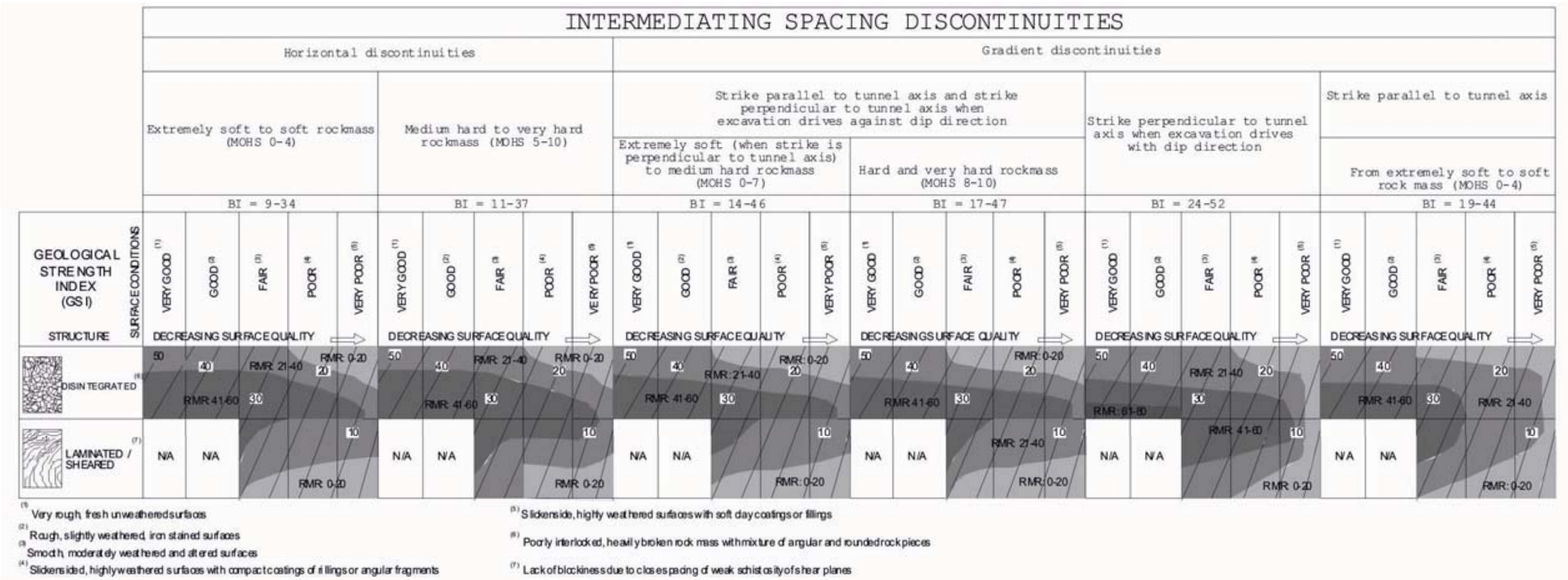


Figure 3 – BQS for intermediate spacing discontinuities

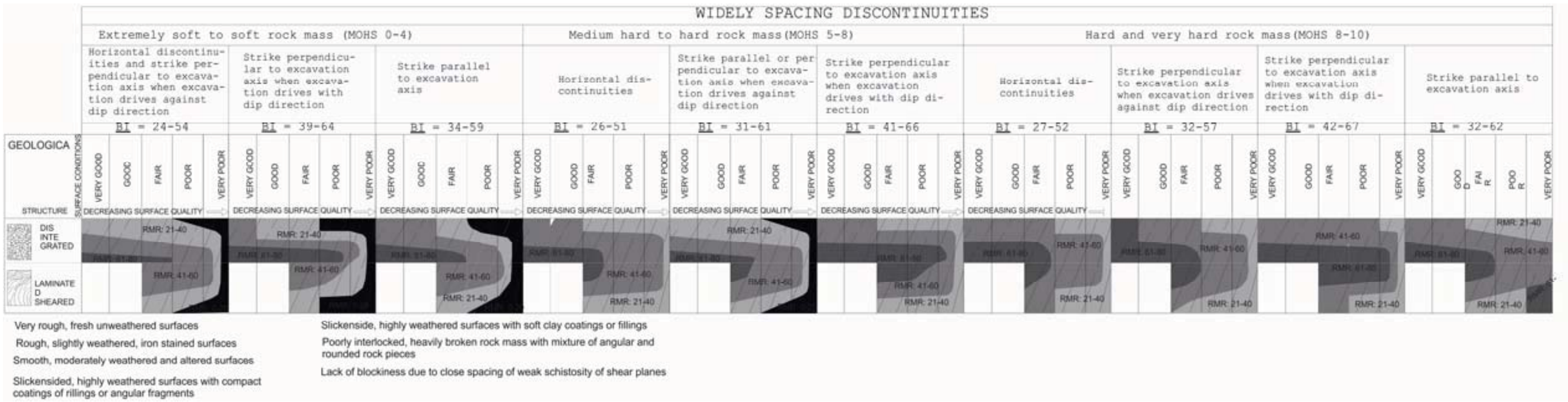


Figure 4 – BQS for widely spacing discontinuities

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

RMR	A/A: 1341-1400 BI:22-47 GSI (part)	A/A: 1401-1480 BI:24-49 GSI (part)	A/A: 1481-1540 BI:26-51 GSI (part)	A/A: 1541-1600 BI:27-52 GSI (part)	A/A: 1601-1680 BI:24-49 GSI (part)	A/A: 1681-1740 BI:26-51 GSI (part)	A/A: 1741-1800 BI:27-52 GSI (part)	A/A: 1801-1880 BI:29-54 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 BI:31-56 GSI (part)	A/A: 1941-2000 BI:32-57 GSI (part)	A/A: 2001-2080 BI:34-59 GSI (part)	A/A: 2081-2140 BI:36-61 GSI (part)	A/A: 2141-2200 BI:37-62 GSI (part)	A/A: 2201-2280 BI:39-64 GSI (part)	A/A: 2281-2340 BI:41-66 GSI (part)	A/A: 2341-2400 BI:42-67 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								

4. 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's easily and wide use, it is a quickly calculator for BI and rock mass quality, which make our choice of excavation, blast (Hino, 1959) and support measures quicker.

The BQ system (Fig. 2-4) connects rock mass classification systems RMR and GSI, structural data, hardness of rock mass, and BI.

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

