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Rock Mass Index (RMI) to Estimate the Shear Strength Parameters of the Rockmass: Case Study from Lesser Himalaya, Jammu & Kashmir, India

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Abstract. Rock Mass Index (RMI) is the method of rockmass classification system which gives emphasis on the block size, joint characteristics and strength of intact rock to express the UCS of the rockmass. The present work focuses on the applicability of RMI in the context of estimation of shear strength parameters, like angle of internal friction (Φ), cohesion (c), etc. and also the 'm' and 's' constants for Hoek-Brown failure criterion from the Anji Khad in Lesser Himalaya of Jammu & Kashmir. Lithology comprises stromatolitic limestone and dolomite of Proterozoic Sirban Group, which has experienced high degree of deformation due to the major thrusting activity (Reasi Thrust) in the region. The geological map of the area and geo-structural scanline surveys has been done for demarcation of different zones (5 zones have been delineated) on the basis of types of discontinuity and degree of jointing. The input data for the calculation of shear strength parameters as well as 'm' and 's' constants of H-B failure criterion were obtained from the characterization of the joints, which were then processed. The results were very much comparable with the data obtained by in-situ shear tests performed in the region earlier. In-situ tests are often performed to get the shear strength parameters, but due to their operational difficulties, high cost and timing factors, are not performed regularly which often create information gap and constructional problems in tunnels, foundation of bridges, etc. Therefore the method of estimation of shear strength parameters by RMi which is reliable and also cost- and time-effective, can be used extensively.

Keywords: RMi, shear strength, NATM, angle of internal friction, cohesion

1 Introduction

The rockmass incorporates type of rock and discontinuities present within it, and these discontinuities have significant impact on the stability of any engineering structures, like tunnels, foundation or slope designs. The shear strength of the discontinuities in rockmass has stronger influence on the mechanical behaviour of rockmass, and the structures often failed due to low shear strength. Even the deformation characteristics and stress distribution in rockmass depend upon the shear strength of the rockmass. Therefore, stability analysis of engineering structures requires assessment of shear strength parameters, i.e., cohesion (c) and angle of internal friction (Φ) of the rockmass (Singh and Goel, 2011). Evaluation of shear strength parameters are mostly done by in-situ shear tests (ISRM, 1981; IS 7746, 1983). However, Palmstrom (1995; 1996a, b, c & d) have applied Rock Mass index (RMI) system to assess the shear strength parameters of the rockmass. As RMI is based on the geological and geotechnical characterisation of rockmass directly on the ground, hence it has some inherent advantages over the use of in-situ shear tests. RMI has been used to (a) determine the constants 's' and 'm' in the Hoek-Brown failure criterion for rockmasses to assess the shear strength parameters, (b) work out ground response curves using the same 's' and 'm' constants, (c) quantify the descriptive NATM classification, and (d) estimate stability and rock support in underground openings.

The present work is an experiment carried out to determine the shear strength parameters by using the RMi of the Sirban Dolomitic Limestone at the vicinity of the major thrust zone in lesser Himalaya by following the method of Palmstrom (1996d). The study area is located at Anji Khad (33°05′N/74°53′E) near Reasi, Jammu & Kashmir, India. The Reasi region of Jammu & Kashmir lies in a hilly terrain of the foreland zone of Himalaya and is drained by major two rivers, namely, Chenab and Anji with their tributaries. Reasi Thrust considered as equivalent to the Main Boundary Thrust (MBT) passes through this region. Massive bedded Sirban Dolomitic Limestone of Proterozoic age occurs as inliers fringed by Shale, Carbonaceous Shale and Limestone of Eocene Subathu Formation and Sandstone-Mudstone of Murree Group (Fig. 1). Siwalik Group of rocks occurs in the south of MBT. The region is under high compressive stress regime, where maximum horizontal stress lies in the NE-SW direction. The rate of strain accumulation in the thrust blocks is very high, due to which frequent earthquakes are inevitable in this region. Singh and Sarwade (2015) evaluated the shear strength parameters in jointed Sirban Dolomitic Limestone from this same area. They have conducted in-situ shear tests on left and right banks of Anji River for the railway bridge to be constructed in this region. The present work centred on the same region and involves (a) Geological mapping and geostructural scanline survey to characterise the discontinuities present within the rock and calculation of RMi, and (b) determination of shear strength parameters by application of RMi. The obtained results of both the present and earlier works of Singh and Sarwade (2015) have been compared and analysed. Further an attempt has also been made here to bring out the validity of this method in application of slope design and/or tunnelling projects.

