A Study on Geotechnical Properties of Weak Rocks in Sudan

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Abstract

Weak rocks are available in different areas in Sudan. These include sandstone, mudstone, siltstone usually referred to as Nubian Formations (N.F.). Clastic limestones are present in other areas of Sudan. Organic limestones in the form of coralline deposits are present in eastern Sudan, mainly on the Red Sea coast. Weak rocks constitute an important geological feature on which the foundations of most of the important structures are resting. The sandstone is also used as a primary building material or as a facing stone over other construction.

The geotechnical properties of these formations were investigated by different insitu and laboratory testing methods. This paper summarizes the origin, distribution of Nubian formation and limestone. The paper also presents most of available data on the geotechnical properties of these formations.

It is concluded that the Nubian formation and limestone coral deposit are weak rocks with poor quality of core samples; hence field testing may give better geocharacterization result for such deposit.

مستخلص:

توجد طبقات من الصخور الضعيفة في أنحاء مختلفة من السودان وهذه الأنواع من الصخور تشمل الحجر الرملي والطين الرملي الذي يعرف بإسم المتكون النوبي، وفي مناطق في شرق السودان توجد في شكل شعاب مرجانية وخاصة بالقرب من ساحل البحر الاحمر، وهذه الصخور الضعيفة تشكل الطبقات التي تؤسس عليها المنشآت المهمة مثل الأبراج متوسطة وعالية الإرتفاع والبنيات الأساسية الأخري ومن ناحية أخري فإن هذه الصخور الرملية تستعمل كذلك كمواد بناء وزينة لواجهات المباني. تمت دراسة الخصائص الجيوتقنية لهذه الصخور الضعيفة بإستعمال الإختبارات المعملية والحقلية المختلفة.

تلخص هذه الورقة أصل المتكون النوبي والحجر الجيري وتوزيعها في المناطق المختلفة في السودان، كما تشمل الورقة كذلك عرض لمعظم البيانات المتاحة عن الخصائص الجيوتقنية لهذه المتكونات. وتخلص الدراسة إلى أن العينات المستخرجة من الصخور الضعيفة في السودان قليلة الجودة ولذلك فإنه من الأفضل أن يتم تقدير الخصائص الجيوتقنية لهذه الصخور من الاختبارات الحقلية.

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1. Introduction

Weak rocks or soft rocks refer to weathered or intact rock materials that have compressive strength (UCS) less than 20 MPa,[1]. In comparison with soil, weak rocks were reported to be harder, more brittle, more dilatant, and discontinuous. In relation to hard rocks, they are softer, less brittle, more compressible and more susceptible to changes induced by variation in effective stress, [2]. Such type of rocks constitute an important bearing stratum for most of the major civil engineering structures such as high rise buildings, bridges, dams, quay walls, elevated Water tanks, large water front structures such as pump station constructed in different parts of the Sudan. Information of the properties of weak rocks presented in this paper is obtained from soil investigations conducted at Engineering Services & Design (ESD) Engineering company and Building and Road Research Institute (BRRI) University of Khartoum in Khartoum state and on the Red Sea coast.

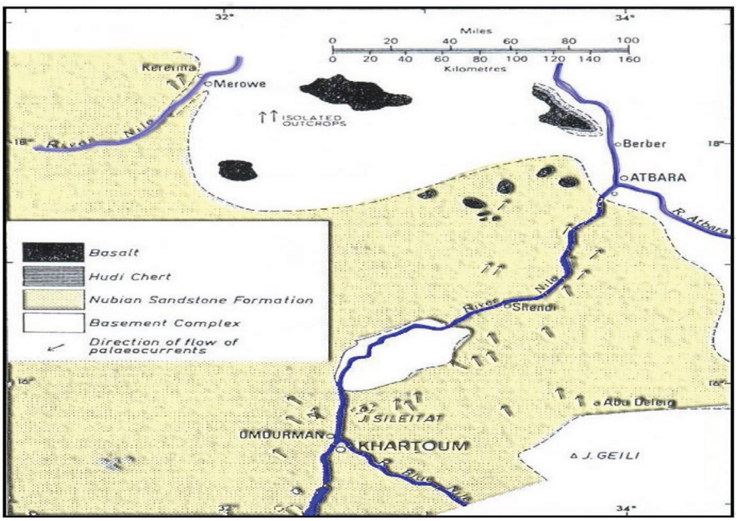


Fig. (1): General Map of Nubian Formation in Sudan (After Whiteman – [9])

