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Geotechnical Investigation - Case Studies (Bori & Bait Almal) Water Station, Khartoum State, Sudan

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ABSTRACT – *This paper includes the results of field investigation, laboratory test results and the conclusions needed for foundation design.*
Field and laboratory soil investigation studies were conducted for the (Bori & Bait Almal) Water Station, Khartoum State, Sudan to know the engineering properties of the foundation soils of the cases studies.
This investigation consisted of drilling four boreholes (two boreholes per site), Burri station both boreholes to depths 20.0m, Bait Almal station both boreholes to depths 9.0m &10.5m, taking soil samples, conducting in-situ tests and doing the necessary laboratory tests. The field work was started on the 01[th] of August 2017 and finished on the 03[th] of August 2017. The laboratory testing was conducted.
The knowledge of the bearing capacity of the soil was obtained through laboratory tests. The bearing capacity of the soil was calculated for the two mentioned sites and based on the geotechnical and structural calculations, the appropriate type of foundation was performed for each site, and it was found that the Raft foundation was the appropriate foundation for the two mentioned sites.
Keywords: *Field investigation, Laboratory test results, Raft foundation, boreholes, Bori, Bait Almal*

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I. INTRODUCTION

Soil investigations are conducted to identify the characteristics and behavior of the soil under the buildings, to know the level of groundwater and the bearing capacity of the soil, and to determine the type of suitable foundation that is appropriate for the nature of the building soil. This field inspection is absolutely necessary before construction on the soil, especially in tall buildings. The importance of geotechnical studies lies in knowing the nature and type of building's soil, by knowing the bearing capacity of the soil mathematically, which helps the structural engineer to choose the appropriate type of foundation for the building's soil [1 - 8].

The purpose of this research is to determine the existing soil profiles and engineering characteristics of the subsurface conditions at the proposed project area. The scope of investigation for this study comprises the following [9 - 14]:

- Collecting information such as geotechnical related to the project sites.
- Measuring the validity of the Earth's natural layer materials of sites.
- Drilling and collect disturbed soil samples for carrying out the laboratory tests to determine the natural and relevant physical properties of the Earth's natural layer pertaining to the site for the purpose of design.
- Analyses the data obtained and give Engineering Consideration and Recommendation.
- Submitting the geotechnical data.

II. ABOUT THIS STUDY

2.1 Site description

The project sites are situated in two locations (Burri, Bait Almal) Khartoum State - Sudan which BURRI Station is located south of the Blue Nile River, the site can be reached through the main Nile Street (Khartoum), Bait Almal is located east of Nile River, the site can be reached through the main Nile Street (Omdurman).

In general, BURRI site is relatively flat. It is boarded by paved road (Nile Street Khartoum) from northern side and near BURRI Bridge, It should be mentioned that the potential building area away from the Blue Nile river about 170m only; Bait Almal site is relatively flat, It is boarded by paved road (Nile Street Omdurman) from east side, and near Alzaiem Alazhari Bridge, It should be mentioned that the potential building area away from the Nile river about 330m only.

General sites plan showing the project sites limits, topographical, boreholes locations and subsurface profile are presented in Figures 1, 2, 3 and 4 for BURRI and Bait Almal sites locations respectively.

Figure.1 Location area of BURRI Station

Figure.2 Boreholes, Elevation plan for BURRI Station

Figure.3 Location area of BAIT ALMAL Station

Figure.4 Boreholes, Elevation plan for BAIT ALMAL Station

2.2 Geology of the Area:

The dominant geologic features of Sudan (Whiteman1971) include the following:

- Precambrian Basement Complex; which consist of igneous, metamorphic and sedimentary rocks.
- Nubian Sandstone of cretaceous age.
- Umm Rawaba Formation; which consist of fluvial soils of tertiary to quaternary ages

Greater Khartoum straddles the confluence of the Blue and White Niles and comprises the three towns of Khartoum, Omdurman and Khartoum North. Khartoum and Khartoum North are situated on alluvial plain deposits laid down by the Blue Nile in the early Holocene, but Omdurman lies on somewhat higher ground underlain by Nubian sandstone.

Geological and geotechnical data indicate that the subsoil conditions at Central Khartoum are characterized by alluvial deposits underlain by Nubian Sandstone at a depth of 25m. The alluvial deposits, locally known as Gezira formations, consist of clays grading into silt and sand with depth [15- 20].

2.3 Prevailing weather conditions

Khartoum features a hot and arid climate, with a minimum average precipitation of 155mm per year (the significant precipitation only occurs on July and August). Khartoum is one of the hottest major cities in the world, where the temperatures may exceed 53C° (127 F°) in mid-summer and the average annual maximum temperature reaches 38C° (100F°). Furthermore, none of it is monthly average maximum temperatures falls below 30C° (86F°). Temperatures cool off considerably during night, with Khartoum's annual lowest average of about 15C° (59F°).

Annual potential evapo-transpiration (PET) is very high through Sudan. The annual PET for Khartoum is approximately 180mm, exceeding the mean annual precipitation of 179mm by a factor of ten. This relationship affects largely the soil moisture and hence the potential swell, since most of soil is a Silty clay soil of expansive nature which might lead to structures damage.

