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Evaluation of Old Netim Basement Rocks (South-Eastern Nigeria) for Construction Aggregates

E. A. Amah[1], E. O. Esu[1], M. I. Oden[1] & G. Anam[1]

[1] Department of Geology, University of Calabar, Nigeria

Correspondence: E. A. Amah, Department of Geology, University of Calabar, Calabar, Nigeria. E-mail: amahedet@yahoo.com

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Abstract

The physico-chemical and engineering properties of the basement rocks from Old Netim, southeastern Nigeria were determined to ascertain their suitability for civil construction purposes. The results indicate that specific gravity (SG) ranges from 1.55 (overburden) to 2.73 (fresh granite gneiss), hardness (H) 1.0 (weathered soft rock) to 6.0 (fresh strong gneiss), compressive strength (α) 19.31 to 77.37 MN/m^2 and the moisture content (W%) 0.11 to 10.12.The moderately high strength of the rocks as well as the low values of water absorption capacity are consistent with the chemical composition of the Oban granite gneiss. The results also indicate that moisture content (W%) decreases with increasing hardness (H), specific gravity (SG) and compressive strength (α) except where rock weathering and underground water cause some adverse effects on the rock quality. The relationship between moisture content (W%), specific gravity (SG) and compressive strength (α) indicates that the fresh basement rocks from Old Netim quarry are capable of withstanding heavy traffic, foundation loads and generally suitable for most civil construction works.

Keywords: basement rocks, construction materials, compressive strength, moisture content

1. Introduction

The high demands for crushed rocks as construction materials in the Cross River State and elsewhere in Nigeria have led to the establishment of many granite quarries by investors for the production of rock aggregates. In southeastern Nigeria, basement rocks are known to occur at Oban and Obudu regions (Ekwueme, 1988, 1990, 2003). These rocks when quarried could provide raw materials at affordable prices for civil engineering purposes. The Oban massif for which Old Netim is an integral part occupies an area of about 10,000km^2 (Ekwueme et al., 1995) and lies between Longitudes (8°00′ and 8°55′E) and latitudes (5°00′ and 5°45N′) The Old Netim village has many of such exposure of the basement rocks lying close to the surface with less overburden cover (Figure 1). However, the quarrying project is capital intensive. Thus, it is important that material properties are evaluated to guide the investors to avoid wasting funds too early, only to realize later that the quality of material at the quarry sites are unsuitable and quantity insufficient for some desired purposes. One of the aims of the project is therefore to provide useful information on the strength of the rocks at the quarry sites; indicate the possible response of the rock fragments to traffic when they are used as sub- base during road construction and as foundation materials in a humid tropical environment with frequent alternation of the wet and dry seasons. To meet the objectives of the project, combination of physical, engineering and chemical tests on the wall rock samples were used. These techniques were considered appropriate since pre-failure characteristics could easily be detected from either one or combination of the tests.

Industrial quarrying started in Old Netim in the early part of 1970s, mainly for the supply of aggregates for road construction in Eastern Nigeria. Current production of crushed granite aggregates is utilized mainly in preparation of concretes for foundation loads, buildings and airfield pavement. In the past some work has been carried out on the evaluation of Nigerian carbonate rocks for construction purposes (Teme & Edet, 1986; Esu et al., 1994). Different authors have also established the economic importance of south western basement complex of Nigeria and most importantly, as a good material for civil constructions (Rahaman 1976; Dada 2006; Bale et al., 2010). Few of the publications about the southeastern basement complex of Nigeria have been on the petrology and petrogenesis of the rocks in the area (Rahman et al., 1981; Ekwueme, 1990; Ukwang et al., 2003).

There has not been any published works on the physical, chemical and geotechnical characteristics of the southeastern basement complex of Nigeria.

The present paper therefore focuses on the basement rocks of Old Netim area in the southeastern part of the Oban massif and summarizes the strength characteristics and raw material potentials of the deposits, especially in relation to the use of the basement rocks for civil construction aggregates.

1.1 Geology

The Geology of the Old Netim quarry site (Figure 1) is simply that of typical basement complex rocks (Rahman et al., 1981; Ekwueme, 1990). It consists of banded gneiss and some schists with intrusions of pegmatitic and doleritic rocks. Typical minerals are quartz, feldspars plagioclase, orthoclase, microcline, biotite, muscovite and some opaque minerals. The quartz are slightly strained in some locations. Chlorite, sericite, garnet and staurolite are common. Drainage channels at the sites are structurally controlled. Faulting is inferred in some parts of the quarry site. At the site some granite gneiss outcrops occurs in-situ. However, the gneiss generally occurs near the surface, having been weathered in-situ to form saprolith or regolith. The weathered profile varies in thickness over the entire site extending from 6.0 to 9.0m in some places (Figure 2).

