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Stability Analysis of Pit Slope in Granitic Rock Mass

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ABSTRACT: Rock mass is a host rock where quarry and mining activities take place. Right from Egyptian time till the dawn of civilization, extractive industries have experienced different levels of economic losses due to lack of proper analysis of the rock mass stability and the mining parameters that could be of economic advantage to the enterprise. The stability analysis of the quarry (Samchase Nigeria Ltd) pit slope in granitic rock mass was carried out using geo-mechanical characterization and stereographic net methods. In the in-situ observation, parameters for Rock Mass Rating were measured and the attitude of the discontinuities were taken with the compass clinometers. The mechanical and physical properties of the five rock samples taken from the field were determined through different laboratory tests. The average point load index (I_s) value was 2.70 Mpa, slake durability test, 96.08, the density, 2.68 kg/m^3 and the slope rock mass rating was 64%. The two methods employed for the stability analysis of the pit slope of Samchase Nig. Ltd's quarry showed that it is good and stable but there exist some blocks that must be controlled so as to maintain the stability for effective quarry operation.
KEYWORDS: Rock mass, Stereonet, Discontinuity, Slope and Stability

I. INTRODUCTION

Rock mass is a host rock for quarrying and mining activities. Right from Egyptian time till the dawn of civilization, extractive Industries have experienced different levels of economic losses due to lack of proper analysis of the rock mass structures and the mining parameters that could be of economic advantage to the enterprise. Also, avoidable accident had occurred because of little knowledge on the dynamic nature of the rock mass (Brown, 1993; Hoek, 2000).

Rock mass comprises of solid and compact parts called intact rocks, which contain fractures on the small scale and it composes of grains with the form of a microstructure that is governed by the fundamental rock forming processes (Hudson & Harrison, 1997; Hudson, 1993). Also, discontinuities such as: joints, bedding planes, folds, sheared zones and faults form part of rock mass which render its structure discontinuous (Oluwaseyi & Ajibola, 2017; Goodman, 1989).

The behavior of intact rock is known mostly through its physical properties. The knowledge of its deformability, strength and failure will help in the determination of support capacity which is one of the desired properties to be reckoned with in engineering. The intact rock can be said to be a continuum or polycrystalline solid that are between discontinuities (Zhang, 2005). It can be described by the petrological name, color, texture, grain size, minor lithological characteristics, density, porosity, strength, hardness and deformability. The geological classification considers the rock mineral and genesis of intact rocks while engineering's is based on strength and deformation properties of the rock. In order to describe rocks quantitatively and to carry out the mechanical and hydraulic estimate of their properties, the following index properties can be employed: porosity, density, wave velocity, point load index, Schmidt hammer rebound number and Slake durability index (Hoek, 2007; Hudson and Harrison 1997). It must be noted that determination of index properties is not a substitute of detailed characterization of rocks (Zhang, 2005).

Likewise, discontinuities in rock mass can be faults, bedding planes that divide sedimentary rocks into beds or strata and the breaks of geological origin called joints along which there has been no visible relative displacement (Bieniawski, 1989). Cleavage which can be fracture or flow type can create significant anisotropy in the deformability and strength of rocks. The International Society of Rock Mechanics defined parameters for the quantitative description of the characteristics of discontinuities are: orientation described by the dip direction (azimuth) and dip of the line of steepest declination in the plane of the discontinuity, spacing which is the perpendicular distance between adjacent discontinuities and the trace length of discontinuities called persistence, and other parameters are roughness, wall strength, seepage, aperture, filling, number of sets and block size (ISRM, 1981). One of the most significant parameters for describing discontinuities is discontinuity intensity which can be expressed in terms of different measures; in one, two or three dimensions (Zhang, 2005).

