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Rock Masses Evaluation for Different Engineering Purposes in and Around Khartoum State-Sudan

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Abstract: This study is concerning with the rock masses classification in Khartoum State for different engineering purposes in accordance to the growing needs of the city. The main classification systems that utilized in this study were: Franklin classification in which he presented the point load strength and the fracture spacing; the Rock Mass Rating system (RMR) which advanced by Bieniawski and NGI-Q Rating, Q system. In the field, some measurements (mainly joint set numbers, separation, continuity and orientations) and rock mass description were carried out in quarries or well exposed rock mass wall. Some sheets were designed to facilitate recording data beside the use of Schmidt hammer for crude joint wall strength and collection of samples for laboratory study (point load and density tests). The reconnaissance survey of the study area did reveal an abundance of naturally occurring construction materials in Sabaloka area. Also simple excavation due to the jointing system was detected for most of the examined rock types.

Key words: Rock mass, point load strength, Schmidt hammer, fracture spacing, rock mass rating

INTRODUCTION

Recently, population is growing up rapidly in Khartoum State which leads to overuse of construction materials. To meat such growth, maximum utilization of engineering geological data is highly requested to determine qualitatively and quantitatively the performance of the available construction materials in the periphery of Khartoum so as to avoid the cost of the transportation from remote areas. To achieve these objectives, the study organized into three phases. The first phase is the general assessment mainly focusing in the field observations, Schmidt hammer and the second phase included some tests (point load and density). In the last phase, the field and laboratory data complied together to have the final results which related to the coarse aggregates assessment.

The nearest area relevant for investigation is Sabaloka area about 80 km northern Khartoum (Fig. 1) which is easily accessible through Atbara-Khartoum highway. The remote aggregates sites and rock quarries are accessible through stable road tracks.

The most advanced methods of the rock quality classification used in this study were point load and fracture spacing, Rock Mass Rating system (RMR) and NGI Quality Index, Q system.

THE GEOLOGY OF THE STUDY AREA

Many researchers from early forties of the past century and up to date have intensively studied the general geology of the study area including Dawoud (1982), Vail (1982), Schrank and Awad (1990), Almond and Ahmed (1993) and Elamein (2001). The Sabaloka region is the significant part of this study because there are many rock types from which in future the coarse aggregates can be extracted. Also there are thick plain of loose sediments and few scattered outcrops of moderate relief in the western part of the study area. Generally speaking, the following lithological units are revealed and arranged geochronologically from older at the bottom to the younger at the top:

- Recent sediment (Nile silt, eolian sand, red quartz gravel).
- Quaternary sediments.
- Cretaceous sediments (Nubian Sandstone Formation).
- Sabaloka Igneous Complex.
- Volcanic Succession: Ignimbrite, Agglomerate, Lower rhyolite and trachy basalt.
- Plutonic intrusions: porphyritic micro-granite and mica granite.