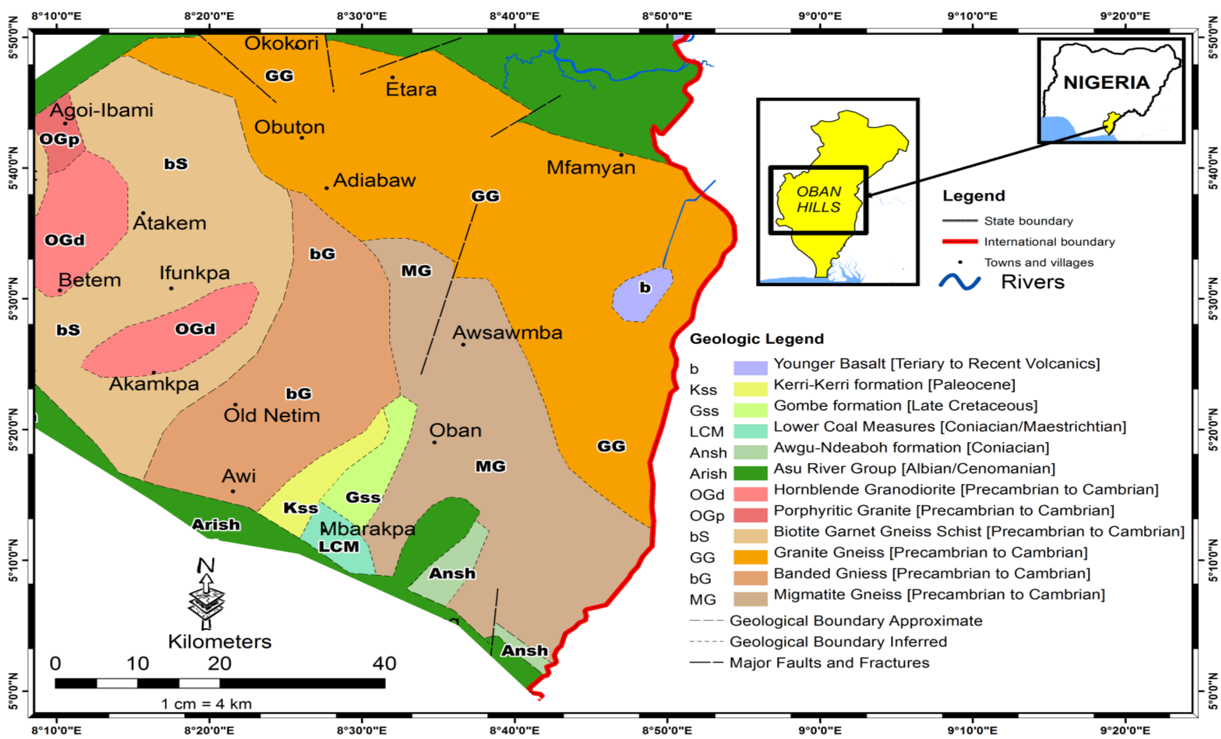

Figure 1. The Geologic map of the study area

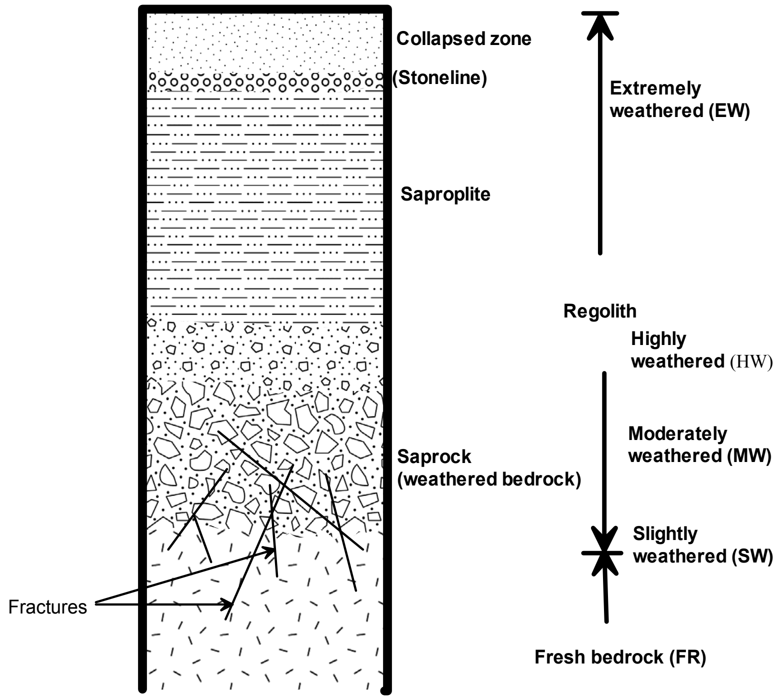

Figure 2. Typical weathering profile in a basement complex terrain (modified from Wright, 1992)