On the other hand, rock mass being the combination of intact rock and discontinuity joints properties should be used in the design of rock structure. Several researchers have developed different system for the classification of rock mass. Deere (1964) introduced Rock Quality Designation (RQD) system as an index for the assessment of rock quality quantitatively. RQD is a cheap and simple method to use but it's not enough because it does not consider discontinuity orientation, discontinuity condition and the type of discontinuity filling. The Rock Mass Rating (RMR) was proposed by Bieniawski (1989) and has been applied in the preliminary design of rock slopes and foundations as well as to the estimation of the in-situ deformation modulus and strength of rock masses. He considered six parameters that can be readily determined in the field and they are: unconfined compressive strength of the intact rock (UCS), RQD, spacing of discontinuities, condition of discontinuities, ground water conditions and orientation of discontinuities (Bahrani and Kaiser, 2013). Also, Geo-mechanical classification method developed by Robertson (1988) can be used for the preliminary estimates of rock mass slope stability.

Furthermore, Geological Strength Index (GSI) method for the evaluation of both hard and weak rock masses was developed. It is simple, fast, and reliable classification method and is based on visual inspection of geological conditions (Hoek, 2000). Also, stereographic projection is an important geotechnical mapping method that projects sphere onto a plane (Fletcher, 2017).

Therefore, the stability analysis of the slope pit in the granitic rock mass of Samchase quarry, situated in Akure North Local Government Ondo State, Nigeria, is a necessity that can ensure effective production and safe working environment.

II. MATERIALS AND METHODS

2.1 LOCATION OF THE STUDY

Samchase Nig. Ltd is situated in Akure North Local Government area of Ondo State, Nigeria with a GPS location of $7^{0}24^{1}27^{11}$N, $5^{0}14^{1}31^{11}$E. The type of rock that is being mined in this company is mainly granitic rock with mineralogical contents such as: quartz, feldspar minor amount of mica and amphiboles with a grey and dark grains texture. Moreover, the granite deposit found in Samchase Nig. Ltd. is about 20-25meters deep and it is an open pit cast with an estimated reserve of 23-30 million tons (Akingbade, 2019).

2.2 Geology of Ondo State

Ondo State belongs to the basement complex of south western Nigeria which lies to the east of the West Africa creation in the region of late Precambrian to early Paleozoic orogenesis. The basement complex rock is composed predominantly of migmatitic and granite-gnesis, quartzite, slightly migmatised to unmigmatised metasedimentry schist and meta-igneous rocks, charnockite gabbro and dioritic rocks and members of the older granites suite mainly granite, granodiorites and syenite (GSN,1966).

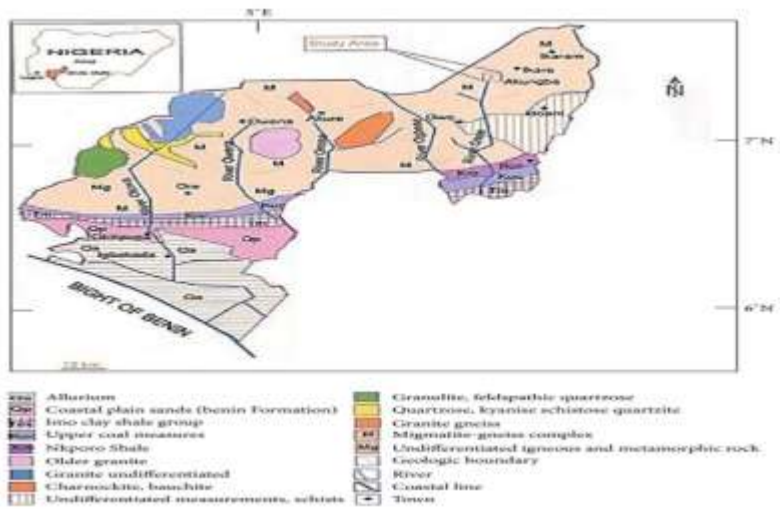

Figure 1: Geological map of Ondo State adapted from the Geological Survey of Nigeria (GSN, 1966).

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2.3 Brief Geology of Akure North LGA in Ondo State

Akure North Local Government Area in Ondo State is underlain by precambian basement complex rocks of South Western Nigeria. Several parts of Africa are underlain by crystalline basement complex rocks. The major types of rocks in Akure North Local Government are granite rocks and charnokite. The granite rocks which are member of the older granite suit occupy about 65% of the total area of Akure. Three principal petrographic varieties are recognized, the fine-grained biotite granite, medium to coarse grained, nonporphyritic biotite – hornblende granite and coarse – porphyritic biotite- hornblade granite (GSN, 1966).

