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BEARING CAPACITY AND FOUNDATION QUALITY OF SUBSOILS IN PARTS OF THE MAIN CAMPUS OF AKWA IBOM STATE UNIVERSITY, IKOT AKPADEN, AKWA IBOM STATE, NIGERIA

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ABSTRACT

The study of the Foundation quality of Subsoils in parts of the main campus of Akwa Ibom State University, Ikot Akpaden, Eastern Niger Delta, Nigeria was carried out with the aim of determining the bearing capacity of the subsoils and designing suitable foundations for the construction of structures. Through field and laboratory investigations carried out, the geophysical study revealed four geo-electric layers namely; the top soil, silty clay, sand, and clayey sand. Six geotechnical boreholes were drilled in the field to a maximum depth of 15m each, with standard penetration tests and cone penetration tests carried out. Soil samples were extracted at 1meters each for different laboratory tests including; moisture content, liquid limit, plastic limit, bulk density, specific gravity, particle size distribution, shear box test, undrained shear strength and Consolidation test. The subsurface stratigraphic profile consists of clayey silty sand (0-7m), sandy silty clay (2-14m) and sand (10-15m) from top to bottom. The clayey silty sand are soft to firm, low to medium compressibility clays with liquid limit, plastic limit and average cohesion values of 23% to 41.5%, 14% to 24% and 14KN/m2 to 64KN/m2 respectively. Ultimate bearing capacity values of the clayey silty sand range from 152.65KN/m2 to 667.94KN/m2. The sandy silty clays are soft, intermediate to high compressibility clays with liquid limit, plastic limit and average cohesion values of 44% to 83%, 25.5% to 51% and 10KN/m2 to 32KN/m2 respectively. Ultimate bearing capacity values of the sandy silty clay range from 269.43KN/m2 to 582.4KN/m2.The sand is poorly graded, medium dense with standard penetration N- values ranging from 13-16. The ultimate bearing capacity ranges from 7878.12KN/m2 to 11423.36KN/m2 respectively. Standard penetration tests and pile bearing capacity analysis indicate that the sands are suitable foundation materials for construction. A Pile foundation terminated within the sand substratum is recommended for large structures.

Keywords: Shallow Foundation, Deep Foundation, Pile Bearing Capacity, Subsoil Stratification

1. INTRODUCTION

A foundation is the portion of a structure that transmits the weight of the structure to the underlying soil or rock Das and Sivakugan (2018). In 2015, the United Nations sustainable development goals (SDG) was established; with goals 9 and 11 aimed at building resilient infrastructure, making cities and human settlements safe and sustainable. For a building to be safe, resilient and sustainable, its foundation should be designed based on results obtained from a series of soil tests involving the engineering properties of the subsoil and geophysical survey. Contrary to this, the safety and sustainability of the structure cannot be assured. This is because the subsoil conditions play a critical role in the stability of foundations (Adebisi and Adeyemi, 2018). As shown by Oke and Amadi (2008), the impact of the imposed load on the subsoil is exacerbated by the thickness and consistency of compressible soil layers. In the Niger delta region, some structures are located in areas with difficult building conditions such as highly compressible clay soils and poor drainages which occur naturally in the region. Occasionally, some civil engineering structures also do not stand the test of time possibly due to the lack of consideration of the importance of the study of the subsurface layers of the soils prior to construction Ashioba and Udom (2023) or the use of inadequate building materials during construction thereby resulting in the collapse of structures. According to the Building Collapse Prevention Guild, 271 buildings have collapsed in Nigeria over the past ten years with the highest numbers of fatalities due to building collapses recorded in Lagos State, one of the most developed and populous cities in the country. In foundation design, geophysics also plays a major role in subsurface soil investigation. It's application provides useful information regarding the early detection of potentially dangerous subsurface conditions Oladele et al. (2015) as well as gives an insight into the subsurface soil stratification especially in areas that are inaccessible for geotechnical boring to take place. Geophysical tools do not replace geotechnical investigations, but supplement them by optimizing locations for geotechnical borings or filling information gaps between boring Oyedele et al. (2015). Several studies over the years on the geotechnical properties of foundation subsoils in different parts of the Niger delta have been carried out by various researchers such as, Teme (2002), Tse and Akpokodje (2010), Atat et al. (2013), Ngah and Nwankwoala (2013), Warmate and Nwankwoala (2018), Ehibor et al. (2019), Ehibor and Akaha (2022), Ashioba and Udom (2023) etc., very few studies have been carried out on the geotechnical properties of foundation soils in the main campus of Akwa Ibom state University, Ikot Akpaden and no study had been carried out on its bearing capacity. Therefore, this study combined geophysical and geotechnical investigations to determine the bearing capacity of sub soils in parts of the main campus of Akwa Ibom state university in order to design suitable foundations for the construction of structures within the campus and to develop maps for shallow and deep foundations that can be used as a guide for futuristic foundation designs.

2. DESCRIPTION OF STUDY AREA

Akwa Ibom State University located in Ikot Akpaden, Mkpat Enin local government area of Akwa Ibom State, Nigeria lies between longitude 7˚46'0^{II}E and 7˚46'45^{II}E and latitude 4˚37'0^{II}N and 4˚37'45^{II}N. This study area is located in the Tertiary Niger Delta sedimentary basin which consists of a regressive clastic succession, which attains a maximum thickness of 12,000m (Orife and Avbovbo, 1982). The lithostratigraphy of the Tertiary Niger Delta can be divided into three major units: Akata, Agbada and Benin formations, in order of decreasing age with depositional environments ranging from marine, transitional and continental settings respectively (Short and Stauble, 1967). The study area falls within the Benin Formation which consists predominantly of fresh water continental friable sands and gravel that are of excellent aquifer properties with occasional intercalation of shales. The formation generally does not exceed 120 meters in thickness and it is predominantly unconfined. The Benin Formation is overlain by various types of quaternary alluvial deposit comprising mainly of recent deltaic sand, silt and clay of varying thickness. These alluvial deposits occur in five major geomorphic units namely: Active and abandoned coastal beaches, Salt water /Mangrove swamp, Fresh water swamp, Sombreiro-Warri Deltaic plain with abundant fresh water swamps and Dry flat land and plain overly the Benin Formation Akpokodje (2001). The Benin formation constitutes the regional aquifer in the Niger Delta. Knowledge of the groundwater conditions in the Niger Delta area are obtained from the work of Etu-Efeotor and Akpokodje (1990), Nwankwoala and Udom (2011) etc. Geomorphologically, Akwa Ibom State is generally a flat, low lying terrain and riverine environment Usoro (2010). The land rises steadily northward from the sea-level at Eket in the south to 150m at Obotme in the north Beka and Udom (2014).

