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ARTICLE

Assessment of Subsurface Competency Using Geotechnical Method of a Proposed Structure F.C.T Nigeria

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ABSTRACT

Structural failure has been recently happenings mostly in the commercially populated states along the coastal line in Nigeria. As a result, an open field at a chosen location in Abuja, Nigeria, was investigated. For the purpose of this study, test bores were drilled and Standard Penetration Tests (SPT) were conducted at every 1.5 m interval up to a maximum depth of 12.0 m with the bearing pressure ranging between 20 kN/m^2 and 1000 kN/m^2. 3 test bores were drilled within the plot location, and samples were obtained at the test bore's locations for laboratory analysis. Findings revealed that subsurface lithology found at the site within the explored depths of 0.0-12.0 m is mostly silty sand, laterite, sandy clay, silty clay, clayey sand, and weathered rock. The findings from the sub-soils of the different places and their bearing pressures were computed with SPT N value. Building foundations may be rigid raft foundations at a depth of 2.0 meters below the present ground level, according to bearing capacity values that range from 20 kN/m^2 to 60 kN/m^2 at 1.5 to 3.0 meters. The recommended building foundations take into account the sub-soil's characteristics at the drilling places at a depth of between 1.0 and 3.0 meters. The structure might also be supported by frictional piles buried 10 meters beneath the surface.

1. Introduction

Building collapses have recently become a significant problem in Nigeria; the frequency and extent of the losses being reported in terms of life and property are shocking and disturbing [1,2]. The majority of the collapses occur in the cities of Lagos, Abuja, and Port Harcourt, both in completed buildings and those still being built [3]. Building collapses are occurring at such an unregulated rate that it is almost impossible to keep track of them all. These structural collapses are frequently linked to the issues of

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subpar building materials, outdated structures, and inadequate foundations investigation before the establishment of high rising structures [4]. Following the transfer of the Federal Capital Territory (FCT) from Lagos to Abuja on the 12th day of December 1991, the city's population has grown quickly [5]. This has led to the requirement of land for infrastructure developments such as the construction of fly-over bridges, sewage treatment and purification facilities, high- and low- rise structures for commercial and residential use, and water supply pipelines to all areas of the city. Engineers, engineering geologists, and planners have all expressed severe worry over this. Due to the heterogeneous nature of the rocks and soils that these structures are built on, a thorough understanding of the geology and Geo-technical features of the rocks and soils in the Federal Capital Territory is crucial for planning and building all engineering structures. Due to recorded occurrences of structural failure and collapse, particularly in Lagos, Abuja, and other regions of the country, the significance of Geo-technical investigation as well as engineering geology has recently been emphasized and encouraged [6]. Among other things, a Geo-technical site investigation entails determining the general suitability, safety, and economic design of foundations and temporary works, understanding the engineering properties of each stratum of soil and rock, and anticipating and addressing challenges that may arise during construction due to ground conditions [7]. The complexity of a site inquiry depends on the type of engineering construction and the nature of the ground conditions [8]. Therefore, a site assessment should aim to anticipate and prepare for challenges that could develop during construction due to the ground and/or local characteristics. Such evaluations should identify the strata that would be severely impacted by the structural load, groundwater quality, the rate and intensity of weathering, and the orientation of the rock masses in terms of their structural integrity. The National Building Code of 1983 states that locations that were once utilized for mine workings are also worth noting and investigating since they could be potential areas for subsidence. Not only do design mistakes damage foundations, but foundation deficiencies like placing them on subpar earth strata also have an impact. A building is seriously threatened by having its foundation constructed on insufficient levels, which can also cause the building to collapse [9,10]. Hence, It is important to recognize that the most competent is not the one to bid the lowest price and in infrastructure projects where the fee for Geo-technical investigations is likely to be less than 0.01% to 0.02%, more weight age has to be given to technical competency rather than the price [11]. In addition to the likelihood of ineffective layers like peat or soft, immature clay, there may also be fissures, fractures, or voids, all of which are harmful to superstructures. Under no circumstances may a site investigation be skipped in an effort to reduce the overall cost of an engineering project. The nature and characteristics of the subsurface conditions can be ascertained with the use of a thorough site study. The lithology was used as a preliminary basis for rock type (top soil layer, weathered layer, and fractured basement) identification, in the (FCT) [12], Malomo et al. [13], Omeje et al. [14] and the lithology of the study area agree with the earlier study mention. Sedimentary rocks and the Basement Complex make up the majority of Abuja's subsurface geology. About 48% of the entire area is made up of the igneous and metamorphic rocks that make up the Basement Complex, while some areas of the land are covered with hills and dissected terrain [14]. Older granite, gneiss, and schists make up the majority of the rocks. It is thought that volcanoes erupted the mountain ranges and a few solitary inselbergs during the Tertiary period. About 52% of Abuja's total land area is covered by sedimentary rocks, which mostly make up the undulating plains. Though a dynamic attribute, soil structure is challenging to define in light of the study area's geology and soil characteristics. The strength and competency of the subsurface host materials must be located and evaluated in order for the engineering structure to have a long lifespan and offer safety for people and property. Some type of soil improvement plan may be advised in regions with poor subsurface conditions that cannot sustain a superstructure, but only after a thorough investigation of the underlying conditions. This has made it necessary to conduct in-depth Geo-technical and geophysical studies of the subsurface structure in order to construct engineering projects now and in the future. Cone Penetration Tests (CPT) soundings for the Geo-technical sector, particularly at sites having discrete geological strata or discontinuous lenses, can be highly useful in characterizing the site. It's a useful technique for determining the subsurface stratigraphy of soft materials, discontinuous lenses, organic materials (peat), potentially liquefiable materials (silt, sands, and granular gravel), and landslides.