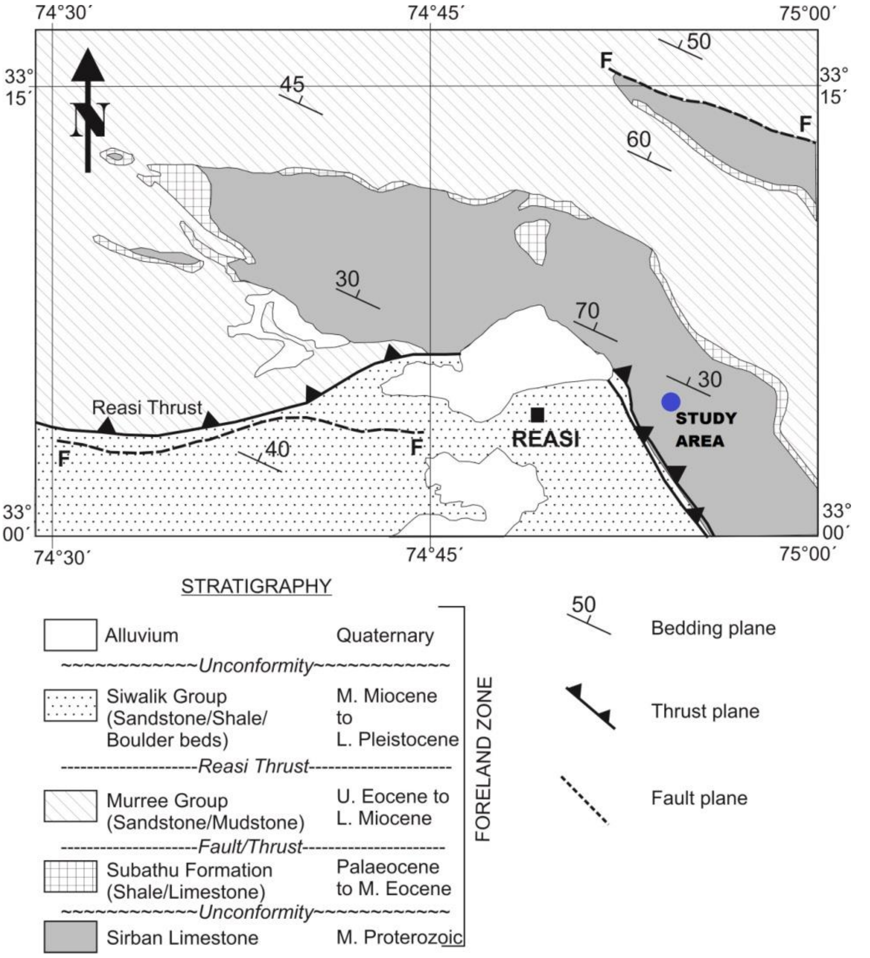


Fig. 1. Simplified geological map of Reasi area, Jammu & Kashmir, India (after GSI 1997 and 2005)

2 Methodologies

The exposures of the rock masses are excellent on both banks (right and left) of the Anji River. On the left bank, the bedded dolomitic limestone is exposed on the cliff, from which most of the geological data have been collected. At a few locations, especially along the small seasonal nallas (rills and gullies), small cones of debris are present. On the right bank of the river, bedded dolomitic limestone is exposed on the much lower level of the hill. Detail geological mapping and geo-structural surveys through scanline method has been done on the left and right banks of the Anji River. The overview of the geological set-up of the region has been obtained from (1) Poonch Quadrangle Sheet (degree sheet) of J&K State, No. 43K (scale 1:250,000) published in 1997 by Geological Survey of India; and (2) Geological Map of the

Himalaya (Western Sector) on the scale of 1:1,000,000 published by Geological Survey of India, Kolkata in 2005. Universal Transverse Mercator (UTM) coordinate system has been used to locate and draw the geological features on the map as well as on scanline diagrams. ISRM methodologies have been adopted for characterisation of rockmass (degree of jointing, type of discontinuities, orientation, spacing, persistence, roughness, apertures, fillings, etc.) from the field for geological mapping and scanline survey (ISRM, 1978). The estimated unconfined compressive strength (UCS) of the rockmass (σ_c) ranges from 40 to 80 MPa, though around the sheared/faulted areas the UCS is around 20 MPa.

