Review of Rock Mass Classification of Tropically Weathered Rock

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Abstract
In tropical climate, limestone is frequnetly exposed to rain water which when absorbed by limestone forms carbonic acid. This further enhances process of dissolution resulting in change in geomechanical properties of limestone. With various geological discontiuties such as faults, folds, joints, water flows through these cavities. The weathering process along these cracks or cavities takes place at faster rate. In this paper, two case studies are reviewed. Rock mass is classified based on lithology, degree of hardness, degree of weathering, % of cavities, Rock Quality Designation (RQD)% and nature of joints. In another case study on limestone deposist from Thailand is classified based on Geological Strength Index (GSI) which enhances blast design. Limestone deposit at Aruwakkalu based on rock structure can be classified as (i) heavily cracked, frequent weak joints, weakly cemented layers (ii) Thin, well-cemented layers with tight joints (iii) Massive intact rock. This limestone deposit is also classified as bedding plane dipping into face, bedding plane dipping into cut and other cases. Existing system of rock mass classification at Sri Lanka is reviwed with case studies. Thus for Aruwakkalu limestone deposit, rock mass can be classified based on type of rock structure, Blastability Index (BI), RQD%, degree of weathering and degree of hardness. Average powder factor of 0.15 kg/t can be correlated with BI.

Keywords: Blastability Index, Geological Strength Index, Karst Limestone, Rock Quality Designation, Rock Structure

1. Introduction

Rock Mass Classification is the system development of placing a rock mass into groups or classes on defined relationships and selecting a specific description (or number) to it on the basis of comparable aggregate properties/characteristics such that forecast on the behavior of the rock mass can be carried out [1]. In rock enginnering, three design strategies are followed namely empirical, analytical and numerical. Rock mass classification is commonly used for prefeasibility, pre design and final design.

In tropical climate, rock will have different degree of weathering which will have varied mechanical properties affecting direct blast performance. Rock properties are not controllable parameters for blasting which may not be understood by field personnel. Rock mass classification system helps field person for blast design and predicting blast performance..

The objective of this study is reviewing rock mass classification of tropically weathered rock and comparing with other rock mass classification systems in tropical region.

Sri Lanka is situated close to the equator and has tropical monsoons: the northeast monsoon (December to March), and the southwest monsoon (June to October). Weathering is physical and chemical process of disintegrating rock and minerals. Carbondioxide in the air is easily dissolved in rain water resulting in carbonic acid which rapidly reacts with limestone rock. There are various geological discontuites such as joints, faults, folds where rain water enters these discontuites Weathering of limestone do occur below surface resulting in karst, dolines or sinkholes and cave formation. During weathering process, gemechanical properties of limestone rock change such as change in pore geometry which result in lower compressive strength or weaker limestone formation [2]. With absorbption of water, limestone becomes weaker. As per British standard, rocks are classified as fresh, slightly weathered, moderatley weathered, highly weathered and completely weathered [3,4].

The challenge for any mining engineer in hard rock mining is to obtain optimum powder factor. The optimum powder can be defined which results in good fragmentation as desired, throw, backbreak and minimize environmental impact due to blasting such as flyrock, ground vibration, airover pressure. Optimum powder factor also results in overall lowest blasting cost. Blastability is the susceptibility of the rock mass property to the blasting which is closely related to powder factor [5].

2. General Information

This section describes some of important terminology and geology of the limestone deposit in Sri Lanka.

2.1 Rock Quality Designation (RQD)

In order to quantify the quality of the rock from drill cores, the concept of the RQD was developed. RQD is defined as the percentage of intact core pieces longer than 100 mm in the total length of a core having a core diameter of 54.7 mm [6]. RQD can be calculated from core logs as well as the field measurement.