1.1 Location and Accessibility

The study area is the Federal Capital Territory (FCT) neighborhood in Abuja, Nigeria. Between Latitudes 9°3.30' and 9°6.30' N and Longitudes 7°27.30' to 7°31.0' E (Figure 1). An excellent road network connecting the city makes the area accessible.

1.2 Topography

The topography of the study area varies from place to place, with the lowest altitudes occurring in the region around the extreme southwest at the River Gurara flood-plains. From there, the ground rises erratically in the east, north, and northwest directions. The highest area of the country is in the northwest, where numerous peaks rise to a height of roughly 760 meters above sea level.

1.3 Climate

Similarly to that, from November to March, the area has its hottest temperatures, which is around 36 °C. The temperature dips to a high of 24 °C during the wet season, which lasts from April to October. According to Adeeko and Ojo [15], the yearly rainfall ranges from 1100 mm to 1600 mm.

2. Geology of the Study

Studies conducted by Truswell and Cope [16], Oyawoye [17], ABU [18], and Turner [19], give a brief description of the geology. The study region is located in the northernmost portion of Nigeria's Precambrian Basement Complex see Figure 2, which is a component of the Pan-African Mobile Belt that runs between the West African and Congo Cratons [20]. High-grade metamorphic and igneous rocks of the Precambrian age almost entirely underlie the study region, with a broad NW-SE trend [21]. These rocks include migmatites, coarse porphyritic biotite hornblende granite, medium-grained biotite granite, biotite hornblende granite, granite gneiss, quartzite, older undifferentiated granite, porphyroblastic gneiss, and migmatites. Generally speaking, the Migmatite-Gneiss Complex, the Schist Belt (Metasedimentary and Metavolcanic rocks), the Older Granites (Pan African granitoids), and the Undeformed Acid and Basic Dykes make up the Basement Complex of Nigeria. Many areas in northern, western and eastern Nigeria are covered by rocks of the Migmatite-Gneiss Complex. The Migmatite-Gneiss Complex has ages ranging from Pan-African to Eburnean. The Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African cycles, which correlate to the four major orogenic cycles of deposition, metamorphism, and remobilization, are thought to be responsible for at least four of the basement rocks (600 Ma). The Cretaceous and Younger Sediments are unconformably overlain by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau, which intrude on the foundation rocks. The metamorphosed supra crustal exogenetic rocks, migmatite complex, intrusive coarse-grained granite, minor intrusions such rhyolites and dolerites, and other tiny formations like quartzite, pegmatite, and quartz vein are among the rocks that were included in the study, according to Grant [22]. From field studies and previous research, numerous structures have been identified in the study area, including foliations in mica schist, hornblende and feldspathic schists, migmatites, and gneisses; layering and planar orientation of flat xenoliths in migmatitic complex; folds in migmatites, gneisses, and occasionally schist; crenulation and elongation of mineral grains or aggregates in the schist belt; joins and faults trending NNW-SSE and SE-NW, respectively [23].

