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Assessment of excavation method of Obajana and Ewekoro limestone deposits

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Abstract: The research work assessed the optimum excavation method of limestone deposits at Obajana in Kogi State and Ewekoro in Ogun state. Geological mapping was carried out to measure the orientations of discontinuities. The orientation data obtained were plotted on stereonets to determine pole concentration and major joint sets using Dips 5.0 software from Rocscience. Two joint sets were identified in Obajana with orientations of $72^0/089^0$ and $88^0/221^0$ while three joint sets with orientations of $61^0/048^0$, $16^0/280^0$ and $90^0/140^0$ were identified in Ewekoro quarry face. Schmidt hammer hardness and Unit weight tests were performed. The results obtained were used to evaluate the Uniaxial Compressive Strength (UCS) and consequently, the Point load index (I_s) of the rock studied. The excavation method was assessed using Discontinuity Spacing Index (I_f), the Point load index (I_s) and the Geological Strength Index (GSI). The discontinuity spacing index was evaluated from the major joint sets identified and the determination of the volumetric joint count (J_v).The geological strength index was estimated using an inbuilt chart of RocLab 1.0 from Rocscience. Excavation assessments revealed that "Very Hard Ripping" is a possible method of excavating Obajana and Ewekoro Type III deposits while the less dense Type I deposit of Ewekoro can be "Ripped". The only feasible excavation method for Ewekoro type II deposit is "Blasting".

Keywords: Dip, Dip Direction, Ripping, Blasting, Dense, Excavation, Joint Sets

1. Introduction

The fundamental objective of excavation process is to remove material from within the rock mass. This results in an opening whose geometry is set by some operational criteria. There are two potential objectives in removing the rock: one is to create an opening; the other is to obtain the material for its inherent value [1]. They show that in order to remove part of a rock mass, it is necessary to introduce additional fractures over and above those occurring in situ. Three critical aspects of excavation are immediately introduced:

(a) The post-peak portion of the complete stress-strain curve must be reached;

(b) The in situ block size distribution must be changed to the required fragment size distribution; and

(c) By what means should the required energy be introduced into the rock?

Tsiambaos and Saroglou [2] posited that in order to describe the excavation method of rocks, different terms have been used, related to the principle of excavation and the mechanics of fracture. These include cuttability, rippability, excavatability, diggability and drillability. According to them, excavation methods may be of:

Digging, when easy or very easy excavation conditions exist,

Ripping, for moderate to difficult excavation conditions, and Blasting for very difficult excavation conditions.

The knowledge of the physical and mechanical characteristics as well as the behavior of the geo-materials to be excavated is vital for the selection of the most effective method of excavation.

All the techniques used for the assessment of excavation method of rock consider the uniaxial compressive strength, weathering degree and spacing of discontinuities. Some of them also include seismic velocity, geomechanical properties of discontinuities such as persistence, aperture, orientation and roughness of joints. The assessments to determine the ease or difficulty with which a rock mass may be excavated are based upon the consideration of the following [3]:

The rock material forming the rock blocks within the in-situ rock mass—because excavation entails fragmentation and rupture of the rock materials when the block volume is large,

The nature, extent and orientation of the fractures, and

The geological structure with respect to folding and faulting.

Initially, Franklin et al. [4] proposed a method to assess the excavation of rock based on the point load strength of intact rock (Is_{50}), and on the fracture spacing index, I_f, which is the mean spacing of discontinuities along a scanline. Atkinson [5] suggested that the ease of excavation can be predicted using the velocity of longitudinal waves in the rock mass for different rock types.

1.1. Excavation Assessment Methods

Choosing of rock excavation methods will or may have implications for many issues in terms of repository layout, long term and operational safety, environmental impact, design and operation of transport vehicles and methodology for backfilling the repository before closure as well as effects on costs and schedules [6].