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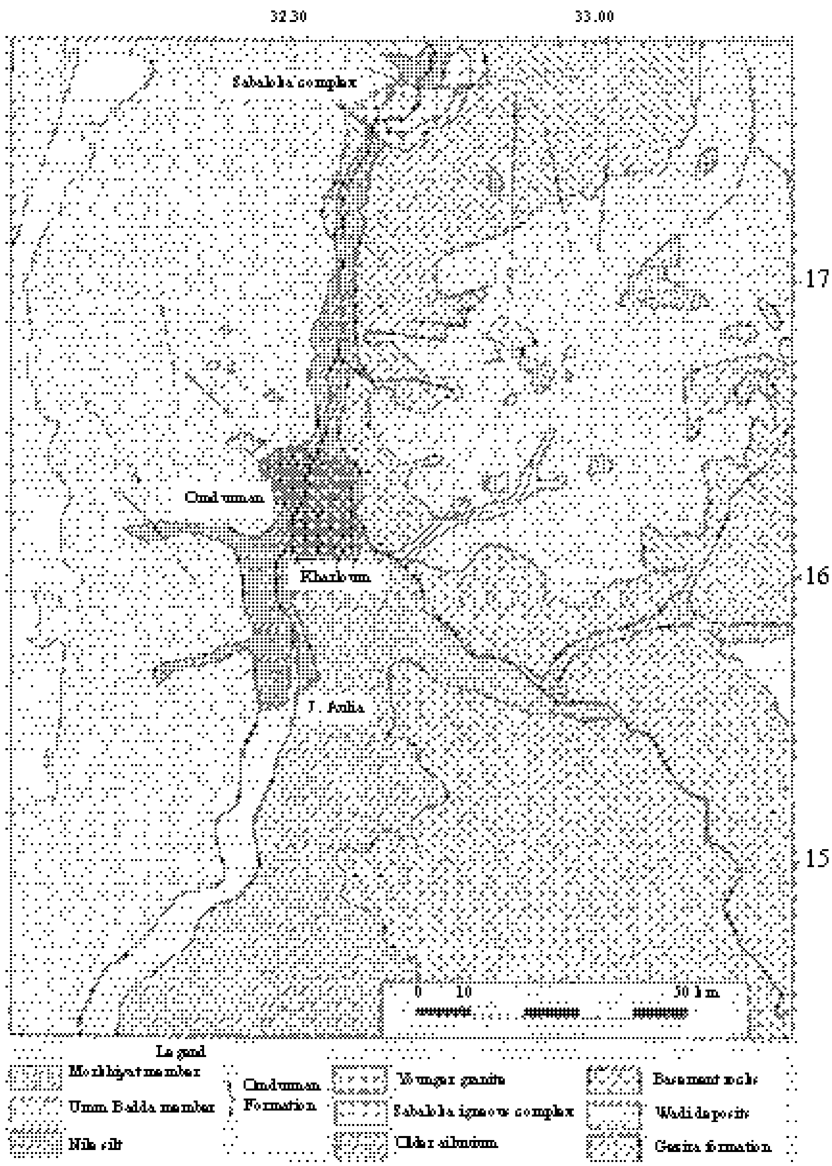

Fig. 1: Geological map of the study area (Awad, 1994)

- El Silietat Esufur Complex (granite and syenite)
- Abu Tuleh Complex (mainly Syenite)
- Sub volcanic sediments
- Older granitoids
- Gneisses and Migmatite
- Granulites

FIELD INVESTIGATION AND DATA COLLECTION

After the recognition of the lithological units in the area, discontinuity data from different rock masses was collected for the purpose of the classification. The collected data was recorded in the Bieniawski's (1974) rock mass and discontinuity survey data sheets. The data sheets established for acquiring a quick and far-reaching description of rock masses in term of intact strength, fracture spacing, fraction separation, joint orientation, joint condition and weathering.

The estimation of joint frequency and joint spacing is carried out for counting the number of discontinuities along traverses of known length. For prediction of the crude joint wall strength, Schmidt hammer was used. Joint orientations (strike and dip) were measured by using compass and the fingertips examined joint roughness.

The degree of weathering was revealed following the criteria of Dearman *et al*. (1972) for the engineering grade classification of weathered rocks.

The following are descriptions of some rock units in the study area:

- Gneisses and Migmatite unit are widely spread in Sabaloka area and from field observations and laboratory studies indicate that they have been formed by the retrogression of the granulites facies (Almond, 1980).
- The Older granitoids includes three types in the study area from which Babados and Suliek granite are the most significant type. Closed field observations indicate that Babados granite is always characterized by intact homogeneous rock mass with two joint sets (dominant NE and subsidiary NW) that divided the mass into relatively huge elongated boulders. These rocks are slightly altered and moderately weathered in term of hand specimen and in the case of rock mass, respectively.
- The fresh sample of El Silietat Es-sufur Complex (granite and syenite) is very massive and slightly weathered with two horizontal joints plus random.
- The Trachy basalt shows intensive jointing system and severe alteration as well as the fragmentation of the rock mass into sugar cube like block. Four joint sets are observed, three vertical and one horizontal, beside random joints.
- The lower rhyolite is moderately weathered and the shape and the size are generally controlled by two major sets of nearly vertical to vertical joint. The difference between the lower and the upper rhyolite is that the latter is lacking the flow bands. The Tertiary basalt is typified by Toryia basalt with three joints filled with clay and rock fragments. These joints are wide enough to break down the rock mass into columnar blocks that can be excavated by loaders. In short the basalt is moderately and slightly weathered for rock mass and hand specimen, respectively.