3. MATERIALS AND METHODS

Six boreholes were drilled in different locations across parts of the main campus to a maximum depth of 15m meters each, using the shell and auger percussion drilling rig. Disturbed soil samples were collected at regular intervals of 1metres, while undisturbed soil samples were retrieved from the cohesive soil strata in the borehole with an open-tube sampler which consists essentially of a lower and upper end screwed into a drive head that is attached to a rod. Standard penetration tests and cone penetration tests were also carried out in the field. The soil samples collected were labelled and classified on the field before transporting them to the laboratory for further analysis including moisture content, atterberg limits, particle size distribution, shearbox test, unconsolidated undrained triaxial test and consolidation.

4. METHOD

4.1. GEOPHYSICAL INVESTIGATION

The survey method employed in this investigation for the foundation studies of subsurface structure is the Electrical Resistivity Method. The success depends solely on the presence of suitable resistivity contrasts between earth materials. Six (6) vertical electrical soundings (VES) were conducted within the project area.

- Maximum Electrode spreads of AB = 600m; and MN = 20m was made.
- Maximum depth penetration of 100.8m was attained.

4.2. STANDARD PENETRATION TEST

Standard penetration tests (SPT) were performed at various depths in the sand horizon. The main objective of this test is to assses the relative densities of cohesionless soils penetrated. In this test, a 50mm diameter split spoon sampler was driven 450mm into the soil with a 63kg hammer falling freely from a distance of 760mm. The number of blows for the first 150mm of penetration is not counted, while those required to drive the spoon 300mm into the soil provides an indication of the relative density of the cohesionless soil stratum and is recorded as the penetration resistance of the soil. This is also referred to as the N-value

4.3. CONE PENETRATION TESTING (CPT)

In situ cone penetration test to estimate the soil bearing capacity were conducted using a 2.5-ton CPT machine. The test involved advancing a 60 0 steel cone with base area of 10cm2 into the ground with the view to ascertain the resistance of the soil. This was achieved by securing a winch frame to the ground by means of anchors. These anchors provide the necessary power to push the cone into the ground at the rate of 2cm/sec and the resistance to the penetration registered on a pressure guage connected to the pressure capsule was recorded. At the end, series of cone resistance and sleeve friction readings were plotted against the depth and the bearing capacities of the subsoil horizons calculated.

4.4. LABORATORY TEST

All tests were performed according to British Standard BS 1377 (1990) and American Society for Testing and Materials, ASTM (1975). The test procedures are discussed below

1) **Atterberg Limits**: Atterberg limits were determined on soil specimens with a particle size less than 0.425mm. The Atterberg limits refers to arbitrary defined boundaries between the liquid limit and plastic states (liquid limit, WL) and between the plastic and the brittle states (plastic limit, WP) of fine-grained soils. The liquid limit is the water content at which a part of soil placed in a standard cup and cut by a groove of standard dimensions flow together at the base of the groove when the cup is subjected to 25 standard shocks. The one-point liquid test was carried out. Distilled water was added during soil mixing to achieve the required consistency. Plastic limit is the water content at which a soil can no longer be deformed by rolling into 3mm diameter threads without crumbling. The difference between the liquid limit and the plastic limit is the plasticity index, IP
2) **Particle Size Analysis**: Particle size analysis were performed by means of sieving. Sieving was carried out for particles that would be retained on a 0.075mm sieve, dry sieving was carried out by passing the soil sample over a set of standard sieve sizes and then shakes the entire units for few minutes with sieve shaker (machine).

Figure 1

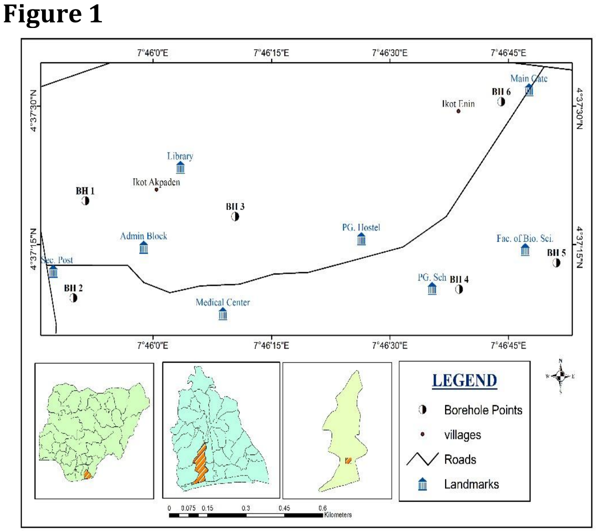


Figure 1 Map of MkpatEnin Showing the Study Area- AkwaIbom State University

Table 1

Table 1 Coordinates of Sample Location		
Sample location	**Longitude**	**LATITUDE**
BH1	E007°45'47.2"	N04°37'23.1"
BH2	E007°45'44.9"	N04°37'14.4"
BH3	E007°45'11.8"	N04°37'17.8"
BH4	E007°46'34.4"	N04°37'11.2"
BH5	E007°46'44.4"	N04°37'14.9"
BH6	E007°46'40.1"	N04°37'31.8"

3) **Unconsolidated undrained Triaxial:** Unconsolidated undrained triaxial compression tests were performed on cohesive samples, relatively undisturbed samples obtained from the open boreholes, with the objective of determining their undrained strength parameters, in accordance with BS1377, Part2, 1990
4) **Direct Shear Test**: The soil specimen is loaded into the shear box which split into two halves along a horizontal plane at its middle. The box is square with 60mm sides and 50mm high. It is made up of brass metal. It is placed inside a larger box-container and mounted on the loading frame. A proving ring is fitted to the upper halve of the box to measure the shear force. The proving ring which butts against a fixed support records the shear force as the box moves and the shear displacement is measured with a dial gauge fitted to the container. Another dial gauge fitted to the top of the pressure pad measures the change in the thickness of the specimen.
5) **Oedometer Consolidation:** Laboratory consolidation tests were carried out on cohesive soil specimens, relatively undisturbed sample with object of determining the compressibility properties of the soils, in accordance with BS 1377.