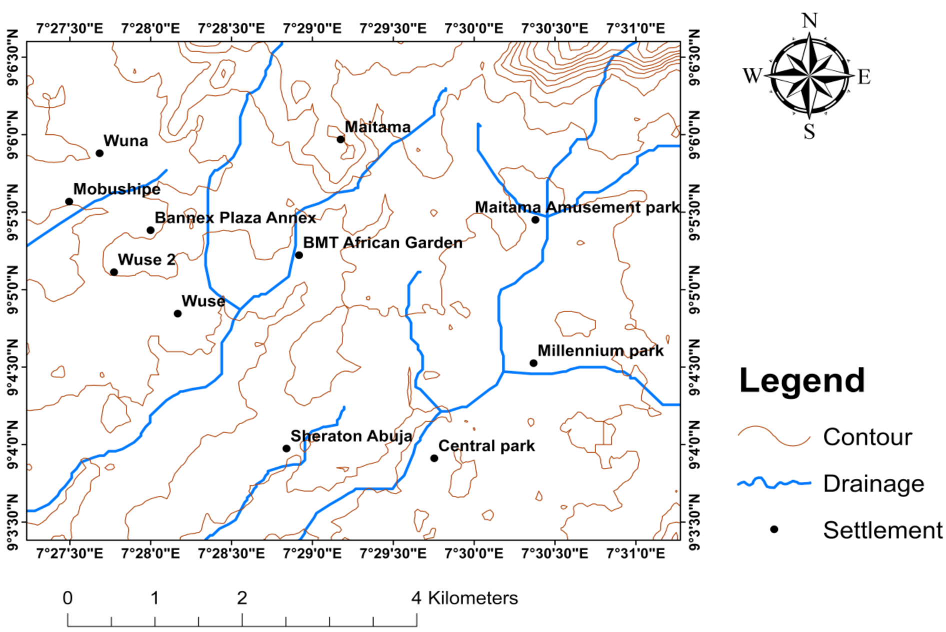

Figure 1. Map of the study area.