Boreholes were drilled to a maximum depth of 50m. Core samples were taken by Total Core Recovery (TCR) & Rock Quality Designation (RQD). In-situ tests such as Standard Penetration Test (SPT), Pressure Meter Test (PMT), Cone Penetration Test (CPT), Dynamic Cone Penetration Test (DCP) and Plate Load Test (PLT) were conducted. Laboratory tests were carried out on the recovered rock samples.

1.1 Weak rocks

The geological origin, distribution and engineering properties of soft or weak rock were studied in depth by various researchers in Sudan and elsewhere [3], [4], [5], [2],[6],[7],[8].

Nubian Formation (NF) is a term which designates the weak rock formation in central, western, northern Sudan as well as neighbouring countries such as Libya, Egypt and Chad. These formations include sandstone, mudstone, siltstone, conglomerates and pebbles.

As shown in Fig. (1), the Nubian Formation in Sudan covers about 28% of the total area of Sudan [9]. The extent of the N.F. covers wide areas extending from the North frontier of Sudan from latitude 22º N into Kordofan. The N.F. was found to extend to longitude 35º E covering areas around Gadaref town and Showak region in eastern Sudan. The Nubian formation rests on the basement complex and overlain by Tertiary or Quaternary deposits, [4] and [9]. Hussein [10] believes that the N.F. is deposited under water. Whiteman [9] reported that Nubian sandstone formation is of continental origin. The thickness of the N.F. in Khartoum varies between 120m and 420m, [4].

Hussein [10], studied the ratio of occurrence of mudstone to sandstone in Khartoum, Fig. (2) depicts the result of this research. Four troughs or basins were indicated in. These are Feteihab basin, Khartoum basin, Omdurman basin, and Barok basin. The ratio of thickness mudstone to sandstone layers ranges between 10% to 400%. In large areas around Khartoum sandstone is predominant. The mudstone occupy the bottom of the indicated basins. The sandstone and the mudstone are characterized with pleasant colors ranging from pale white, reddish, yellowish, grayish and combinations of different colors. The coloration is attributed to the cementing agents such as the iron, silica, limestone and dissolved chemicals associated with these formations.

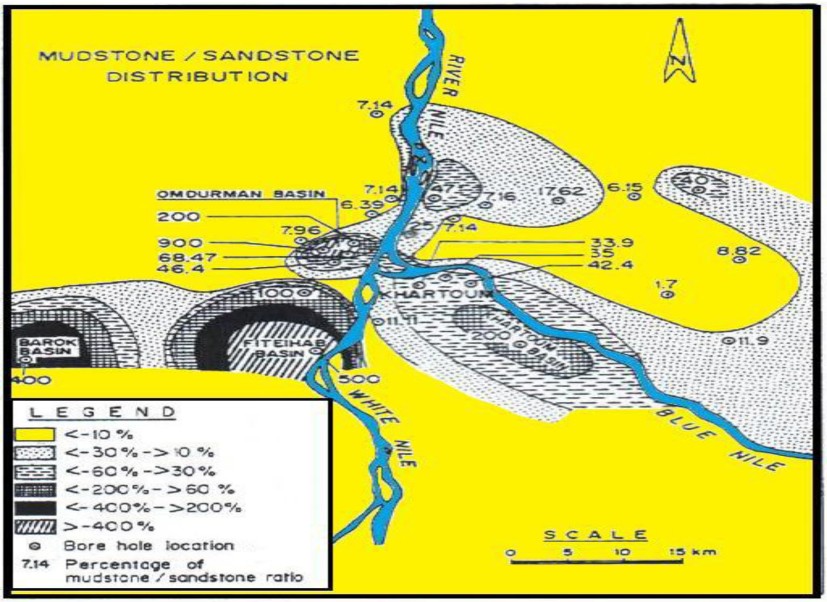


Fig. (2): Ratio of Mudstone to Sandstone in Khartoum State (After Hussein [10])