5. DATA ANALYSIS

5.1. BEARING CAPACITY ANALYSIS FOR DEEP FOUNDATION DESIGN

Field standard penetration test N-values were corrected using the formula

N1 = 15 + ½ (N – 15)........................eqn (1)

N1 – corrected field standard penetration Test N-value

N – Field standard penetration test N-value from 300mm penetration.

5.2. PILE CAPACITY ANALYSIS

The bearing capacity of piles for deep foundation was determined using the methods of Peck, Peck et al. (1974), Terzaghi (1960) and Berezantev (1961). The general equation for the total load on the pile Q can be expressed as:

Qult (KN) = Qb + Qs……………………..eqn (2)

Where;

Qult (KN) = Ultimate bearing capacity of soil

Qb (KN) = Base resistance (offered by the soil)

Qs (KN) = Shaft resistance (offered by the shear stresses between the soil and the shaft)

For the ultimate base resistance in sand:

Qb (KN) = Abase + q0 Nq ....eqn (3)

Where;

Abase (m^2) = Base area of pile (πdl2/4)

d(mm) = Diameter of pile (306mm steel piles)

q0 (KN/m2) = Effective overburden pressure (γ x h) .... eqn (4)

h(m) = Thickness of strata

γ (KN/m3) = Unit weight (pwet x g)/100 ....eqn (5)

ρwet (Kg/m3) =Bulk density

g(m/s2) = Acceleration due to gravity (9.81)

Nq = A bearing capacity coefficient which depends on the angle of internal friction (Ø)

For the ultimate shaft resistance in sand.

Qs (KN) = Ashaft. Ks. q0/2. tan δ ....eqn (6)

Where;

Ashaft (m2) = Area of Shaft (πdl) ....eqn (7)

π = 3.142

d(mm) = Diameter of pile (306 for steel piles)

L(m) = Length of pile

Ks (N/m2) = Earth pressure coefficient which depends on the type of pile used (0.75 for steel piles)

q0/2 (KN/m2) = Average effective overburden pressure over soil layer (γ x h)/2 ....eqn (8)

Tan δ = Angle of pile friction (20^0 for steel piles)

For the safe Axial pile capacity of the soil:

Qallow. (KN) = Qb +Qs/F. S .... eqn (9)

Qallow. = Safe Axial pile capacity of soil

Qb = Base resistance

Qs = Shaft resistance

F.S = Factor of safety (2.5)

5.3. BEARING CAPACITY FOR SHALLOW FOUNDATION

Terzaghi (1943) bearing capacity equation for shallow foundation (Strip footing)

qd= cNc + γDfNq + ½(γBNγ) ....eqn (10)

qd (kN/m^2) = ultimate bearing capacity

c= unit cohesion

γ (KN/m^3) = effective unit weight of soil

B= width of footing (600mm for concrete strip foundation)

Df (m) = depth of foundation

Nc, Nq and Nγ = bearing capacity factors which are a function of Ø

6. RESULTS AND DISCUSSION

Subsurface Soil Stratigraphy

The subsurface soil stratigraphy from geotechnical borings carried out on the field is shown in Figure 2.

Figure 2

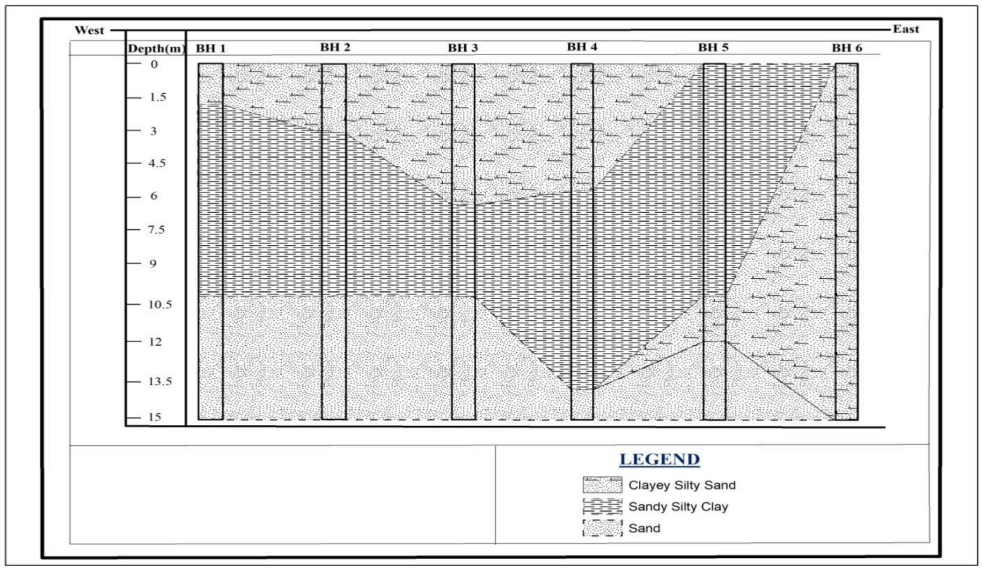
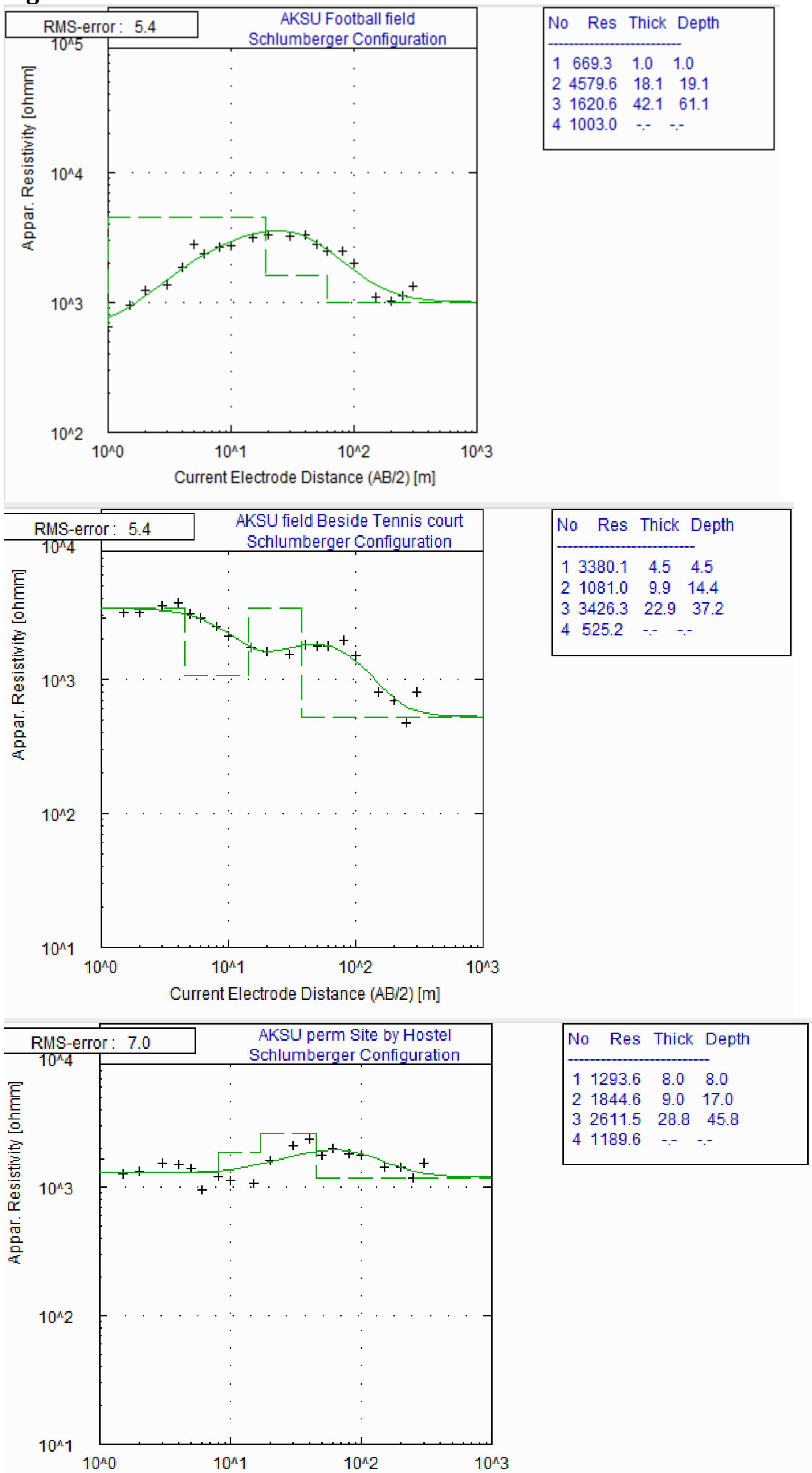