According to the authors, the main advantage with mechanical excavation is that the operation is more or less continuous with a very constant and high excavation quality as the human factor cannot impact the quality to the extent possible with Drill and Blast. A disadvantage is that cost is higher, not necessarily due to excavation costs itself, but rather to downstream costs as the circular shape creates voids of no use but that need expensive backfilling. Accordi The strength of jointed rock masses depend upon the interlocking between individual rock pieces as said by Hoek [7]. The force binding their mineral crystals together can be easily broken and the instability in underground excavation mostly occurs as a result of the careless blasting during excavation.

Although a number of methods are available to predict excavatability, no particular method is universally accepted for several reasons, e.g., lack of awareness of previous case studies or difficulties in determining input parameters and limitations of applicability to a specific geological environment. A successful classification system should be easy to use (quantifiable data, easy to determine, user friendly) and should also give information about currently available equipment [2].

The oldest graphical indirect rippability assessment method is that of Franklin et al., [4]. It considers two parameters: the fracture spacing, I_f, and strength values of intact rock. Franklin's method has been re-evaluated and modified by many researchers: the most well known being [8]. Although this graph allows excavatability to be assessed rapidly, the subdivisions have become outdated as more powerful, more efficient equipment has become available [2].

The Franklin et al. [4] chart shows that most of the rock masses would have to be excavated with blasting to loosen the rock mass and some with ripping. However, using rippers, is quite conservative and predicts more difficult excavation conditions than is actually the case with modern machinery.

Pettifer and Fookes [8] emphasized the value of a three dimensional discontinuity spacing index as this provides a more realistic assessment of the average block size. With Pettifer and Fookes [8] chart (Figure 3), the evaluation of excavatability is simple and hence the chart is still commonly used [9], [10].

In predicting excavation method using the Rock Mass Rating (RMR) and Rock Quality Index (Q), Abdullatif and Cruden [11] proposed that a rock mass can be dug up to Rock Mass Rating (RMR) values of 30 and ripped up to RMR values of 60 while a rock mass rated as "good" or higher would require blasting. They also state that rocks with a Q value up to 0.14 can be dug but those with Q values above 1.05 require ripping. However, they pointed out that the use of Q as a guide to excavation methods presents problems, as there is an overlap where rocks with Q values between 3.2 and 5.2 can be ripped and/ or require blasting.

As a guide on choosing excavation method for intact rock using discontinuity spacing inde (I_f) and point load strength index (I_{s50},), Tsiambaos and Saroglou [2] postulated the following with the classification methods of Franklin et al. [4] and Pettifer and Fookes [8]:

(a) Rock masses that have a joint spacing, I_f, greater than 0.3–0.5 m and a point load strength of intact rock greater than 1 MPa have to be excavated using either hydraulic breaking or blasting.

(b) Rock masses with fracture spacing of less than about 100 mm (close to very close spacing according to ISRM 1981) can be excavated by rippers or diggers irrespective of the point load strength of the intact rock.

(c) Rock masses exhibiting a point load index for intact rock of less than about 0.5 MPa can be excavated easily by ripping or digging, irrespective of fracture.

2. Methodology

2.1. Geological Mapping

The scanline technique of Geological mapping was carried out. The Dips and Dip directions of the discontinuities were measured with the clinometers and expressed in degrees as two and three digit numbers respectively as recommended by ISRM, 1981. The discontinuity spacings were also measured.

A total number of 150 and 250 discontinuities were mapped for Obajana and Ewekoro deposits respectively which are in accordance to ISRM [12] and Wyllie and Mah [13]. This is presented in discontinuity survey data sheet in Table 1.

Table 1. *Orientations of Identified Joint sets*

JOINT TYPE	OBAJANA	EWEKORO
Joint Set I	$72^0/089^0$	$61^0/048^0$
Joint Set II	$88^0/221^0$	$16^0/280^0$
Joint Set III	-	$90^0/140^0$

2.2. Density and Unit Weight

The objective of the test is to measure the dry density and consequently, the unit weight of rock samples of irregular form from Obajana and Ewekoro deposits. The Saturation and Buoyancy technique for irregular rock sample was adopted and the procedures follow the standard suggested by ISRM [12] and conform to ASTM [14].