2. Method of Study

The bulk of samples for this work were rock cores and powder obtained from drill holes at the proposed quarry sites. The drill holes locations were accurately surveyed using the Garmin 76 Global Positioning System (GPS) to obtain their latitude and longitude as well as the relative elevation data. Each borehole had a maximum depth of 15m and samples collected at 3m depth intervals were placed in polythene bags which were accurately labeled. Bulk samples were also obtained from rock outcrops in-situ and cut into cubes for the compressive strength test.

2.1 Physical and Engineering Tests

The following physical and engineering tests were performed on the rock specimens from Old Netim quarry sites: Specific gravity (SG), Hardness (H), moisture content (w) and compressive strength (α). The specific gravity was determined by using a 50cm^3 density bottle. This method was found suitable because the samples were in powder form. The Moh's Hardness (H) is defined as the resistance to scratching by various implements. The scale of Hardness ranges from very soft (grade 1) to very hard (grade 10). Rocks at the sites are composed of mineral aggregates, thus a number of Moh's hardness tests were performed and the average results taken. Moisture content w% (the weight of water in the samples to weight of solids) was carried out as described by ASTM 2216-71.

The uniaxial compressive strength of the rock blocks was also determined using the Universal Testing Machine (UTM) model AXM500-50KN. The compressive strength measurements on standard specimens of 50 mm in diameter and 50 mm in length with coplanar end-faces were performed (with an accuracy of 0.1%). The load was applied to the end-faces of the specimen with a strain rate of 1,000 N/s until failure. The maximum load is defined as the uniaxial compressive strength. The results are presented in Table 1.

2.2 Chemical Tests

The representative samples used for chemical analysis were dried at 105°C for 4 hours, in order to determine the loss on ignition (LOI). The samples were then analyzed for Si, Al, Ca, Mg and S, using the Atomic Absorption Spectrophotometer. The amounts of Na and K in the samples were also determined by the flame photometry technique. The results were checked against standard samples collected from a nearby Strabarg quarry and the agreements were generally good.

Table 1. Physical, chemical and mechanical properties of samples from Old Netim quarry, Akamkpa