Figure 2 Stratigraphic Profile of Sub Soils in the Main Campus of Akwa Ibom State University Showing the Different Lithologies

7. GEOPHYSICAL INVESTIGATION

The geo-electric sections in Figure 3 revealed four geo-electric layers which are; the top soil, silty clay, sand, and clayey sand. This preliminary study of the lithology is similar to the field investigation study which reveals three different lithologies from soil samples obtained during drilling from 0-15m depth namely, clayey silty sand, sandy silty clay and sand. The top soil has resistivity values ranging from 669.3 to 2108.1Ωm and its thickness varies from 1 to 4.5m. The silty clay layer is characterized by resistivity values that range between 283.7Ωm to 4576.6Ωm and its thickness varies from 2.2 to 27.1m. The sand layer is characterized by resistivity values 396.1Ωm -7835.5Ωm and its thickness varies from 22.9 to 54.1m. The clayey sand that underlies VES 4 and 5 locations is characterized by resistivity value that range between 117 and 159.5Ωm. The electrical resistivity values for VES 1 TO VES 6 shows high resistivity values. The resistivity values for sand were greater than silty clay. It shows that electrical resistivity can be used to depict different types of soils. High moisture content and fine grained soil (silt and shale) has influenced the lower electrical resistivity values of clay and shale compared to that of sand. These results differ from Evaluation of Pavement Instability Section Using Integrated Geophysical and Geotechnical Methods in a Sedimentary Terrain, Southern Nigeria by Adebiyi et al, (2018).

Figure 3


RMS-error : 5.4
AKSU Football field
Schlumberger Configuration
No Res Thick Depth
1 669.3 1.0 1.0
2 4579.6 18.1 19.1
3 1620.6 42.1 61.1
4 1003.0 -.- -.-
Appar. Resistivity [ohmm]
10^5
10^4
10^3
10^2
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
RMS-error : 5.4
AKSU field Beside Tennis court
Schlumberger Configuration
No Res Thick Depth
1 3380.1 4.5 4.5
2 1081.0 9.9 14.4
3 3426.3 22.9 37.2
4 525.2 -.- -.-
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
Current Electrode Distance (AB/2) [m]
RMS-error : 7.0
AKSU perm Site by Hostel
Schlumberger Configuration
No Res Thick Depth
1 1293.6 8.0 8.0
2 1844.6 9.0 17.0
3 2611.5 28.8 45.8
4 1189.6 -.- -.-
Appar. Resistivity [ohmm]
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3