The saturated volume of the sample was calculated as follows:

$$V_s = V_2 - V_1 \quad (1)$$

Where V_s is the saturated volume of the sample, V_1 (ml) is the initial water level and V_2 (ml) is the final water level in the cylinder after the immersion of the irregular rock sample. The dry density of the rock samples was calculated using the following formula:

$$\rho_d = \frac{M}{V_2 - V_1} \quad (2)$$

Where ρ_d is the dry density of the rock samples, and M (g) is the oven dried mass at a temperature of 105°C.

$$\gamma = \rho_d \times g \quad (3)$$

The unit weight γ was then evaluated using Equation 3: where **g** = Acceleration due to gravity = 9.81 m/s^2.

2.3. Hardness Test

The type N of Schmidt hammer was used for the test conducted on the lump samples for the determination their hardness. The rebound value of the Schmidt Hammer is used as an index value for the intact strength of rock material, but it is also used to give an indication of the compressive strength of rock material [12].The result of the hardness test is used to evaluate the Unconfined Compressive Strength (UCS) and consequently, the Point Load Index Values [15].

The standard method followed in determining the hardness was as described by ISRM [12] and ASTM [14].

The measured test values for the samples were ordered in descending order. The lower 50% of the values were discarded and the average obtained of the upper 50% values to obtain the Schmidt Rebound Hardness [12].

The average values obtained from the Type – N machine was converted to Type – L readings by using the relationship established by Aydin and Basu [16]:

$$R_N = 1.0646R_L + 6.3673 \quad (4)$$

where R_N = Rebound Hardness value from Type N Hammer, and

R_L = Rebound Hardness value from Type L Hammer.

2.4. Unconfined Compressive Strenght (UCS)

The Uniaxial Compressive Strength of the rock samples were estimated from the values of the equivalent Type L Schmidt Hammer Hardness and the density of the rock.

The UCS values were estimated by an Equation developed by Xu and Mahtab [17]:

$$UCS = 12.74Exp(0.02 \times R_L \times \rho) \quad (5)$$

Where UCS = Uniaxial Compressive Strength (MPa), RL = Rebound Hardness value of Type L Hammer, and $\boldsymbol{\rho}$ = Density of rock (g/cm^3).

The UCS was used for the strength classification and characterization of the intact rock for the generalized Hoek – Brown criterion and equivalent Mohr – Coulomb criterion for obtaining the friction angle and the cohesion.

2.5. The Point Load Index (I_s)

The Point Load Index (I_S) Values were estimated from the Uniaxial Compressive Strength (UCS) values using the relationship established by Osman [18]:

$$I_S = 0.047UCS - 0.3287 \quad (6)$$

The I_S (like the UCS) was also used for the strength classification and characterization of the intact rocks. It was further used with the Fracture Spacing Index (I_f) and the Geological Strength Index (GSI) for the assessment of the most economic excavation method with the aid of appropriate charts.

2.6. Representation of Geological Data

The Geological data collected were interpreted and analyzed using the stereographic projections of the dip sand dip directions of the discontinuities. This revealed the orientations of the major discontinuity sets present. The dips and dip directions of the discontinuities were plotted by using Dips 5.0 software from Rocscience.

2.7. Assessment of Excavation Method

The excavation method was assessed by two approaches. The first was the use of discontinuity spacing index (I_f) and the Point Load Index (I_s). The revised excavatability chart (Figure 3) proposed by Pettifer and Fookes (1994) and the franklin's chart (Figure 4) were used for this purpose. The excavation charts consider the types of excavation equipment and require engineering geological parameters such as the discontinuity spacing index (I_f) and the point load strength index (I_S). Mean discontinuity spacing was measure separately for both Obajana and Ewekoro Quarry faces and the discontinuity spacing (I_f) was calculated from the following Equation by ISRM (1981):

$$I_f = \frac{n}{J_v} \quad (7)$$

Where n = Number of major joint sets identified, and

Jv = Volumetric Joint Count.

The Volumetric Joint Count Jv was calculated from the Equation suggested by ISRM (1981):

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} \dots \dots + \frac{1}{S_n} \quad (8)$$

Where S_1, S_2, $S3$ ….. S_n are discontinuity spacing of n joint sets.