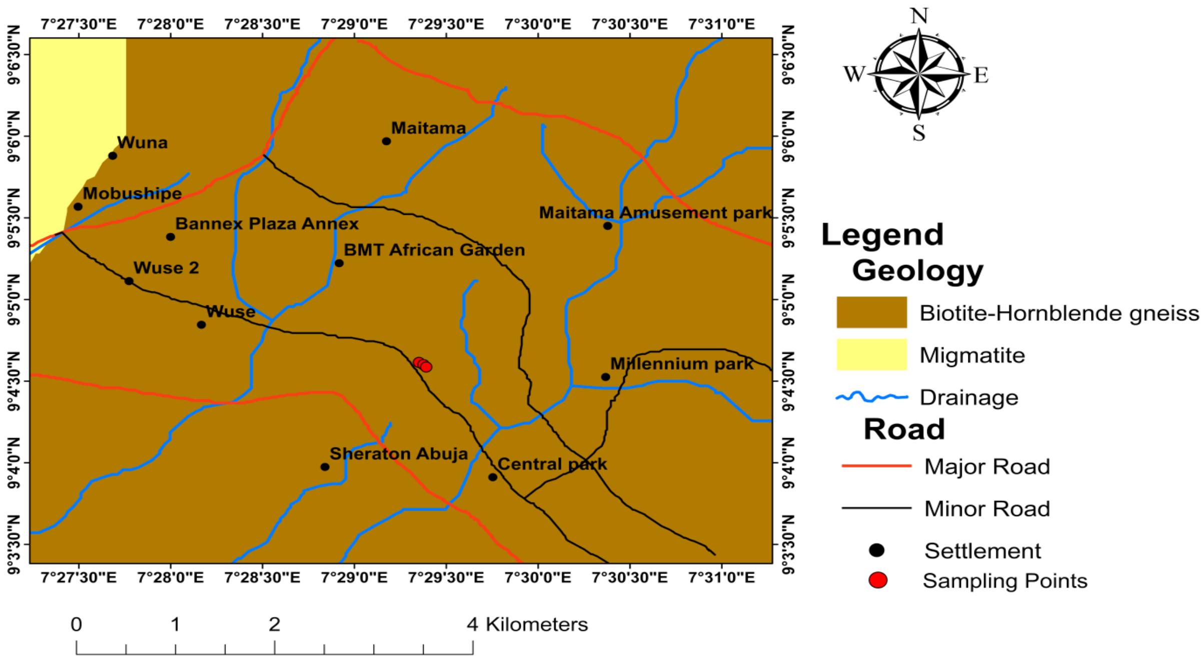

Figure 2. Geological map of the Federal Capital Territory, Abuja showing the different rock types.

3. Materials and Methods

3.1 Field Investigations

The rotary drilling rig was used to create three deep boreholes. Using the rotary drilling method, the test borings were dug 11-12 m below the surface of the ground. Routine and Standard Penetration Tests (SPT) using the wet drilling method, the test borings were boring to the point of refusal. Samples were taken at 1.5 m intervals throughout each test bore. Standard Penetration Tests (SPT) were performed at intervals of 1.5 m. As per ASTM D1586−1990 and BS 5930, the sampling method involved driving a standard split spoon. This was accomplished by repeatedly striking a 760 mm-high wall with a hammer weighing 63.5 kg. In Appendix B, the relationship between depth and penetration resistance (N-value) is depicted. Visually categorized samples that were recovered from the borings described above were geologically logged. They were then brought to the lab to have the parameters determined.

3.2 Laboratory Testing

To enhance the accuracy of the field identification and classification tests, laboratory tests were conducted on chosen disturbed and undisturbed samples taken from the boreholes. The tests were carried out in line with the applicable British Standard, as defined in BS 1377. These are the several test types that were performed.

3.3 Soil Classification Tests

In order to improve the description and identification, these were performed on the samples that were acquired. These tests fall under these categories: Particle Size Distribution Test, Determination of Moisture Content, Atterberg Limit, Specific Gravity, and Bulk Density Tests.

3.3.1 Soil Strength Tests

These mainly require figuring out the strength characteristics that can be used to compute the bearing pressure of the soil. Unaltered samples were subjected to a triaxial compression test, whereas disturbed samples were subjected to a shear box test. These are the tests included in this category: (i) Triaxial Compression Test. (Figure 3) (ii) Shear Box Test (Figure 4).

3.3.2 Soil Deformation Tests

The one-dimensional consolidation test was used to calculate the consolidation (settlement over time) and ascertain how the soil was responding to deformation. (i) Consolidation Test.

3.3.3 Chemical Tests

This was done in order to gauge the number of chemical components in the soil and see if it would be detrimental to the structure's foundation. (i) PH Value of Water in Soils. (ii) Sulphate and Chloride Content of Water in Soils.

3.4 Bearing Capacity Analysis

The properties of the soil's shear strength, as well as the depth and dimensions of the foundation, determine the permitted bearing pressure imposed by it. The laboratory shear strength compression tests that were performed on undisturbed samples resulted in the calculation of the bearing capabilities for typical digging locations. Equations (1) and (2) represent computations for common uninteresting places.