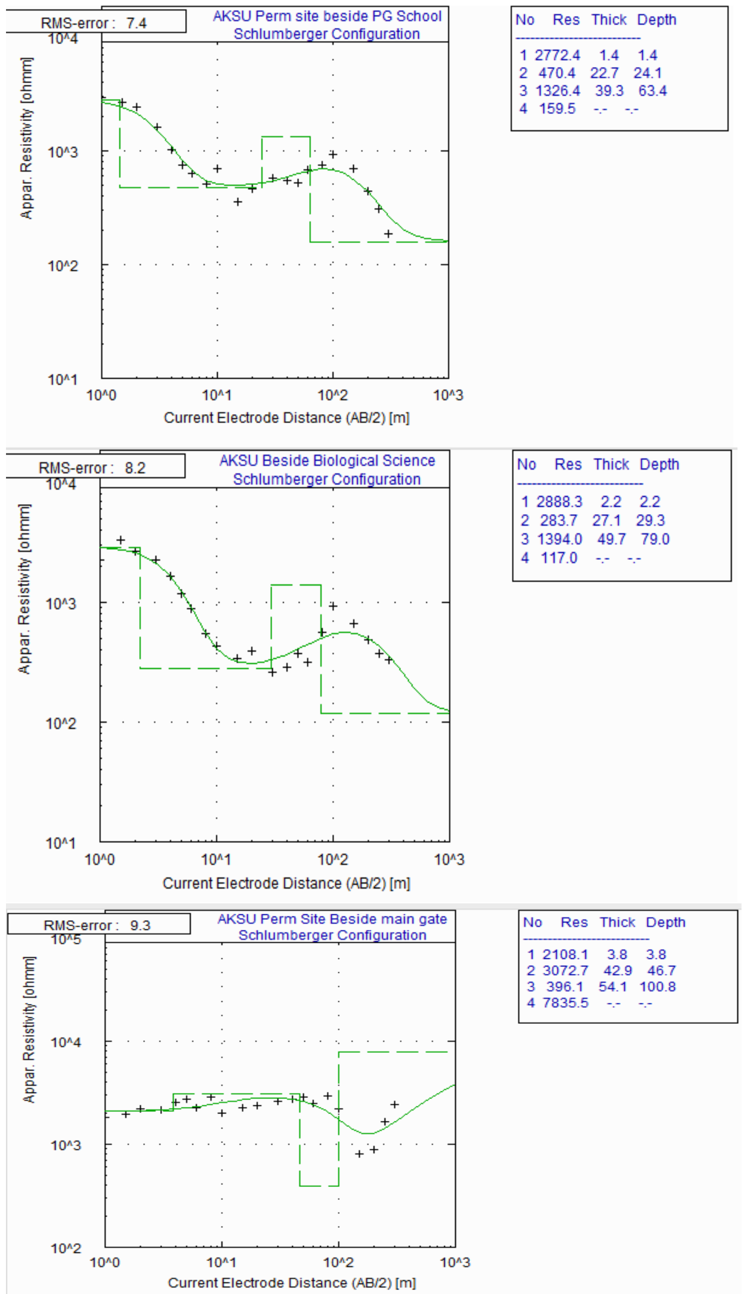


Figure 3 Graphical Representation of VES1 to VES 6

8. ENGINEEERING PROPERTIES OF CLAYEY SILTY SAND LAYER

The clayey silty sand which forms the top soil layer in BH1 to BH4 extends from 0-2m in BH1, 0-3m in BH2, 0-7m in BH3 and 0-6m in BH4. It occurs as the bottom layer in BH5 at a depth of 10-12m and forms the entire lithology in borehole 6. Results for the engineering properties for clayey silty sand layer are shown in Table 2. Moisture content of the soil ranges from 17.5% in BH6 to 41.1% in BH 2 while the percentage of fines (clay & silt) range between 28.32% in BH5 to 49% in BH4. The moisture content of a soil varies greatly with season, clay and organic content, Akpokodje (1986), as shown by the range in the percentages of fines in this layer. The soils are of low plasticity in BH2, BH3 and BH5 with liquid limit values of 23%

to 36%, plastic limit values of 14% to 23% and plasticity index values of 9% to 14% respectively. Intermediate plasticity clays exist in BH1, BH4 and BH6 with average liquid limit values of 40%, 36% and 41.5% respectively and plasticity index values of 17% in BH1, 17.5% in BH6 and 14% in BH4. The low plasticity values of the clayey, silty sands in BH2 and BH3 may be attributed to the percentages of fines 48.07% and 38.93% respectively present in these boreholes. Generally, the liquid limit of the clayey, silty, sands which fell below 50% indicates a low to medium compressibility of this soil according to British (1999) and a low to medium swelling potential as shown by the plot of all the soils above the A-line in the region of low to intermediate plasticity (CL - CI) on the plasticity chart in Figure 4. Similar plasticity values have been obtained by Ehibor et al. (2019) for soils in Uyo town, Akwa Ibom state. The particle size distribution graph in Fig. 5 shows a poorly graded, fine to medium to coarse grained sand, with minimal gravel fractions in BH1, BH2 and BH6. This indicates that the sand whose mean diameter (D_{50}) ranges from 0.08mm to 0.50mm are free draining. Average undrained cohesion and angle of internal friction values ranges from 14KN/m^2 in BH2 to 64KN/m^2 in BH6 and 3˚ in (BH2 and BH3) to 5˚ in BH1 respectively. The low angle of internal friction values are attributed to expansive clays as reported by Obiora and Umeji (2004). The low to high cohesion value of the clays, are characteristic of firm to very soft clays. The average values of the coefficient of consolidation (Cv) ranges from 35.88m^2/yr in BH3 to 52.80m^2/yr in BH6, while the values of the coefficient of compressibility (Mv) is between 0.175m^2/MN to 0.34m^2/MN in BH4 to BH3. Bearing capacity analysis of this clay layer using the method of Terzaghi (1943) for Strip footing at various depths gave ultimate bearing capacity values ranging between 169.54kN/m^2 to 667.94kN/m^2 in BH2 to BH6 as shown in Table 2 and on the bearing capacity map in Figure 6. The allowable bearing capacity values ranges from 56.51kN/m^2 to 222.65kN/m^2 in BH2 to BH6.

Table 2

Table 2 Average Values of the Engineering Properties of Clayey Silty Sand

Sample location	BH1	BH2	BH3	BH4	BH5	BH6
Depth	0-2	0-3	0-7	0-6	10-Dec	0-15
Moisture content (%)	17	41.1	20.2	21.3		15
LL (%)	40	23	35	36	34	41.5
PL (%)	23	14	23	22	20	24
PI (%)	17	9	12	14	14	17.5
%FINES (silt and clay	33.13	48.07	38.93	49	28.32	36.73
D_{50}	0.39	0.5	0.11	0.08	0.23	0.3
USCS	CI	CL	CI	CL	CL	CL-MH
Cohesion	48	14	54	34		64
Ø (˚)	5	3	3	4		4
Cv(m^2/yr)			35.88	41.12		52.8
Cohesion	48	14	54	34		64
Mv(m^2/MN)			0.34	0.175		0.25
q_d=(KN/m^2)	387.15	169.54	636.08	299.8		667.94
q_a=(KN/m^2)	129.05	56.51	212.27	99.83		222.65