LABORATORY TESTS

Point load strength test: The point load tests of some samples were determined in accordance to BS 812 part 113-1990. Average of several measurements was taken as the point load strength index (I_s). For each selected site the fracture spacing index (I_f) was measured for three to four traverses and the average was taken as the final values. The values of I_s and I_f of the different rock types are shown in Table 1.

The resultant data was presented graphically in the Franklin (1971) discrimination diagram of the rock mass classification for general purposes (Fig. 2).

Density test: The density of the rock depends on the specific gravity of the rock-forming mineral. Densities of the samples have been determined by obtaining their weights in air and water and the following formulae are used for calculation.

$$\text{Density} = W_a/V \quad (\text{g cm}^{-3})$$
$$V = W_a - W_w$$

Where:

W_a = Weight of rock specimen in air (g).
W_w = Weight of rock specimen in water (g).
V = Volume of the rock specimen (cm^3).

Table 1: Rock mass classification of the selected samples from the study area based on Franklin *et al.* (1972)

Sample no.	Name of rock	Point load strength (MPa)	Fracture spacing	Degree of weathering	Q
1	Basalt (Sabaloka)	2.69	0.08	W	H
2	Micro-granite (Sabaloka)	4.25	0.52	MS	VH
3	Light ignimbrite (Sabaloka)	3.33	0.23	MW	H
4	Dark ignimbrite (Sabaloka)	7.08	0.22	MW	VH
5	Suleik granite (Sabaloka)	5.10	16.67	VS	VH
6	Babados granite (Sabaloka)	4.31	2.50	MS	VH
7	Silicified sandstone (Sabaloka)	1.71	0.54	MW	H
8	Argillaceous sandstone (Sabaloka)	1.65	0.16	W	H
9	Grey gneiss (Sabaloka)	1.65	0.23	MW	VH
10	Upper rhyolite (Sabaloka)	4.08	0.12	MW	VH
11	Lower rhyolite (Sabaloka)	3.45	0.09	MW	VH
12	Syenite (Silietat)	7.08	1.35	MS	VH
13	Sandstone (Omdurman)	1.52	2.32	MW	H
14	Sandstone (Omdurman)	1.52	0.63	MW	H
15	Sandstone (J. Aulia)	1.52	2.16	MW	H
16	Basalt (J. Toryia)	5.63	0.53	MS	VH

