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Assessment of Sub-Soil Geotechnical Properties for Foundation Design in Part of Reclaimed Lekki Pennisula, Lagos, Nigeria

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Abstract: Assessment of engineering geologic condition was undertaken in Phase I housing estate in Lekki Pennisula, Lagos, Nigeria with a view to delineating the stratigraphy and estimating the engineering properties of shallow formations for construction purposes particularly in foundation applications. Field techniques such as borings, Standard Penetration Test and Cone Penetration Test were deployed. 2 boreholes were drilled each to termination depth of 30.0m. Samples of strata encountered were subjected to laboratory analysis such as natural moisture content, grain size testing and Atterberrg limits tests. The results showed that the subsurface is underlain essentially by loose to medium dense silty sand (0.0 – 3.0m) with average SPT-N value of 11, friction angle of 32^0, natural water content of 17.0 – 22.0% overlying a soft silty clay (3.0 – 4.50m) with low cohesion value of $24.0KN/m^2$, SPT-N of 4, q_c value of 23, unit weight of $15.50KN/m^3$ and high natural water content of 88 – 92% cum void ratio of 1.14. Beneath these layers is very loose clayed sand (4.50 – 9.0m) having low q_c of 18, SPT-N of 5, angle of internal friction of 30^0. These layers are further underlain by medium – dense sand (9.0 – 30.0m) having (20 – 32) SPT-N values, (0.40 – 0.45) void ratios, (19.50 – $20.50KN/m^2$) unit weight and (32 – 33^0) angle of internal friction which are typical of appreciable foundation material. The poor engineering properties of the soil within the shallow foundation zones preclude the adoption of shallow foundation for the proposed structure. Pile foundation installed to at least at 12.0m within the mechanically stable medium – dense sandy strata is recommended for the proposed structure.

Keywords: *Geotechnical Properties, Pile Safe Working Load, Standard and Cone Penetration Test, Boring, Lekki Pennisula, Lagos Nigeria.*

1. Introduction:

The incessant occurrence of structural failures particularly buildings in Lagos metropolis is a source of concern to government, individuals and professionals within the built environment. Even though the absence of proper pre-construction survey has been mentioned as one of the numerous causes of this ugly incidence, property developers still neglects the incontrovertible fact that the success of any major construction project is dependent on the suitability of the subsurface soil which will withstand loadings from the intended structure. Therefore, the nature of the soil or rocks supporting the structures becomes an important issue for the safety, economy, serviceability, structural integrity, durability, sustainability and low maintenance cost [1]. Sub-soil geotechnical data is an important requirement for proper design and construction of civil engineering structures to prevent structural failures [2, 3, 4, 5, 6, 7]. This is particularly important since Lagos metropolis is underlain by stratified sedimentary deposits with a high degree of lithologic variability [8] making depth to foundation in most locations unresolved. Also, lands hitherto considered unsuitable for engineering applications is now being reclaimed from water bodies for infrastructural development. Such reclaimed lands have been reported to contain certain mechanically unstable geomaterials which may be inimical to the foundation of engineering structures [9, 10, 11]. Geo-engineering investigation can be undertaken using laboratory and field scale procedures. Field scale investigation is often favoured because it provides an objective assessment of geologic materials under insitu condition devoid of human interference that often occur during laboratory testing. Among in-situ testing methods are Standard Penetration Test (SPT) and Cone Penetration Test (CPT) which are employed to identify soil type and stratigraphy along with being a relative measure of strength. SPT is currently the most popular due to its ease of performance and extensive correlation with parameters used in foundation design, it is the prevalent method in evaluating the allowable bearing pressure for foundation design. It is a routine part of almost every soil exploration program [12]. It is used to determine the density of granular strata and correlate the undrained shear strength of cohesive soils. Also, Cone Penetration Test (CPT) is also deployed as a method of field site investigation and replaced the traditional methods such as drilling and sampling due to its fastness, ability for continuous measurements, strong theoretical background, detailed profiling of the subsurface, repeatability and economical behaviour [13]. In this study, SPT and CPT methods complimented by geotechnical laboratory tests were deplored to estimate the insitu conditions of shallow formations viz-a-viz their suitability in engineering applications especially as foundation material. Lekki Pennisula where the study was carried out is within Coastal Swamps and Lagoon environment that characterized Lagos metropolis with possible accumulation of soils with undesirable engineering properties. The area is being rapidly developed necessitating the need to provide geotechnical database for infrastructural development.

