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Geo-Engineering Evaluation of Rock Masses for Crushed Rock and Cut Stones in Khartoum State, Sudan

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Abstract: The purpose of this study is to find artificial coarse aggregates and cut stones around Khartoum. To meat the objectives of the study, data from both field and laboratory are collected. The field data includes geological investigations based on different methods and samples collection, whereas the laboratory tests consists of specific gravity, water absorption, impact value, crushing value, Los Angeles abrasion, soundness tests. The field and laboratory results were weighed and compiled together to reveal the engineering performance of the different rock masses in term of cut stone and crushed aggregates. The results show that most of the examined rock masses are suitable for crushing, building and dressed stones. For decorative slabs only foliated granite and syenite masses can be used.

Key words: Cut stone, coarse aggregates, impact value, Los Angeles abrasion, crushed value

INTRODUCTION

Recent reports prepared by the Geological Research Authority of the Sudan (GRAS) and other workers in Khartoum State showed that there is a shortage in construction material (mainly natural coarse aggregates) due to the rapid development in Khartoum State. Tackling this issue by focusing mainly on searching for building material is the main objective of this study, putting in consideration all the economic and quality factors. To render this objective, characterization of the field occurrence, geology, geomorphology and local environment were carried

In field, the rock mass designation (RQD) was determined in accordance with Hudson and Priest (1979) formula for economic factor and lack of the rock core. Also joint set number was obtained. RQD and joint set number for each rock mass unit were determined in many traverses and the average was recorded.

The standard aggregates quality test were determined for samples collected from the study area in accordance with appropriate standards as mentioned later. The tests include Specific Gravity (SG), water absorption, Los Angeles abrasion test value (LAA), Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV) and soundness test. For accuracy of tests results, each test was carried three times and the average was recorded.

MATERIALS AND METHODS

The study area includes Khartoum area and Sabaloka region which is bounded by latitudes 15° and 16° N and longitudes 32° and 3°30" E (Fig. 1). Geologically, Delany (1955), Kheiralla (1966), Whiteman (1971), Ahmed (1968, 1977), Rabba (1976) and Vail (1982) have studied the area and mentioned many sequences. From these sequences the following rock types which were very significant due to the aim of the study were studies in details. These rock types are basalts, granites, ignimbrites, rhyolites, syenites and sandstones which were shown in Table 1.

Closed field observation showed that Babados and Suleik granites reflect great similarity and characterized by intact homogeneous rock mass with two set of joints. The good-looking appearance of the large K-feldspar crystals and the intactness behaviour provided a good condition for utilizing this rock as ornamental slabs (Fig. 2, 3). Part of Suliek granite was quarried as facing stone three decades ago (Kheirelseed, 2002); from the appearance of the Fig. 3 some quarrying marks are obviously seen.

In Silietat Es-Sufur Complex, the fresh sample is very hard, massive, slightly weathered, with two horizontal joints and easily excavated.

The trachy basalt occupies the basal part of the volcanic succession and extends discontinuously along