BH 1 at depth of 1.5 m

$$Q_{ulimate} = CNc + \Upsilon DNq + 1/2\Upsilon BN\Upsilon \quad (1)$$

where C = 2 kN/m^2 = 16.00 kN/mγ, Ø = 7°, Υ = 16.00 kN/m^3, B = 1.0 m, D = 1.50 m. The Bearing capacity coefficients (shallow foundations): Nc = 8.15, Nq = 0.27, γ = 2.0 N. Therefore, q (Ult.) = 35.11 kN/m^2; Factor of safety = 2.5; Q (allowable) = 14 kN/m^2.

BH 1 at depth of 4.5 m

$$Q_{ulimate} = CNc + \Upsilon DNq + 1/2\Upsilon BN\Upsilon \quad (2)$$

where C = 33 kN/m^2 = 16.00 kN/mγ, Ø = 7°, Υ = 17.80 kN/m^3, B = 1.0 m, D = 4.50 m. The Bearing capacity coefficients (shallow foundations): Nc = 8.15, Nq = 0.20, γ = 2.0 N. Therefore, q (Ult.) = 316.53 kN/m^2; Factor of safety = 2.5; Q (allowable) = 126 kN/m^2.

Figure 3. Triaxial compression test equipment.

Figure 4. Shear box test equipment.

4. Results and Discussion

4.1 Geotechnical Properties

The studies carried out in laboratories provided information on the geotechnical characteristics of the soils found at the various layer formations of the overburden.

The outcomes from the laboratory tests performed on soil samples from the borehole are displayed below, along with the minimum and maximum values within each range. (see Table 1)

Table 1. Results of laboratory tests performed on soil samples from the borehole.

Soil Property	Min.	Max.
Natural Moisture Content (%)	10	29
Liquid Limit (%)	26	46
Plastic Limit (%)	14	28
Plasticity Index (%)	10	18
Passing # 200 Sieve (%)	10.56	50.84
Bulk density (kN/m^3)	16.00	19.5
Apparent Cohesion (kN/m^2)	0	6
Angle of Internal Friction (Ø)	4	39
Coefficient at Compressibility (m^2/kN)	6.1×10^{-4}	3.80×10^{-3}
Coefficient at Consolidation (m^2/yr)	2.90×10^{-1}	1.8
Specific Gravity	2.60	2.68

The soil's plastic limit ranged from 14% to 28%, its liquid limit from 26% to 46%, and its plasticity index is in the range of 10% to 18.4% (Table 1). The bulk density ranges from 16 to 19.5 and the natural moisture content is between 10% and 29% (see Table 1). According to Table 1, the ranges for apparent cohesion, angle of internal friction, compressibility coefficient, and coefficient at consolidation are 0 to 6 kN/m^2, 4 to 39, 6.1×10^{-4} to 3.8×10^{-3}, and 2.90×10^{-1} to 1.8, respectively. Based on field and lab measurements, soil-bearing capacity calculations are made. The SPT N30 value obtained from the field data and the laboratory strength characteristics of the recovered samples served as the basis for the bearing capacity for the chosen borings. Table 2 contains the values that were acquired.

Table 2. Bearing capacity values.

Depth (m)	Bearing Pressures (KN/m^2)		
	BH1	BH2	BH3
0.0	-	-	-
1.5	30	20	40
3.0	20	30	60
4.5	110	140	90
6.0	200	360	110
7.5	> 1000	> 1000	370
9.0	> 1000	> 1000	430
10.5	> 1000	> 1000	> 1000
12.0	EB	EB	> 1000
			EB

EB is End of boring.