On the basis of degree and character of discontinuities from detail geo-structural scanline surveys, five zones have been delineated: (I) moderately jointed zone (joint spacing 0.2 to 0.6 m), (II) closely jointed zone (joint spacing 0.06 to 0.2 m), (III) very closely jointed zone (joint spacing <0.06 m), (IV) open jointed zone, and (V) sheared/faulted zones. Joint characterisation has been done on the basis of ratings of (i) joint roughness factor (jR), (ii) joint alteration factor (jA), and (iii) joint length and continuity factor (jL). RMI of the rockmass has been calculated by using the inherent parameters like compressive strength (σ_c) of intact rock and the jointing parameters (JP). Detail theoretical description of the methodology for determination of shear strength parameters is beyond the scope of the present work. The RMI parameters, such as (i) scale factor of compressive strength (fσ), (ii) joint condition factor (jC), and (iii) jointing parameter (JP) have been calculated. These followed by estimation of constants of Hoek-Brown (H-B) failure criterion ('s', m_b and h) and shear strength parameters (friction angle (Φ_i), shear stress (τ_i) and cohesion (c_i) by following the methods of Palmstrom (1996d) (Table 1).

Table 1. The input data and calculation sheet for determination of shear strength parameters from RMI

	INPUT DATA	
1	Rock characteristics	Type of rock
I	Rock compressive strength (MPa)	Σc
II	H-B's m-factor for intact rock	m_i
2	Joint characteristics	
I	Joint roughness factor	jR
II	Joint alteration factor	jA
III	Joint length and continuity factor	jL
3	Block volume (m^3)	Vb
4	Effective normal stress (MPa)	σ'
	CALCULATIONS	
5	RMI parameters	
I	Scale factor of compressive strength	Fσ

II	Joint condition factor	jC
III	Jointing parameter	JP
IV	Rock Mass Index	RMi
6	Shear strength parameters	
I	Instantaneous friction angle (°)	Φ
II	Shear stress (MPa)	T
III	Instantaneous cohesion (Mpa)	C

3 Results

Detail geological mapping reveals that the geological succession around this area comprises dolomitic limestone (stromatolitic) of Sirban Group (Fig. 2). The bedding plane is unidirectional, steeply oriented (50-70°) towards N-NE, with local variations along the faults. Other three prominent sets of joints with random joints occur (65/025, 70/280, 50/150). W-NW-ly (70/280) steeply dipping joint set is very persistent. It has been further inferred that the region is characterized by moderate jointing except at some locations, where the density of jointing is high to very high. There are numerous major and minor faults (oriented 65/300, 30/055, 45/160) and three major NNE-SSW trending sinistral faults sliced the region. They are identified by variation of dip and strike of beds along the fault planes, scarps and presence of calcite veins and slickensides. These faults are transverse to the MBT or Reasi Thrust. With these major faults, some minor faults NNW-SSE and NW-SE trending are also present; fault planes are defined by smooth polished and/or slickensided surfaces and are often associated with fault gouge and calcite veins. Some shear zones have also been delineated which have soft fillings.

