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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: *Blastability, rock mass, quality, classification.*

Περίληψη

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

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 alteration in varying stress conditions, may be explored in a different manner under specified blast design, explosive characteristics and specified legislative constraints depending on structural characteristics.

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 the blastability index, which is calculated based on geotechnical characteristics. Rock mass quality can also be estimated using the already known classification systems. The relation between discontinuity characteristics and blastability index for every possible structural appearance of the poor rock mass is estimated. The above estimations can be used in a new classification system called "Blastability Quality System (BQS)".

The rock mass in this 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 are tightly connected.

2. Connecting Blast Ability and Quality Ability

The laminated and sheared rock mass, with lack of blockiness due to the close spacing of weak 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 the GSI diagram (Hoek, 1983, Hoek & Brown, 1997, Marinos and Hoek, 2000) , is 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.

Table 1 – Specific gravity influence (SGI).

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

Taking into account the parameters of the Blastability Index (Scott, 1996) (BI = 0.5 x (RMD+JPS+JPO+SGI+H) (Lilly, 1986), the Blastability Index (BI) is calculated for every possible combination of the above parameters, which refers to powdery/friable rock mass. That means RMD (rock mass description) is equal to 10 (powdery / friable rock mass). JPS (joint plan spacing) is used equal to 10 for closely spacing, 20 for intermediate spacing and 50 for widely spacing. JPO (joint plane orientation) is used equal to 10 for horizontal discontinuities, 20 for inclined discontinuities where the excavation drives against dip direction, 30 for inclined discontinuities with strike parallel to face, 40 for declined discontinuities where the excavation drives with dip direction. SGI (specific gravity influence) is calculated using specific gravity of rocks (t/m^3) (table 1). 2400 different rock mass combinations are estimated (tables 2, 3, 4).