1.2 Omdurman superficial deposits

In Omdurman city west of the Nile, the N.F. is usually encountered at ground surface as an outcrop, while in Khartoum city the N.F. lies below 20m depth. Some geologists refer to this formation as Omdurman formation [10]. The superficial deposits in Omdurman city is generated from weathering on the Nubian Formation in this locality. It is composed of clay, silt, sand, pebbles, conglomerates and sometimes mixed with calcium carbonates nodules. Outcrops of semi-intact rock are frequently encountered in different areas. Historically the buildings in old Omdurman city were founded on relatively good quality Nubian Formations and still without distress. Recently buildings in old Omdurman city were noted to deteriorate and some foundation failures were noted, Nada A/ Rahman [11]. These deteriorations were attributed to the presence of perched water at foundation levels, accumulated on impermeablestrata of mudstone at shallow depths.

However serious foundation problems rose in relatively new districts in the north, southand east of the city. The distresses of buildings in these districts were attributed to presence of collapsible soils or swelling soils originated from the weathered rock formation in these localities. Hassan [3], reported that mudstone from feteihab district in Omdurman city, is composed of kaolinite and quartz minerals. In the studies by El-Hag, [12] in Al-Feteihab district showed that mudstone contains appreciable percentage of Montmorillonite mineral. This finding explains the heave and other distresses of structures realized at Omdurman Islamic University campus at Elfeteihab district in Omdurman. Recent studies on damaged buildings in Omdurman, [13], revealed the existence of collapsible soils in different districts shown in Fig. (3). The buildings in these districts experienced pronounced failures ranging from small cracks to complete failure of the building.

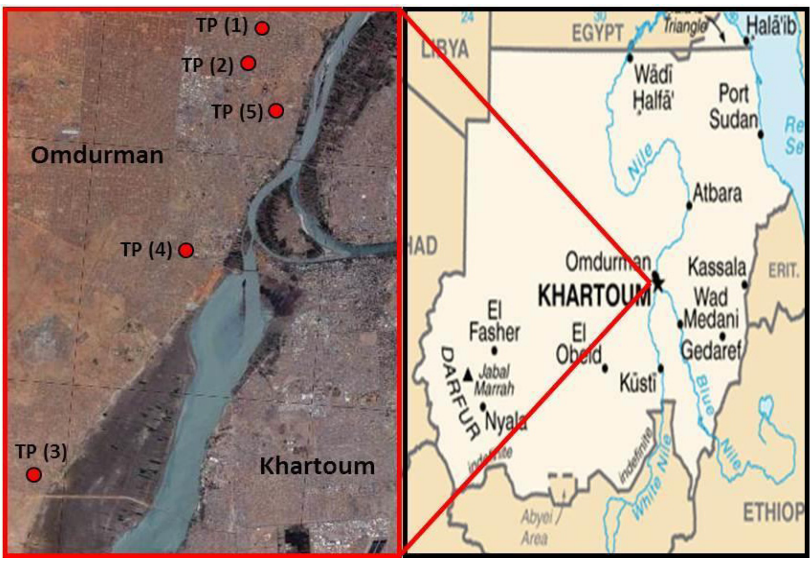


Fig. (3): Areas in Omdurman Known to have Collapsible Soils

2. Experimental work

The core samples obtained in the field are visually inspected. The color, the mineral type, the fractures, discontinuities and the natural moisture content were recorded. The Total Core Recovery (TCR) and Rock Quality Designation Number (RQD) were noted. The results of the Pressure Meter Tests (PMT) were analyzed. Classification tests as well as strength tests were conducted. A summary of the results will be highlighted in this section.