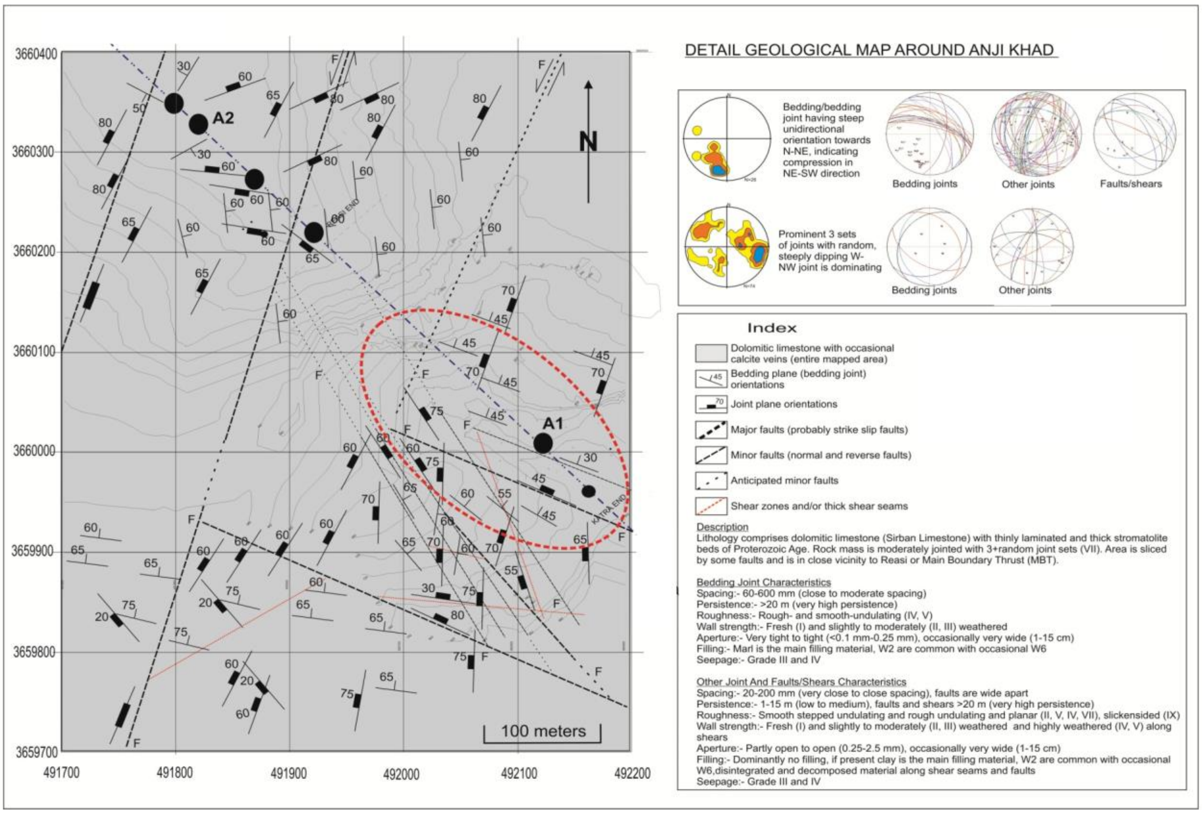
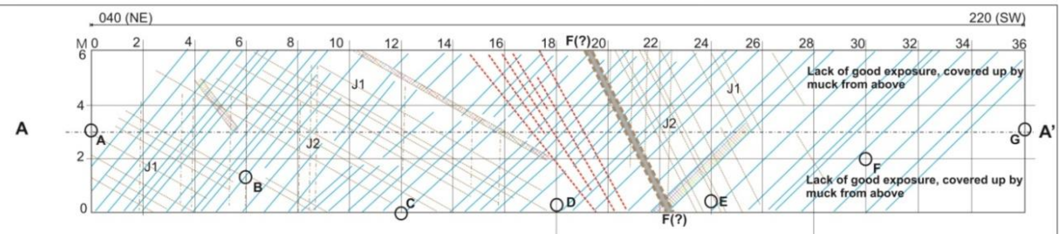


Fig. 2. Detail Geological map around Anji Khad , Reasi, Jammu 7 Kashmir, India. A1 and A2 are the locations of in-situ shear tests of Singh and Sarwade (2015)

The unconfined compressive strength (UCS) of the intact rock (σ_c) ranges from 40 to 80 MPa, though around the sheared/faulted areas the UCS is around 20 MPa. The discontinuities are bedding joints, tectonic joints, faults and shears. All the discontinuity planes are quite persistent and have different characteristic features (Fig. 3 & 4; Table 2). The block volumes (Vb) and diameter of blocks (Db) have also been estimated (Palmstrom, 1995) (Table 3). The scale factor for compressive strength (fσ) joint condition factor (jC), ratings of jointing parameter (JP) and Rock Mass Index (RMi) have been ascertained on the basis of block diameter (Db) and combination of three characteristic features of discontinuity planes, like joint roughness, joint alteration and joint length (Table 4). From the analysis it has been inferred that the values of jC, JP and RMi decreases from Zone I to Zone V, whereas the fσ increases from Zone I to Zone V. The author here used the Hoek-Brown (H-B) failure criterion to determine the shear strength parameters of the rockmass, and for that he used the RMi to estimate the constants, like, ‘s’ and m_b in H-B failure criterion (Table 4). The results of residual shear strength parameters like, cohesion (c), friction angle (Φ) and shear strength obtained by Singh and Sarwade (2015) are 0.38 to 0.71 MPa, 48.97° to