S/N	Sample number	Lithologic description	Physical properties			Chemical Properties in Weight Percent								Compressive strength/Class	Standard range
			H	W%	SG	LOI	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	SO_3	$CaCO_3$	a MN/m^2	a MN/m^2
1	BH/1/3	Weathered overburden, pegmatitic	2-4	10.12	1.94	12.53	84.47	1.72	2.21	0.05	1.54	0.32	2.75	19.31 L	
2	BH1/2/78	Granite Gneiss, Pegmatitic	3	1.59	2.36	5.57	66.02	3.61	9.75	-	0.71	0.48	1.26	20.88 V L	
3	BH1/3/9	Granite Gneiss, Pegmatitic	2-4	0.63	2.41	3.00	69.14	4.21	11.59	0.07	9.41	0.27	0.73	24.62 VL	
3	BH1/4/11	Granite Gneiss, Pegmatitic	3-6	0.32	2.73	2.76	71.59	3.27	8.93	0.07	0.82	0.33	1.46	23.60 VL	
5	BH1/5/13-15	Granite Gneiss, Pegmatitic	2-4	0.11	2.49	1.48	74.46	3.87	10.73	0.11	0.62	0.39	1.11	24.62 VL	
6	BHG/1/6	Overburden		2.40	1.55	4.12	76.88	6.54	6.52	0.24	0.21	0.33	0.38		
7	BHG/2/9	Granite Gneiss, fresh rock	2-4	2.07	2.52	2.23	80.08	6.88	9.56	0.24	0.51	0.34	0.91	54.42 M	
8	BHG/3/10-12	Sound rock, Granite gneiss	3-6	0.99	2.59	1.00	38.80	5.91	37.41	0.05	0.71	2.02	1.26	77.3 M	
9	BHG/4/13-15	Sound rock, Granite gneiss	2-4	0.50	2.48	0.93	71.07	5.24	13.66	0.04	0.71	2.02	1.26	64.50 M	
10	BH8/1/12	Weathered rock, soft	2	1.86	1.45	4.60	72.94	3.27	11.51	0.16	1.23	0.77	2.20	18.90 VL	
11	BH8/2/15	Moderately hard rock	2-4	0.49	1.50	67.32	3.61	3.61	11.03	0.09	0.51	0.44	0.91	35.09 L	
12	B5A/5/14-15	Hard rock, fresh	2-4	0.95	2.48	1.44	71.53	2.92	14.66	0.16	0.61	0.72	1.09	64.01 M	
13	COT/1/A	Standard sample fresh	4-6	0.11	2.58	9.13	70.64	4.60	14.46	0.16	0.41	0.33	0.73	75.42 M	80-250
14	COT/2/C	Standard sample fresh	4-6	0.15	2.63	8.10	72.31	2.15	15.93	0.13	0.71	0.62	1.26	76.60 M	
15	BHY35/1/13-15	Granite gneiss,fresh	4-6	0.50	2.40	17.10	64.31	3.32	12.92	0.09	1.43	0.62	2.55	56.23 M	
16	BHY38/1/6-9	Weathered rock weak	2-4	1.89	1.58	5.01	63.59	9.20	19.78	0.01	1.94	0.53	3.46	20.88 VL	
17	BH6/2/6	Fresh rock, strong	4-6	6.00	2.60	9.00	68.23	1.38	19.04	0.07	1.43	0.31	2.55	52.85 M	
18	BHG/1/9	Weathered rock, weak	2	6.00	2.39	2.11	74.62	5.16	12.64	0.05	2.30	0.37	4.11	20.10 VL	
19	BH7/1/5-6	Fresh rock, strong, gneiss	2-4	0.85	2.54	0.70	71.64	2.75	13.75	0.14	2.46	0.60	4.39	77.20 M	
20	BH7/2/10-12	Fresh rock, strong, gneiss		0.50	2.53	0.31	77.79	2.53	7.33	0.09	1.43	0.24	2.55	64.45 M	
21	BHY1/1/3	Weathered rock, soft, buff colour	1	0.41	2.51	2.44	80.15	2.32	12.54	0.13	2.05	0.06	3.66	19.0 VL	
22	BHY1/2/3-6	Slightly weathered rock	3	0.29	2.36	14.31	68.44	3.18	10.90	0.09	2.56	0.32	4.57	54.00 M	
23	BHY1/3/6-9	Weathered rock but strong	4	0.08	2.26	11.46	63.86	6.11	15.79	0.14	2.15	0.13	3.84	38.42 L	
24	BHY1/4/9-12	Fresh rock, strong	4	0.08	2.53	10.29	70.28	3.52	12.88	0.14	2.25	0.41	4.02	75.2 M	
25	BHY1/5/12-15	Fresh rock, strong	3-4	0.82	2.56	9.63	66.64	5.76	13.92	0.16	3.07	0.23	5.48	52.20 M	
26	BH2/1/9	Fresh rock, strong	2-4	0.44	2.52	0.82	66.20	4.12	6.54	0.14	1.84	0.17	3.29	45.59 L	
27	BH2/2/12	Slightly weathered rock	3	0.37	2.43	1.00	73.75	2.92	8.28	0.10	1.53	0.89	2.73	37.76 L	
28	BH2/3/14-15	Coarse-grained rock, fresh	3	0.08	2.20	0.48	65.85	4.04	11.18	0.16	1.33	0.25	2.38	64.50 M	
29	BH3A/1/10-12	Weathered rock, not strong	3	0.28	1.53	1.40	70.26	4.39	19.41	0.14	2.05	0.33	3.66	12.01 L	
30	XY1/1/4-6	Fresh rock, strong, gneiss	3	0.09	2.51	9.07	71.32	3.27	14.29	0.05	1.64	0.35	2.93	68.10 M	
31	B2A/1/6	Weathered pegmatite	2	0.21	2.35	1.80	75.08	5.84	16.42	0.18	0.41	0.20	0.73	20.41 VL	
32	B2A/2/9	Slightly weathered pegmatite	2	2.14	2.40	4.00	73.16	5.76	8.98	0.36	0.82	0.43	1.46	35.09 L	
33	B2A/3/13	Pegmatite	3	0.85	2.45	2.00	68.44	5.33	10.47	0.05	0.62	0.50	1.11	42.5 L	
34	B2A/4/15	Slightly weathered pegmatite	2	1.85	2.44	2.02	71.02	2.58	14.68	0.18	1.03	0.32	1.84	42.59 L	
35	B1A/1/6	Weathered pegmatite	2	2.55	2.37	5.18	71.11	3.09	14.99	0.04	1.12	0.27	2.00	19.23 VL	
36	B1A/4/10-12	Granite gneiss, weathered	2-4	2.60	2.29	3.45	78.92	3.69	10.85	0.07	1.84	0.42	3.29	43.45 L	
37	B1A/5/14-15	Fresh granite gneiss	2-4	0.15	2.48	1.11	72.62	5.12	8.74	0.11	1.64	0.72	2.93	77.37 M	
38	BHY/22/1/13-15	Fresh hard rock, gneiss	2-6	0.11	2.54	8.35	70.26	3.26	15.00	0.03	1.74	0.43	3.11	64.50 M	

a= After Deere and Miller (1966), VL= Very Low strength, L= Low Strength, M= Medium Strength, H= High Strength, VH= Very High strength