Wn- Natural moisture content(%) LL – Liquid limit (%) PL – Plastic limit (%) PI – Plasticity index (%) Cu – Cohesion KN/m^3 Ø-Frictional angle, Cv=Coefficient of consolidation(m2/yr) SPT Standard penetration test (N-value)qa-ultimate bearing capacity (kN/m^2)IL-Liquidity index (%) Mv - Coefficient of volume compressibility (m^2/MN) USCS- Unified soil classification scheme

Figure 4

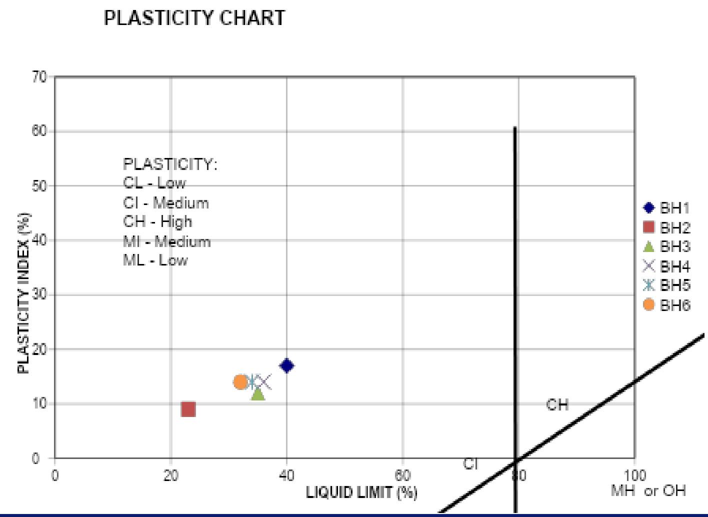


Figure 4 Cassagrande Plasticity Chart of Clayey Silty Sand Layer

Figure 5

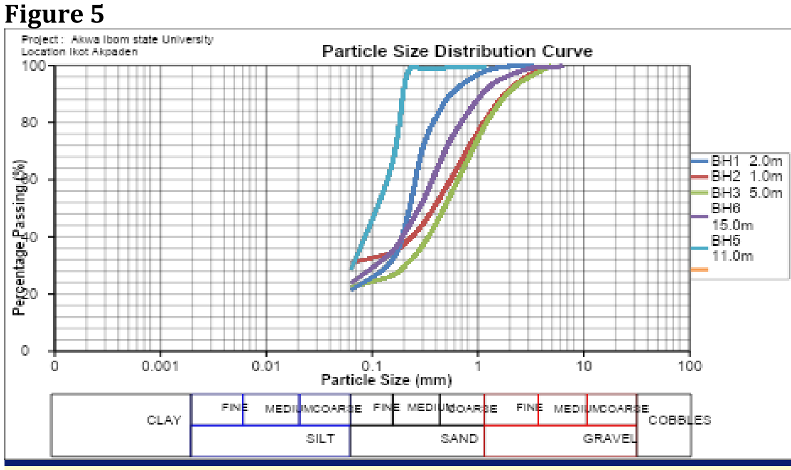


Figure 5 Particle Size Distribution Curve of Clayey Silty Sand Layer

Figure 6

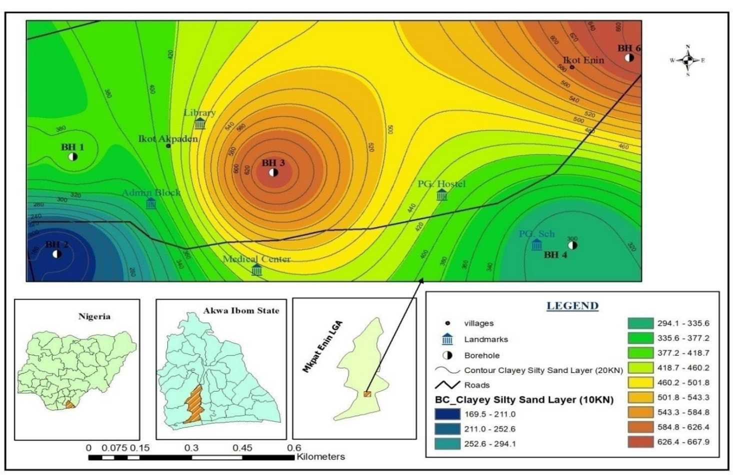


Figure 6 Bearing Capacity Map of Clayey Silty Sand Layer

9. ENGINEERING PROPERTIES OF SANDY SILTY CLAY LAYER

The Sandy silty clay layer which underlies the top layer consists of light to dark grey soft clay with ranges from 2m to 14m in BH1 to BH5. It extends from 2-10m in BH1, 3-10m in BH2, 7-10m in BH3 and 6-14m in BH4. It forms the top layer in BH5 at a depth of 0-10m.This unit is not found in BH6. The engineering characteristics of this layer are displayed in Table 3 which show**s** that the sandy, silty clays which generally have a higher percentage of fines than the top soil are of intermediate plasticity (CI) in BH5 with liquid limit values of 44%, moisture content values of 50.3% and plasticity index values of 18.5%. A high plasticity silt (MH) exists in BH2 and BH4 with plasticity index value of 23% to 29%, liquid limit of 56% to 65% and moisture content value of 22.9% to 73.9%. A very high plasticity silt (MV) exist in BH1 and BH3 with plasticity index value of 24% to 32%, moisture content of 39.3% to 44.9% and liquid limit of 72% to 83% .Similar moisture content and plasticity index values in the Niger delta have been obtained by Ehibor et al. (2019) Ezenwaka et al. (2014) and Ashioba and Udom (2023). The soil in BH5 plots above the A-line in the region of intermediate plasticity clay, while soils in BH1 to BH4 plot below the A-line in the region of high (MH) and very high plasticity silts (MV) on the Casagrande plasticity plot in Figure 8. This implies an intermediate to high compressibility of the soils according to BS5930 (1999) with an intermediate to high swelling potential. The particle size distribution graphs in Figure 9shows a poorly graded fine to medium to coarse grained sand with minimal gravel fractions in and has a mean diameter (D50) ranging from 0.14mm to 0.50mm. The moisture content, liquid limit and plasticity index values are higher than the clayey silty sand layer. Average undrained cohesion and angle of internal friction values are 10KN/m^2 in BH3 to 32KN/m^2 in BH4 and 2˚ in BH3 to 7˚ in BH1. The low cohesion value indicates soft clays. The average values of the coefficient of consolidation (Cv) 8.64m^2/yr in BH2 to 11.55m^2/yr in BH1, while the range values of the coefficient of compressibility (Mv) is between 0.36m^2/MN in BH5 to 0.48m^2/MN in BH1. Bearing capacity analysis of this clay layer using the method of Terzaghi (1943) for Strip footing at various depths gave ultimate bearing capacity values ranging between 269.43kN/m^2 in BH3 to 582.4kN/m^2 in BH4 as shown in Table 3 and on the bearing capacity map in Figure 7. The allowable bearing capacity value ranges from 89.81kN/m^{2}to 194.15kN/m^2.