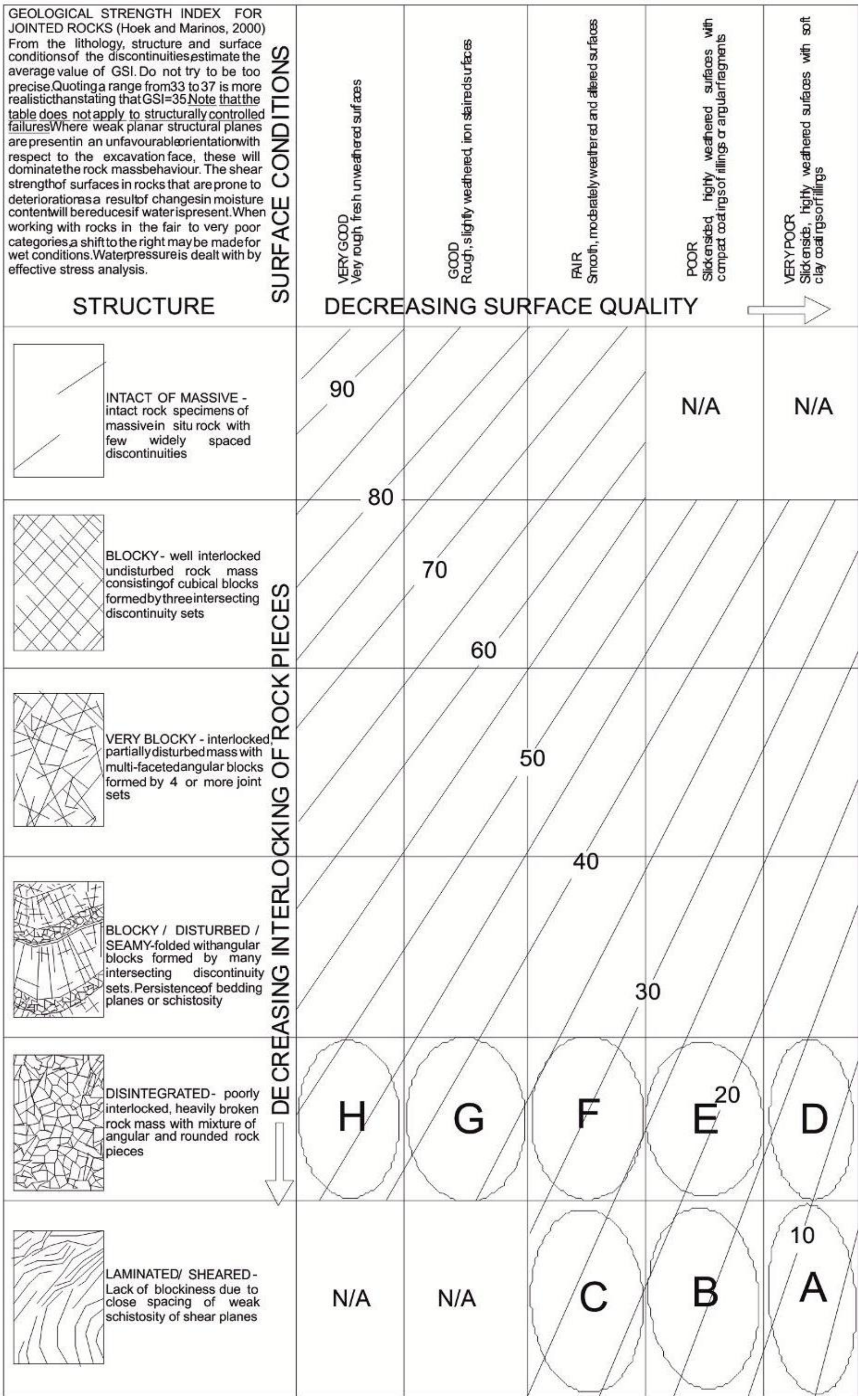


Figure 1 – Eight part division of GSI diagram.

The blastability index, of a rock mass with closely spaced discontinuities is calculated as shown in table 2. The blastability index, of a rock mass with intermediate spaced discontinuities, is calculated in table 3. The blastability index, of a rock mass with widely spaced discontinuities, is calculated in table 4. The parameters of BI calculation are also presented in the above tables, where the different rock mass types are numbered from 1 to 2400.

Subsequently, the above rock structures are grouped according to RMR range and GSI parts, taking into account rock mass hardness a well as discontinuities' spacing and orientation. Additionally, the calculation of the range of BI is presented in tables 5, 6, 7, 8, 9, 10, 11, 12. GSI range is calculated, in tables 5,6,7,8, for every rock mass type with a specific RMR. The different types of rock mass are also numbered from 1 to 2400 and they are grouped together according to RMR range. In the same tables, GSI parts are equivalent to RMR range. Actually, 90000 rock mass types are investigated. In tables 9, 10, 11, 12 the blastability index is appeared for the above grouped rock masses in addition to the GSI parts. In the same tables the RMR range is equivalent to the 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), derive from the above estimations (Fig. 2-4). Figure 2 refers to rock mass with close spaced discontinuities. The above rock planes may strike parallel or perpendicular to tunnel axis. The underlying rock, which strike parallel to tunnel axis, may be extremely soft of medium hard or hard and very hard. The blastability index is calculated to be 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 the GSI and RMR range. Furthermore, the underlying rock, which strikes 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 is calculated to be 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 the GSI (Hoek., 1994) and RMR range.