III. SOIL EXPLORATION

The elements of soil exploration depend mostly on the importance and magnitude of the project, but generally should provide the following:

❖ Information to determine the type of foundation required such as a shallow or deep foundation.

❖ Necessary information with regards to the strength and compressibility characteristics of the subsoil to allow the Design Consultant to make recommendations on the safe bearing pressure or pile load capacity.

Soil exploration involves broadly the following:

- Planning of a program for soil exploration.
- Collection of disturbed and undisturbed soil or rock samples from the holes drilled in the field. The number and depths of holes depend upon the project.
- Conducting all the necessary in-situ tests for obtaining the strength and compressibility characteristics of the soil or rock directly or indirectly.
- Study of ground-water conditions and collection of water samples for chemical analysis.
- Geophysical exploration, if required.
- Conducting all the necessary tests on the samples of soil /rock and water collected.
- Preparation of drawings, charts, etc.
- Analysis of the data collected.
- Preparation the final conclusions.

3.1 Drilling

Four boreholes were drilled at the project site between 1st and 3rd August2017, BURRI site both boreholes to 20.0m depth below the existing ground surface, BAIT ALMAL site to depth 10.5m and 9m, the locations of the drilled boreholes were determined and marked in the field by the client representative. Boreholes details are presented in **Table 1,** and are also shown in **Figure 5 and 6.** Borehole drilling was executed with "drilling Machine.

Table.1: depth and type of drilling

Boreholes,	Location	Depth (m)
B.H.01	BURRI	20.0
B.H.02	BURRI	20.0
B.H.01	BAIT ALMAL	09.0
B.H.02	BAIT ALMAL	10.5

Figure.5 Drilling photo for BURRI Station

Figure.6 Drilling photo for BAIT ALMAL Station

3.2 Sampling

Disturbed samples

Disturbed soil samples were collected as per contract, visually described and placed in watertight plastic bags to maintain their nature moisture content, properly marked with borehole name, sample depth and date, and taken to our laboratories for testing.

IV. LABORATORY TESTING

The tests carried out on the basis of the following regulations:

- Determination of particle size distribution ASTM 422-62
- Determination of the Atterberg limits ASTM 93
- Determination of water content on the basis of DIN 18121
- Compaction ASTM 698
- Triaxial or Direct Shear ASTM 2850
- Consolidation ASTM 2435

The results of Laboratory tests were summarized in the forms of Laboratory Test Results. Figure 7 illustrates the Sieve analysis test procedure and the results are given in Tables 2 & 3 and Figures 8 & 9. Soil Classification (AASHTO, USCS) are given in Tables 4 & 5. The Atterberge Limit test results are presented in Tables 6 & 7 and Figures 10 & 11. Compaction Test results are shown in Tables 8 & 9 and Figures 12 & 13.

The Consolidation Test results are illustrated Tables 10 & 11 for Burri and Bait Almal sites locations respectively.

4.1particle size distribution

Sieve analysis is carried out by using a set of standard sieves. Sieves are made by weaving two sets of wires at right angles to one another. The square holes thus formed between the wires provide the limit which determines the size of the particles retained on a particular sieve. The sieve sizes are given in terms of the number of openings per inch. The number of openings per inch varies according to different standards. Thus, an ASTM 60 sieve has 60 openings per inch width with each opening of 0.250 mm.

Figure.7 Sieve analysis test procedure

Table.2 Sieve analysis test results of Burri Water station

Depth(m)	**10.5**	**12.0**	**13.5**	**15.0**	**16.5**	**18.0**	**19.5**
Size	%	%	%	%	%	%	%
(mm)	**passing**	**passing**	**passing**	**passing**	**passing**	**passing**	**passing**
25	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
19.5	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
12.5	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
9.5	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
4.75	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
2.00	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.8**	**99.9**
1.18	**100.0**	**100.0**	**99.0**	**98.5**	**98.2**	**95.9**	**95.5**
0.85	**99.9**	**100.0**	**97.7**	**96.5**	**95.8**	**91.3**	**90.9**
0.425	**99.3**	**99.5**	**92.5**	**91.6**	**89.0**	**79.1**	**66.5**
0.25	**98.4**	**99.3**	**82.9**	**90.5**	**87.5**	**76.7**	**64.2**
0.15	**74.7**	**82.2**	**66.8**	**66.8**	**72.7**	**57.3**	**54.1**
0.075	**73.6**	**64.2**	**55.4**	**55.2**	**55.1**	**44.0**	**44.1**