1.1. The Study Area:

The focus area of this research is Ladipo Omotosho axis of Lekki Phase I Housing Estate, Lekki Pennisula, Lagos, Nigeria. It is a naturally formed Pennisula located in the eastern part of Lagos, flank in the west by Victoria Island and Ikoyi districts, in the south by Atlantic Ocean, north by Lagos lagoon and east by Lekki lagoon. The site is designated for the construction of residential buildings. The area is located on coordinates $6^0 29' 36"$N/$3^0 43' 14"$E and 6.493394^0N/3.720668^0E. The drainage is channeled into the lagoon. Geologically, it falls extensively within the Eastern Dahomey Basin (fig. 1). The Basin is a combination of inland/coastal/offshore sedimentary basin in the Gulf of Guinea [14]. The lithology based stratigraphic classification of Dahomey basin by Jones and Hockey [15] is suitable for this study since lithology is a key parameter controlling the suitability of materials for engineering purposes. Stratigraphically, the basin is divided into Abeokuta Formation, Ilaro Formation, Coastal Plain Sands and Recent Alluvium sediments [16]. Deposition of Cretaceous sequence in the eastern Dahomey Basin began with the Abeokuta Group, consisting of the Ise, Afowo and Araromi Formations [17]. The Ise Formation, the oldest, unconformably overlies the basement complex and consists of conglomerates and sandstones at base and in turn overlain by coarse to medium grained sands with interbedded kaolinite. Overlying the Ise Formation is the Afowo Formation, which is composed of coarse to medium grained sandstones with variable but thick interbedded shales, siltstones and claystone. The Araromi Formation overlies the Afowo Formation and is the youngest Cretaceous sediment in the basin [17]. It is composed of fine to medium grained sandstone overlain by shales, siltstone with interbedded limestone, marl and lignite. The Ewekoro Formation, an extensive limestone body, overlies the Araromi Formation. The Ewekoro Formation is overlain by the Akinbo Formation, which is made up of shale and clayey sequence. Overlying the Akinbo Formation is Oshosun Formation which consists of greenish – grey or beige clay and shale with interbeds of sandstones. The Ilaro Formation overlies conformably the Oshosun Formation and consists of massive, yellowish, poorly, consolidated, cross-bedded sandstones. The Quaternary sequence in the eastern Dahomey basin is the Coastal Plain Sands and recent littoral Alluvium [18] and consists of poorly sorted sands, silts and clay deposits with traces of peat in parts. The sands are in parts crossbedded and show transitional to continental characteristics. The age is from Oligocene to Recent. It directly underlies the study area and is composed of deposits which can be divided into the littoral and lagoonal sediments of the coastal belt and the alluvial sediments of the major rivers. They consist predominantly of unconsolidated sands, clays and mud with a varying proportion of vegetative matter. The Coastal Plain Sands and recent littoral Alluvium serve as foundation of engineering structure within the study area.

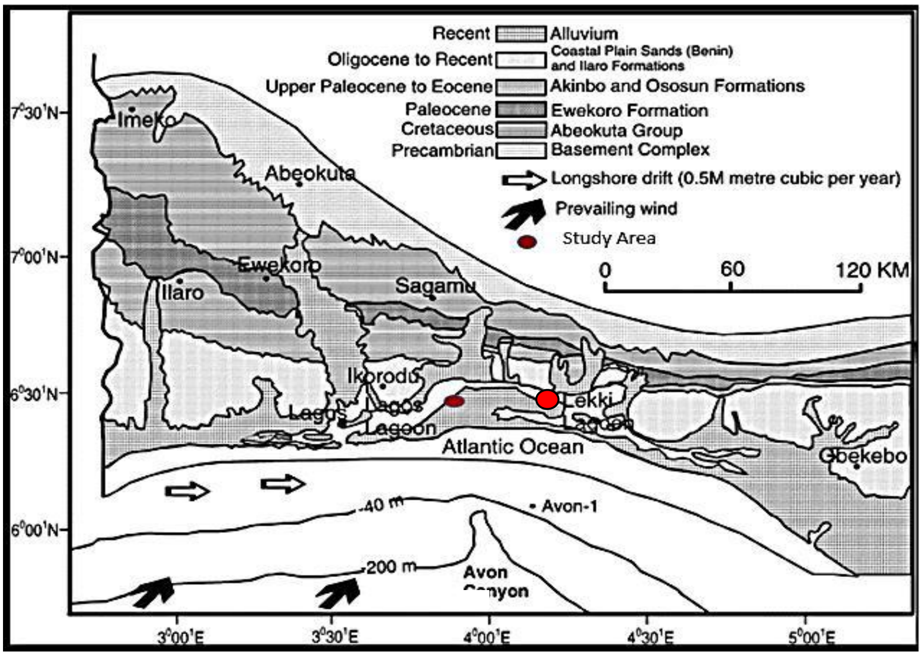

Figure 1: Location and geology of the study area modified after [11]