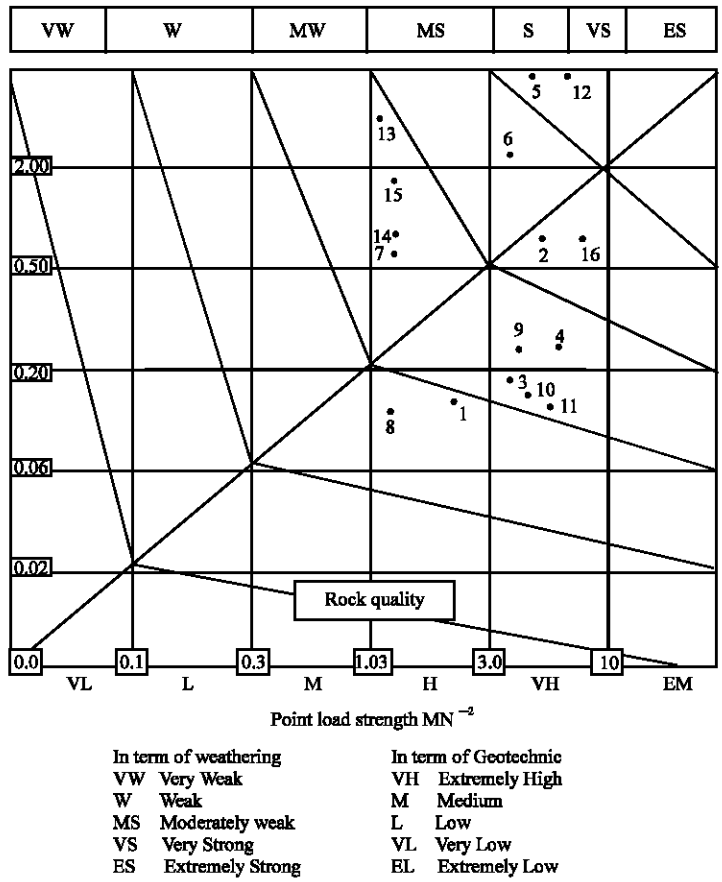

Fig. 2: Chart of rock mass classification for general purposes (Franklin *et al*., 1971)

THE ROCK MASS RATING SYSTEM (RMR SYSTEM)

The main parameters of these classifications are:

- Rock quality designation.
- The unconfined compressive strength/point load strength.
- The degree of weathering.
- The separation, spacing, orientation and continuity of discontinuity.
- Groundwater flow.

In this study, the rock mass was divided into different domains depending on their weathering condition. Due to the absence of the rock core, the RQD values were estimated from the average frequency of discontinuities. Consequently, the Hudson Priest (1979) formula for estimation of RQD was utilized.

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

Where:

λ = The average discontinuity frequency/meter.

In this system a weighed numerical value was given to each parameter, the total rock mass rating being the sum of the weighed values of the individual parameters, the higher the total rating, the better rock mass quality (Table 2).

THE NGI QUALITY INDEX CLASSIFICATION SYSTEM (Q SYSTEM)

The system was developed by Barton *et al*. (1975) who compiled six parameters as in the following equation:

$$Q = (RQD/J_n).(J_r/J_a).(J_w/SRF)$$

Where:

RQD = Rock Quality Designation

J_n = Joint set number

J_r = Joint roughness number

Table 2: The Engineering classification of jointed rock masses in the study area based on method proposed by Bieniawski (1973)

Sample no.	Point load (MPa)	RQD (%)	Space of discontinuity	Orientation of discontinuity	Condition of discontinuity	Groundwate condition	Total rating	Class no.	Description
	Rating								
1 *	2.0	3.0	5	6	10.0	10	36	IV	Poor
2	5.0	20	10	10	10.0	10	65	III	Fair
3	2.0	20	20	10	0.0	10	62	III	Fair
4	5.0	20	20	13	10.0	10	78	II	Good
5	5.0	20	25	13	10.0	10	83	II	Good
6	5.0	20	25	13	10.0	10	83	II	Good
7	1.0	20	25	10	10.0	10	76	II	Good
8	1.0	17	10	10	0.0	10	48	IV	Poor
9	5.0	20	20	13	5.0	10	73	II	Good
10	2.0	17	10	10	10.0	10	59	III	Fair
11	2.0	14	5	10	10.0	10	51	III	Fair
12	10.0	20	25	13	0.0	10	78	II	Good
13	1.0	20	20	10	5.0	10	66	III	Fair
14	1.0	20	20	10	0.0	10	61	III	Fair
15	1.0	20	20	6	10.0	10	67	III	Fair
16	5.0	20	20	6	6.0	10	67	III	Fair

*: Names of samples as in Table 1 from 1 to 16

Table 3: Rock mass quality values in the study area based on method proposed by Barton *et al.* (1975)

Name of rock	Location	RQD/J_n	J_r/J_a	J_w/SRF	Q
Basalt	Sabaloka plateau	0.68	1.00	1	0.44
Micro-granite	Rawyan	10.93	2.00	1	21.68
Light ignimbrite	Sabaloka plateau	10.04	1.50	1	13.54
Dark ignimbrite	Six cataract	10.44	1.50	1	15.74
Suleik granite	Sabaloka	14.90	4.00	1	99.60
Babados granite	Sabaloka	24.98	3.40	1	74.64
Silicified sandstone	Rawyan	16.40	1.50	1	24.61
Argillaceous sandstone	Um Marahik	9.90	1.50	1	14.43
Grey gneiss	Algamrab	16.50	4.00	1	72.22
Upper rhyolite	Sabaloka	8.08	2.67	1	15.78
Lower rhyolite	Sabaloka	5.39	2.67	1	15.17
Syenite	El silietat	8.32	1.50	1	33.28
Sandstone	Markhiat	8.09	1.50	1	10.89
Sandstone	Jebel Aulia	6.60	2.00	1	13.32
Basalt	Jebel Toryia	6.55	0.17	1	1.10

J_a = Joint alteration number.
J_w = Joint water reduction factor.
SRF = Stress Reduction Factor.