4.2 Settlement Analysis

4.2.1 Consolidation Settlement

The results of the laboratory (oedometer) tests are used to estimate primary consolidation settlement on the sandy clay between the depths of 1.5-3.0 m based on the increase in the effective vertical pressure induced by the loads from the structure. Conventional settlement relationship containing coefficient of volume compressibility (Mv) was used in the analysis see Equation (3):

Therefore,

$$S = Mv \times \Delta\sigma \text{ x } H \quad (3)$$

where, Mv = Average coefficient of volume compressibility obtained for the effective pressure increment in the particular layer under consideration. Δσ = Average effective vertical stress imposed on the particular layer resulting from the foundation pressure. H = Thickness of the particular layer under consideration. The foundation level is 2.0 m.

The acceptable limit of the coefficient of volume change (Mv) for heavy over-cemented clays, stiff weathered rocks, and hard clays was given by Carter (1983) as 0.05×10^{-3} kN/m^2. Terzaghi and Peck [22] also looked into the coefficient of consolidation (Cv) of a few Geotechnical materials, with granular soils such as rock fill having a Cv of 0.02 + 0.01, shale and mudstone having a Cv of 0.03 + 0.01, inorganic clays and silt having a Cv of 0.04 + 0.01, and organic clays and silts having a Cv of 0.05 + 0.01. Results from Table 3 indicated that, except for layer 3, Mv values for layers 1 and 2 were below the permitted limits. The low to a moderate value of Mv for layer 1 and layer 2 (Table 3) suggests that any structure built on the soils won't experience excessive settling that exceeds the allowed limit. The low values of Mv at a constant depth and a certain pressure range are crucial.

The effective stresses for the various layers are computed below using Fadum's chart see Table 3.

Table 3. Consolidation settlement analysis.

Layer	Mv (m^2/kN)	dp (kN/m^2)	H (m)	Mv x dp x H (m)
1	3.45E-4	100	0.5	0.00173
2	3.80E-4	50	1.5	0.0285
3	5.65E-4	25	3.0	0.0283
ρ_c	-	Σ(Mv x dp x H)		0.0247

The estimated average consolidation settlement is 24.7 mm.

4.2.2 Immediate Settlement

The immediate settlement was carried out using Equations (4) and (5) respectively.

$$\rho i = 100 \times B \frac{(l-v2)}{(Eu)} \times Ip \quad (4)$$

Ip = 0.80

$$\rho i = 100 \times 1.0 \times \frac{1-0.25^2}{3200} \times 0.22 \quad (5)$$

ρi = 0.00644 m at corner of loaded area.

Settlement at the center multiplies by 4, 6.44 mm × 4 = 25.76 mm.

4.2.3 Maximum Total Settlement

It is the summation of the immediate settlement and secondary settlement as shown in Equation (6).

$$\rho_{total} \rho_{immediate} + \rho_{consolidation} = \quad (6)$$

And it gives a product of 50.46 mm when computed.

4.2.4 Differential Settlement

With a calculated maximum settlement of about 50.46 mm, the maximum differential settlement would be approximately 50% of the maximum settlement. In reality, differential settlement, which causes one part of a structure to rotate or deflect relative to other parts, is what has a negative impact on a structure.

The maximum total settlement of about 50.46 mm while the expected maximum differential settlement is 50.46/2 = 25.23 mm.

4.3 Pile Capacity Computations

Taking into account the soil overburden found between 0.0 and 30.0 meters below the surface. The end-bearing resistance and skin friction of the portion of the shaft in contact with the soil that is supporting the pile are the only factors that affect the carrying capacity of piles driven into clays and clayey silts.

The total pile capacity = Qb + Qs

Qb = base resistance Pressures

Qb = qb.Ab = Nc × Cub × Ab

Nc, bearing capacity factor = 9 for clay & Silt

Ab = Area of base of pile (based on diameter of pile) and

Qs = qs.As = α × CuAs

where Qs = Skin friction, qs = shaft friction, Cu = undrained shear strength, and As = area of shaft.

The values of the Pile load capacities at the various boring points are given in Table 4.