2.0 Materials and Methods:

2.1 Boring &Standard Penetration Testing (SPT):

Two boreholes were drilled to depth 30.0m each with 250mm, 200mm and 150mm diameter steel casings using a Percussion motorized Shell and Auger rig employing light cable percussion boring techniques with a fully equipped motorized Pilcon Wayfarer drilling rig. The position of borehole 1 and 2 coincide with that of CPT P_2 and P_5 respectively. CPT P_1 to P_2 is approximately 50.0m apart on a straight line such that the distance between CPT P_1 and P_7 is 240.0m. During drilling operations, disturbed soil samples were regularly taken at depth interval of 0.75m and whenever a change of stratum is observed. All samples comprise those from the split spoon of standard penetration test and those of the cutting shoe of 100mm diameter sampler. All samples recovered from the borehole were examined, identified and classified in the field. They were later taken to the laboratory for detailed investigations where a total of 12 and 4 samples were subjected to grain size distribution test by wet sieving and Atterberg limit tests respectively. Effort was made to ensure that all strata encountered were tested appropriately. Standard Penetration Test (SPT) was also carried out at 1.5m intervals in both cohesive and cohesion less soils with disturbed samples recovered from the SPT sampling tool. In carrying out the SPT test, a 50mm diameter split spoon sampler is driven into the soil using a 63.5kg hammer with a 760mm drop, and the penetration resistance is expressed as the number of blows (SPT-N-value) required obtaining a 300mm penetration below an initial 150mm penetration seating drive. The SPT-N-values were corrected for borehole and dilatancy where necessary and all pertinent borehole data, penetration resistance, and sample data were recorded on the boring log sheet (figures 2 – 3). In boreholes, SPT results are routinely used to provide an estimate of density, consistency, unconfined compressive strength and shear strength parameters.

2.2 Cone Penetration Testing (CPT):

Cone penetration testing can be utilized for a wide range of geotechnical engineering applications. The Cone Penetration Test is a means of ascertaining the resistance of the soil. Seven CPT tests were carried out to a depth approximately 6.0m. The tests were performed using a 2.5-Ton nominal capacity manually powered CPT machine. Penetration resistance (qc) and the depth of penetration were recorded at each station (table 1). Most of the test reached refusal before the anchors pulled out of the subsurface. The layer sequences were interpreted from the variation of the values of the cone resistance with depth. On the basis of the expected resistance contrast between the various layers, inflection points of the penetrometer curves were interpreted as the interface between the different lithologies or density variation. The cone penetration test is economical and supplies continuous records with depth.

2.3 Classification Tests:

A series of classification tests were carried out on the samples in strict compliance with relevant geotechnical engineering standards including British standards [19, 20, 21, 22] Laboratory classification tests were conducted on a number of soil samples to verify and improve on the field identification. These tests include natural moisture content, unit weights, Atterberg limits (liquid and plastic) and grain size distribution.

3.0 Analysis:

The poisson ratio and modulus of elasticity were evaluated from the method of [23]. The angle of internal friction was estimated from penetration tests based on [24, 23, 25] methods.

Plasticity Index (PI) = LL – PL, where LL = liquid limit, PL = plastic limit

Liquidity Index (LI) = $\frac{w - PL}{PI}$

Where w = Natural water content, PL = plastic limit, PI = plasticity index.

Using the equation of ultimate bearing capacity for a driven pile;

$Q_f = q_f \times A_b + f_s \times A_s$ where

Q_f = ultimate load that can be applied at the top of the pile,

q_f = ultimate bearing capacity of the stratum on which the pile is supported,

f_s = the average shearing resistance of soil per unit area,

A_b = area of the pile at the base,

A_s = cylindrical surface area of the pile.

SPT-N method was employed using [26] equation for driven pile;

$q_f = 40 \times N \times \frac{D}{B}$ (limited by 400N) ……………..(i)

$f_s = 2N_a$ where

N is the SPT-N at the vicinity of the base of the pile,

N_a is the average SPT-N value over the embedded depth of the pile.

Since the above equation is applicable for driven piles, the value of q_f obtained was further multiplied by 0.33 while that of f_s was multiplied by 0.5 to derived corresponding values for bored piles.

Allowable bearing capacity:

$q_a = q_u/F.S$ ………………………………………(ii)

where F.S. is factor of safety = 2.5.