51.39° and 6.89 to 7.59 MPa respectively . In comparison it has been found that in the present work the correlation coefficient (R^2) of each parameter is having strong positive correlation ($\Phi/\tau = 0.984$, $\Phi/c = 0.962$ and $\tau/c = 0.995$) whereas correlation coefficient (R^2) of each parameter of Singh and Sarwade (2015) is not having strong positive correlation (($\Phi/\tau = 0.793$, $\Phi/c = 0.032$ and $\tau/c = 0.368$).

SCANLINE SAMPLING AT KATRA END (LEFT BANK OF ANJI RIVER), ANJI KHAD



Joint orientation	Bedding joint 35-45/040; J1 60/190; J2 vertical (130-310 orientation)	Bedding joint 35-45/040; J1/fault 70/285; J2 vert.	Bedding joint 35-45/040; J1 70/285
Joint spacing	20-200 mm bedding joints and other joints	20-200 mm bedding joints and other joints	60-200 mm bedding joints
Joint persistence	>20 m and 1-5 m bedding and other joints, shears 1-5 m	1-20 m bedding and other joints, shears/fault >15 m	1-20 m bedding and other joints
Joint roughness	Bedding joints IV, V, other joints II, VII, VIII, IX	Bedding joints IV, V, other joints II, VII, VIII, IX	Bedding joints IV, V, other joints II, VII
Wall strength	Bedding joints S2, S3, R2; other joints S2, S3, R1, R2	Bedding joints S2, S3, R2; other joints R1, R2	Bedding joints S2, S3, R2
Joint aperture	0.25 mm- 10 mm; 1-20 cm occasionally	0.25 mm- 10 mm; 1-20 cm occasionally	0.25 mm- 10 mm
Joint filling	Marl in bedding joints, disintegrated/fractured or crush of wall rock	Same	Marl in bedding joints
Seepage	I, II, IV, V	I, II, IV, V	-------

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Co-ordinates
A:- E492131.518/N3660023.939/763.000m
B:- E492126.018/N3660020.955/761.625m
C:- E492118.790/N3660016.988/759.859m
D:- E492112.988/N3660013.841/760.694m
E:- E492109.731/N3660011.721/760.811m
F:- E492103.591/N3660007.458/761.894m
G:- E492098.242/N3660007.298/763.332m

Bedding joints
Other major joints
Other minor joints
Shear seams (thin <20 cm)
Open joints
Fault (?)

Lithology- Dolomitic limestone (stromatolitic and laminated)

Spacing in mm
20-60- Very close
60-200- Close
200-600- Moderate

Persistence in m
1-3- Low
3-10- Medium
10-20- High
>20- Very high

Roughness
II- Smooth, stepped
IV- Rough, undulating
V- Smooth, undulating
VII- Rough, planar
VIII- Smooth, planar
IX- Slickensided, planar

Wall strength
S2- Soft clay
S3- Firm clay
R1- Very weak
R2- Weak

Aperture in mm
0.1-0.25- Tight
2.5-10.0- Mod. Wide
10-100- Wide/extr. Wide

Seepage
I- Dry
II- Damp
IV- Signs of outwash
V- Washed out completely

Fault (?)- 20-25 cm wide, there are signs of outwash material

Fig. 3. Representative scanline survey from Anji Khad area

A) Vertical bedding joints in dolomictic limestone

B) Dol. Lst. with numerous closely spaced joints and ~5 cm thick calcite vein

C)Rough and smooth undulated bedding joint surfaces

D) Shear/fault zone with gouge in the center. Thickness of gouge is 15 cm

F) Low angle fault and occurrence of numerous shear seams

G) Joint apertures having soft infilling material with grown grasses

Fig. 4. Field photographs showing characteristic features of the rockmass. The stick in photographs is 1.5 m