4.4 Chemical Test Result

The findings of the chemical tests show that the levels of sulfate and chloride are between 151.48 and 163.11 mg/L and 170.45 and 185.62 mg/L, respectively, with pH values between 6.37 and 6.50. The pH value is regarded as slightly acidic, and the levels of sulfate and chloride are regarded as moderate and within safe limits.

4.4.1 Subsoil Condition and Groundwater Condition

From the beginning of the boreholes until their conclusion, the stratigraphies of the subsurface deposits as seen from the logs of test bores conducted at this location shared commonalities in type and strength characteristics. All of the test borings have shown that silty sand, clayey sand, sandy clay, laterite, and worn rock are among the components.

Lekmang, et al. [24] claim that there are substantial differences in Abuja's particle size distribution when analyzed from disturbed soil samples taken from boreholes. The majority of the soil samples are well-graded, ranging from clay, silt, sand, and gravel. In certain places, a mixture of two or more of the aforementioned soils is seen. Important foundation soils are dense sands and gravels because they can support loads greater than 600 kN/m^2 with little settling [25]. In order to preserve the stability and integrity of the structure, areas with dense sands and gravel can support structures that weigh more than 600 kN/m^2, while areas with particularly loose sand, soft clays, and silts should not be loaded above 150 kN/m^2.

4.4.2 Lateritic Soil

Layers of stiff to extremely stiff reddish brown, fine-grained alluvial sands that were mixed with reasonably solidified clay that was poor in flexibility and materials from the lateritic iron crust were found to be between 0.0 and 0.35 meters thick.

4.4.3 Silt-fine Sand

Between 0.35 and 1.40 meters thick, this layer of permeable loose sand and silts is common.

4.4.4 Clay Sandy

These were found between 0.85 and 5.75 meters and are composed of very stiff, somewhat cemented clay and medium-grained sand.

4.4.5 Silty Clay

Between 2.50 and 4.0 meters, these are a horizon of densely consolidated silts, sands, and alluvial deposits material with high mica content of variable degrees and partially combined with worn rock in some spots.

4.4.6 Clayey Sand

These were found between 0.0-0.75 m and 4.0-7.35 m from the various boring locations. They are highly stiff, fairly cemented clay with medium-grain sand particles.

4.4.7 Weathered Rock

Extremely to weathered granite rock layers that are highly micaceous and found to be combined with clayey sandy silt at the surface are reported to have good bearing pressure at depths between 5.50 and 12.0 meters.

Table 4. Safe load capacity for pile (400 mm∅ & 600 mm∅).

S	Depth of boring (m)	Adhension Factor	Pile Diameter (m)	Pile length (m)	Unit shaft friction qs (KN/m^2)	Shaft area AS (m^2)	Shift friction QS (KN)	End Resistance, Qb (KN)	Total Pile Capacity (KN)	Safe Pile Capacity FOS=3.0 (KN)
BH1	11.0	0.90	3.142	0.4	10.0	432	12.57	1131	6560	2187
BH1	11.0	0.90	3.142	0.4	10.0	456	12.57	1131	6866	2289
BH1	12.0	0.90	3.142	0.4	10.0	267	12.57	1131	4491	1497
BH2	11.0	0.90	3.142	0.6	10.0	432	18.85	2545	10689	3563
BH2	11.0	0.90	3.142	0.6	10.0	456	18.85	2545	11147	3716
BH2	12.0	0.90	3.142	0.6	10.0	267	18.85	2545	7584	2528

4.4.8 Groundwater Table

The phreatic surfaces were examined from every boring point, and pictures were taken 24 hours afterward (static). The groundwater tables ranged in depth from 1.60 to 2.56 meters at the time this inquiry was finished in August 2019. Seasonal and annual variations are anticipated. Each drilling site's water level is described in Table 5 while the SPT results obtained at the test bores are presented in Table 6 and Figure 5.

Table 5. Water table level.

S/No	Test	Co-ordinate		Water Table
		Easting	Northing	
1	BH1	333959	1003700	1.30
2	BH2	334003	1003675	1.15
3	BH3	334030	1003648	0.95

Table 6. The result of SPT obtained at the test bores.