2.1 Geotechnical properties

(TCR) and (RQD) were established in the field, while the unconfined compression test (UCS), the jar durability test, and point load tests were conducted in the laboratory. The histograms (TCR) and (RQD) were drawn for the sandstone and mudstone core samples obtained in Khartoum state. These are shown in Figs. (4-a) to (4-d). The (TCR) of the mudstone samples is slightly of better quality than the sandstone core samples which indicating less weathering. The (RQD) for both sandstone and mudstone are very poor reflecting low strength and relatively high degree of weathering.

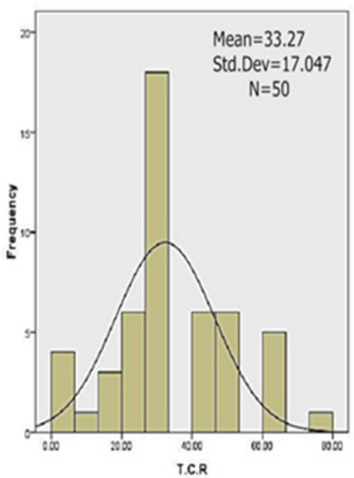


Fig. (4-a): Histogram of TCR Sandstone with Normal Distribution Curve

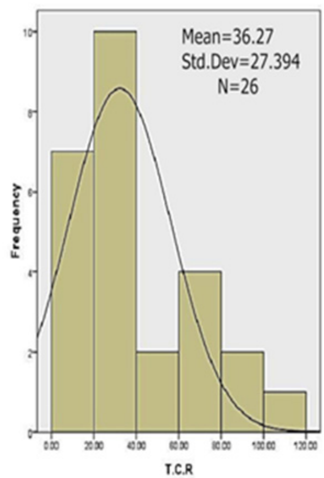
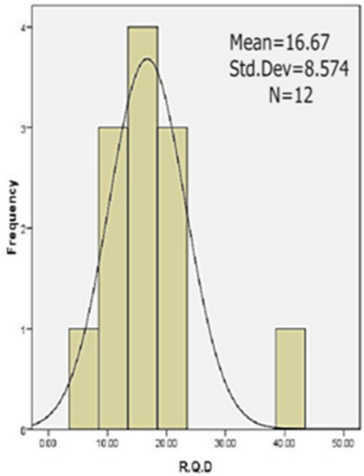


Fig. (4-b): Histogram of TCR Mudstone with Normal Distribution Curve



ïg. (4-c): Histogram of RQD Sandstone
vith Normal Distribution Curve

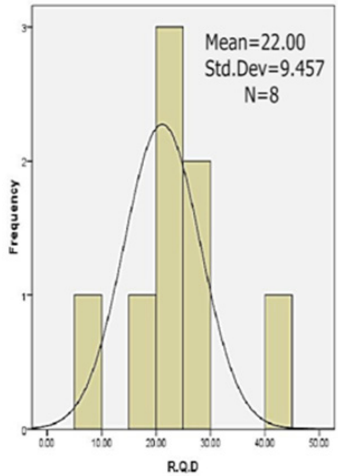


Fig. (4-d): Histogram of RQD Mudstone
with Normal Distribution Curve

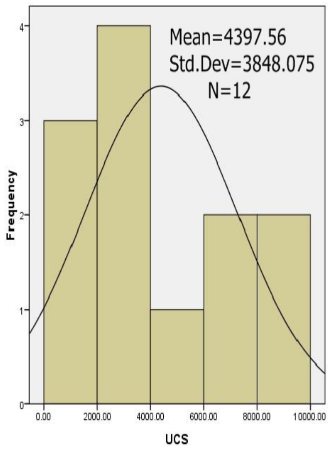


Fig. (5-a): Histogram of UCS for Sandstone
Distribution Curve

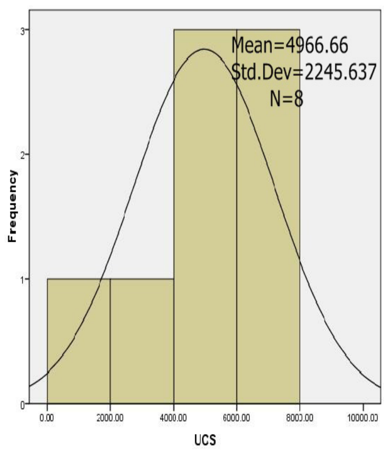


Fig. (5-b): Histogram of UCS
forMudstonewith Normal
with Normal Distribution Curve

