Global Journal of Researches in Engineering
Civil And Structural Engineering
Volume 13 Issue 8 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Deep Foundations in Formations with Thick Layers of Intermediate Geomaterials and Deep Stable Strata

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Abstract- This work entails the foundation studies, analysis and design that was conducted for a proposed development in the central area of the federal capital of Nigeria. The work encompasses extensive field work, experimental regime, laboratory testing and analyses of the deduced data. The work entails boring of twenty (20 Nos.) rotary drillings with rock coring as well as fifty (50 Nos.) mechanised percussion drilling with standard penetration tests (SPT). The latter gave refusal at between 8.15 and 9.65m while the rotary drilling depths were between 21 – 40m. These revealed sandy silt, silty sand, laterite, lateritic clay and concretionary laterite as the overburden material. Weathered and fresh basement rock were proved between 15 and 40m. Geophysical survey, by the use of vertical electrical sounding predicted weathered and fresh basement rock at varying depth of 18 -50m. The bearing capacity of the overburden material range from 28 – 400kN/m2 (Factor of safety of 2.5) and >1000kN/m2 for fresh basement rock. 600mm and 900mm ϕ bored and cased piles were recommended as foundation for the facility up to depth of 50m below the ground level. This is to take care of the depth to the stable strata resulting from the thickness of the intermediate geomaterial.

Keywords: foundations, bearing capacity, intermediate geomaterial, fresh rock, piles, stable strata.

GJRE-E Classification : FOR Code: 090599

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Deep Foundations in Formations with Thick Layers of Intermediate Geomaterials and Deep Stable Strata

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Abstract- This work entails the foundation studies, analysis and design that was conducted for a proposed development in the central area of the federal capital of Nigeria. The work encompasses extensive field work, experimental regime, laboratory testing and analyses of the deduced data. The work entails boring of twenty (20 Nos.) rotary drillings with rock coring as well as fifty (50 Nos.) mechanised percussion drilling with standard penetration tests (SPT). The latter gave refusal at between 8.15 and 9.65m while the rotary drilling depths were between 21 – 40m. These revealed sandy silt, silty sand, laterite, lateritic clay and concretionary laterite as the overburden material. Weathered and fresh basement rock were proved between 15 and 40m. Geophysical survey, by the use of vertical electrical sounding predicted weathered and fresh basement rock at varying depth of 18 -50m. The bearing capacity of the overburden material range from 28 – 400kN/m2 (Factor of safety of 2.5) and >1000kN/m2 for fresh basement rock. 600mm and 900mm ϕ bored and cased piles were recommended as foundation for the facility up to depth of 50m below the ground level. This is to take care of the depth to the stable strata resulting from the thickness of the intermediate geomaterial.

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I. Introduction

Deep foundation, that necessitates the use of piles to carry loads from heavy superstructure to stable underlying structure are preceded by an extensive region of foundation investigation. This is done to characterize the underlying soil and rock formation and their attendant engineering parameter vis-à-vis their ability to offer adequate support to the facility. Expectedly, characterization of the underlying soils would be done taking cognizance of the expected load from superstructure and all external loading elements.

This work is premised on the investigation carried out for an extensive building development that includes a 150m tower, in the central area of Abuja, the Federal Capital Territory of Nigeria in the North central geopolitical zone. The work entails field investigations, laboratory test analysis, foundation analysis and design.

The underlying characteristics of the area, that elicit special interest, is the occurrence of a thick layer of intermediate geomaterials, ranging from 18 – 40m in some of the deep borings carried out for the studies. This was also shown by geophysical survey carried out which revealed deep layers of weathered/fractured rock. The depth to firm strata, indicated by fresh basement rock was up to 50m at some of the locations.

- Location, Description and Geomorphology of the Area

The location for the study, from which the data for this studies are deduced, is in Abuja, the Federal Capital of Nigeria within the north central region of Nigeria. This is located within longitude 70 and 80E and latitude 8030' and 9030' N.

The area is in a typical basement complex formation and comprises of granite rock of the gneiss migmatite complex which are granite rocks of the Precambrian era.

The data were obtained as output from the extensive geotechnical investigations for a facility that comprises of a cocktail of different buildings. This includes a 150m tower.

The area is in a built up area with relatively level terrain and sparse vegetation.

a) Stratigraphy

The formation that underlies this area is predominantly lateritic soils which were proved between 15 – 36m. These are underlain by thick layers of intermediate geomaterial (weathered rock) which were further underlain by fresh basement/fractured rock. These were observed from 15 – 50m.