Depth (m)	SPT N Value			Lithology
	BHI	BH2	BH3	
0.0	-	-	-	Silty sand, laterite, clayey sand
1.5	3	2	4	Sandy clay, silty clay
3.0	2	3	6	Sandy clay, silty clay
4.5	11	14	9	Sandy clay, clayey sand
6.0	20	36	11	Clayey sand , weathered rock
7.5	100	100	37	Weathered rock
9.0	100	100	43	Weathered rock
10.5	100	100	100	Weathered rock
12.0	EB	EB	100	Weathered rock
			EB	

EB is end of boring.

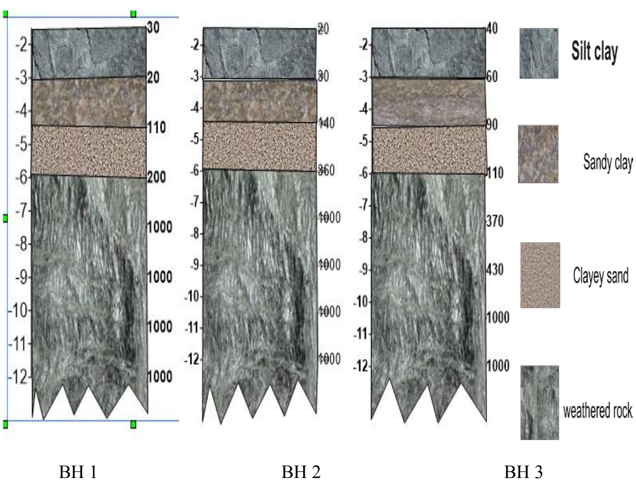

Figure 5. Columnar sections of the test bore showing the lithology with their pressure readings.

5. Conclusions

By combining laboratory and Geo-technical approaches, a study of subsoil competency for the construction of engineering structures has been conducted in Abuja, Nigeria. This was necessary to offer information about the area's subsoil's geologic makeup and proficiency. Results showed that the proposed subsoil examination includes clayey sand overburden, lateritic material, silty sand, sandy clay, and silty clay in the studied depth range of 0.0 to 7.35 meters. At a depth of between 5.55 and 12.0 meters, where drilling was stopped, these were further overlain by worn granite rock. 3 No test bores in total, up to a maximum depth of 12.0 meters below the surface of the ground, were carried out for this inquiry. The water table was found to be between 0.95 and 1.25 meters deep at the time of the examination. The results of the standard penetration test (SPT) showed that at low depths, the bearing pressure of the subsoil at the site is average, but increases as depth increases.

5.1 Subsurface Concrete Protection

Since the chemical composition of the subsoil won't have a negative impact on the concrete, ordinary Portland cement with a cement content of no less than 370 kg/m^3 and a water-to-cement ratio of 0.40 might be used, and safeguards are required to safeguard subsurface reinforced concrete.

5.2 Drainage Management

Ample drainage should be provided around the site to drain away surface and run-off water during and after construction taking into account the topography of the site. Waterproof material should be utilized at the foundation's hardcore level to prevent water intrusion due to the high water table level that is located near the surface. In general, appropriate filling and a consistent slope should be used so that water cannot infiltrate around the buildings.

5.3 Recommendations

The material explored beneath the recommended shallow foundation level is expected to undergo some degree of settlement when fully loaded. Generally, the subsoil is expected to undergo some settlements due to the consolidation of the materials beneath at shallow depths before the weathered rock strata. The estimated settlement computation in section 8.0 gives a guide on the settlement pattern expected under loadings. Considering the high water table level encountered within the depth of 0.95-1.30 m, waterproof material should be used at the foundation hardcore level to prevent the ingress of water. Generally, proper filling and a uniform slope be adopted in such a way that water will not be able to percolate around the buildings.

Conflict of Interest

There is no conflict of interest.

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