Figure 3 refers to rock mass with intermediate spaced discontinuities (Deere and Deere, 1988). The rock mass may consist of horizontal or gradient discontinuities. In case there are only horizontal discontinuities, the rock mass may be extremely soft to soft or medium hard to very hard. The blastability index is calculated between 9 and 34 for the first case and between 11 and 37 for the second case. In case of gradient discontinuities, the rock mass may strike perpendicular to tunnel axis when excavation drives against dip direction, the rock mass may strike perpendicular to tunnel axis when excavation drives with dip direction, and the rock mass may strike parallel to tunnel axis. Where the rock mass strikes perpendicular to tunnel axis, when excavation drives against dip direction, the rock mass may be extremely soft to medium hard or hard and very hard. The blastability index is calculated between 14 and 46 for the first case and between 17 and 47 for the second case. Where the rock mass strikes perpendicular to tunnel axis, and excavation drives with dip direction, the blastability index is calculated to be between 24 and 52. Where the underling rock strikes parallel to tunnel axis, the rock mass may be medium hard, or extremely soft to soft. The blastability index is calculated to be 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 the 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 spaced 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 is calculated to be 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 is calculated to be between 39 and 64 when strike is perpendicular to tunnel axis, when excavation drives with dip direction. The blastability index is calculated to be between 34 and 59 when the strike is parallel to tunnel axis. Concerning medium hard to hard rock mass, the blastability index is calculated to be between 26 and 51 where the discontinuities are horizontal.

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

The blastability index is calculated to be between 31 and 61 where the strike is perpendicular to tunnel axis, when excavation drives against dip direction. The blastability index is calculated to be between 41 and 66 where the strike is perpendicular to tunnel axis, when excavation drives with dip direction. Concerning hard and very hard rock mass, the blastability index is calculated to be between 27 and 52 where the discontinuities are horizontal. The blastability index is calculated to be between 32 and 57 where strike is perpendicular to tunnel axis, when excavation drives against dip direction. The blastability index is calculated to be between 42 and 67 where strike is perpendicular to tunnel axis, when excavation drives with dip direction. The blastability index is calculated to be 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.

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 developed, where; rock mass quality 1 refers to closely spaced discontinuities (Priest &Hudson, 1976), 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 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	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 every GSI classification part.

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.

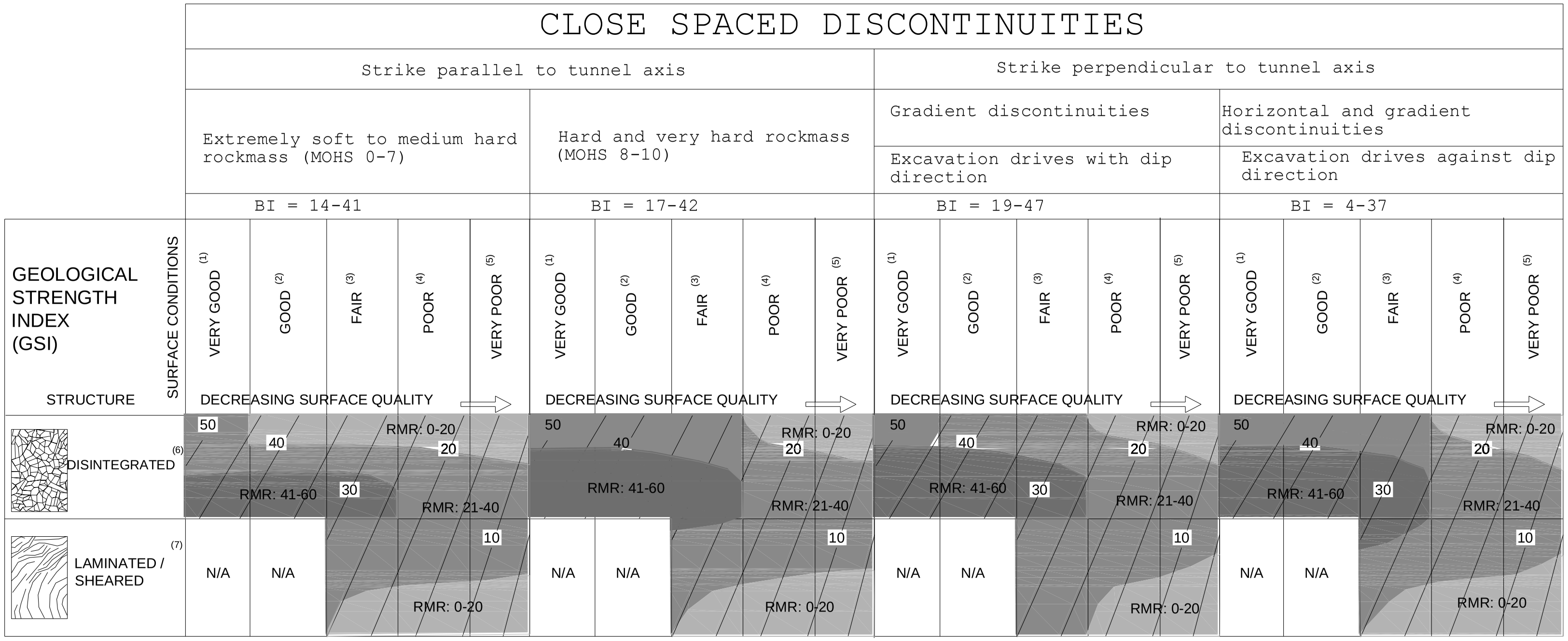
GSI (PART)	A/A: 2081-2140	A/A: 2141-2200	A/A: 2201-2280	A/A: 2281-2340	A/A: 2341-2400
	RMR	RMR	RMR	RMR	RMR
0-12 (A)	13-58	45-46,49-68,72-73	16-33	23-61	31-63
012-23 (B)	15-60	23-60	20-50	25-65	33-65
22-32 (C)	29-30,33-62,64-65	37-38,41-60,64-65	32-50,52-55	39-70	47-65,67-70
007-17 (D)	13-58	21-58	16-50	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