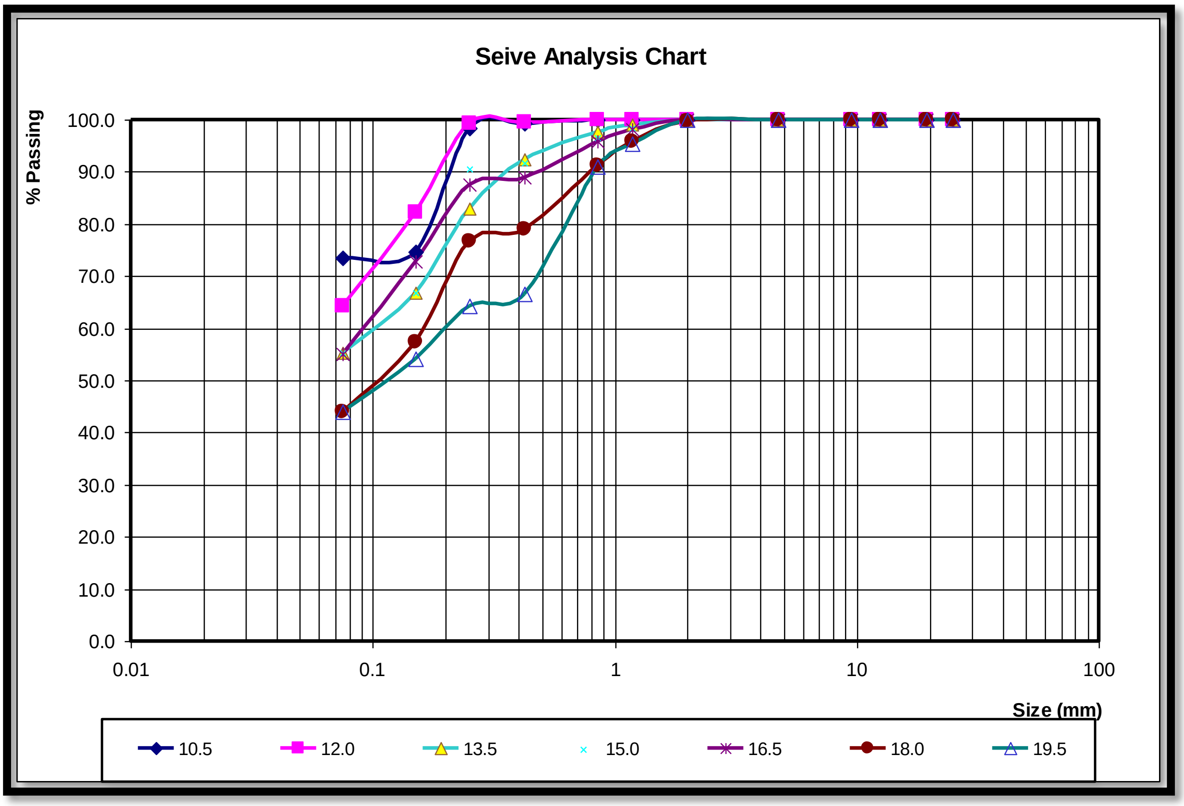

Figure.8 Sieve analysis test results of Burri Water station

Table.3 Sieve analysis test results of Bait Almal Water station

Depth(m)	**1.5**	**3.0**	**4.5**	**6.0**	**7.5**	**9.0**
Size (mm)	% **passing**	% **passing**	% **passing**	% **passing**	% **passing**	% **passing**
25	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
19.5	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
12.5	**96.3**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
9.5	**92.7**	**93.3**	**100.0**	**100.0**	**96.1**	**100.0**
4.75	**68.7**	**92.4**	**89.5**	**98.7**	**90.8**	**97.1**
2.00	**53.7**	**81.0**	**83.2**	**95.9**	**86.3**	**94.8**
1.18	**49.7**	**71.5**	**80.6**	**93.1**	**82.9**	**93.1**
0.85	**48.4**	**66.3**	**79.2**	**94.5**	**81.0**	**92.0**
0.425	**45.9**	**63.7**	**73.5**	**87.5**	**77.3**	**89.4**
0.25	**44.7**	**60.3**	**67.1**	**86.4**	**76.3**	**88.6**
0.15	**38.1**	**54.5**	**56.5**	**79.6**	**71.2**	**84.8**
0.075	**36.3**	**48.0**	**52.2**	**73.9**	**68.0**	**81.1**