The UCS for the sandstone and mudstone are shown in Fig. (5). The sandstone samples recorded UCS of the order up to 10,000 kPa, about 20% higher than the maximum value recoded by the mudstone. Generally both types of rocks have low UCS. This is attributed to the failure planes within these rocks as well as the discontinuities noted in these rock types and relatively high degree of weathering. The UCS for the sandstone was drawn against the percentage passing sieve #200. The result is shown in Fig. (6). The trend of the curve indicates decrease of the UCS with increasing percentage finer than #200.

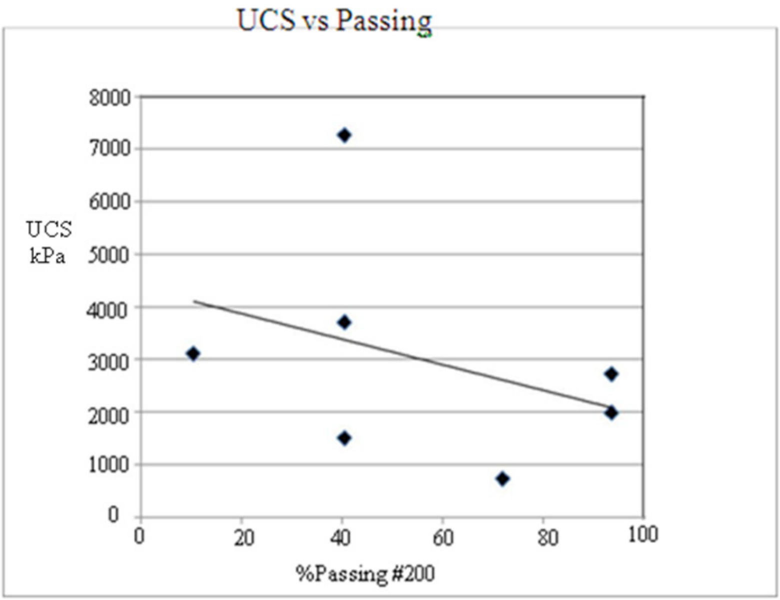


Fig. (6):Unconfined Compressive Strength vs. Percentage Passing # 200 Sieve

The effect of water on the crushing strength of sandstone is shown in Fig (7). The strength is noted to drop very fast at low moisture content for both types of rocks. Hence testing weak rock to determine the unconfined compressive strength (UCS), is very sensitive to the initial moisture content of the rock. The UCS can be determined at moisture content very close to its natural moisture content.

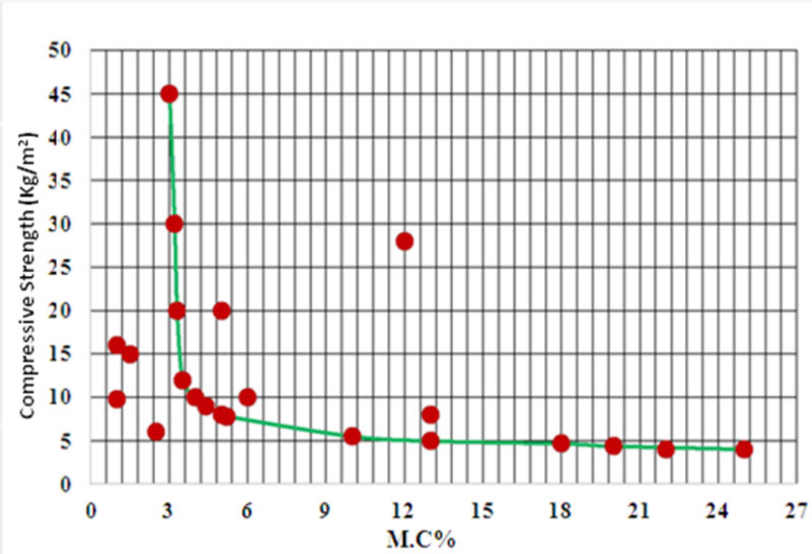


Fig. (7): Variation of Uni-traxial Compressive Strength with Water Content for the Sandstone, after Hassan [3]

The point load test was conducted on samples from Dongola and Neyala. The results were drawn against TCR and RQD. The results are shown in Fig. (8) and Fig. (9). The point load index increases with the increase of both TCR and RQD.