Looking at the above diagram, we can easily conclude that

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

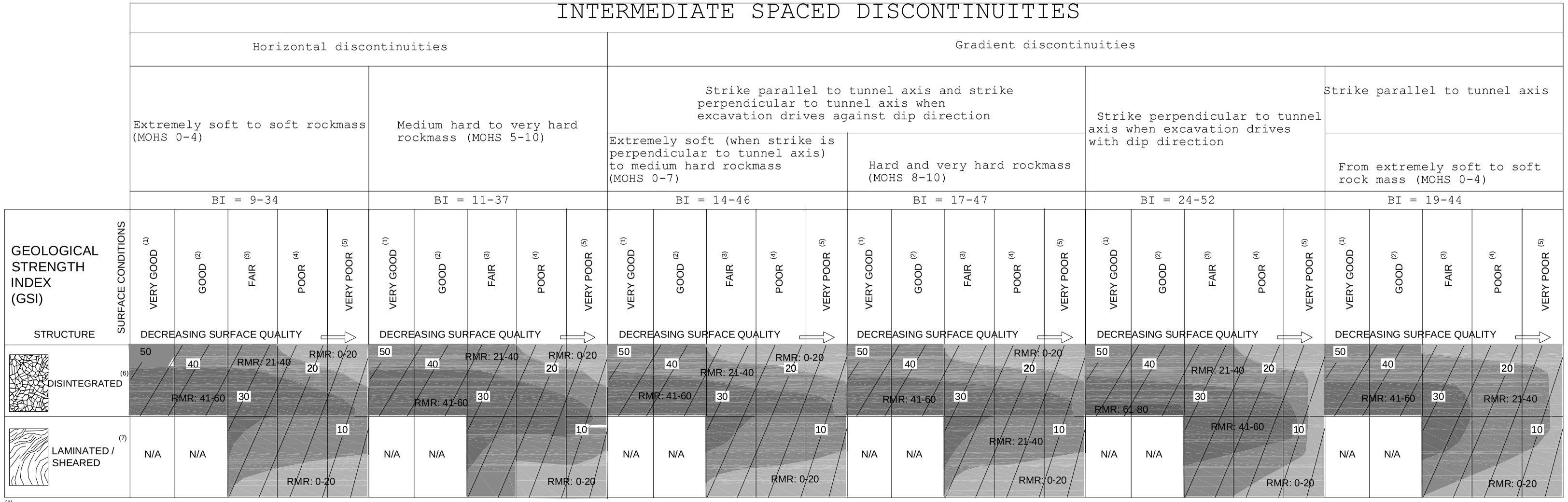
Table 9 – GSI estimations for different types of rock mass with specific RMR range.