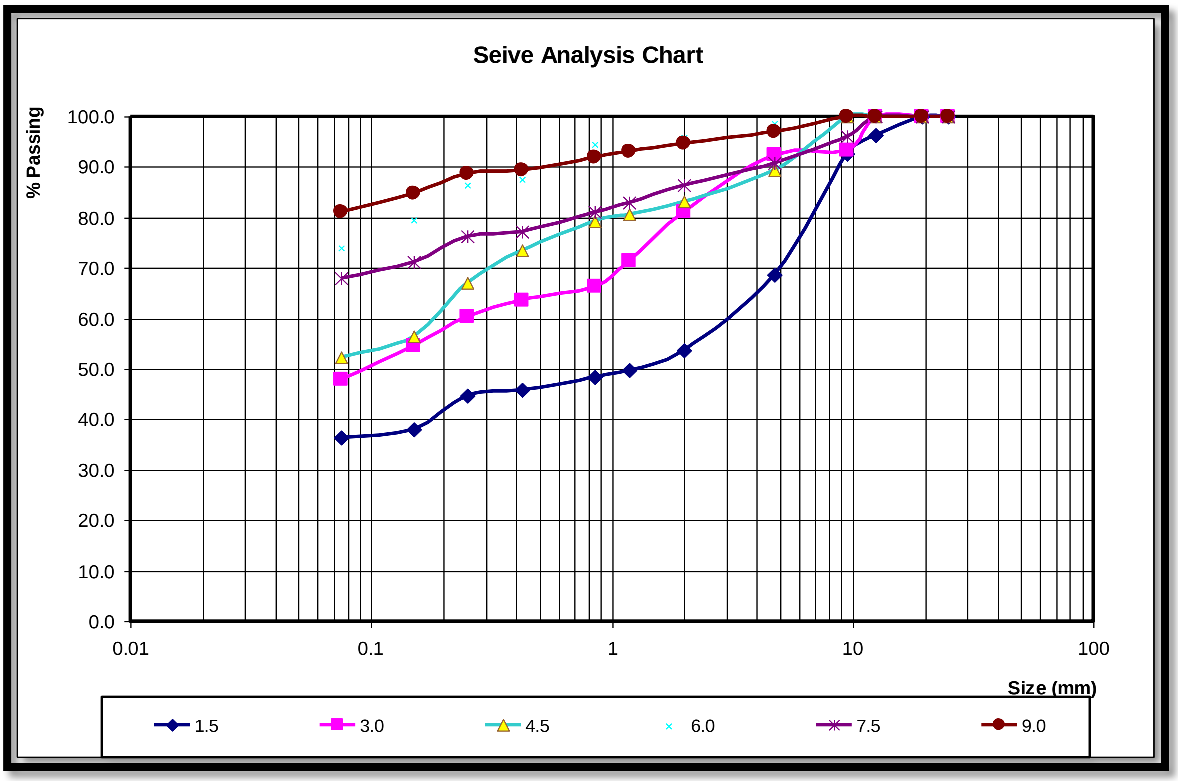

Figure.9 Sieve analysis test results of Bait Almal Water station

Table.4 Soil Classification test results of Burri Water station

DEPTH(m)	Sieve Analysis				Atterbarig Limit			Classification	
	Pass No.4	**Pass No.10**	**Pass No.40**	**Pass No.200**	**L.L**	**P.L**	**P.I**	**AASHTOO**	**USCS**
10.0 – 10.5	100.00	100.00	99.30	73.60	44.20	20.52	23.68	A-7	CL
11.5 – 12.0	100.00	100.00	99.50	64.20	45.50	32.44	13.06	A-7	ML
13.0 – 13.5	100.00	100.00	92.50	55.40	28.70	15.40	13.30	A-6	CL
14.5 – 15.0	100.00	100.00	91.60	55.20	28.00	15.68	12.32	A-6	CL
16.0 – 16.5	100.00	100.00	89.00	55.10	27.00	14.40	12.60	A-6	CL
17.5 – 18.0	100.00	99.80	79.10	44.00	24.80	15.14	09.66	A-4	CL
19.0 – 19.5	100.00	99.90	66.50	44.10	21.10	11.50	09.60	A-4	CL

Table.5 Soil Classification test results of Bait Almal Water station

DEPTH(m)	Sieve Analysis				Atterbarig Limit			Classification	
	Pass No.4	**Pass No.10**	**Pass No.40**	**Pass No.200**	**L.L**	**P.L**	**P.I**	**AASHTOO**	**USCS**
0.0 – 1.5	68.70	53.70	46.90	36.30	-	-	N.P	A-3	SM
1.5 – 3.0	92.40	81.00	63.70	48.00	33.40	23.79	09.61	A-4	GM
3.0 – 4.5	89.50	83.20	73.50	52.20	27.35	14.59	12.76	A-6	CL
4.5 – 6.0	98.70	95.90	87.50	73.90	49.40	28.72	20.68	A-7	ML
6.0 – 7.5	90.80	86.30	77.30	68.00	30.20	15.48	14.72	A-6	CL
7.5 – 9.0	97.10	94.80	89.40	81.10	43.80	13.87	29.93	A-7	CL

Table.6 Atterberge limit test results of Burri Water station

Depth(m)	**10.50**	**12.00**	**13.50**	**15.00**	**16.50**	**18.00**	**19.50**
L.L%	54.65	58.50	42.20	38.80	28.00	31.30	36.00
P.L%	32.85	37.20	23.20	23.36	15.89	20.60	27.08
P.I%	**21.80**	**21.30**	**19.00**	**15.44**	**12.11**	**10.70**	**8.92**