The point load index (I_s) was estimated from the Uniaxial Compressive Strength (UCS) value using Equation (6), and their values were used to determine the best excavation method.

The second approach is the use of Geologic Strength Index (GSI) values and point load index (I_s) as proposed by Tsiambaos and Saroglou [2] and the chart is shown in Figure 5. The *GSI* classification of the excavated rock was estimated using RocLab 1.0 while the I_s was estimated using Equation (6).

3. Results and Discussion

3.1. Analysis of Geological Data

The orientations of the discontinuities in dips and dip directions were measured as well as the discontinuity spacing. Graphical representations of orientations of the discontinuities mapped are shown in Figures 1 and 2. Two major joint sets were identified in Obajana quarry face with average orientations of 72°/089° and 88°/221°. Three joint sets were identified in the quarry face of Ewekoro with average orientations of 62°/048°, 16°/280° and 90°/140°. Summary of this result is shown in Table 1.

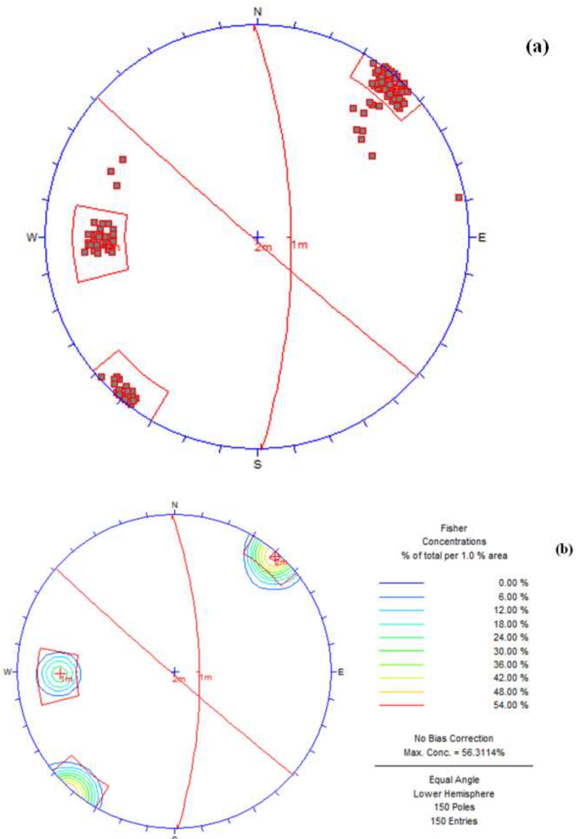

Figure 1. *(a) Pole Plot (b) Contour plot of Obajana Quarry Face*

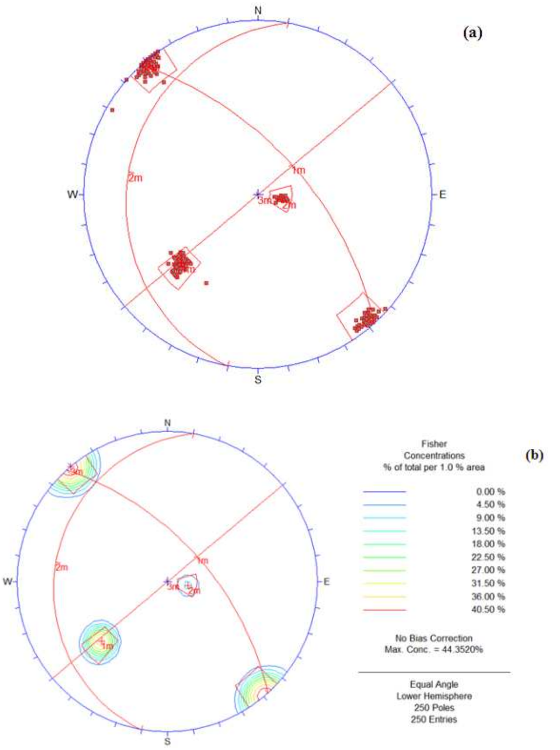

Figure 2. *(a) Pole Plot (b) Contour plot of Ewekoro Quarry Face*

3.2. Unit Weight Result

The density and the unit weight results are shown in Table 2. The density of all the rock samples tested varies between 2.4 – 2.7 g/cm^3 while thier estimated unit weight varies between 23.56 – 26.51 kN/m^3. Ewekoro has three different types of deposits as evident from visual inspection. The three rock types have average densities of 2.40, 2.70 and 2.50 g/cm^3 respectively while their average unit weights are 23.56, 26.51 and 24.51 kN/m^3 respectively. Obajana deposit has only one type of rock with an average density of 2.6 g/cm^3 and an average unit weight of 25.51 kN/m^3.