Figure 2: Location Map of Akure North Local Government

2.4 Field Observation and Measurement

Pit slope of Samchase quarry was observed in order to ascertain its state and conditions of discontinuities. Global positioning system (GPS) and Compass clinometers were used to measure the elevation, dip and dip direction of the joint sets. Joint spacing, persistence and aperture of the joints were measured with measuring tapes, then; the types of material that filled the joints and its roughness were noted. The basic friction angle ($\varphi_{b)}$ was estimated by tilt tests on saw-cut rock surfaces proposed by Barton and Bandis (1990) in which two plates samples were prepared and caused to be laid one upon the other, then they are raised at one end until the upper rock samples began to roll over the other, and the angle formed was read and recorded to calculate the basic friction angle (Zhang, 2005).

Geomechanical classification method and stereographic net were used for the stability analysis of the quarry pit slope. The following parameters were considered: strength of the intact granitic rock, Rock Quality Designation (RQD), joint spacing and the condition of discontinuities. RQD was determined by the following empirical relationship:

$$\mathrm{RQD} = 115 - 3.3\lambda_v \ldots\ldots\ldots\ldots\ldots \text{equation (1)}$$

(source: ISRM, 1978)

Where:

$$\lambda_v = \frac{1}{s_1} + \frac{1}{s_2} + \frac{1}{s_3} \ldots\ldots\ldots\ldots\ldots.. \quad \text{equation (2)}$$

And, λ_v : Volumetric frequency

s_1, s_2 and s_3 : mean discontinuity set spacings.

After the determination of the RQD (equation 1), then the adjusted Rock Mass Rating (RMR) was obtained using Table A of the appendix. In order to estimate the stability state of the rock mass slope, the value of SMR, which is the adjusted RMR, was determined by the expression in equation 3 as shown below:

$$\mathrm{SMR} = \mathrm{RMR}_{basic} - (F_1 x F_2 x F_3) + F_4 \ldots\ldots\ldots\ldots\ldots \quad \text{equation (3)}$$

(Bieniawski, 1989)

From equation 3, F_1 represents the parallelism between the slope and the discontinuity strike, F_2, measure the discontinuity dip in the plane mode of failure, F_3 establishes the relationship between the slope angle and the discontinuity dip and F_4, depends o whether one it is a natural slope or one excavated by presplitting,

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smooth blasting, mechanical excavation, or poor blasting. The values of the above parameters were obtained from Table C of the Appendix.

2.5 Determination of the Physical Properties of Intact Rock

Five samples were collected from the Quarry site of Samchase Nigeria Limited locations in Akure North Local Government Area in Ondo State. Each sample is about 1.2 kg of weight collected with the use of sledge hammer. The rock samples were prepared differently according to the ISRM standard to determine the density, specific gravity of the rock, Point Load index and slake durability test. They were cut into standard pieces with the aid of crushing machine and then into diametric dimension of 100 mm by 50 mm for point load test at the laboratory of the Federal Polytechnic Ado-Ekiti.

The point load index strength (I_s) was calculated with the following equations:

$$I_s = \frac{P}{D^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{equation (3)}$$

III. RESULTS AND DISCUSSION

Table 1 shows the Physical and mechanical properties of Samchase Nig. Ltd. According to the geo-mechanical classification methods, an empirical method proposed by Bieniawski (1989), the Rock Mass Rating (RMR) were estimated (Table A of the Appendix) and the following are the rating parameter: the average mean point-load strength index of the granitic rock mass is 2.70 Mpa (Table 1) which fell within the rating of 7 (Table A of the Appendix); RQD is 81.11 % with a rating of 17; the average joint spacing is 0.3252 m and its rated 10, and the joint condition is slightly rough, the joint aperture is less than one and the wall is slightly weathered, it is rated 25; therefore, the Rock Mass Rating (RMR) is 74 %. According to Bieniawski (1989), when RMR is greater than forty (40) then, there is need to determine stability by the orientation and strength along the joints (Table A of the Appendix). The SMR value is therefore 64 % which is of class II (Table A of the Appendix). This means that granitic rock mass slope is good and stable but some blocks are formed which needs to be controlled for maximum safety during quarry operations.