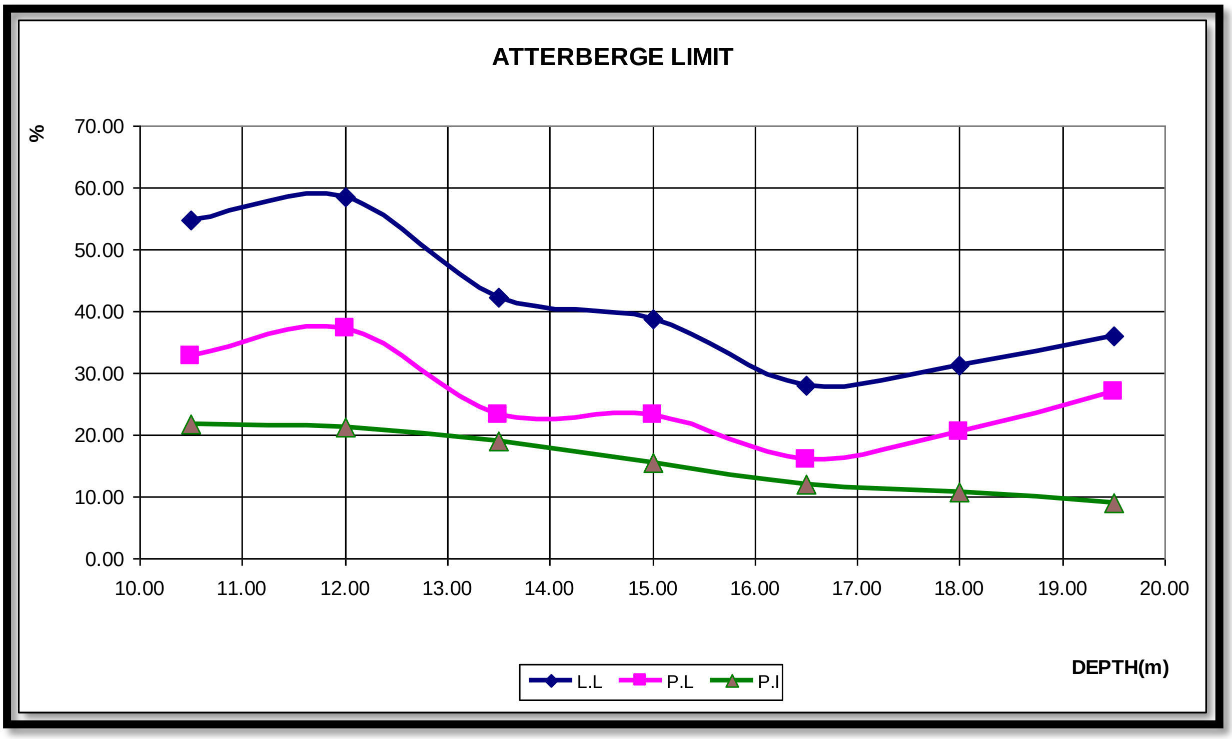

Figure.10 Atterberge limit test results of Burri Water station

Table.7 Atterberge limit test results of Bait Almal Water station

Depth(m)	**1.50**	**3.00**	**4.50**	**6.00**	**7.50**	**9.00**	**10.50**
L.L%	28.20	27.00	28.50	25.70	25.00	23.80	28.70
P.L%	16.33	14.17	14.80	18.89	17.17	17.82	21.32
P.I%	**11.87**	**12.93**	**13.70**	**6.81**	**7.83**	**5.98**	**7.38**