Table 3

Table 3 Average Values of the Engineering Properties of Sandy Silty Clay

Sample location	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**
Depth	02-Oct	03-Oct	07-Oct	Jun-14	0-10
Moisture content (%)	44.9	73.9	39.3	22.9	50.3
LL(%)	83	56	72	65	44
PL(%)	51	33	48	36	25.5
PI(%)	32	23	24	29	18.5
USCS	MV	MH	MV	MH	CI
% Fines(silt and clay)	86	85.6	35.4	77.8	28.32
D_{50}	0.5	0.32			0.14
LL(%)	83	56	72	65	44
Cohesion	20	17	10	32	25
Ø(˚)	7	3	2	5	5
Cv(m^2/yr)	11.55	8.64			10.26

$M_v(m^2/mn)$	0.48	0.63			0.36
$q_d=(KN/m^2)$	324.44	282.98	269.43	582.4	371.2
$Q_{allow}=(KN/m^2)$	108.15	94.33	89.81	194.15	107.2

Figure 7

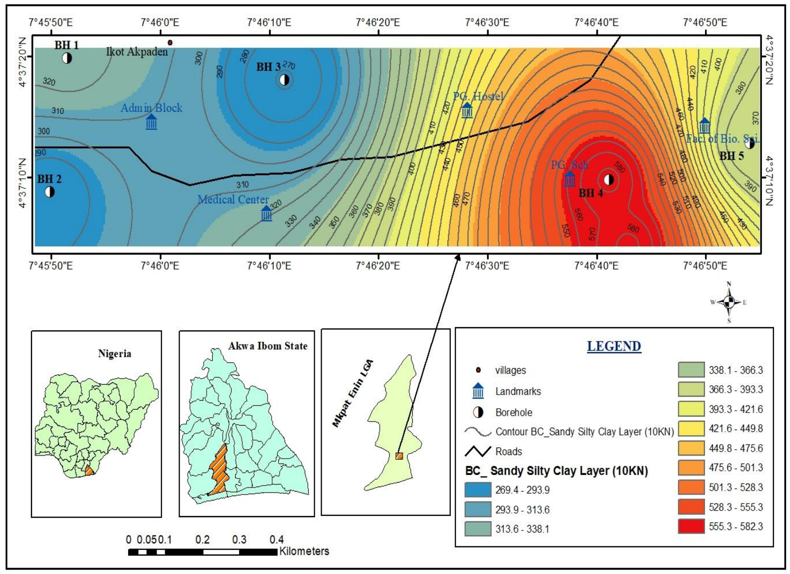


Figure 7 Bearing Capacity Map of Sandy Silty Clay Layer

Figure 8

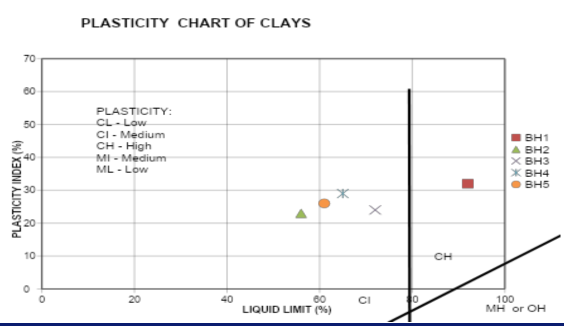


Figure 8 Cassagrande Plasticity Chart of Sandy Silty Clay Layer

Figure 9

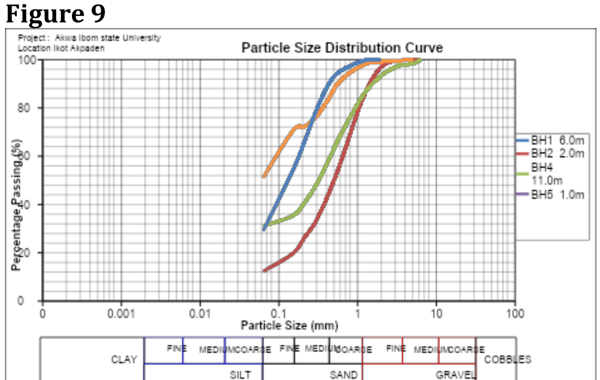


Figure 9 Particle Size Distribution Curve of Sandy Silty Clay Layer

10. SAND LAYER

A sand layer which is the bottom unit ranges from 10m to 15m depth in BH 1 to BH 5. It extends from10 to 15m in BH1, BH2 and BH3, 14-15m in BH 4 and 12-15m in BH5.The sand is absent in BH6 from 0-15m depth. Results for this layer are presented in Table 4. The fine sand fractions have average values ranging from 3% in borehole 3 to 22% in borehole 2, the medium sand fractions range between 37% in borehole 1 to 62% in borehole 4 and 5 and coarse sand fractions range between 24% in borehole 5 to 49% in borehole1. Average percentage of gravel ranges from 4 to 8% in Borehole 1 to 5. The coefficients of uniformity values range from 2.4 in borehole 4 to 2.9 in borehole 2 classifying the sands as poorly graded (SP) according to the unified soil classification system. Thus, the Sands are free draining. Standard penetration test was carried out at a depth of 13m and 15m in borehole 1, 10 m and15m in borehole 2 and 3, 15m in borehole 4 and 12 and 15m in borehole 5. Standard penetration tests gave N-corrected values from 14 to 16 indicative of the medium density of the sand. This horizon constitutes a suitable foundation for medium and large engineering structures. Piles are therefore needed to transfer the weight from the overlying structures to this horizon. Thus, a pile bearing capacity analysis was carried out using the methods of Peck, Peck et al. (1974), Terzaghi (1960) and Berezantsev (1961) at depths of 13m in BH1 and 15m in BH2, BH3 BH4 and BH5. The analysis gave ultimate bearing capacities which range from 7878.12KN/m^2 in BH1 to 11423.36KN/m^2 in BH2 and allowable bearing capacities range from 3151.22KN/m^2 in BH1 to 4569.34KN/m^2 in BH2. These results are shown in Table 5 and on the bearing capacity map in Figure 10. This horizon therefore also constitutes a good termination depth for pile.