3. Results and Discussion

The results of the physical properties (H, W%, SG) , the chemical properties such as the (LOI, SiO_2, Fe_2O_3, CaO, MgO and SO_3) in weight percents and engineering characteristics are shown in Table 1. Table 2 indicates Data for the compressive strength (α) in relation to the end use of the rocks.

3.1 The Specific Gravity

The specific gravity of samples tested ranges from 1.55 (overburden) to 2.73 (fresh granite gneiss). They tend to increase with increasing rock quality or strength. In a case where the SG shows an unexpected decrease with depth, some weathering of the rock must have taken place or the fracture might contain water. This is clearly indicated in BH1 (BH1/5/13-15) in which the SG drops from 2.73 at a depth of 11m to 2.49 at a depth of 13 to 15m (Table 1). Unweathered rocks at the site generally have SG values ranging from 2.40 to 2.70 as exemplified by 20 out of the 36 samples tested for SG having values in this range . The other 16 samples have SG less than 2.40, generally are in the weathered/overburden depth range. In addition to weathering, the mechanical drilling process may tend to introduce micro fractures in the samples. This might be responsible for slightly lower SG values observed in some specimens.

3.2 Moisture Content (W%)

The results (Table 1) reveal that the water content ranges from 0.11 to 10.12%. There is a general decrease in the water content of the samples with increasing depth. That is, more water is contained in the weathered overburden materials than in the sound rock sections. The implication of the decrease of moisture with depth is that fractures (if any) in the rocks at the site also decrease with depth. Hence, swelling pressure potential due to the present of clay mineral resulting from weathering of the aluminosilicates is very low (Edet, 1992)

3.3 Moh Hardness (H)

The hardness H ranges from 1.0 for weathered soft rock to 6.0 for fresh granite gneiss. The low hardness obtained for overburden materials indicate poor sample quality. Increase hardness is directly related to improve rock quality and strength.

3.4 Compressive Strength (α)

Table 1 indicates results of the compressive strength of rocks samples at the proposed quarry site. It ranges from 19.31 to 77.37 MN/m^2. Generally, the rock strength results reveal slightly low values compared to the standard range values of 80.0 to 250.0MN/m^2 for fresh metamorphic rocks such as gneiss (Deere & Miller, 1966). The low values are direct effects of the humid tropical conditions that causes weathering on the surface rocks at the propose site. As a matter of fact, all the samples crushed were weathered samples collected on the surface. Fresh samples collected with the aid of bulldozer at the site shows a relatively higher crushing strength and materials judged to be better civil construction aggregates. Moreover, the sample quality from both Moh's hardness and the specific gravity tests indicate increasing rock quality with depths. Also, it is expected that the compressive strength of rock at the site will increase with a corresponding improvement in depth. In-situ identification, field observations and chemical tests (Table 1) have confirmed that the compressive strength results were affected by chemical composition of the granite gneisses and that of the intrusive igneous rocks. Both rocks, in the presence of water will decay into clay (kaolinite) and silica according to the equation below:

$$2KAlSi_3O_8 + 2H_2O + CO_2 \longrightarrow Al_2Si_2O_5\left(OH\right)_4 + K_2CO_3 + 4SiO_2$$

(Orthoclase) Carbonic acid Kaolinite + Pot.Carbonate + Silica

Furthermore, in the above equation, sodium (Na) or calcium (Ca) may be present instead of potassium (K) if the mineral in question is another type of feldspar. The main end product, Kaolinite is formed in all such cases. This chemical change in the rock produces definite alteration in the physical constitution of the rock: a soft (H = 1) clay mineral is formed in place of a hard mineral (feldspar, H = 6), thereby affecting the strength of the rock very significantly.

3.5 Correlation Diagrams

Figure 3 shows the relation between specific gravity SG and SiO_2 content. The diagram shows that the higher the SG the higher the SiO_2 content except for weathered materials. In the weathered samples, the SiO_2 content is high while the specific gravity is low. This is clearly seen in some of the weathered pegmatite samples (1 and 21) in which the SiO_2 component reach 80% and above. This was also confirmed by a plot of SG against moisture content and weathering grades (Figure 4).