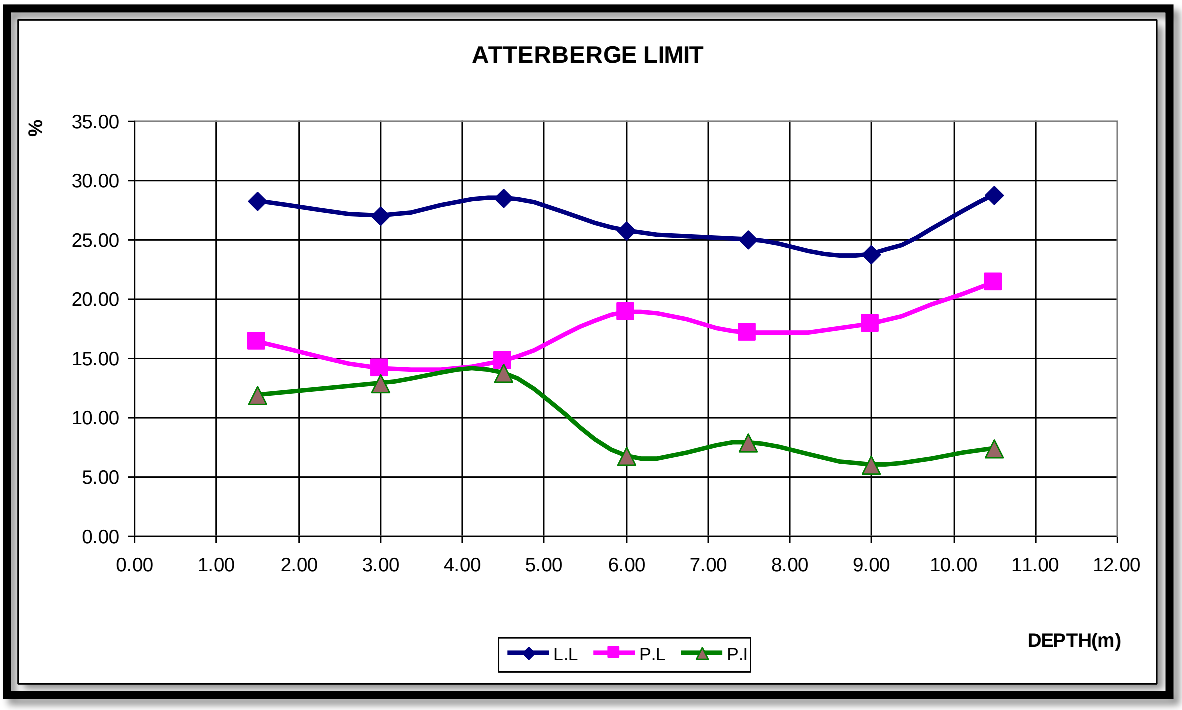

Figure.11 Atterberge limit test results of Bait Almal Water station

Table.8 Compaction test results of Burri Water station

TEST NO.		1	2	3	4	5	RESULTS
B.H.1	DRY DENSITY (gm/cm³)	1.49	1.49	1.59	1.61	1.41	**1.62**
	WATER CONTENT (%)	10.54	15.89	22.05	27.79	37.37	**28.0**
B.H.2	DRY DENSITY (gm/cm³)	1.50	1.65	1.74	1.60	1.46	**1.75**
	WATER CONTENT (%)	12.28	16.53	24.71	30.71	33.00	**24.0**

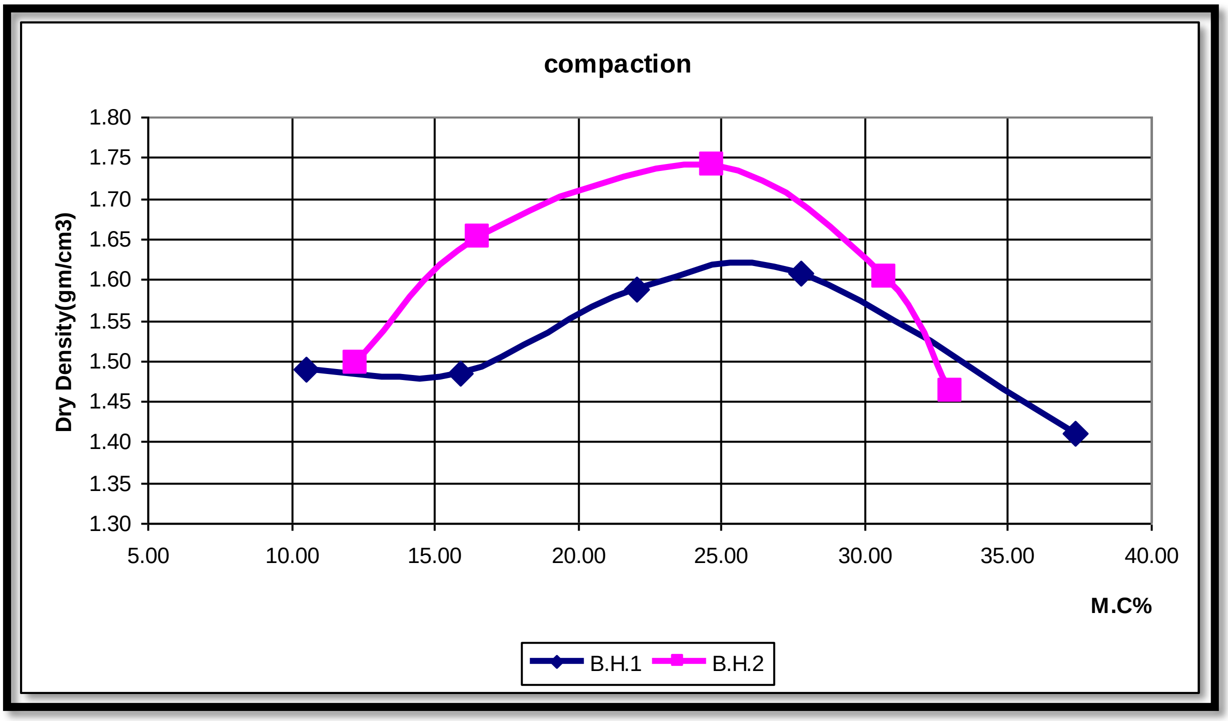

Figure.12 Compaction test results of Burri Water station

Table.9 Compaction test results of Bait Almal Water station

TEST NO.		1	2	3	4	5	RESULTS
B.H.1	DRY DENSITY (gm/cm³)	1.457	1.496	1.469	1.384	1.252	**1.48**
	WATER CONTENT (%)	27.61	32.41	36.01	43.06	51.11	**32.6**
B.H.2	DRY DENSITY (gm/cm³)	1.573	1.729	1.755	1.597	1.456	**1.77**
	WATER CONTENT (%)	14.5	17.92	22.34	26.52	31.07	**20.0**