Table 2a. *Density and Unit Weight Result for Obajana Deposit*

Sample	Dry mass M (g)	V1 cm^3	V2 cm^3	(V2-V1) cm^3	Density g/cm^3	Unit Weight kN/m^3
1	71.5	400.0	427.0	27.0	2.65	25.98
2	70.5	395.0	421.5	26.5	2.66	26.10
3	60.4	380.0	403.0	23.0	2.63	25.76
4	60.1	370.0	394.0	24.0	2.50	24.57
5	65.4	360.0	385.5	25.5	2.56	25.16

Table 2b. *Density and Unit Weight Result for Ewekoro Type I Deposit*

Sample	Dry mass M (g)	V1 cm^3	V2 cm^3	(V2-V1) cm^3	Density g/cm^3	Unit Weight kN/m^3
1	62.4	353.0	379.0	26.0	2.40	23.54
2	69.9	350.0	379.0	29.0	2.41	23.65
3	67.1	347.0	375.0	28.0	2.4	23.51
4	63.9	343.0	370.0	27.0	2.37	23.22
5	64.5	338.0	364.5	26.5	2.43	23.88

Table 2c. *Density and Unit Weight Result for Ewekoro Type II Deposit*

Sample	Dry mass M (g)	V1 cm^3	V2 cm^3	(V2-V1) cm^3	Density g/cm^3	Unit Weight kN/m^3
1	72.6	410.0	437.0	27.0	2.69	26.38
2	65.6	408.0	432.5	24.5	2.68	26.27
3	56.5	405.0	425.5	20.5	2.76	27.04
4	68.0	402.0	427.0	25.0	2.72	26.68
5	60.0	394.0	416.5	22.5	2.67	26.16

Table 2d. *Density and Unit Weight Result for Ewekoro Type III Deposit*

Sample	Dry mass M (g)	V1 cm^3	V2 cm^3	(V2-V1) cm^3	Density g/cm^3	Unit Weight kN/m^3
1	57.7	350.0	373.0	23.0	2.51	24.61
2	67.1	346.0	373.0	27.0	2.49	24.38
3	64.8	340.0	365.5	25.5	2.54	24.93
4	68.4	330.0	357.5	27.5	2.49	24.40
5	54.3	325.0	347.0	22.0	2.47	24.21

Table 3 is a summary of the density result while Table 4 is that of the unit weight. The results show that type II deposit of Ewekoro has the highest density and unit weight values while type I of the same Ewekoro has the least.

Table 3. *Summary of density Results*

Test No	Obajana	Ewekoro Type I	Ewekoro Type II	Ewekoro Type III
1	2.65	2.40	2.69	2.51
2	2.66	2.41	2.68	2.49
3	2.63	2.40	2.76	2.54
4	2.50	2.37	2.72	2.49
5	2.56	2.43	2.67	2.47
AVG	**2.60 (g/cm^3)**	**2.40(g/cm^3)**	**2.70 (g/cm^3)**	**2.50 (g/cm^3)**

Table 4. *Summary of Unit Weight Results*

Test No	Obajana	Ewekoro Type I	Ewekoro Type II	Ewekoro Type III
1	25.98	23.54	26.38	24.61
2	26.10	23.65	26.27	24.38
3	25.76	23.51	27.04	24.93
4	24.57	23.22	26.68	24.40
5	25.16	23.88	26.16	24.21
AVG	**25.51 kN/m3**	**23.56 kN/m3**	**26.51 kN/m3**	**24.51 kN/m3**

3.3. Schmidt Hammer Hardness Values

The rebound values of type N Schmidt Hammer was obtained and the results are shown in Table 5 with the test result arranged in descending values. The lower 50% of the values were discarded and the average obtained of the upper 50% values for each of the rock samples as suggested by ISRM [12].The average of the upper half is taken to represent the average rebound values of the hardness test. Table 6 is the result of the average of the upper 50% values.