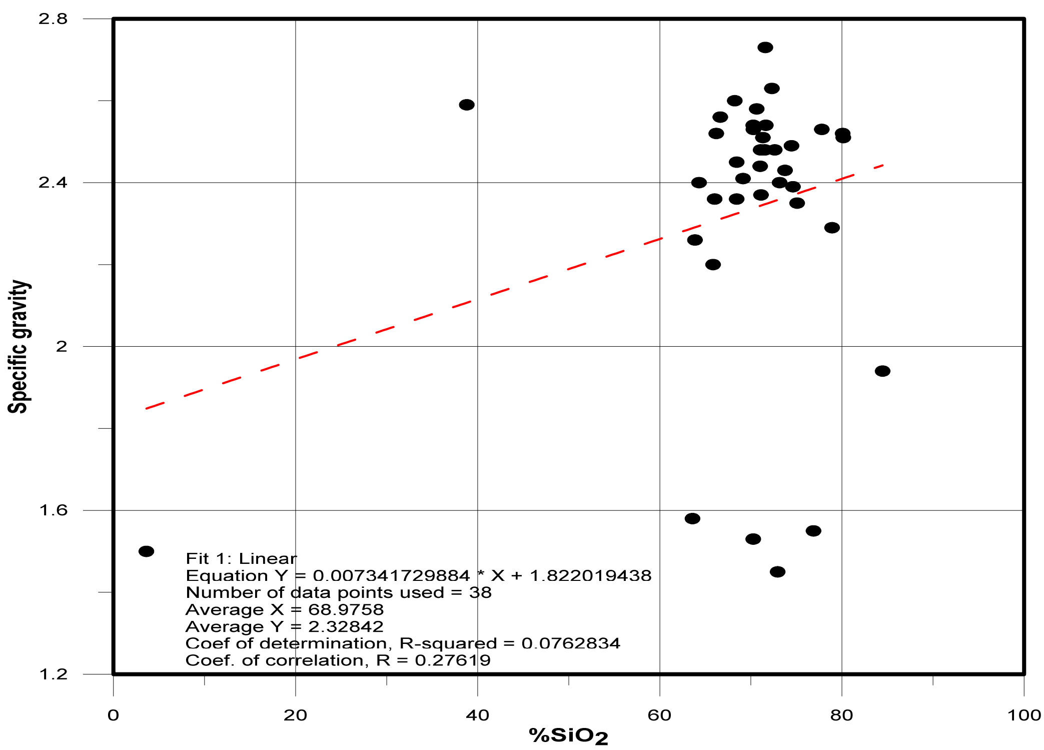

Figure 3. Specific gravity vs SiO_2

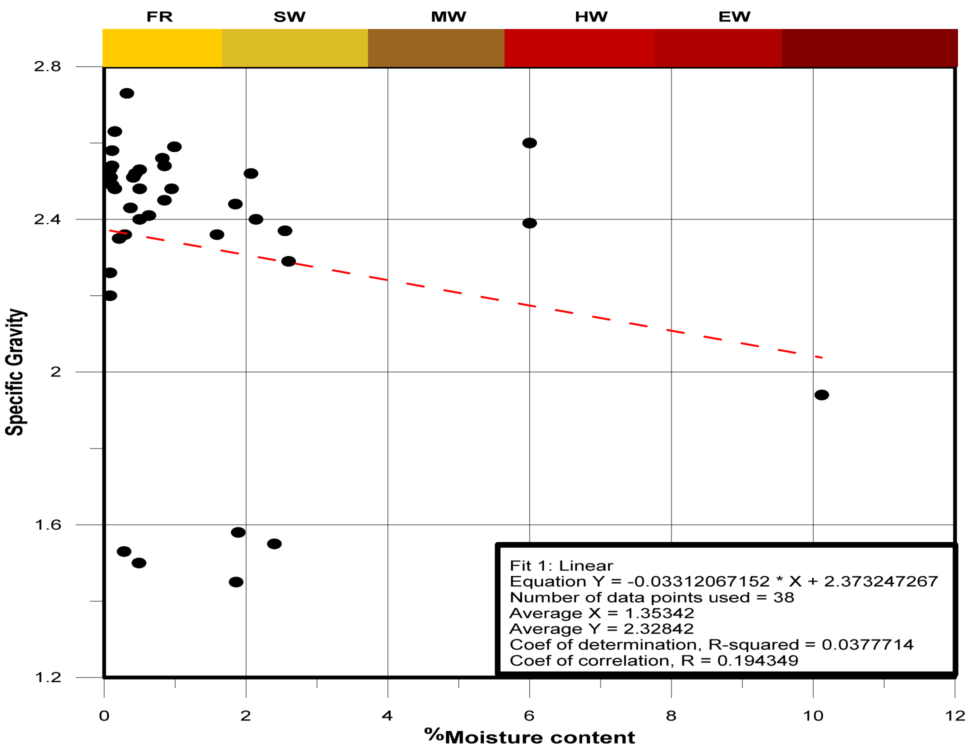

Figure 4. Specific gravity vs Moisture content

The curve (Figure 4) shows a general increase in the water content with low specific gravity especially for samples collected at shallow depths consisting of mainly weathered over burden materials. A plot of SG against compressive strength (Figure 5) and compressive strength versus moisture content and weathering grades(Figure 6) clearly reveal that the higher the specific gravity SG the higher the compressive strength and the lower the moisture content which implies increasing rock quality with depth.