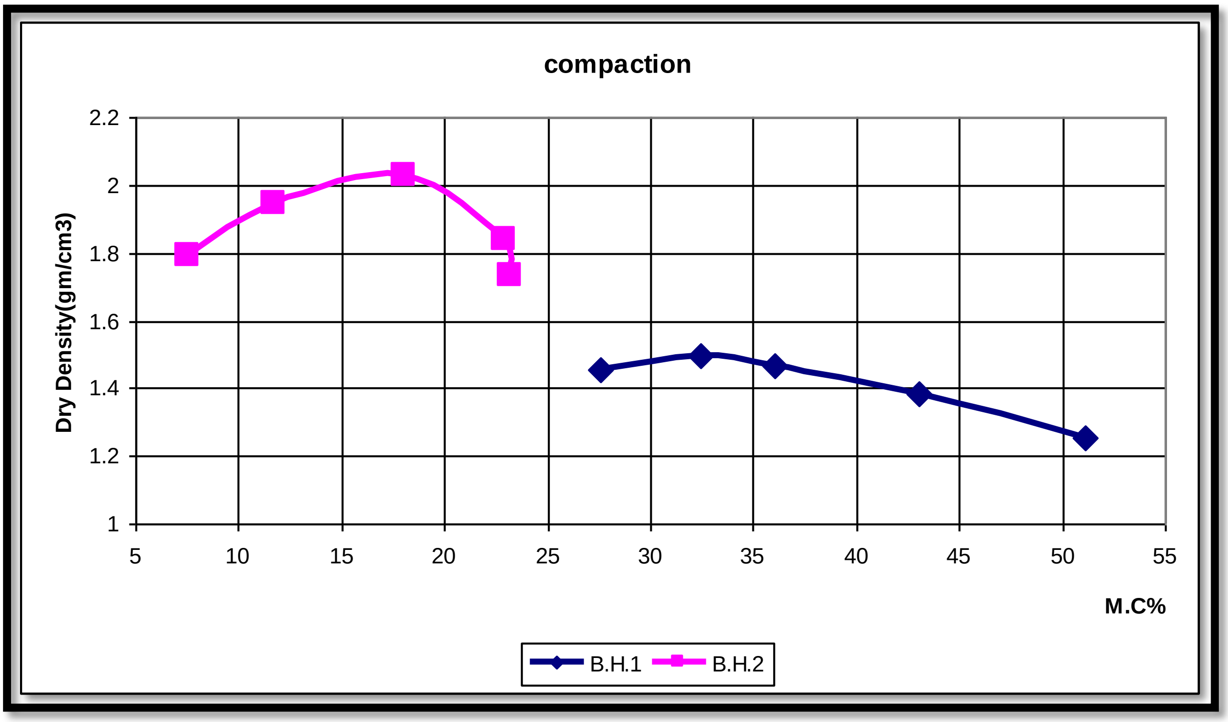

Figure.13 Compaction test results of Bait Almal Water station

Table.10 Consolidation test results of Burri Water station

	Sample Depth (m)	Specific Gravity	Consolidation Coefficients				P_c KN/m^2	Bulk Density (KN/m^2)	Moisture Content (%)
			m_v cm^2/KN	C_c	C_s	C_v Cm^2/min			
B.H.1	10.5	2.73	1.71	0.127	0.025	0.011	76.8	21.3	24.0
B.H.2	10.5	2.78	1.49	0.102	0.019	0.024	62.5	19.7	22.0

Table.11 Consolidation test results of Bait Almal Water station

	Sample Depth (m)	Specific Gravity	Consolidation Coefficients				P_c KN/m^2	Bulk Density (KN/m^2)	Moisture Content (%)
			m_v cm^2/KN	C_c	C_s	C_v Cm^2/min			
B.H.1	9.0	2.80	2.96	0.102	0.030	3.370	57.4	21.0	28.8
B.H.2	9.0	2.77	2.06	0.154	0.039	0.004	57.9	17.1	26.0

V. PREVAILING WEATHER CONDITIONS

Although Sudan lies within the tropic, the climate ranges from arid in the far southwest to tropical wet and dry in the far southeast. Temperatures do not vary greatly with the season at any location. The most significant climatic variables are rainfall and the length of the dry season depending on which of two air flows predominates, dry northeast winds from the Arabian Peninsula or moist southeasterly winds from the Congo River basin.

From January to march, the country is under the influence of the dry northeasterly winds. There is practically no rainfall countrywide except for a small area in northwestern Sudan was the winds have passed over the Mediterranean bringing occasional light rains. By early April, the moist southwestern winds have reached Khartoum, and in August it extends to its usual northern limits around Abu hammed, although in some years the humid air may even reach the Egyptian border. The flow becomes weaker as it spreads north. In September the dry northeastern winds begin to strengthen and to push south and by the end of December they cover the entire country. Temperatures are highest at end of the dry season when cloudless skies and dry air allow them to soar. The far south, however, with only a short dry season, has uniformly high temperatures throughout the year. In Khartoum, the warmest months are May and June, when average highs are 40°C and temperatures can reach 48°C.