4 Discussions

The study area is located at close vicinity of a major thrust, i.e. Reasi Thrust or Main Boundary Thrust (MBT), due to which the Sirban Dolomitic Limestone of Proterozoic age experienced significant tectonic deformation. High compressive stress in the region created tectonic joints and tilted the rock. The bed thickness of dolomitic limestone ranges from 10 to 50 cm, and the zones having lesser bed thickness have more closely spaced bedding joints as well as the tectonic joints. The degree of jointing has influenced the strength of the rock; relatively thinner beds are more prone to the effect of weathering also. Therefore, there are variations in the UCS of the intact rock (20 to 80 MPa) also. In addition to the UCS, the jointing parameters (JP) have incorporated, which provided the Rock Mass Index (RMi) of the rockmass (cf. Palmstrom, 1996a).

Table 2. Characteristic features of the discontinuity surfaces with their ratings

Joint characteristics	ZONES				
	Zone I	Zone II	Zone III	Zone IV	Zone V
Joint roughness (jR)	Rough slightly undulating	Rough planar	Rough planar	Smooth planar	Polished/ slickensided
Rating	4	2	2	1	0.75
Joint alteration (jA)	Thin filling of clay	Thin filling of clay	Thin filling of clay	No joint wall contact, filling of soft clay	No joint wall contact, filling of soft clay
Rating	4	4	4	8	8
Joint length and continuity (jL)	10-30 m, continuous	10-30 m, continuous	10-30 m, continuous	10-30 m, continuous	>30 m, continuous
Rating	0.75	0.75	0.75	0.75	0.50

Table 3. Geomechanical properties of the rockmasses of different zones

Features	ZONES				
	Zone I	Zone II	Zone III	Zone IV	Zone V
Discontinuity types and spacing	moderately jointed zone (Joint spacing 0.2-0.6 m)	Closely jointed zone (Joint spacing 0.06-0.2 m)	Very closely jointed zone (Joint spacing <0.06 m)	Open jointed zone	Fault/shear zone
UCS	80 MPa	60 MPa	40 MPa	40 MPa	20 MPa
Vb (m^3)	0.0045	0.0015	0.0009	0.0007	0.0004
Db (m)	0.20	0.11	0.09	0.08	0.06

Hoek-Brown (H-B) failure criterion (Hoek and Brown, 1980; Hoek, 1983; Hoek et al., 1992) provides the means of estimating the strength of jointed rockmasses. RMi has been applied to determine the constants ‘s’ and ‘m’ of the H-B failure criterion (Table 4). Earlier Hoek and Brown (1980) and Hoek et al. (1992) adapted the classification systems of RMR and Q system to determine the ‘m’ and ‘s’ constants, but these systems include external factors like ground water and stresses. Subsequently Hoek (1994) and Hoek et al. (1995) developed GSI system and linked it for estimation of failure criterion. GSI is based on a good geological model of the area, emphasizing on geological structures and surface conditions, but does not fulfill the requirement of engineers who believe in numbers and not in qualitative approach (Hoek and Marinos, 2000; Hoek and Brown, 2018). As constants ‘m’ and ‘s’ depend up on the properties of the rock, these values lower as the rockmass condition deteriorates from Zone I to Zone V in this present work (Table 4).

A positive correlation has been found as higher the spacing of the joints, higher the block volumes, diameter of the blocks and also the UCS of the rockmass (Table 3) (cf. Ramamurthy, 1993; Ramamurthy and Arora, 1994; Singh, 1997; Singh et al., 2002; Singh and Rao, 2005; Singh and Singh, 2012). These have resulted in gradual deterioration of shear strength parameters from Zone I to Zone V and thus have the strong positive correlation coefficient (R^2) among each parameter (Table 4). On comparison of results of present study with that of earlier work (Singh and Sarwade, 2015), it has been found that the values of Φ, c and τ of present work are much less. Results obtained from Singh and Sarwade (2015) does not show a strong positive correlation coefficient (R^2) among each parameter. These variations are mainly due to (1) difference in methodology of determination of shear strength parameters, and (2) the present work conducted at the surface whereas Singh and Sarwade (2015) conducted their test underneath the ground (in drifts having significant overburden), where weathering effect is minimal. Here characterization of geological features disposed on the area as well as their quantitative analysis have been done and used as foremost criteria to classify each zones (Zone I to Zone V), therefore the determined shear strength parameters can be easily relatable with the geological features, e.g. moderately jointed zones (Zone I) have high Φ, c and τ, whereas faulted/sheared zones (Zone V) have very low Φ, c and τ (Table 4).