RMR	A/A: 001-80	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	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												



(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 close spaced discontinuities.



(1) Very rough, fresh unweathered surfaces

(2) Rough, slightly weathered, iron stained surfaces

(3) Smooth, moderately weathered and altered surfaces

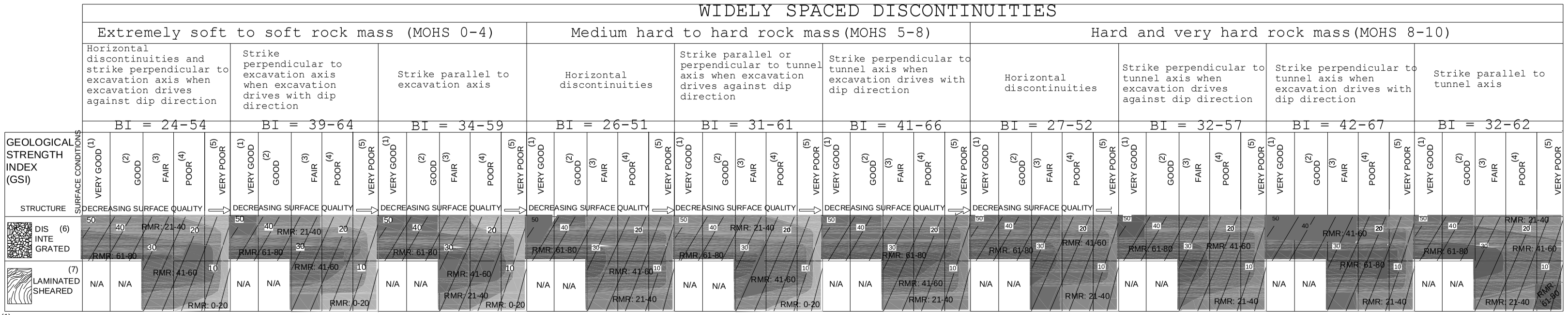
(4) Slickensided, highly weathered surfaces with compact coatings of rillings or angular fragments

(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 3 – BQS for intermediate spaced discontinuities.



(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 fillings 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 4 – BQS for widely spaced discontinuities.

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.

Table 11. GSI classification part for 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.

Table 12. GSI classification part for 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								

4. Blastability Quality System (BQS)

The 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 easy and wide use, it is a quick 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 the rock mass classification systems RMR and GSI, structural data, hardness of rock mass, and BI.

Initially, the discontinuities spacing is characterized. Secondly, the orientation of discontinuities in addition to the hardness of the rock mass is described. Having completed the above classification, the BI range can easily be determined. By visually inspecting the rock mass, we can easily distinguish discontinuity spacing and orientation. Also, we can estimate rock mass hardness using a Schmidt Hammer.

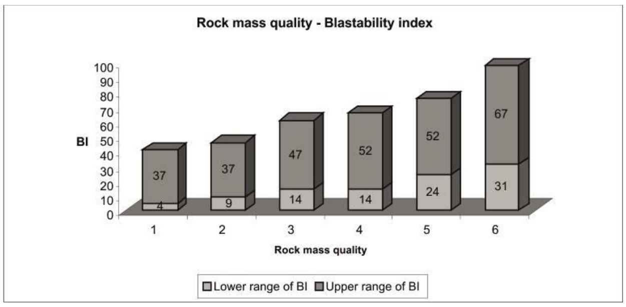


Figure 5 – Rock mass quality versus BI.

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

5. Conclusions

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

Evaluating the rock mass quality estimated by the RMR and GSI classification systems together with the calculated blastability index, a useful system, called Blastability Quality System (BQS), is created.

This "blastability quality system" can be a useful "in-situ tool", for estimating poor and friable rock masses, 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, discontinuity 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 viable tool for estimating the quantity of explosions and support measures to be decided using the already known methodology.

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