Northern Sudan, with its short rainy season, has hot daytime temperatures year round, except for winter months in the northwest where there is precipitation from the Mediterranean in January and February. Conditions in highland areas are generally cooler and the hot daytime temperatures during the dry season throughout central and northern Sudan fall rapidly after sunset lows in Khartoum average 15°C in January and have dropped as low as 6°C in January after the passing of a cool front in Winter. In Khartoum, average humidity and maximum temperatures(C) are shown inTable.12.

Table.12.Average humidity and maximum temperatures(C)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Humidity%	20	15	12	11	13	18	32	41	30	21	20	22
Max Temp C°	32.1	33.2	37.8	40.5	42.6	40.7	39.5	37.9	39.8	40.0	35.7	33.0

This unfavorable climate imposes adverse conditions on the concrete structures, such as:

- High temperature and high seasonal changes.
- High humidity and high change in relative humidity.
- Strong drying winds.
- Condensation at night.
- High solar radiation.

VI. WATER TABLE DEPTHS

Water Table Depths are presented in Table.13 for Burri and Bait Almal sites locations respectively.

Table.13. Water Table Depths for Burri and Bait Almal sites locations

	B.H.1	**B.H.2**
Burri (Khartoum)	6.0 m	6.0m
Bait Almal (Omdurman)	7.5m	7.5m

VII. CONCLUSIONS

According to the comprehensive field and laboratory investigations, subsurface conditions, engineering analysis and practical experience, it can be concluded that the proposed structure can be satisfactorily supported by the ground at the site, provided that the followings conclusions are taken in to consideration:

❖ **Burri Water Station:**

- Soil generally is moisture inorganic clays (CL) or inorganic SILTs (MH), at foundation depth (10.0 to10.5) m.
- The underground water to a depth of (6.0) meter.
- Plasticity index high plastic at foundation depth (10.0) m, medium-expansive soil.
- The Soil is moisture inorganic clays or silts (CL), (MH), high plasticity at proposed depth, you need to do improved materials, and must be well compacted before placing the raft foundations.
- Allowable bearing capacity = 375.0 Mpa at depth 10.5m

❖ **Bait Almal Water Station:**

- Soil generally is moisture inorganic clays (CL) or silty sand (SM), at foundation depth (9.0 to10.5) m.
- The underground water to a depth of (7.5) meter.
- Plasticity index high plastic at borehole one, and low plastic at borehole two.
- The Soil is moisture inorganic clays (CL), silty sand (SM),low plasticity at proposed depth, you need to do improved materials on location boreholes one and must be well compacted before placing the raft foundations, but no need to do improved materials on location boreholes two.
- Allowable bearing capacity = 431.0 Mpa at depth 9.0m

REFERENCES

[1]. Smith, G. N. & Smith, I. G. (1998) “Elements of Soil Mechanics”, 7th Edition, Blackwell Science.
[2]. Bowles, J. E. (1997) “Foundation Analysis and Design”, McGraw-Hill Inc.
[3]. Terzeghi, peck&mesri, “soil mechanics in Eng. Practice” third john wiley&sons, 1996.
[4]. Das, B. M. (1993) “Principles of Geotechnical Engineering”, 3rd Edition PWS Publishing Company, Boston.
[5]. Hsai-yang fang, “foundation engineering handbook”, second Edition, Van Nostrand Reinhold, 1991.
[6]. M.J.Tomlinson, “foundation Design construction” fifth edition longmanscientific&technical, 1986.
[7]. I.S.Dunn et al “foundation of geotechnical analysis” pp 282-288.
[8]. Joesph E. Bowles, Foundation Analysis and Design, Fifth Edition, 1994
[9]. N.E.Simons and B.K.Menzies, A Short Course in Foundation Engineering.
[10]. BS 5930: 1999: Code of Practice for Site Investigations
[11]. BS 1377: 1990: Methods of Test for Soils for Civil Engineering Purposes

[12]. Das, Braja M. 2011, Principles of foundation Engineering, 7th Edition Cengage Learning, Stamford, CT.
[13]. AASTHO LRFD BRIDGE DESIGN SPECIFICATIONs, 4th edition
[14]. Das, Braja M. 2006. Principles of Geotechnical Engineering. 6th Edition. Cengage Learning, Stamford, CT.
[15]. Terzahi, Karl; Peck, Ralph B.; Mesri, Gholamreza. 1996. Soil Mechanics in Engineering Practice. 3rd Edition. John Wiley & Sons, Inc.
[16]. British Standards. Code of Practice for Site Investigations; British Standards: London, UK, 1999.
[17]. AMERICAN SOCIETY FOR TESTING and MATERIALS (2007). Annual Book of Standards,Vol. 04.08,West Conshohocken, PA.
[18]. Douglas, B.J., and Olsen, R.S. (1981). "Soil Classification Using the Electric Cone Penetrometer, Cone Penetration Testing and Experience," ASCE Fall Convention
[19]. MarkT. Bowers, P. E, Geotechnical Engineering Principles and practices of Soil Mechanics and foundation Engineering, 270 madison Avenue New York 10016.
[20]. Sims, J. T. 1996. Lime Requirement. p. 491-515. In: Methods of Soil Analysis, Part 3—Chemical Methods. Soil Science Society of America, Madison, WI, USA.

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