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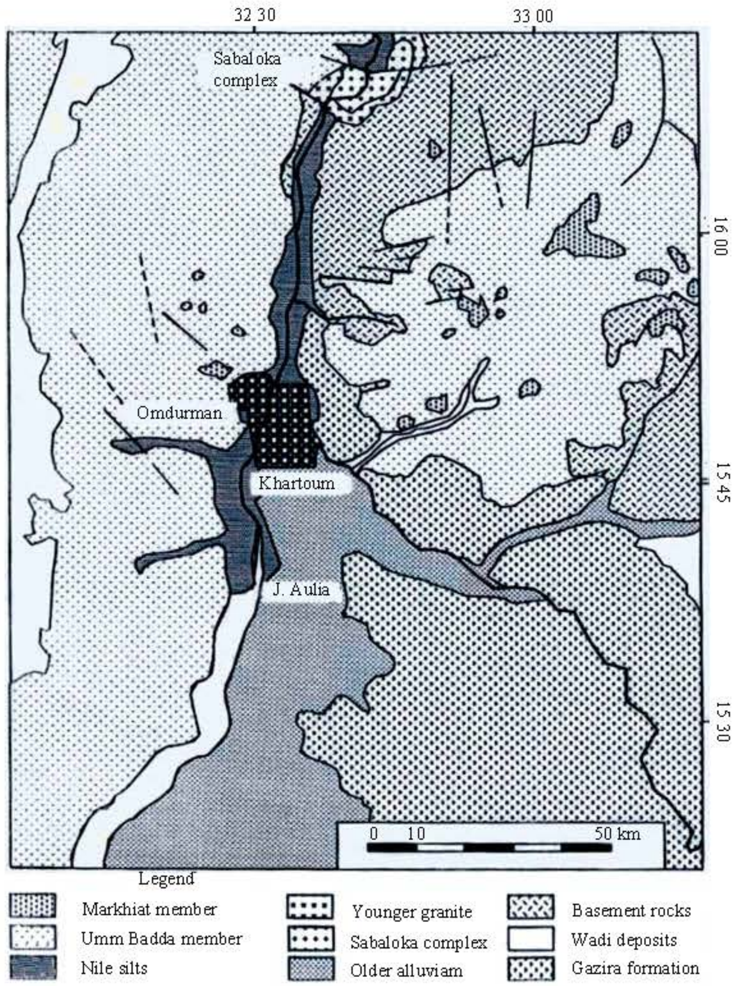

Fig. 1: Geological map of the study area (After Awad, 1994)

the eastern margin of the volcanic plateau with thickness of few meters and four sets of joint and highly altered.

The lower and upper rhyolite block is controlled by two major set of joints and random joints give rise to irregular block shapes of different sizes. In micro-granite, spheroidal weathering is selectively affecting numerous parts of the intrusion particularly at the upper section of the rock masses. The alteration zone penetrates deeper into the rock mass and associate with discoloration. The Tertiary basalt was found in three quarries, the basaltic mass always demonstrates three set of joint filled with clay and rock fragments and it was intensively quarried for crushed aggregates (Fig. 4).

In this study, the rock masses were divided into different domains depending on their weathering condition. Every joint set of the examined rock masses was individually treated. Due to the absence of the rock core, the Rock Quality Designation (RQD) values were estimated from the average frequency of the discontinuities. Consequently, Hudson and Priest (1979) formula for estimation of RQD was applied.

$$RQD = 100e^{-0.1\lambda}(0.1\lambda + 1)$$

where, λ is the average discontinuity frequency per meters.

Usually the RQD is in percentage and high RQD indicates the intactness of the rock mass and few discontinuities per length (Table 2).

Due to the significant of the joint set number (J_n) in rock masses, for each rock type was calculated and presented as ratio with RQD, RQD/J_n. This ratio gives the block size of the rock mass (Hoek and Brown, 1980). The results were show in Table 2.

Table 1: Summary of the geological characteristics of lithological unit in the study area

Lithological units	Age	Characteristics
Wind blown-sand and superficial gravels	Recent	Occurrence: occurs as sand and Nile silts Lithology: san, gravel and silt Distribution: Qos Abudulu, sand sheet from Kordofan to Nile valley. Structural setting: lying on the Nubian sandstone Formation
Sediment of clay plain	Quaternary	Occurrence: Unconsolidated sediments Distribution: area between White and Blue Nile Lithology: clay, silt, sand and gravel Structural setting: lying unconformably on either Nubian Sandstone Formation or directly on the Basement Complex
Tertiary volcanic rock	Tertiary	Occurrence: batholithic intrusion Distribution: two small outcrop west of Omdurman Lithology: olivine basalt Structural setting: intruded within the Nubian Sandstone Formation.
Post-orogenic Basement Complex	Middle and late Paleozoic	Occurrence: ring dyke, batholithic intrusion covered by ash-flow deposition Distribution: Sabaloka inlier and Silietat Lithology: porphyritic micro-granite, felsite dyke and reibeckite quartz granite Structural setting: unconformably overlain by Nubian Sandstone Formation
Syn-orogenic Basement Complex	Pre-Cambrian	Occurrence: batholithic intrusion Distribution: extending from Suliek to Babados outcrops Lithology: granulite, grey gneiss and migmatite. Structural setting: unconformably overlain by Nubian Sandstone Formation