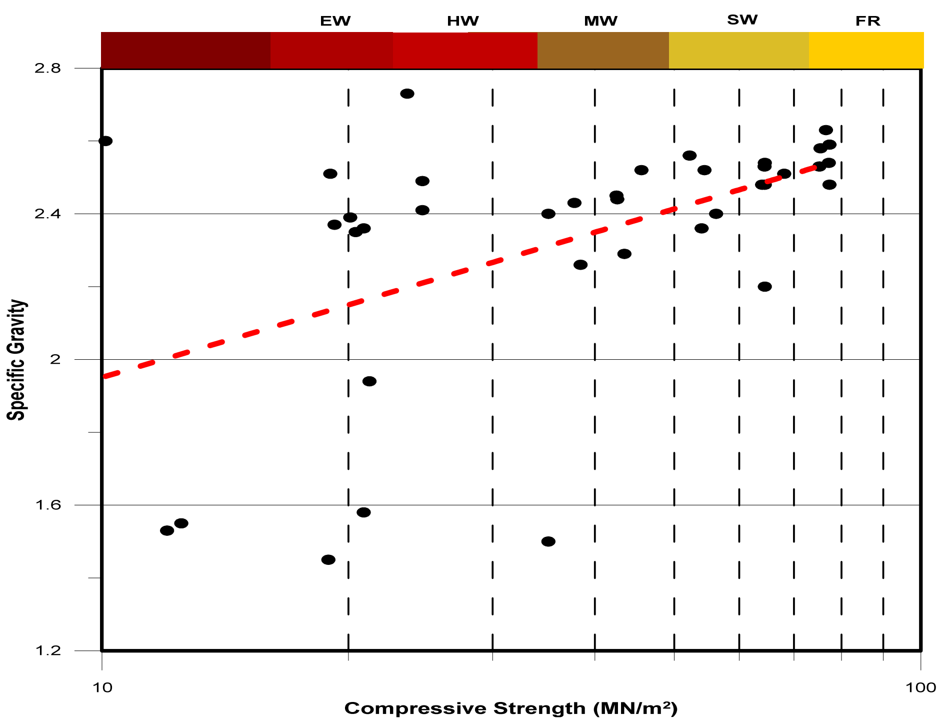

Figure 5. Specific gravity vs compressive strength

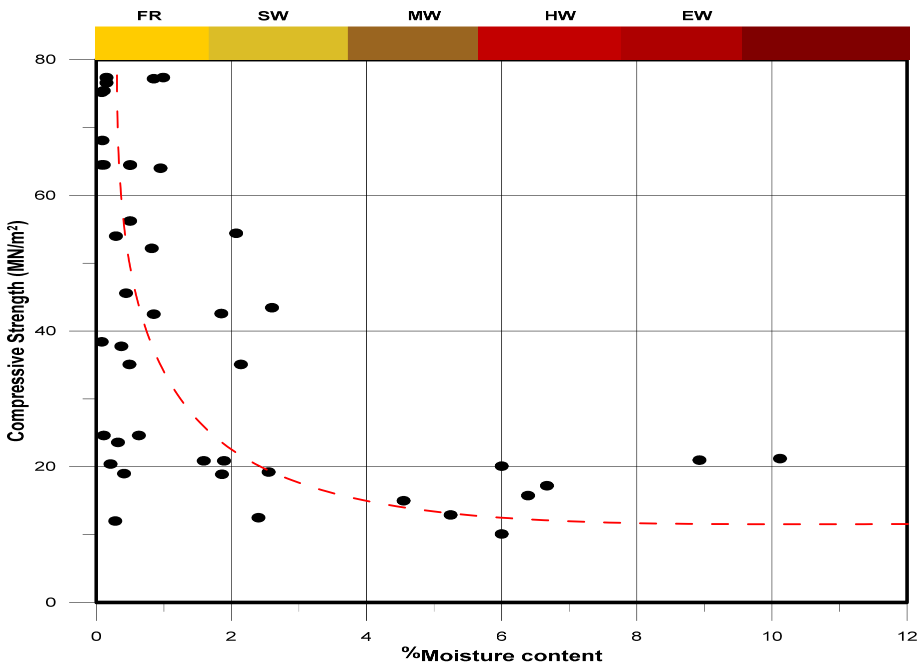

Figure 6. Compressive strength vs Moisture content

3.6 Estimation Scheme

The correlation diagrams above indicate some internal structural composition of the rocks in which fractures/microcracks and weathering contribute significantly to the rock strength. Weathering and structural defects (fractures /joints/microcracks) generally will decrease the strength of the material, accelerate the rate of alteration and increase the amount of saturation (Edet, 1992). This relationship forms the basis of the estimation scheme. In this scheme compressive strength is plotted against the moisture content, W% and divided the plot into five classes: A, B, C, D and E. This is used as a basis for describing the state of rock strength (Figure 6) in relation to the end use (Table 2).

Table 2. Rock strength in relation to the end use

Compressive strength (MN/m^2)	Moisture contents (%)	Degree of weathering	Classes	End use
< 20.0 (very low)	> 8 (very high)	EW	E	Unsuitable for embankments foundation, airfield and highway pavement.
20.0-40.0 (low)	6-8 (high)	HW	D	Suitable for foundations and embankments.
40.0-60.0 (medium)	4-6 (medium)	MW	C	Suitable for civil constructions works/airfield pavements
60.0-80.0 (high)	2-4 (low)	SW	B	Very suitable for civil construction works.
>80 (very high)	< 2 (very low)	FR	A	Most suitable for all civil construction works.

EW – Extremely weathered

HW – Highly Weathere d

MW – Moderately Weathered

SW – Slightly Weathered

FR – Fresh Rock

3.7 Application

It is expected that rock aggregates from this proposed quarry would be used for preparing concrete mixture for embankments, foundations and also heavy dynamic loads found in highways and air-field pavements. Hence, it has become necessary to categorize the test results in relation to the end use of the rock aggregates. These rock samples with compressive strength (80-40) MN/m^2 are fresh to moderately weathered rocks with 0-4% water content. They are classified under grades A, B, C and are suitable for most civil construction works, such as airfield pavements and high way construction because of their high strength with zero or minimum water content (Table 2, Figure 6). 60% of the test results are within these grades. Rock samples whose crushing strength fall in the range (20-40) MN/m^2 (class D) are suitable for use in foundations and embankment constructions in-spite of their low compressive strength. About 30% of the test results presented fall within this category (Table 2, Figure 6).