Table 5. *descending Values of Schmidt Rebound Hardness*

	S/N	Obajana	Ewekoro I	Ewekoro II	Ewekoro III
Upper 50% Values Averaged	1	46	39	50	42
	2	45	37	49	42
	3	43	37	48	41
	4	42	37	48	41
	5	41	36	47	40
	6	41	36	46	39
	7	40	36	46	39
	8	39	35	45	38
	9	39	35	45	37
	10	39	34	44	35
Lower 50% values Discarded	11	39	34	40	33
	12	38	31	39	31
	13	36	30	38	31
	14	34	29	35	30
	15	31	25	33	30
	16	31	25	31	28
	17	28	23	29	27
	18	26	19	29	25
	19	25	18	26	24
	20	20	17	25	19

Table 6. *Upper 50% Values of Schmidt Rebound Hardness and their Averages*

S/N	Obajana	Ewekoro I	Ewekoro II	Ewekoro III
1	46	39	50	42
2	45	37	49	42
3	43	37	48	41
4	42	37	48	41
5	41	36	47	40
6	41	36	46	39
7	40	36	46	39
8	39	35	45	38
9	39	35	45	37
10	39	34	44	35
Average	**41.5**	**36.2**	**46.8**	**39.4**

Type N Schmidt Hammer test is mostly use for concretes while ISRM [12] recommends the use of type L for rocks. Therefore the average values of type N obtained were converted to type L reading using Equation (4). The results are shown in Table 7.

Table 7. *Conversion of Type N Schmidt Hammer values to Type L Values*

Samples	N Values	L Values
Obajana	41.5	35.1327
Ewekoro I	36.2	29.8327
Ewekoro II	46.8	40.4327
Ewekoro III	39.4	33.0327

The result shows that Ewekoro Type II deposit has the highest value of the rebound hardness and closely followed by Obajana.

3.3. UCS and the Point Load Index Values

The Uniaxial Compressive Strength (UCS) of the rock samples was evaluated from the Schmidt Hammer hardness and density values using Equation (5). The Point load Strength was in turn estimated from the UCS values by using Equation (6). Table 8 shows the Uniaxial

Compressive and Point Load Strengths results and their classification as given by Broch and Franklin [19].

Table 8. *UCS, Point Load Values and their Rock Class*

Samples	UCS (Mpa)	Is (Mpa)	Rock Class
Obajana	69.04	2.92	High to Very High Strength
Ewekoro I	47.91	1.92	High Strength
Ewekoro II	96.00	4.18	Very High Strength
Ewekoro III	58.70	2.43	High to Very High Strength

All the rock types tested are of "Very High Strength class" to "High Strength Class". Ewekoro type II deposit has the highest value which is in agreement with its high unit weight and hardness values.

3.5. Prediction of Excavation Method

In order to predict the best method of excavating the deposits, the mean spacing of discontinuity sets as obtained from pole plots were calculated and the result is presented in Table 9.

Table 9. *Mean Discontinuity Spacing values*

	SET 1 (m)	SET 2 (m)	SET 3 (m)
Obajana Face I	2.3747	0.3502	-
Obajana Face II	1.7611	0.3340	-
Ewekoro	0.1599	0.4212	0.2273

Two different methods were used to assess the excavatbility of the deposits. The first method is by using Discontinuity spacing index (I_f) calculated using Equations (7) and (8); and The Point Load Strength Index (I_s) evaluated from the uniaxial compressive strength (UCS). Pettifer and Fookes chart shown in Figure 3; and Franklin Excavation chart (Figure 4) were used.

The second method considered the Geological Strength Index (*GSI*) and the Point Load Index as proposed by Tsiambaos and Saroglou [2]'. The GSI was estimated from RocLab 1.0 and the Chart for this method is shown in Figure 5.