II. Research Methodology

The work entailed field investigation as well as laboratory test and analysis. These data formed basic inputs into the analysis design of foundations for infrastructural developments. These are to precede the construction of this facility.

a) Field Investigation

The field work was facilitated by a combination of geophysical and geotechnical investigation to characterize the underlying strata.

A geophysical investigation was done with the use of a terameter to measure the resistivity of the ground and delineate the lithology as a function of their respective resistivities. ABEM Terrameter SAS 300c was used to conduct resistivity surveys. These were done at

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designated vertical electrical sounding (VES) points chosen to coincide with points where geotechnical borings were conducted. Geotechnical investigations entailed carrying out a total of fifty seven (57 Nos) mechanized percussion drilling with standard penetration test (SPT) and rotary drilling with rock coring at twenty seven (27) points. These tests were in accordance with BS 1377 (1990) and ASTM D 420, D 1586-08a, D 1587 – 08 and D 2113 – 08(2009); further guides were provided by Kulhawy and Mayne (1990) as well as Mitchel (1978). Mayne (2001) and Meyerhof (1956) have highlighted the use of various penetration testing techniques (including SPT) for site characterization.

The prescribed U-tube (Acker, 1974 and ASTM D 1587 – 08, 2009) was used to recover undisturbed samples while the split barrel sampler as presented by BS 1377 (1990) and ASTM D 1586 – 08a (2009) was used for disturbed spoon samples. The results of the standard penetration test (SPT) N-values are shown in Table 1 and the plot are shown in figure 1.

Table 1 : N-values from penetration test

Depth (m)	N - values
0 -0.6	16 - 100
1.5 – 2.1	7 - 100
3.0 – 3.6	20 – 100
4.5 – 5.1	35 – 100
6.0 – 6.6	52 - 100
7.5 – 8.1	58 - 100
9 – 9.6	>100

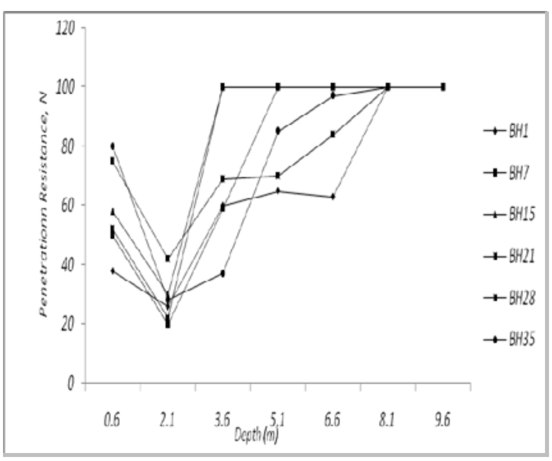

Figure 1 : Plot of Penetration Resistance (N-value) against Depth

- Laboratory Testing

The tests conducted for this work include:

a) Particle size distribution (PSD) test;
b) Atterberg's limits test;
c) Direct shear tests;
d) Consolidation/oedometer test.

All of these tests were done in accordance with specification laid out in BS 1377 (1990) and ASTM D 2850 – 03a(2007), D 2435 – 04, D 3080 – 04,D 1486 – 04, D 4767 – 06, D 6528 – 07 and D 2487 – 06e1 (2009).

III. Results and Discussion

Table 2 show a summary of the results of laboratory tests on recovered disturbed and undisturbed samples.

The index property tests reveals a proportion of fines, as shown by the percentage passing the #200 test sieve to be between 2 and 63.2% and liquid limit (LL) ranging between 19.7 and 45 % as well as plasticity index (PI) of between 1.3 and 25.4 %. The strength properties of the soils gives cohesion ranging from 0 – 47 kN/m2 and friction angle ranging from 14 -430. There properties are plotted in figures 2 – 5.

Table 2 : Geotechnical properties of recovered samples from test borings

Property	Range of test values
Natural moisture content, NMC (%)	3 - 38
Liquid limit, LL (%)	19.7 – 45
Plastic limit, PL (%)	9 - 30
Plasticity index, PI (%)	1.3 – 25.4
Percentage passing No. 200 test sieve	2 – 63.2
Specific gravity	2.3 – 2.81
Unit weight (kN/m^3)	16.28 – 83
Angle of internal friction (^{0})	14 - 43
Cohesion (kN/m^2)	0 - 47