2.2 Geological Strength Index (GSI)

The RMR system or the Geomechanics Classification was developed by Bieniawski during 1972-1973 in South Africa to assess the stability and support requirements of tunnels [7]. The GSI was introduced to facilitate the determination of rock mass properties of both hard and weak rock masses for use in rock engineering [8]. GSI resulted from combining observations of the rock mass conditions with the relationships developed from the ex-perience gained using the RMR-system [9]. The relationship between rock mass structure (conditions) and rock discontinuity surface conditions is used to estimate an average GSI value represented in the form of diagonal contour. It is recommended to use a range of values of GSI in preference to a single value [10]. This simple, fast and reliable system represents nonlinear relationship for weak rock mass, can be tuned to computer simulation of rock structures[11] and can provide means to quantify both the strength and deformation properties of a rock mass.

2.3 Blastability Index [BI]

Lilly developed a blasting index based on rockmass description, joint density & orientation, specific gravity and hardness [12]. This index can closely be related with powder factor. To use Lilly's blastability index, it is required to establish a site specific relationship between this Blastability Index and the Powder Factor. This can be established either with the help of historical blast records or from trial blast results. Lilly proposed the following formula –

Bl = 0.5 x (RMD + JPS + JPO + SGI + H)

Where, BI = Blasting Index

RMD (Rock Mass Description) = 10, for powdery/friable rockmass

= 20 , for blocky rockmass

= 50 , for totally massive rockmass

JPS (Joint Plan Spacing) = 10 , for closely spacing (<0.1 m)

= 20 , for intermediate (0.1 – 1.0 m)

= 50 , for widely spacing (>1.0 m)

JPO (Joint Plane Orientation) = 10 , for horizontal

= 20 , for dip out of the face

= 30 , for strike normal to face

= 40 , for dip into face

SGI = Specific Gravity Influence,= 25 x ´ specific gravity of rock (t/m3) – 50

H = Hardness in Mhos scale (1 – 10).

Blastability index for each site has to be correlated with powder factor and may increase or decrease with respect to blastability index value.

2.4 Porosity and Cavity

In limestone due to dissolution of water, pores are created. Porosity is the ratio of volume of voids or space divided by total volume of rock. Porosity is a measure of how much rock has open space.

Cavities are created by network of pores which may extend from few centimetres to couple of meters. Cavity may be void or filled with clay.

2.5 General Information and Geology of Limestone Deposit in Sri Lanka

Aruwakkalu Limestone is a part of Sri Lanka's Jaffna limestone, which underlies the whole of Jaffna Peninsula and extends southwards mostly along the west coast. As shown in Figure 1. Limestone deposit is of Miocene age in the south - western part of the Aruwakkalu which is approximately 40 km from Puttalam Cement Works.

Figure 1 - Jaffna Limestone Deposit [13]

The limestone deposit has occurred in Miocene period. Before millions years ago Sri Lanka and India was together and then it was started to divide. Then big lagoon was created between

Sri Lanka and southern part of India. In that lagoon there were large amount of coral reefs which contain fossils. Then the lagoon dried and corals were also dried. It is believed that Kala Oya flowed through this location. Then clay layers and sand layers were deposited on this died limestone. Then red earth included to the cavities which present in limestone. It is believed that red earth is an Aeolian deposit which has come with wind from South India. Red earth has very fine particles. The deposit consists with 6 layers as shown in Table 1.

Table 1 - Layers in Aruwakkalu Limestone Deposit [14]

Layer Number	Description
First	Red earth
Second	Low grade limestone
Third	Clay
Fouth	Low grade limestone
Fifth	High grade limestone
Sixth	The base

Figure 2 - Aruwakkalu limestone deposit's third layer (black arrow) [14]

The red earth layer consist with Al_2O_3, Fe_2O_3, and Ilmenite etc. The red earth has mixed with second limestone layer through its pockets. Due to that it is considered as low grade limestone. The last layer is the base. It consist with higher grade limestone. But the problem is the moisture content of that is high due to increasing of water level. Because of impurities, such as clay, sand, organic remains, iron oxide and other materials, many limestone exhibit different colors, especially on weathered surfaces [14].