Table 2: Results of field descriptions and measurements of RQD and J_n in the study area

Rock type	Texture	Degree of weathering	RQD	J_n	RQD/J_n
Trachy basalt*	Fine	High	6.60	1.5	0.68
Porphyritic micro-granite*	Medium	Medium	98.11	9	10.93
Light ignimbrite*	Fine	Medium	92.86	9	10.04
Dark ignimbrite*	Fine	Slight	94.40	9	10.44
Babados granite*	V.Coarse	Slight	99.92	4	24.98
Silicified sandstone (J.Rawian)	Medium	Slight	98.41	6	16.40
Argillaceous sandstone (Markhyiat)	Medium	Medium	89.11	9	9.90
Grey gneiss*	Coarse	Medium	98.98	6	16.50
Upper rhyolites*	Fine	Medium	72.55	9	8.08
lower rhyolites*	Fine	Medium	80.85	15	5.39
Syenite (J Silietat)	Coarse	Slight	98.79	12	8.32
Sandstone(Markhyiat)	Medium	Medium	97.09	12	8.09
Sandstone (J.Aulia)	Medium	Medium	99.07	15	6.60
Crushed basalt (J.Toryia)	Fine	Medium	98.25	15	6.55

*The samples were collected from Sabaloka Region

Fig. 2: Large block of Babados foliated granite (Sabaloka region)

The degree of weathering was obtained as a descriptive term in the field and categorized into five groups; non-weathered, slight weathered, moderately

Fig. 3: Intact large block of Suliek granite (the light marks depict the ancient quarried mass more than three decades ago)

Fig. 4: Toryia basalt with dirty appearance showing false severe weathering which in fact only few mm deep

weathered, highly weathered and earth like materials. Similarly, the texture described in five groups; very coarse, coarse, medium, fine and glassy texture.

RESULTS

The experiments were done in accordance with different standard methods. Specific gravity and water absorption test has been carried for 14 rock samples (Table 3) to determine the bulk and apparent specific gravity and absorption ratio (AASHTO Designation, T 85-88 (1990), American Society for Testing and Material, 1997a).

Measurement of resistance of mineral aggregates of standard grade to the action of abrasion and impactness were identified by Los Angeles abrasion test (9 samples) based on AASHTO Designation 96-87 (1990). Aggregate Impact Value (AIV) and Aggregate Crushed Values (ACV) were determined according to British Standard 812 part 112-1990 and British Standard 812 part 110-1990, respectively (Table 4).

Soundness test for determination of the resistance of aggregates to disintegration under the action of saturated solution of sodium sulfate were carried for 12 samples (American Society for Testing and Material, 1997b).

From the fieldwork and tests results which depicted in the above tables, ratings of the parameters were derived (Table 5) and used in accordance with desired required materials (Table 6, 7 and 8) in the discussion below.

DISCUSSION

In the field work results which are summarized in Table 2, from the texture, the rock masses can be grouped into three: fine (6 samples), medium (5 sample) and coarse (3). As known the fine texture material, are having higher strength than the coarse one and it is costly in excavation process. Texture result and others results were weighed and summed to have complete picture in the following paragraphs.

Degree of weathering result shows only one sample was highly weathered (trachy basalt) and the rest slight to medium.

The RQD results of the rock masses (Table 2) depict that most of the samples attained high RQD values which correspond to excellent quality (Barton *et al*., 1975). Only one rock mass is very poor which is trachy basalt. This result is due to the numerous columnar joints in basalt.