Table 1: Physical and mechanical properties of Samchase Nig. Ltd

SAMPLE	SG.%	Slate Durability Test	Density (kg/m^3)	Point load Index (MPa)
1	2.12	96.60	2.65	2.12
2	2.02	95.46	2.75	2.99
3	2.04	96.68	2.57	1.59
4	2.03	96.60	2.83	4.43
5	2.29	95.04	2.62	2.35

With the structural data of strike/dip, recorded in table 3 and 4, stereonets (fig. 3 and 4) were constructed with the aid of dip program for the Quarries of Samchase Nigeria Limited and Sizhe Company. On the stereonet one of the planes visualized represents the strike and dip of the quarry faces (340^o /76^o for Samchase Nig. Ltd) and the other "slip limit" to the stereonet. Variability cones which represent one and two standard deviations of orientation uncertainty centered on the calculated means were also shown along with the windows that enclose the mean joint sets cluster with a very significant maximum concentration greater than 6%.

Table 2: Joint Orientation Data Analysis for Samchase Quarry Itaogbolu.
(G.P.S $7^0 24^i 27^{ii}$N, $5^0 14^i 31^{ii}$E Quarry face Orientation value: dip 76^0. Strike 340^0)

S/N	G.P.S LOCATION	DIP ANGLE			DIP DIRECTION			JOINT SPACING (mm)		PERSISTENCE (mm)			APERTURE (mm)			REMARK
	ELEVATION	**J_I (^{0})**	**J_2 (^{0})**	**J_3 (^{0})**	**J_I (^{0})**	**J_2 (^{0})**	**J_3 (^{0})**	**J_I**	**J_2**	**J_I**	**J_2**	**J_3**	**J_I**	**J_2**	**J_3**	**TYPE OF FILL**

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	(m)															
1	233	20	22	24	040	114	224	190	315	590	600	410	5	4	9	Sand fill
2	241	46	52	48	320	288	234	80	270	340	400	660	2	4	5	Sand fill
3	244	38	44	52	226	164	270	145	330	310	770	360	8	5	6	No fill
4	271	62	38	50	308	328	320	220	180	480	310	350	2	9	7	No fill
5	270	40	46	42	060	248	356	200	250	900	600	999	10	10	8	Sand fill
6	270	46	38	40	086	060	200	200	235	510	600	980	10	19	9	Sand fill
7	267	32	40	50	040	054	072	90	150	350	180	340	4	5	7	No fill

In order to carry out the analysis of the stability of the quarry face slope, toppling can only takes place when planes slide with respect to one another, and for slip to occur, the bedding normal must be inclined less steeply than a line inclined at an angle equivalent to the friction angle above the slope (Goodman, 1980). Then, the plane of the slip limit of the rock mass is represented on the stereonet as the 2nd plane. Its dip is the difference between pit slope and the friction angle of the granite rock (32^o) and the dip direction is equal to that of the quarry face slope (240^o), therefore the attitude of the slip limit is $240^o/44^o$. The kinematic bounds is placed on the plot with a cone of dip direction of 070^o and cone angle of 60^o that places two limits plus or minus 30 degrees with respect to the face dip direction. Planes must be within 30 degrees of parallel to cause slope to topple. So, the zone bounded by the cone curves (figure 3) is the toppling region and the Poles plotted within the region indicate a toppling risk for the Samchase Nig. Ltd. quarry slope. The attitude of the mean poles of the joints that fall within the toppling risk region are $061^o/37^o$ and $230^o/42^o$. As it can be observed, the risk is not of high threat because the poles do not represent a near vertical plane.