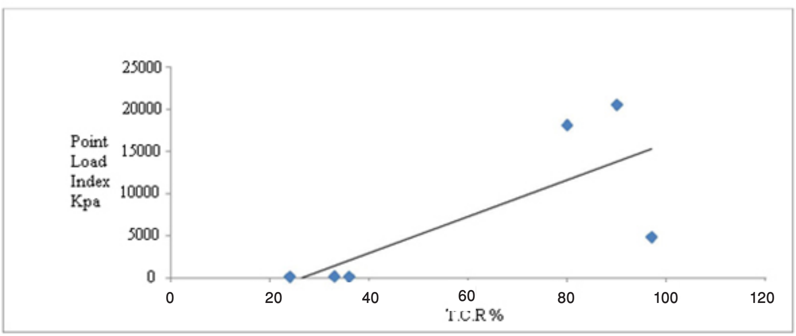


Fig. (8): T.C.R% vs Point Load

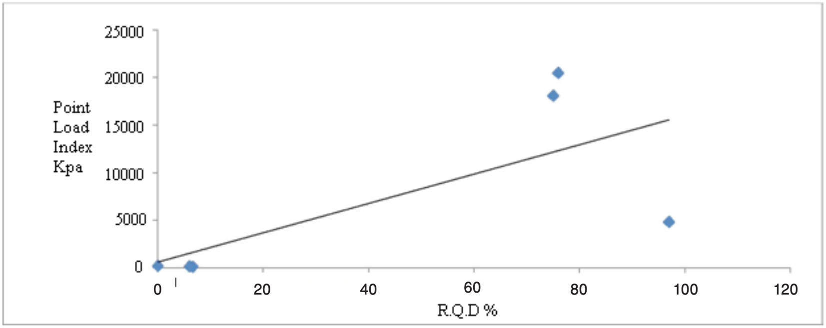
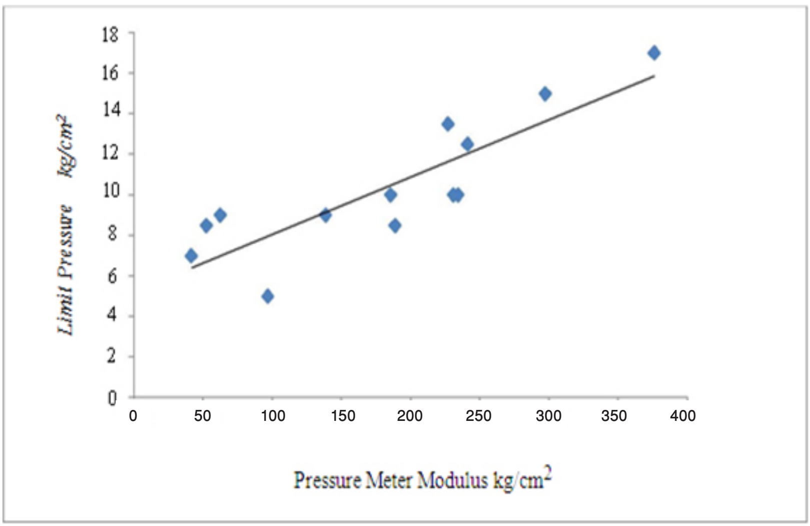


Fig. (9): R.Q.D vs Point load Index

The Menard pressuremeter test was conducted in the sandstone and mudstone at different depths. The pressure meter modulus was drawn against the limiting pressure. A linear relationship between pressuremeter modulus and limit pressure is shown in Fig. (10).