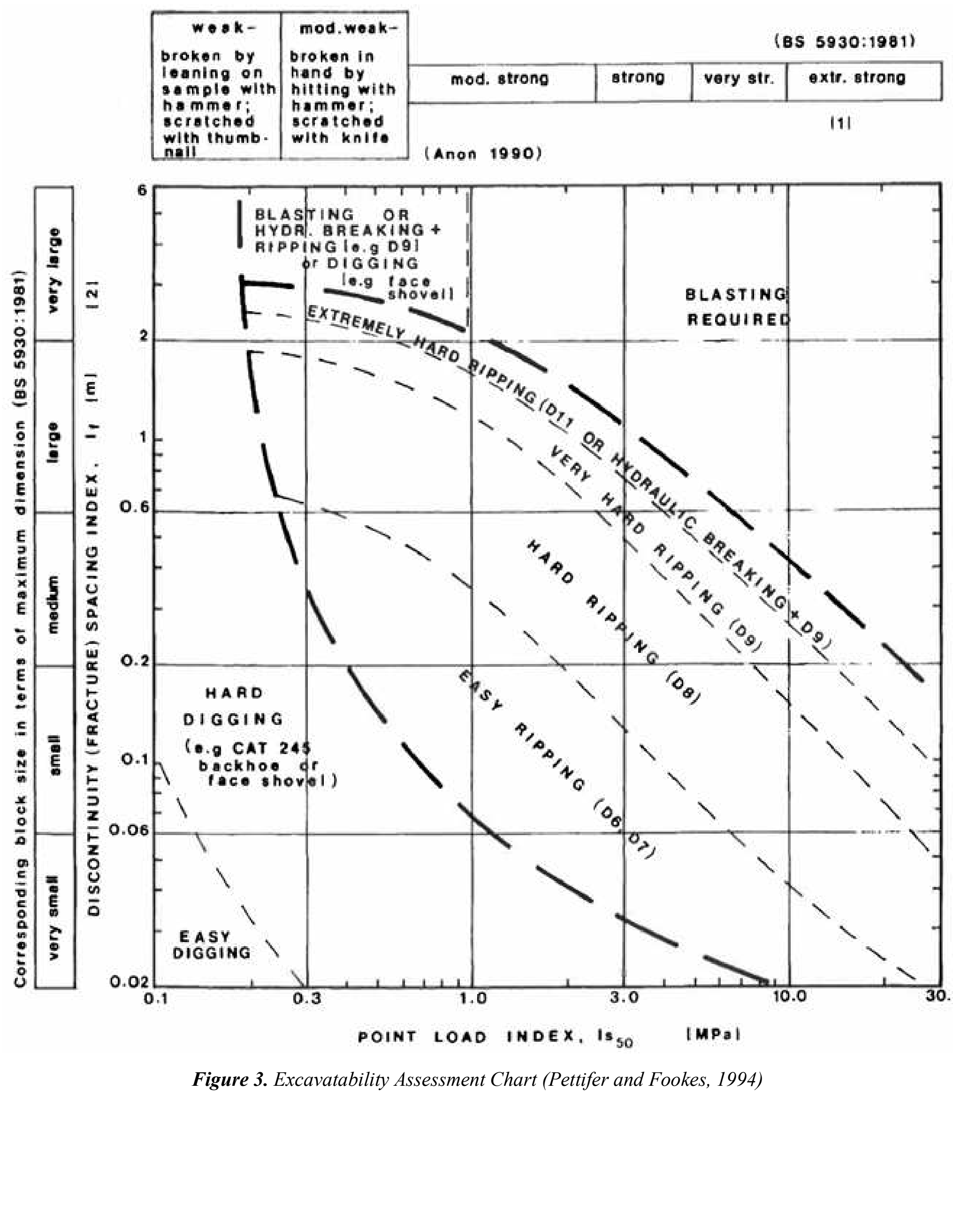

Figure 3. *Excavatability Assessment Chart (Pettifer and Fookes, 1994)*

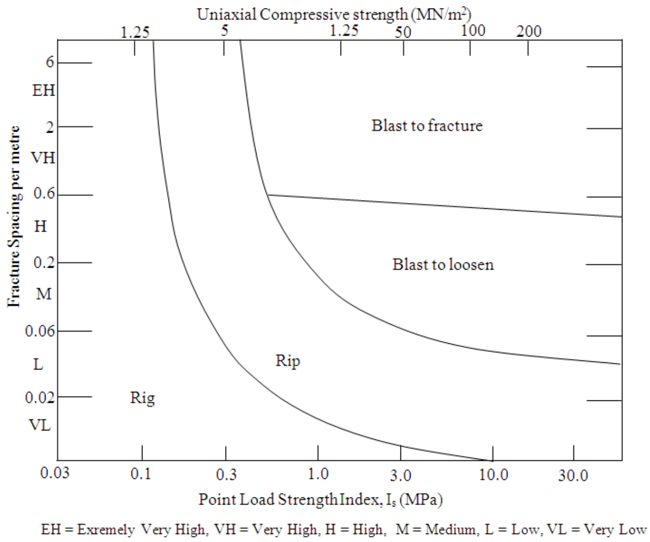

Figure 4. *Franklin's Excavation chart (Edited From Franklin et al, 1971)*

The parameters obtained for the determination of prediction of the possible and best excavation methods are shown in Table 10 where 'n' represent the number of joint set. The two faces of Obajana have 2 joint sets while that of Ewekoro is 3. The average Point Load Strength (I_s), and that of Geological Strength Index (GSI) were used for Ewekoro deposits which has three different rock types. For the first technique, Pettiffer and Fookes Chart shows that both faces of Obajana quarry can be excavated by "Very Hard Ripping" while Ewekoro deposit can be excavated (based on the average value) by "Ripping". On Franklin's excavation chart (Figure 4), the results indicated that all the rock types must be blasted to loosen.

Table 10. *Determined Parameters for Excavatability assessment*

	n	Jv	If	Is (Mpa)	GSI