Table 4

Table 4 Average Values of the Engineering Properties of Sand

PARAMETERS	BH1	BH2	BH3	BH4	BH5
Depth (m)	Oct-15	Oct-15	Oct-15	14-15	Dec-15
%FINE SAND	3.5	22	5	8	11.5
% MEDIUM SAND	36	47	46	63	62
% COARSE SAND	49	36	45	26	24
% GRAVEL	7.5	8.5	0	3	3.5
D10	0.33	0.28	0.26	0.21	0.19
D50	0.77	0.66	0.57	0.44	0.39
D60	0.98	0.84	0.7	0.5	0.47
CU	2.8	2.9	2.7	2.4	2.5
USCS	SP	SP	SP	SP	SP
SPT N- value	14	15	14	16	13
SPT N1-value	15	16	15	15	14
UNIT WEIGHT	20.4	21	19.7	20.8	20.2

D10=Effective particle size D50=Mean particle size CU=Coefficient of uniformity SPT N1 -Value= Standard Penetration test corrected N- Value

Table 5

Table 5 Pile Bearing Capacity Analysis of Sand Horizon

BOREHOLE NUMBER	DEPTH(M)	QULT(KN/m^2)	QALLOW(KN/m^2)
1	13	7878.12	3151.25
2	15	11423.36	4569.34

3	15	9446.78	3778.71
4	15	9038.26	3615.3
5	15	11201.55	4480.62

Figure 10

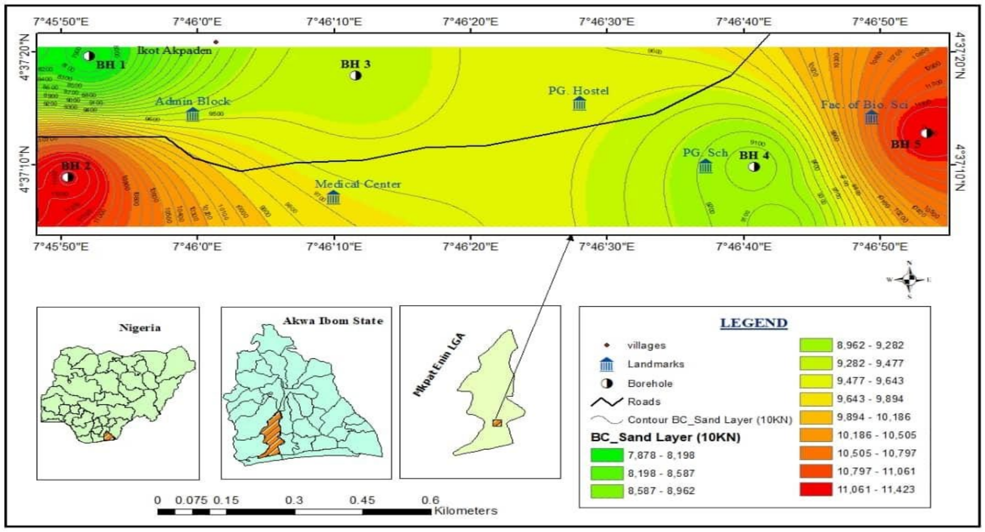


Figure 10 Bearing Capacity Map of Sand Layer

Figure 11

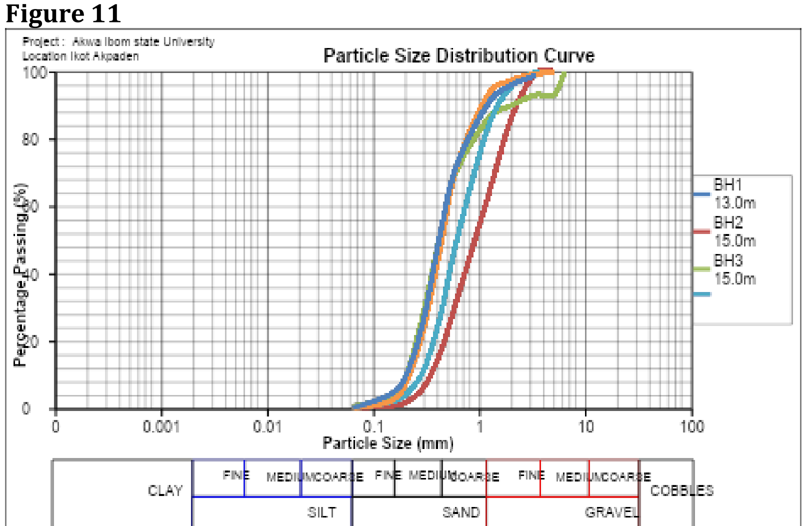


Figure 11 Particle Size Distribution Curve of Sand Layer

11. CONCLUSION

Integrated geophysical and geotechnical investigation was carried out in the main campus to determine their bearing capacity and generate maps for shallow and deep foundation designs. The geophysical investigation revealed four geo-electric layers which are; the top soil, silty clay, sand, and clayey sand. The general subsoil stratification of the main campus is made up of clayey silty sand, sandy silty clay and sand. The ultimate bearing capacities of the clayey silty sand are between

152.65KN/m² and 667.94KN/m² and sandy silty clay between 269.43 KN/m² and 582.4KN/m². The medium dense sands have ultimate and allowable pile bearing capacity ranges from 7878.12KN/m² to 11423.36KN/m² and 3151.22KN/m² to 4569.34KN/m² respectively. Standard penetration tests and pile bearing capacity analysis indicate that the sands are suitable foundation materials for construction. A Pile foundation terminated within the sand substratum is recommended for large structures.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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