The joint set number is ranging from few joints (1.5), to four joint sets or more (15), (Barton *et al*., 1975). Generally, the studied rock masses were between three to four joint sets from which we concluded that some rock types can be excavated by loader without blasting. The ratios of RQD/J_n is directly showing that the smallest block size showed by trachy basalt and the largest size depicted by Babados granite. The RQD/J_n parameter was utilized to give an abstraction about the crude block sizes of the examined rock masses. The higher RQD/J_n value, the more massive rock and can be used as slabs. Hence, it can be taken as primary criterion for the quarrying method. In other words, the small RQD/J_n is preferred for crushed stone.

Table 3: Specific gravity and water absorption test results

Rock type	Specific gravity	Water absorption (%)
Trachy basalt	2.45	0.69
Porphyritic micro-granite	2.66	0.68
Light ignimbrite	2.53	0.53
Dark ignimbrite	2.58	0.13
Babados granite	2.57	0.48
Silicified sandstone	2.30	2.39
Argillaceous sandstone	2.41	1.40
Grey gneiss	2.61	0.61
Upper and lower rhyolites	2.49	1.71
Syenite	2.62	0.36
Sandstone(Markhyiat)	2.15	5.44
Sandstone (J.Aulia)	2.10	6.70
Massive basalt	2.86	0.14
Crushed basalt	2.59	0.74

Concerning the laboratory tests, the Specific Gravity (SG) is often considered to be a good indicator of the strength or quality of an aggregate type. Geotechnically, in pavement, SG of aggregates is between 2.6 to 2.7 up to 2.9. From the results of the studied samples (Table 3), about five rock masses can be used in pavement.

The water absorption values which are indirectly measure of porosity, ranging from 0.68% (trachy basalt) to 6.90% (sandstone of Jebel Aulia). Owning to this result, all samples of low water absorption can be used as building stone in the rainy area whereas those with high value are suitable for the arid zone.

Los Angeles Abrasion (LAA) test for the selected samples showed that the syenite samples reflected a high percentage whereas the upper and lower rhyolites depicted low value. LAA values are specified for subbase and base material in addition to wearing surfaces. Low value of LAA indicates harder aggregates. It is internationally accepted that the LAA should not exceed 30% in the engineering uses. In the study all the rock types can be used with exception of syenite.

The Aggregate Impact Value (AIV) test measures the resistance of aggregate to resist sudden impact. It was performed for the same samples that have been subjected to LAA test. The higher value was revealed by syenite while the lower value recorded by the trachy basalt. As fact, the lower AIV value is more resisting sample. Thus, trachy basalt is the premium one to be used in engineering works that require great impactness. It has been recommended that AIV greater than 30% should not be used in concrete mix. Regarding the tested samples, all are usable.

Table 4: Los Angeles abrasion, aggregate crushing value, aggregate impact value and soundness tests results

Rock type	Los Angeles abrasion test (LAA) %	Aggregate crushing value (ACV) %	Aggregate impact value (AIV) %	Soundness test %
Trachy basalt*	12.62	13.77	3.47	6.7
Porphyritic micro-granite*	24.90	20.59	8.00	6.9
Light ignimbrite*	21.40	15.12	9.97	9.0
Dark ignimbrite*	19.18	11.32	7.52	5.8
Babados granite*	31.20	32.12	18.68	8.8
Grey gneiss*				13.0
Upper and lower rhyolites*	11.14	16.89	3.72	7.4
Syenite N(J Silietat)	33.22	22.63	5.42	4.4
Syenite S (J Silietat)	32.40	23.95	16.30	5.0
Sandstone(Markhyiat)				3.2
Sandstone (J.Aulia)				3.1
Crushed basalt (J.Toryia)	12.40	23.50	3.94	3.6

* The samples were collected from Sabaloka Region

Table 5: Ranges and rating of essential parameters that used in evaluation of rock for crushed, dressed and ornamented stones