Obajana Face I	2	3.2766	0.6104	2.92	70
Obajana Face II	2	3.5618	0.5615	2.92	70
Ewekoro I	3	13.028	0.2303	2.84	70

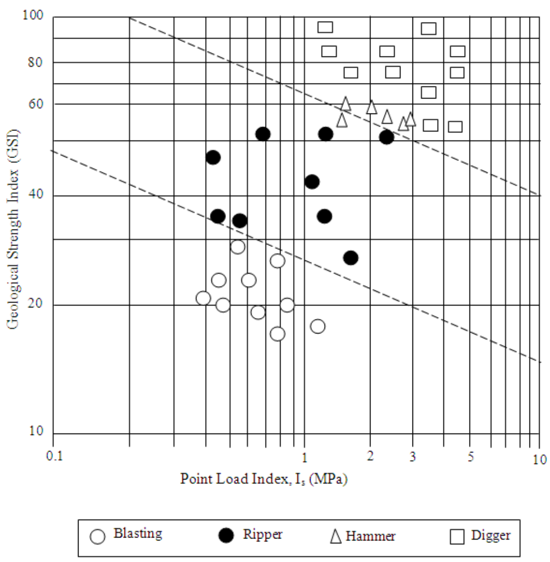

Figure 5. *Tsiambaos and Saroglou Chart (Edited From Tsiambaos and Saroglou, 2010)*

The second technique that utilizes Tsiambaos and Saroglou Chart (Figure 5) also shows an agreement with Franklin's chart that all the rock types require blasting for excavation.

4. Conclusion

Blasting is not the only feasible method of excavating Obajana and Ewekoro deposits. Very Hard Ripping is a possible option for Obajana and Ewekoro Type III deposits while the less dense part of Ewekoro deposit (Type I) can be easily ripped. Type II deposit of Ewekoro can only be excavated economically by blasting.

Recommendation

Very Hard Ripping technique can be used to excavate Obajana deposit while Ripping is viable for the less dense portion of Ewekoro deposit. This will reduce costs and the harmful environmental effects of blasting.

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