Table 4. Estimation of shear strength parameters of rockmasses

	Zone I	Zone II	Zone III	Zone IV	Zone V
Type of rock			Dolomitic Limestone		
σc (MPa)	80	60	40	40	20
Mi	8.4	8.4	8.4	8.4	8.4
jR	2	2	2	1	0.75
jA	1	4	4	8	12
jL	2	0.75	0.75	0.75	0.5
Vb (m^3)	0.0045	0.0015	0.0009	0.0007	0.0004
σ′ (MPa)	1	1	1	1	1
Fσ	0.8797	0.8448	0.889	0.9117	0.9641
jC	0.75	0.375	0.375	0.0937	0.0312
JP	0.0115	0.0065	0.0052	0.0008	0.0001
RMi	0.924	0.393	0.208	0.032	0.002
S	0.00013	0.00004	0.00002	0	0
Mb	0.4835	0.3365	0.2904	0.0888	0.0243
H	1.1409	1.2661	1.4607	2.5015	11.9634
Φ (°)	44.38	38.53	33.34	22.58	9.63
‘τ (MPa)	1.485	1.195	0.994	0.624	0.297
c (MPa)	0.507	0.399	0.336	0.208	0.128

The analysis of physical and engineering properties (especially the shear strength parameters) of the rocks is important for the design of the structures. In practice the rocks are invariably intersected by discontinuities, which govern the strength and deformational behavior. Therefore, the engineering properties assessed by laboratory tests on intact rocks are not suitable for use directly in analysis and design. Further in-situ shear tests are too costly, time taking and usually done prior to construction process. There are several models for the determination of shear strengths like RMR based Mohr-Coulomb failure criterion, Patton's Model, Q-index based Barton Model. However, Mehrotra (1992) clarified that the shear strength is under-estimated or over-estimated by these methods. Later GSI based Hoek-Brown failure criterion became the most widely used method for shear strength determination. But in this case also only geological features and disturbances to the rockmass are involved, and no measurements like joint mapping and quantitative analysis of joints, etc are done in field. Subsequently Ramamurthy criterion (Ramamurthy, 1993; Ramamurthy and Arora, 1994) and modified Mohr-Coulomb criterion (Singh and Singh, 2012) has also came into existence. However, the most reliable method of shear strength determination is Hoek-Brown failure criterion due to its extensive acceptability to the engineering geologists and engineers. Thus, the RMi system of Palmstrom (1996d) for classification of rockmass and application of the same for determination of constants 's' and 'm' in the Hoek-Brown (H-B) failure criterion for rockmasses to assess the shear strength parameters is quite useful. This method is cost effective, not so time taking and can easily be done at any stage of design, construction, etc. Applications of RMi are manifold: (1) it can be used to work out ground response curves using the same 's' and 'm' constants, (2) also useful for quantification of the descriptive NATM classification, and (3) to estimate stability and rock support in underground openings.

5 Conclusions

Five zones have been delineated (Zone I to V) on the basis of the discontinuity types and spacing of discontinuities in Sirban Dolomitic Limestone. The rockmass is poor with low UCS values throughout and intersected by numerous discontinuities, thus having low shear strength parameters (Φ, c and τ). The correlation coefficient (R^2) among each shear strength parameter having strong positive correlation. When compared with the in-situ tests done earlier in this area, the values of present obtained results are quite low. This may be due to the variation in methodology and location. In-situ tests are often performed to get the shear strength parameters, but due to their operational difficulties, high cost and timing factors, are not performed regularly which often create information gap and constructional problems. Therefore the method of estimation of shear strength parameters by RMi which is reliable and also cost- and time-effective, can be used extensively. Therefore, there are ample scopes for future studies on this aspect of RMi rockmass classification system.

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