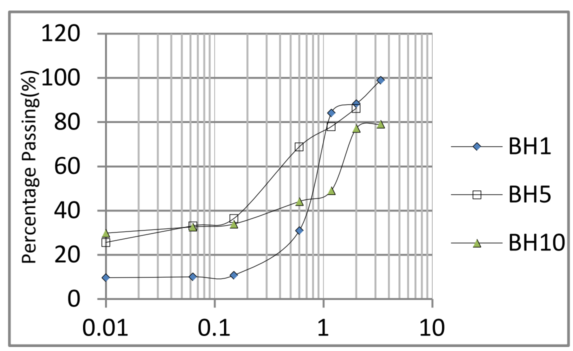

Figure 2 : Particle size distribution curve (PSD) for selected samples

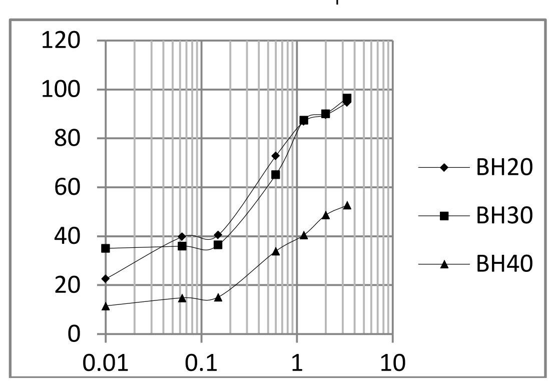

Figure 3 : Particle size distribution curve (PSD) for selected samples

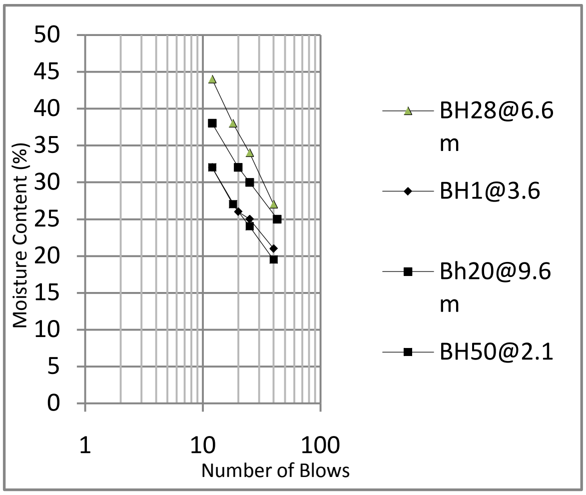

Figure 4 : Plot of liquid limit test result for recovered cohesive samples

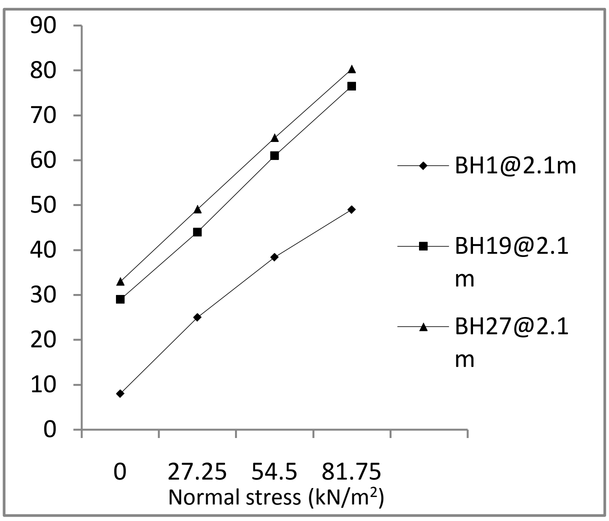

Figure 5 : Plot of shear strength properties for selected recovered samples

a) Stratification of the Lithologies

The stratigraphy of the location is as deduced from geophysical survey, percussion drilling and rotary drilling with rock coring. This is specifically with the purpose of delineating the various lithologies in the location. For this location, the stratigraphy comprises of a dense layer of laterite and lateritic clays up to 18m. These are further underlain by a dense layer of weathered/fracture basement rock with the fresh dense granite rock up to depth of 28.5-50.0m.

Oliver (1996), Kinnicut et al (1996) and Smith (1989) used various techniques to model ground conditions for development of stratigraphies.

The various stratigraphies are shown in table 3 and in the plot of the geophysical survey result shown in figure 6.