Limestone deposit at Aruwakkalu can be classified based on rock structure as under [15]:

(i) Heavily cracked, frequent weak joints, weakly cemented layers

(ii) Thin, well-cemented layers with tight joints

(iii) Massive intact rock.

Figure 3 - Aruwakkalu limestone deposit's sixth layer [14]

This limestone deposit is also classified as bedding plane dipping into the face, bedding plane dipping into cut and other cases.

3. Case Studies on Rock Mass Classification

This section describes where limestone mines are in tropical climate and rock mass classification is done for the purpose of blasting.

3.1 Limestone Deposit at Thailand

Limestone mine is in Thailand producing 5 million tonnes per annum. Limestone was previously classified as overburden, low grade limestone, high grade limestone and dolomatic limestone based on results of chemical analysis during exploration stage. The same was not suitable for the purpose of blasting. Geological study was undertaken and limestone was classified as blocky, very blocky, blocky/seamy and disintegrated [16, 17]. GSI values varied 40-70 (blocky), 30-60 (vey blocky), 20-50 (blocky/seamy) and 15-45 (disintegrated) and average blastability index values were 56(blocky), 46(very blcky), 41(blocky/seamy), and 33 (disintegrated) [18]. At production faces, limestone is fresh, slightly weatherd and moderatley weathered. In development face, limestone is moderately and highly weathered. This approach of rock mass classification has improved blast fragmentation and enhanced productivity of a mine [19]. Further paramters for rock mass classification for this limestone deposit are RQD%, degree of weathering, degree of hardness, % cavities, bedding or fracture attitude, bedding thickness.

3.2 Limestone Deposit at Cambodia

This limestone deposit is under development where exploration has been completed. Mine roads and production faces are being developed. Limestone deposit consist of hills where at one of hill bottom cave is also found. Limestone deposit in Cambodia consist of karst limestone. In most of the area, limestone is fresh, slightly weathered and moderately weatherd. Limestone around cavities is moderately weathered and highly weathered. 99% of cavities in karst limestone are found with argillaceous limestone and upper cherty limestone. Based on cavity classification, 74% drilling area has average cavities of 0.37% which is least. 9% of drilling area has >20% of cavities or 2% of total area which is highest and concern for blast performance from fly rock, fragmentation and back break point of view. Rock mass is classified based on borehole logs and shown in Table 1 having RQD%, degree of weathering and degree of hardness as parameters. Table 2 illustrates % of cavity in borehole, bedding angle and fracture attitude as parameters for classification of rock mass Table 3 shows bedding thickness and jointing and fracture spacing as parameters for classification of rock mass [20,21].

Table 1 - Classification of rock mass based on RQD%, weathering and Mohs scale of hardness [22]

Class	RQD%		Degree of weathering	Degree of hardness
1	< 25%	Very poor rock	Completely weatherd rock	Very soft rock; Mohs<1
2	25-50%	Poor rock	Highly weathered rock	Soft rock; Mohs 1 to 3
3	50-75%	Fair rock	Moderately weathered rock	Medium hard rock; Mohs 2.5 to 4.5
4	75 -90%	Good rock	Slightly weathered rock	Hard rock; Mohs 4.5 to 6
5	90-100%	Very good rock	Fresh rock	Very hard rock; (Mohs >6)

Table2 - Classification of rock mass based on cavity , bedding angle and fracture attitude [22]

Class	% Cavity invidual BH	% Total drilling	Overall cavity area %	Bedding angle	Fracture Attitude
1	< 3%	74	0.37	Very gentlr dip	10 - 5^0
2	3 to 6%	13	0.59	Gentle dip	5^0- 20^0
3	6 to10 %	0	0	Moderate dip	20^0-45^0
4	10 to 20%	4	0.64	Steep dip	45^0-80^0
5	>20%	9	2.07	Very steep dip	80^0-90^0

Table 3 - Classification of rock mass based on bedding thickness, jointing and fracture spacing [22]