Rock samples with compressive strengths less than 20MN/m^2 (class E) are considered unsuitable for embankments, foundations, air field and highway pavements .This is due to their high water contents and very low compressive strength. Rocks under this class E are mainly weathered overburden materials which must be removed before engineering loads are placed on them to avoid engineering geological hazards. A decrease in the compressive strength of these rocks could also be attributed to the presence of fractures, joints or microcracks, arising from the geological cause such as pressure relief from erosion, meteorite shock impact and cementation from circulating ground water or due to sampling procedure (e.g drilling, blasting and hammering), (Wang & Simmons, 1978; Kowallis, 1982). Contributions to the weakness of the rock due to the presence of micro cavities should not be overlooked because nearly all rocks, even dense crystalline varieties such as granite, dunite or quartzite, contain micro-cavities (Sprunt & Brace, 1974).

4. Conclusions

On the basis of the assessment scheme (Table 2) and the physical, chemical and engineering properties, the Oban basement rocks at Old Netim Area are judged adequate for road constructions, airfield Pavement, foundations and other civil engineering works, irrespective of the weather conditions. Classes A and B of the classification scheme represent fresh rock (FR) and slightly weathered (SW) rocks. They show better rock quality for construction than the highly weathered (HW) and extremely weathered (EW) overburden materials which are classified under fields D and E. Class C is regarded as intermediate or transitional. The specific gravity (SG), hardness (H), chemical and petrographic data compare favourably well with the results obtained from standard samples collected from nearby Strabarg Quarries and construction sites. The compressive strength results obtain from weather beaten samples appear to be low. However, with the expected improvement in sample quality with depth, the crushing strength will definitely improve. This view is strongly supported by the improved strength tests result on samples collected from freshly exposed rocks at the site. The suitability of these materials can be further emphasized by the fact that some of these rocks were specifically quarried for road constructions and there has been no apparent failure to date. Hence, the materials are found to be generally suitable for most civil construction works. However, more drill holes have to be located to confirm material estimates and overburden thickness at the site. More so, Abrasion tests, Los Angeles Flakiness Gauge and the Elongation Index tests as well as Sieve analysis of the rock fragments should be carried out and displayed periodically for customers' consumption in order to win their continued patronage.

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