Table 3 : Lithology from percussion and rotary drilling

Depth (m)	Description of soil and rock formation
0 – 3	Silty sand, sandy silt, sandy clay, clayey sand, clayey silt, laterite, lateritic clay and concretionary laterite
3 – 6	Laterite, lateritic clay and concretionary laterite
6 – 9	Laterite, lateritic clay and concretionary laterite
9 – 12	Laterite, lateritic clay and sand
12 – 15	Sand, clayey sand, silty clay and lateritic clay
15 – 18	Sand and silty clay
18 – 21	Sand and highly weathered rock
21 – 24	Sand, sandy clay and weathered rock
24 – 27	Sand, sandy clay, clayey sand and weathered rock
27 – 30	Sand, weathered rock and fresh rock
30 – 33	Sand, weathered rock and fresh rock
33 – 36	Sand, weathered rock and fresh rock
36 -39	Weathered rock and fresh rock

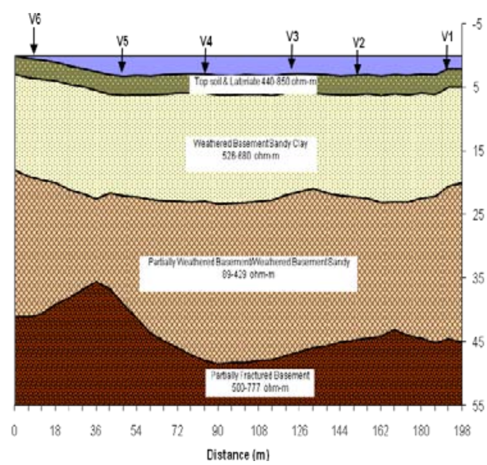

Figure 6 : Geoelectric section obtained from resistivity survey

b) Foundation Analysis and Recommended Design

Preliminary ground characterization by percussion drilling with penetration testing shows overburden depth of between 0 and 33m comprising predominantly of laterites and latentic clays with bearing pressures of between 70 and 1000 kN/m^2. The layers of weathered/fractured basement between 18 – 39m have bearing capacities of >1000kN/m^2. Fresh basement rock lies between 28.5-50m. However, fresh rock was encountered at 28.5m only in one of the borings, while most of the basement formation was observed near 50m depth.

The combined factors of the type of facilities to be constructed at this development (which include a 150m high tower) and the characteristics of the underlying foundation necessitates the use of deep foundation. This specifically entails the use of long piles

Global Journal of Researches in Engineering (E) Volume XIII Issue VIII Version I Year 2013

to transmit the load from the superstructure to the depth of fresh basement rock strata.

The capacity of the piles was deduced using the soil parameters derived from the characterization and testing to analyse the soil-pile interaction. The capacity of the piles were deduced as a combination of end bearing and frictional resistance. Shoda (2007) Sahadja (2011), Medubi et al (2012) and Mason (2012) have all analysed various techniques of pile capacity evaluation in various lithologies and for various types of facilities. The Meyerhof's method was used for this work.

The capacities of piles deduced for this work are shown in Table4.

Table 4 : Pile capacity results for 900mm ϕ

Boring No.	Pile Diameter (m)	Pile length (m)	End Resistance (kN/m^2)	Friction Resistance (kN/m^2)	Total pile capacity (kN)	Safe Pile Capacity,kN (FOS=2.5)
BH1	0.900	50.0	1825.179	1291.4	3116.579	1247
BH2	0.900	50.0	2445.067	1730	4175.067	1670
BH3	0.900	50.0	2295.253	1624	3919.253	1568
BH6	0.900	50.0	1913.936	1354.2	3268.136	1307
BH7	0.900	50.0	2136.112	1511.4	3647.512	1459
BH8	0.900	50.0	1405.136	994.2	2399.336	960
BH9	0.900	50.0	1772.603	1254.2	3026.803	1211
BH10	0.900	50.0	1833.376	1297.2	3130.576	1252
BH40	0.900	50.0	1599.045	1131.4	2730.445	1092
BH41	0.900	50.0	1700.24	1203	2903.24	1161
BH42	0.900	50.0	1990.821	1408.6	3399.421	1360
BH45	0.900	50.0	1837.333	1300	3137.333	1255
BH46	0.900	50.0	2128.197	1505.8	3633.997	1454
BH49	0.900	50.0	2285.643	1617.2	3902.843	1561
BH50	0.900	50.0	2483.509	1757.2	4240.709	1696

IV. Conclusion

The work entailed a detailed study of ground condition, analysis of derived parameters with respect to foundation design and evaluation of foundation type appropriate for the stated condition. The investigations of the ground condition were facilitated by the use of geotechnical and geophysical studies to characterize the area.

The materials encountered were predominantly laterites with bearing pressures ranging from 70 – 1000kN/m^2. Weathered/fractured basement underlay the overburdens layers at between 15 – 50m with bearing pressures of >1000kN/m2. Fresh basement granites rock were observed between 18.5-50m Deep foundation, specifically end bearing piles were deduced as the appropriate means of transferring the structural loads to the underlying formation. The piles have pile capacity of between 960 – 1931 kN as deduced from the soil parameters obtained from all the relevant test.

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