The above equation can be simplified into three parameters (Hoek and Brown, 1980), which are crude outputs of: (RQD/J_n) as block size, (J_r/J_a) as inter block shear strength and (J_w/SRF) as an active stress.

The rock mass description and ratings for each of the six parameters are shown in Table 3.

RESULT AND DISCUSSION

From the result of the density, the tested rock samples are grouped into three categories: low density (2.2-2.5 g cm^{-3}), which mainly includes sandstones; medium density (2.5-2.7 g cm^{-3}), that clarified by micro-granite, ignimbrite, Babados granite, rhyolite and syenite; and high density (> 2.7 g cm^{-3}) which includes Toryia basalt, trachy basalt and Suleik granite. As known the high density means low absorption, low porosity and high compressive strength. The last group is recommended for the general usages.

The (R) values of Schmidt hammer and the densities are utilized to yield an approximate estimation of the compressive strength of the selected rock samples. Deere and Miller (1966) diagram is used to achieve this goal Fig. 3. From the results (Table 4), the basalt of Toryia acquired the highest strength value and the sandstone of Rawyan scored the lowest value. These results can be interpreted texturally, that the fine-grained rock are usually well packed and harder than the coarse-grain variety. The low strength of trachy basalt is due to the weathering and intensive jointing.

The RQD of most studied rock masses attained high values, which correspond to excellent quality. Concerning the Franklin method, Suleik granite, syenite, Babados granite and Toryia basalt came in the first order quality, whereas the trachy basalt is still having low superiority. According to Bieniawski's classification, eight rock masses are grouped as class II (good) and two ranked as class IV (poor) including trachy basalt and sandstone of

Table 4: Compressive strength values from Schmidt hammer and the density values (Deere and Miller, 1966)

Sample no.	Density (g cm^{-3})	Schmidt hamme r(N)	Compressive strength (MPa)	Sample no.	Density (g cm^{-3})	Schmidt hammer (N)	Compressive strength (MPa)
1	2.75	35	62.10	8	2.39	29	39.20
2	2.59	44	90.47	9	2.34	50	100.00
3	2.53	40	70.55	10	2.53	42	84.40
4	2.61	52	121.50	11/12	2.63	57	81.25
5	2.77	44	91.90	13/14	2.24	31	42.50
6	2.59	41	78.85	15	2.20	30	40.25
7	2.34	30	38.10	16	2.93	35	127.00