Class	Bedding Thickness		Jointing and Fracture spacing	
1	Very thickly bedded	>100 cm	Wide fracture spacing	>90 cm
2	Thickly bedded	30-100 cm	Moderaly close fracture spacing	20-90 cm
3	Medium bedded	10-30 cm	Close facture spacing	10-20 cm
4	Thinly bedded	3-10 cm	Very close fracture spacing	5-10 cm
	Very thinly bedded	1-3 cm		
5	Thickly laminated	0.3-1 cm	Extremely close fracture spacing	< 5 cm
	Thinly laminated	0.1- 0.3 cm		

This limestone deposit was under development. Rock mass classficiation system helped, field personnel to know areas having more cavities which is the matter of conceren of blast performance.

4. Discussion

Initially rock mass classification system was developed by Terzaghi for tunnels with steel support [23]. Further various rock mass classification systems: New Australian Tunneling Method (NATM), Rock Quality Designation (RQD), Ricj Struture Rating (RSR), Rock Mass Rating (RMR), Rock Mass Quality (Q) and Strength Block Size (RMI) were developed mainly for tunnelling where the objective is to support excavated area from construction stage till tunnelling work is completed [23-35]. RMR, Q and GSI are also used for slopes, underground excavation and foundation where consideration of gravitional forces is important. For foundation, structure above foundation should be able to withstand. In all cases including blasting, rock mass strength is important. However, in case of blasting, rock is to be broken instead of supporting other rock mass. Desirable fragmentation and minimization of environmental impacts are important.

Limestone deposit in Sri Lanka is comparable with limestone deposits in Thailand and Cambodia. Due to tropical climate, degree of weathering may vary. Degree of weathering can be compared with global weathing standard followed in Britain. Based on the field observation, limestone in Sri Lanka can be classified into three categories : moderatley weathered, highly weathered and completely weathered Further paramteres considered for rock mass classification at Thailand and Cambodia can be considered for rock mass classification at limestone deposit at Sri Lanka. Only difference is that limestone deposit at Sri Lanka is weathered more as compared to Thailand and Cambodia. Paramneters related to geological discontinuties consisting of joint orientation, bedding orientation will have less impact. In limestone at Sri Lanka explosives energy will be absorbed in rock mass instead of fragmenting further. Limestone deposit at Sri Lanka is also classified based on structures and thus blastability index and GSI will be important parameters to be considered.

5. Conclusions

(1) Aruwakkalu Limestone deposit at Sri Lanka can be classified based on degree of weathering into three main categeries moderatley weathered, highly weathered and completely weathered.

(2) Limestone deposit at Sri Lanka is more weathered as compared to limestone deposits in Thailand and Cambodia. Limestone deposit in Sri Lanka does not have cavities similar to Karst Liemstone of Cambodia. In limestone of Sri Lanka, these cavities might have been filled with clay and hence empty cavities are not visible.

(3) Powder factor and BI needs to be correlated for each face based on degree of weathering.

(4) Exploration data of Aruwakkalu limestone deposit needs to be critically examined for if cavity are present and classify based on bedding thickness and angle, joint spacing and orientation, fracture attitude.

(5) Bottom layer of limestone deposit contains water which will impact blastability of limestone.

(6) Thus for Aruwakkalu limestone deposit, rock mass can be classified based on type of rock structure, BI, RQD%, degree of weathering and degree of hardness. Average powder factor of 0.15 kg/T can be correlated with BI.

(7) RQD, GSI, BI are also important parameters for rock mass classification which are identified gaps. With further collection of data, field observation and recording of blast performance will enable for strenghthening of rock mass classification system. Knowledge of rock mass classification will enhance blast design and obtain better blasting results.

(8) After adequate data of Aruwakkalu limestone deposit is collected on various rock mass properties-degree of weathering, RQD% and GSI compared with powder factor and BI, rock mass classification system can be further strenghthened.

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