Parameter						
RQD/Jn	Sub-range	0-6	6-12	12-18	18-24	>24
	Rate for crushed rocks	5	4	3	2	1
	Rate for cut stone	1	2	3	4	5
ACV	Sub-range	0-5	5-10	10-15	15-20	>20
	Rate	5	4	3	2	1
AIV	Sub-range	0-4	4-8	8-12	12-16	>16
	Rate	5	4	3	2	1
LAA	Sub-range	0-10	10-20	20-30	30-40	>40
	Rate	5	4	3	2	1
Soundness	Sub-range	0-2	2-4	4-6	6-8	>8
	Rate	5	4	3	2	1
Texture	Description	V. coarse	Coarse	Medium	Fine	Glassy
	Rate for crushed rock	1	2	3	4	5
	Rate for ornamented slabs	5	4	3	2	1
Water absorption	Sub-range	0-0.4	0.4-0.8	0.8-1.2	1.2-1.6	>1.6
	Rate	5	4	3	2	1
Degree of weathering	Description	Non weathered	slight	moderate	high	Earth like material
	Rate	0	-1	-2	-3	-4

Table 6: Total rating scores of some rock types for crushed rocks

Rock type	The rating score of RQD/Jn	ACV	AIV	LAA	Soundness	Texture	Water absorption	Deg. of weath.	Total rate
Trachy basalt	5	3	5	4	2	4	4	-3	24
Porphyritic micro-granite	4	1	4	3	2	3	4	-2	19
Light ignimbrite	4	2	3	3	1	4	4	-2	19
Dark ignimbrite	4	3	4	4	3	4	5	-1	26
Babados granite	1	1	1	2	1	1	4	-1	10
lower rhyolites	5	2	5	4	2	4	1	-2	21
Basalt (J.Toryia)	4	1	5	4	4	4	4	-2	24
Upper rhyolite	4	2	5	4	2	4	1	-2	20
Syenite (J Silietat)	4	1	4	2	3	2	5	-1	20

Table 7: Total rating scores for some rock types for dressed stone

Rock type	The rating score of: RQD/J_n	Soundness	Water absorption	Deg. of weathering.	Total rate
Trachy basalt	1	2	4	-3	4
Porphyritic micro-granite	2	2	4	-2	6
Dark ignimbrite	2	3	5	-1	9
Light ignimbrite	2	1	4	-2	5
Babados granite	5	1	4	-1	9
Upper rhyolite	2	2	1	-2	5
Basalt (J.Toryia)	2	4	4	-2	8
lower rhyolites	1	4	1	-2	4
Syenite (J Silietat)	2	3	5	-1	8
Sandstone (Markhyiat)	2	4	1	-2	5
Sandstone (J.Aulia)	2	4	1	-2	6

Table 8: Total rating scores for some rock types for ornamented slabs

Rock type	The rating score of RQD/J_n	Soundness	Texture	Water absorption	Deg. of weathering	Total rate
Trachy basalt	1	2	2	4	-3	6
Porphyritic micro-granite	2	2	3	4	-2	9
Light ignimbrite	2	1	2	4	-2	7
Dark ignimbrite	2	3	2	5	-1	11
Babados granite	5	1	5	4	-1	14
Upper rhyolite	2	2	2	1	-2	5
Basalt (J.Toryia)	2	4	2	4	-2	10
lower rhyolites	2	2	2	1	-2	5
Syenite (J Silietat)	2	3	4	5	-1	13

In Aggregate Crushing Value (ACV) test, the higher value was scored by syenite and the lowest value obtained from trachy basalt. The result is equivalent to that obtained by AIV test. Also all the samples could be utilized in different uses. In addition, the selected samples can be used in all asphalt and concrete works since the ACV values are less than 45% (Fattohi *et al*., 1990).

The soundness test of the tested samples showed that the grey gneiss scored the highest value while syenite recorded the lowest value. Generally speaking, most of the examined samples obtained low soundness value in particular the sandstones, which indicate that no constituents reacted with the solution. The rest of the samples more or less are resistant to the disintegration.