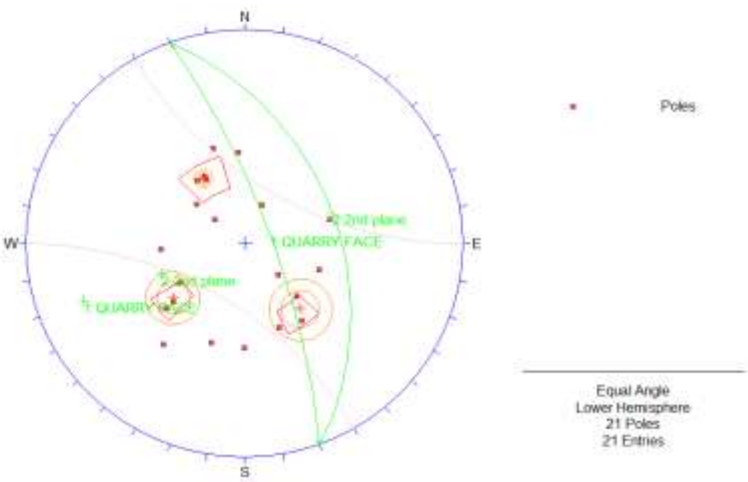

Figure 3: Stereographic net showing the region of toppling risk

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On the other hand, the stereographic net for the Planar Sliding analysis is shown in figure 4. The Daylight Envelope for the Pit Slope plane is represented in the net and any pole falling within this envelope is kinematically free to slide if frictionally unstable. Also, the friction cone of 32 degrees is located in the net and any pole that falls outside of this cone represents a plane which could slide if kinematically possible. Therefore, the zone formed by the Daylight Envelope and the pole friction circle encloses the region of planar sliding. The poles in this region which represent 42 % of the planes studied can and will slide and make the planar risk to be high in the quarry slope.

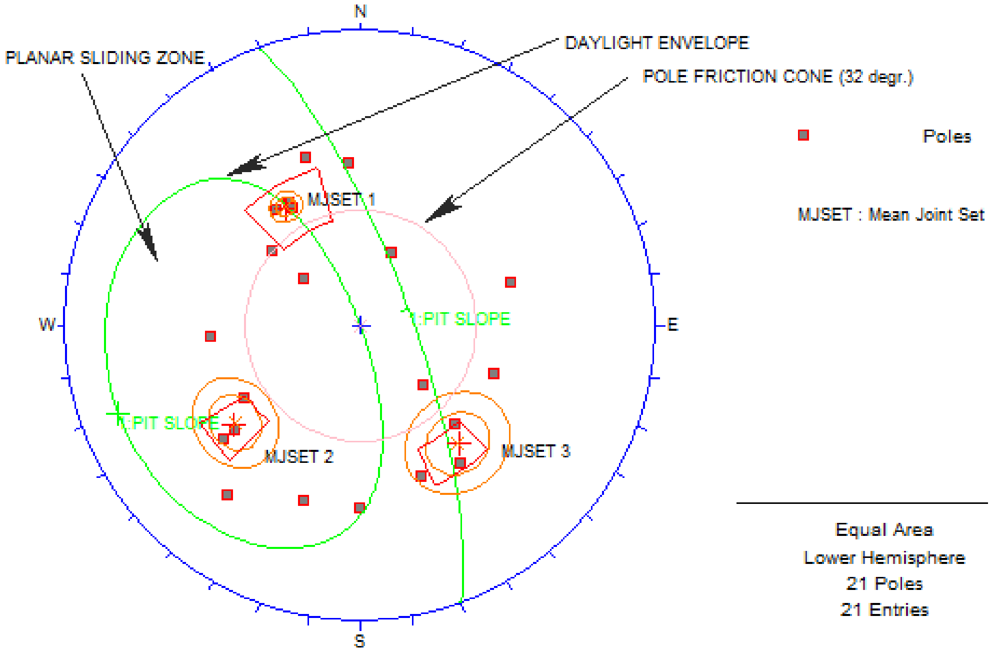

Figure 4: Stereographic net for planar sliding analysis

And finally, the stereographic net for wedge sliding analysis is shown in figure 5 and the significant mean joint planes and the friction cone plane were added to the stereonet. The zone outside the pit slope but enclosed by the friction cone represents the zone of wedge sliding. In this study, the unstable slope is found in the intersection of planes with attitudes 323^{o}/43^{o} and 230^{o}/43^{o} which is located within wedge sliding zone.