*: Names of samples as in Table 1 from 1 to 16

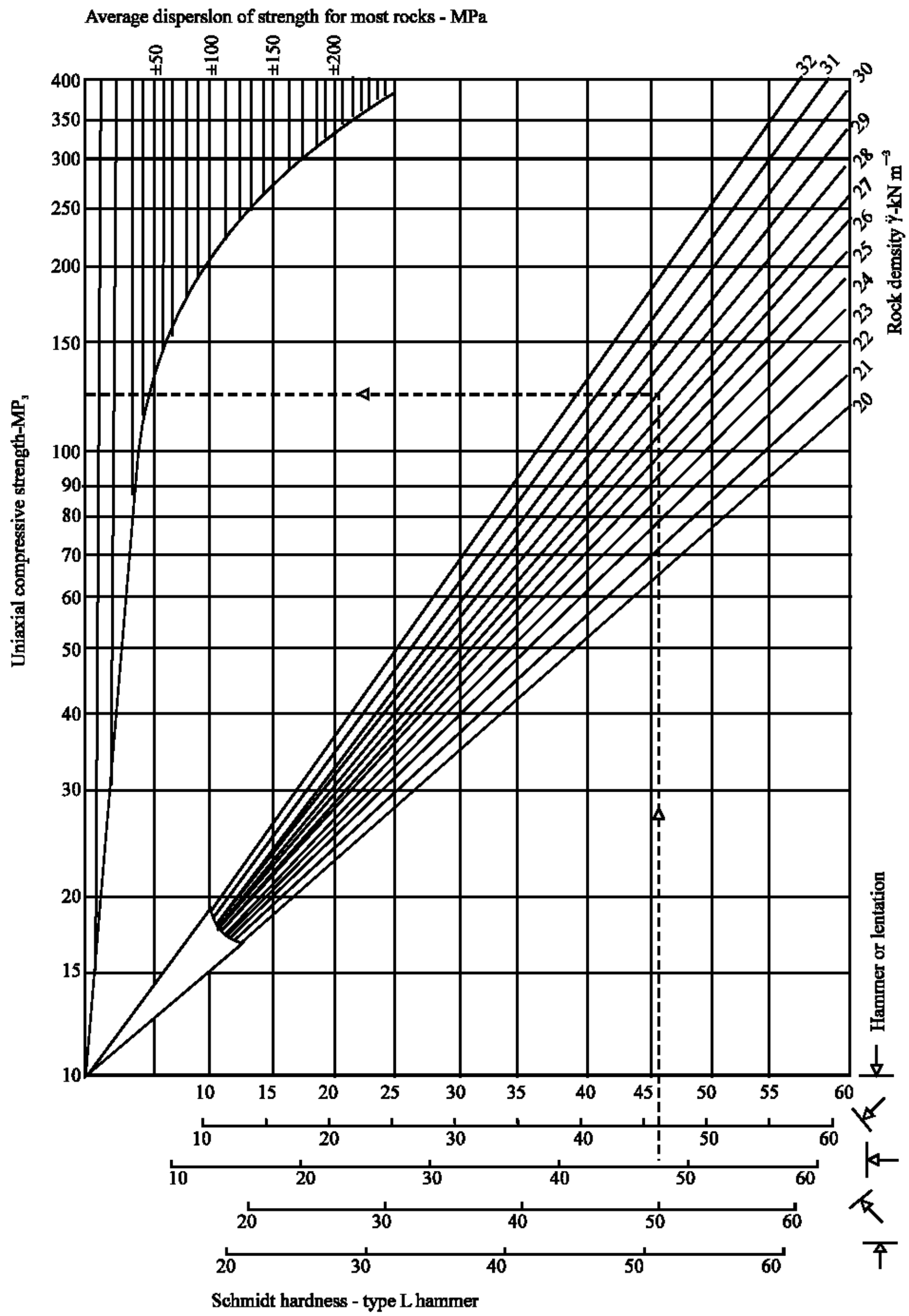

Fig. 3: Rock strength chart based on Schmidt hardness (Deere and Miller, 1966)

Jebel Aulia. From Barton *et al.* (1975) method, Babados granite obtained the highest Q value whereas Sabaloka basalt has the lowest value. It is concluded that the classification systems of Barton and Bieniawski give comparable results when weighed against that of Franklin method.

CONCLUSION

Determination of the strength properties of in-place rock which estimated by testing rock outcrop throughout the study area with Schmidt hammer and the density values gave quick estimation of the uniaxial compressive strength. It is important to notify that the quality values obtained from these methods are valuable for any project to be constructed on or within the examined rock masses. Nevertheless, this does not make an obstruction to use some of these systems' parameters for evaluation of the rock masses for general uses. In other words, the parameters of rock quality classification system could be partially utilized in indirect way to evaluate the engineering workability of the different rock types in term of block, hand specimen or gravel. The majority of rock masses ranging from high to very high quality(class II) that can be used in all works required high strength rock mass. As it was mentioned above that many rock masses have at least two sets of joint which implies that simple quarrying can be run for most of the rock masses. For coarse aggregates, the dense and high quality rock mass can be exploited after carrying out addition tests in the proposed second phase of this study.

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