From the above discussion, it is obvious that one parameter is not enough for determining the quality of rock mass for certain engineering use. According to this fact, the relative quality of the individual rock type for specific purpose is determined by compilation of the available geological and geotechnical parameters. The compilations were carried out by weighing these parameters through a simple rating system. The rating procedure is as following:

- Each parameter is individually treated where its range value of the entire examined rock is determined primarily.
- The acquired total range is divided into five sub-ranges that initiated from the lowest value and gradually increase with constant rate, which is equal to about 20% of the total range.
- A weighed numerical value is given to each sub-range, which orderly raised or reduced with constant rate.
- The total rate score being the sum of weighed value of the individual parameters.
- The higher the total rate scores the better the rock quality for the desired usage.

The weighing results of the parameters for crushed and cut stones are presented in Table 5.

Rock masses desired for the purpose of the crushed aggregates were weighed using four geological factors (RQD/J_n, degree of weathering, water absorption and texture) and four geotechnical parameters (ACV, AIV, LAA and soundness).The rating output (Table 6) showed that the total score ranging between 10 and 26.The lowest score is registered by Babados granite (foliated granite) and the highest rating is depicted by trachy basalt, dark ignimbrite and Toryia basalt which are ranging between 24 to 26 The rest of the examined rock masses more or less scored similar value ranging between 19 up to 21. The abundance of dark ignimbrite and lower rhyolite in the study area could be considered as alternative future source of crushed aggregates

Table 7 showed the parameters used for classification of the rock masses for the purpose of dresses stones in which three geological factors (RQD/JN, texture and degree of weathering) and one geotechnical parameter (soundness) were used to achieve this goal. The high ratings were recorded by four rock types including dark ignimbrite, Babados granite, Toryia basalt and Syenite. Porphyritic micro-granite and the sandstone of Jebel Aulia came in the second order.

Ornamented slabs were determined by totaling rate of five parameters including RQD/J_n, soundness, texture, water absorption and degree of weathering. Babados granite and syenite are the best rock quality within the examined types. Also porphyritic micro-granite, Basalt (J. Toryia) and the dark ignimbrite can be utilized when the best quality consumed. The rest of the examined suites seem to be inappropriate as ornamented slabs since they show a remarkable low score (Table 8).

With the exception of texture, the same parameters and factors used for dressed stone and decorative slabs could be used in evaluation of the rock masses as source of building materials. Babados granite, dark ignimbrite, Toryia basalt and syenite are recommended to be used as building stone for heavy construction since they reveal the highest score among the examined suite. Lower rhyolite, light ignimbrite and sandstones are suitable for light building. The trachy basalt is extremely unrecommended due to the intensive jointing which resulted in small block sizes.

CONCLUSION AND RECOMMENDATION

This research depicts the methods by which artificial coarse aggregates and cut stones could be assessed by using geological factors and geotechnical parameters. The field and laboratory results which were weighed and compiled together revealed the engineering performance of the different rock masses in term of crushed aggregates, dressed stones, ornamented slabs and building stone. The outputs show that the majority of the rock masses are ranging from high to very high quality in term of rock quality designation

The best rock types for crushed aggregates are the dark ignimbrite, Toryia basalt, trachy basalt, lower rhyolite and syenite, respectively. Due to the overuse of the near sources, syenite is preferable with reference to the economic factors. In future, the great quantity of ignimbrite and lower rhyolite could be considered as alternative sources of crushed aggregates.

Suitability of the rock masses as decorative slabs were shown by Babados granite and syenite and to some extends by dark ignimbrite.

Babados granite, Toryia basalt and syenite are recommended to be used as building stones for heavy constructions types. Also it was found that all the rock masses of low water absorption ratio can be used as base building materials in the rainy area. With exception of sandstones all the rock types could be used in concrete mix since their crushing value less than 45% and the impact value less than 30%. In addition, most of the tested masses more or less resistant to disintegration, showing no constituents reacted with the used solution in particular the sandstones.

For searching of building materials whether natural aggregates or rock masses, attention seriously should be paid to the geology, paleoenvironment and the sedimentological system of the area under study.

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