Fig(10): Pressure meter Modulus Vs Limit Pressure

3. Weak rocks from red sea coast

3.1 Preamble

The coralline deposits are originally derived from coral reef, of biological origin and are classified as biogenesis materials, consisting of remains of marine plants or animals such as coral shells, of mollusks, algae, oysters, and different kinds of algae. Soil investigation programs were conducted in Port-Sudan and Suwakin cities and in different sites on the Red Sea coast. Rock densities, UCS, SPT, PMT, point load tests, Plate Load tests (PLT), CPT, DCPT and classification tests were carried out. The rocks were classified according to the unified classification system (USCS) and according to the classification system proposed by Tarig et al [14]. The latter classification system, which is developed locally, adequately described the materials encountered as well as their engineering properties.

3.2 SPT, CPT & PLT

The characterization of coralline deposits at Portsudan town using SPT, CPT and PLT is demonstrated by the case study presented by Osman, and Ali, [15]. The presence of voids in these materials and the heterogeneous nature of these deposits, as well as to the brittle and crushable nature of the coralline deposits complicates the site investigation and the laboratory testing. In this case study soil investigation program was conducted at warehouses site in Portsudan town. The first phase of the investigations boreholes was drilled, SPT was conducted at various depths and soil and core samples were taken. The coral limestone at this site was noted to have great variability and voids within the deposits. The auger boring method in this investigation was reported to break down the coral formation to small sizes, thus altering the original shape of the deposits and posing a problem for the visual inspection of the recovered samples. Problems were also encountered in laboratory testing, inserting the sampler damages cementing bonds and causes crushing of the soil grain. The hard pressing of the sampler also increased the density of the material. Other problems were noted regarding the trimming and placement of the sample in the testing machine. The results of this soil investigation phase when assessed met littlerecognition by the consultants, and a second phase of soil investigation wasplanned.In-situ testing was carried out. This consisted of drilling test pits, taking core samples, conducting static cone penetration tests (CPT) and carrying out plate load tests. Results of the second phase of the investigation lead to better characterization of the coralline deposits and recommendations for the engineering design of the foundation.

3.3 Summary of engineering properties of coralline deposits

The main tests conducted on the coralline deposits comprised UCS, SPT , CPT, DCPT, densities, PMT, Point load Index, jar slake durability tests and laboratory classification tests. A summary of these test results are shown below:

3.3.1 TCR, RQD, the Point Load Index and UCS

Histograms of (TCR) & (RQD) are shown in Fig. (11). the total recovery as well as the rock quality is very poor. This reflects the heterogeneous nature of these deposits and poor strength of the recovery cores.
The histograms of the point load index are shown in Fig. (12). Maximum value of 10 KPa was recorded. In Fig.(13), the histogram of the UCS for the coralline deposits is presented. A maximum value of 8000 kPa was recorded. This value is on the low range of the strength of weak rocks. The plot of the bulk density of the coralline deposits against UCS is shown in Fig (14). The trend of the data indicates that the increase of the UCS with the increase of the density of the deposits.

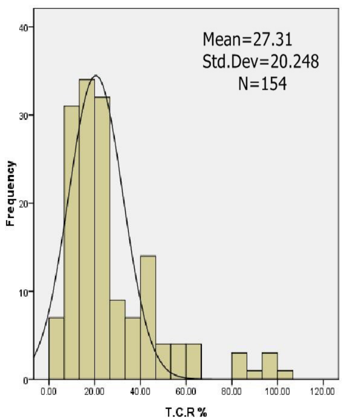


Fig. (11-a): Histogram of TCR% Limestone Portsudan with Normal Distribution Curve