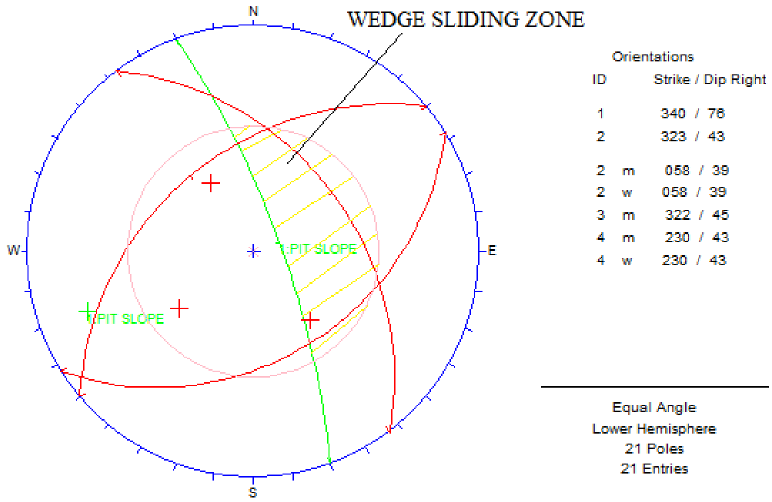

Figure 5: Stereographic net of wedge sliding

IV. CONCLUSIONS

a) In this study geo-mechanical characterization of the granitic rock mass Samchase Nig. Ltd's Quarry revealed that the pit slope contains three different oriented joint sets, intact rocks and conditions of discontinuities.

b) According to the stereographic analysis, the Quarry pit slope is liable to potential planar and wedge sliding and that the toppling failure is minimum.

c) Therefore, the two methods employed for the stability analysis of the pit slope of Samchase Nig. Ltd's quarry showed that it is good and stable but there exist some blocks that must be controlled so as to maintain the stability for effective quarry operation.

REFERENCES

[1]. Akingbade, A. O. (2019). Mechanical and Structural Analysis of some Selected Rock in Akure North Local Government Ondo State. Oluwaseyi A. O. A Project Submitted in Partial Fulfillment of the requirement for the Award of HND in Mining Engineering Option. 39p.

[2]. Bahrani N. and Kaiser P. K. (2013). Strength degradation of non-persistently jointed rock mass International Journal of Rock Mechanics & Mining Sciences 62: 28–33.

[3]. Bandis, S. C. (1990). Mechanical properties of rock joints. Proc. Int. Syrup. on Rock Joints, Loen, Norway, Eds: N. Barton & O. Stephanson, Balkema, Rotterdam, 125-140.

[4]. Barton, N. and Bandis, S. C. (1990). Review of predictive capabilities of JRC-JCS model in engineering practice. Proc. Int. Symp. on Rock Joints. Loen, Norway, Eds: N. Barton & O.Stephansson, Balkema, Rotterdam, 603-610.

[5]. Bieniawski, Z.T. 1989: "Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil and Petroleum Engineering". J. Wiley.

[6]. Brown, K.I. (1993); Evaluation of the point load strength for soft rock classification, Proceedings of the fourth international conference ground control in mining, Morgantown, WV, 220-226.

[7]. Deere, D. U. (1964). Technical Description of Rock Cores for engineering purposes. Rock Mech. and Rock Engineering., 1: 107-116.

[8]. Fletcher S. J., (2017). Data Assimilation for the Geosciences. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA. Jan. Retrieved: 31, 2021 from: https://www.sciencedirect.com/book/9780128044445/data-assimilation-for-the-geosciences

[9]. Goodman, R.E. (1980). Introduction to Rock Mechanics (Chapter 8), Toronto: John Wiley, 254-287.

[10]. Goodman , L. I. (1989).The influence of core sample geometry on the axial point-load test, International Journal of Rock Mechanics and Mining Sciences and Geomechanical Abstract, 20 (6), 291-295.

[11]. GSN. (1966). Geological Map of Ondo State. Geological Survey of Nigeria

[12]. Hoek K.I. (2000). A discussion on the decrease of Unconfined Compression Strength Between Saturated and Dry Rock samples. Polytechnic University of Valencia, Spain.

[13]. Hoek, E. 2007: Practical rock Engineering. Rock Mass Properties. In-situ and Induced Stresses. Canadá. 237p, www.rocscience.com.