At the final stage we can combine structure and surface conditions in order to estimate Geological Strength Index (GSI) (Hoek & Brown, 1980) and Rock Mass Rating (RMR).

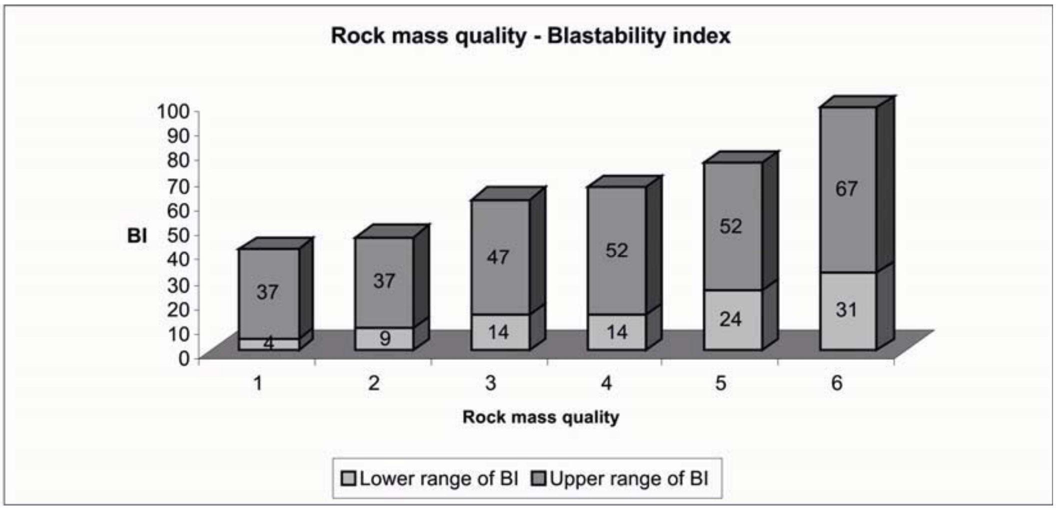


Figure 5 – Rock mass quality versus to BI

5. Conclusions

Taking into account the calculations of BI for every possible poor rock mass quality, the wider the space of discontinuities is, the bigger the BI is. Also, the BI is lower to horizontal formations than to gradient formations. Finally, the BI is higher where the excavation drives with dip direction than where it drives against it.

Taking into account rock mass quality estimating by RMR and GSI classification systems and the calculated blastability index, a useful system has been created called Blastability Quality System (BQS). This can be a useful tool for in situ estimations, which (at the present) can be used for poor and friable rock mass, 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 BI. It can be easily applied during the excavations, in order to estimate rock mass quality and the range of BI very quickly. This is a good help for quantity of explosions and support measures to be decided using the already known methodology.

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