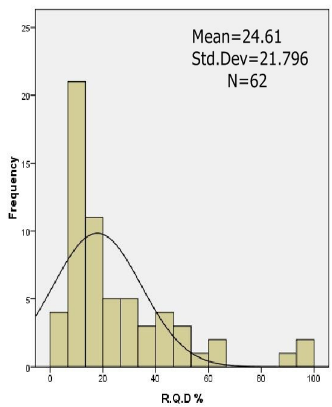


Fig.(11-b): Histogram of RQD% Limestone Portsudan with Normal Distribution Curve

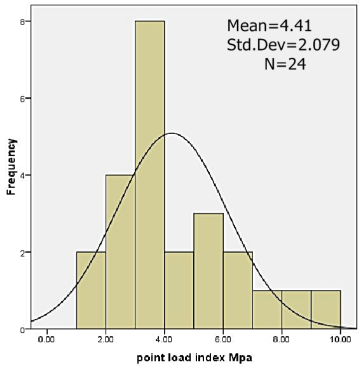


Fig. (12): Histogram of Point Load Index Limestone Portsudan with Normal Distribution Curve

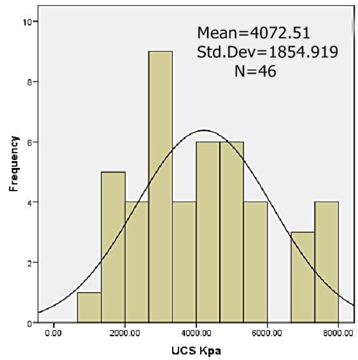
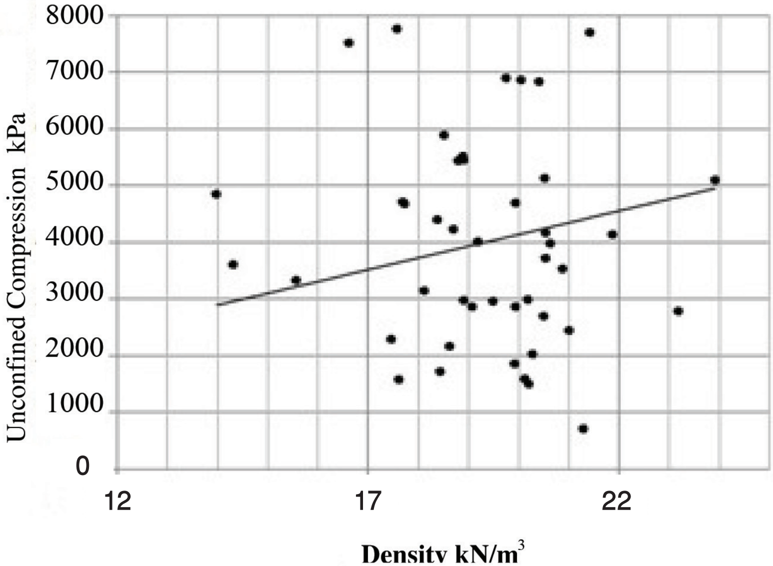


Fig. (13): Histogram of UCS Limestone Portsudan with Normal Distribution Curve



Fig(14): Unconfined Compression kPa vs. Density kN/m³

4. Conclusions

The paper presented most of the available geotechnical data of soft or weak rocks in Sudan. There are many definitions available in the literature for weak or soft rocks. The simplest definition given is concerned with the UCS. Weak rocks are defined as those rocks having UCS tests less than 20MPa. The weak rocks in Sudan, include sandstone and mudstone referred to by geologists as Nubian Formations and organic lime stones at the Red Sea coast. The geotechnical properties of weak rocks in Sudan exhibit great variability.

Field tests comprise the Standard Penetration Test (SPT), Dynamic Cone Penetration Test (DCPT), Cone Penetration Test (CPT), and Pressure Meter Test (PMT). The laboratory tests conducted include, classification tests, unconfined strength test (UCS), triaxial tests, point load tests, slake durability tests.

The Nubian formation as well as the coralline deposits has low UCS. This is attributed to relatively high degree of weathering, presence of failure planes and discontinuities.The strength of sandstone is noted to be very sensitive to the increase of the moisture content. It is recommended to carry out strength test at moisture content very near to the natural moisture content of sample.

The Nubian Formations are characterized with fractures, discontinuities resulting in low (TCR) low (RQD) and low (UCS). This applies also to the coralline deposits on the Red Seacoast. The materials of the latter are more heterogeneous, with great variability both inthe vertical and horizontal directions. The strength of the coralline deposits is generally lowerthan the Nubian Formation and are more compressible.

5. References

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