[14]. Hudson, T. and Harrison, M. O. (1997). The influence of core sample geometry on the axial point-load test, International Journal of Rock Mechanics and Mining Sciences and Geomechanical Abstract, 20 (6), 291-295.

[15]. Hudson,T. (1993). Point-load strength: an index for classification of rock material, Bulletin of the International Association of Engineering Geology, 44, 27-33.

[16]. ISRM, (1978). Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses. International Society for Rock Mechanics, Commission on Standardization of Laboratory and Field Tests. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 15: 319-368.

[17]. ISRM, (1981). International society of rock mechanics commission on testing methods, suggested method for determine point load strength. International Journal of Rock Mechanics Minerals Science and Geomech. pp. 47-60.

[18]. Oluwaseyi A. O. & Ajibola O. O. (2017). Engineering characterization of Oro Descanso underground gold mine deposit in Placetas, Cuba. FUOYE, Journal of Engineering and Technology, Oye-Ekiti, 2(2).

[19]. Robertson A. M. (1988). Estimating Weak Rock Strength. AIME-SME Annual

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 7 July 2021, pp: 1993-2001 www.ijaem.net ISSN: 2395-5252

Meeting. Phoenix, AZ, preprint, No. 88 - 145.

[20]. Zhang, L. 2005: Engineering Properties of Rocks. Volume 4, Elsevier Geo-Engineering book series, United Kingdom, p 292.

APPENDIX (Source: Bieniawski, 1989)

Table A. Modification of the Geomechanics Classification for Rock Slopes[a]

Bieniawski (1979) Ratings for RMR

	Parameter		Ranges of Values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range, uniaxial compressive strength test is preferred		
		Uniaxial compressive strength (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50	<25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		>2 m	0.6–2 m	200–600 mm	60–200 mm	<60 mm		
	Rating		20	15	10	8	5		

4	Condition of discontinuities	Very rough surfaces. Not continuous. No separation. Unweathered wall rock	Slightly rough surfaces. Separation < 1 mm. Slightly weathered walls	Slightly rough surfaces. Separation < 1mm. Highly weathered walls	Slickensided surfaces. Or Gouge < 5 mm thick. Or Separation 1–5 mm Continuous	Soft gouge > 5 mm or Separation > 5 mm Continuous
	Rating	30	25	20	10	0
5	Groundwater in joint	Completely dry	Damp	Wet	Dripping	Flowing
	Rating	15	10	7	4	0

Table B. *Joint Adjustment Rating for Joints*[b]

Case		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P	$\lvert\alpha_j - \alpha_s\rvert$	>30°	30–20°	20–10°	10–5°	<5°
T	$\lvert\alpha_j - \alpha_s - 180°\rvert$					
P/T	F_1	0.15	0.40	0.70	0.85	1.00
P	$\lvert\beta_j\rvert$	<20°	20–30°	30–35°	35–45°	>45°
P	F_2	0.15	0.40	0.70	0.85	1.00
T	F_2	1	1	1	1	1
P	$\beta_j - \beta_s$	>10°	10–0°	0°	0°–(−10°)	<−10°
T	$\beta_j + \beta_s$	<110°	110–120°	>120°		
P/T	F_3	0	−6	−25	−50	−60

P = plane failure. α_s = slope dip direction. α_j = joint dip direction.
T = toppling failure. β_s = slope dip. β_j = joint dip.

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Table C. *Adjustment Rating for Methods of Excavation of Slopes*

Method	Natural Slope	Presplitting	Smooth Blasting	Regular Blasting	Deficient Blasting
F_4	+15	+10	+8	0	−8

$SMR = RMR - (F_1 \times F_2 \times F_3) + F_4$

Tentative Description of SMR Classes

Class No.	V	IV	III	II	I
SMR	0−20	21−40	41−60	61−80	81−100
Description	Very poor	Poor	Fair	Good	Very good
Stability	Very unstable	Unstable	Partially stable	Stable	Fully Stable
Failures	Large planar or soil-like	Planar or large wedges	Some joints or many wedges	Some blocks	None
Support	Reexcavation	Extensive corrective	Systematic	Occasional	None

[a]By Romana (1985).