4.0 Results:

4.1. Lithologic Log & Standard Penetration Test:

The result of boring and Standard Penetration Test is as presented in borehole logs in figs. 2 and 3. Five geotechnical and lithologic layers were delineated from ground surface to about 30.0 m depth. These comprise essentially of silty sand, organic clay, clayed sand and sandy deposits which are characteristics of swamp and creek environments. The first layer is made up of loose to medium dense silty sand (0.0 – 3.0m) with an average SPT-N value of 11 (fig. 2) which can only withstand low foundation pressure. The second layer consist of soft dark grey organic silty clay (3.0 – 4.50m) with an average SPT-N of 3 rendering it unsuitable as foundation material. The relative sensitivity of the second layer portends danger to any structure sited on the first layer due to its tendency to settle appreciably under imposed load. The third layer consist of very loose dark grey clayed silty sand (4.50 – 9.0m) with average SPT-N value of 4 pointing to its poor engineering properties since it is probable to high initial settlement under load due to the looseness of it grains. The fourth layer composes of medium dense sand (9.0 – 20.0m) with an appreciable average SPT-N value of 20 typical of material that can withstand moderately high foundation pressure. Beneath these is a layer of dense sand having appreciable average SPT-N value of 31 typifying a material capable of mobilizing significant foundation pressure. It is noteworthy to mention that the last two highly resistive layers are the most competent as foundation material under heavy loadings.

4.2. Cone Penetration Test:

The result of cone penetration test is shown in table 1. It indicates that that the subsurface soil has resistance range of 2 – 172kg/m^2. It is observed that at depths 0.0 – 1.25m, the soil exhibit low resistance < 50kg/m^2 (table 1) which is typical of very low foundation material. However, an increase in resistance from 44 – 75kg/m^2 was observed at depths approximately 1.25 – 2.0m, followed by an erratic increase and decrease in resistance from 14 – 76kg/m^2 upto depth approximately 8.0m pinpointing the heterogeneous nature of the subsurface material and their relative instability as foundation soil. P_6 exhibit low resistance upto depth 9.0m. It is important to mention that the subsurface soil upto that depth consists of poor engineering material. Gradual increase in resistance at depth 9.25 – 12.0m from 52kg/m^2 in P_6 to 172kg/m^2 in P_7 respectively is an indication of relatively competent and mechanically stable layer capable of mobilizing appreciable foundation pressure under loading.

4.3. Classification Tests:

The results of grain size analysis and Atterberg consistency tests is shown in tables 2 and 3. Analysis of the result showed that the samples of cohesion less soil at different depths have (0.09 – 0.20) $d_{10,}$ (0.15 – 0.30) d_{30}, (0.27 – 0.44) d_{60}, (1.9 – 4.30) C_u and (0.75 – 1.20) C_c. The soil are generally classified as poorly graded sand since their coefficient of uniformity (C_c) <6 [27, 28]. Also, the soft clay at the second layer (88 – 92%) natural water content is high pointing to its undesirable engineering properties as well as excessively high compressibility potential which render them technically unsuitable as foundation materials. The plasticity index (table 3) which ranges from 48 - 52% is close to 55% limit set by [29] for materials with high compressibility potentials and are therefore classified as poor engineering material. In addition, the liquidity index range of 1.33 – 1.46 is quite high since it is > 1 typifying a sensitive clay staratum which is prone to liquefaction under sudden load.

Table 1: Cone penetration test data

	Cone Readings(kg/cm^2)						
Depth(m)	P_1	P_2	P_3	P_4	P_5	P_6	P_7
0.25	4	4	3	2	2	4	6
0.50	5	8	10	7	5	6	6
0.75	8	10	12	10	8	8	10
1.00	30	24	20	18	22	12	20
1.25	44	40	30	34	36	22	36
1.50	66	54	44	46	54	36	44
1.75	72	66	54	50	68	40	54
2.00	75	70	66	58	74	46	64
2.25	56	50	46	40	48	32	66
2.50	46	42	40	36	36	26	50
2.75	30	24	22	26	28	22	42
3.00	35	30	28	28	32	24	44
3.25	32	28	22	25	28	24	30
3.50	24	26	20	20	20	22	26
3.75	20	18	18	16	20	20	26
4.00	20	15	14	14	21	16	20
4.25	20	14	14	14	21	16	20
4.50	15	20	16	14	16	16	20
4.75	15	18	14	14	17	18	16

5.00	16	15	14	14	16	16	16
5.25	15	17	15	16	16	18	16
5.50	12	15	14	14	14	16	15
5.75	11	10	12	14	12	14	15
6.00	15	15	14	16	14	14	12
6.25	12	14	14	14	12	14	15
6.50	15	14	14	14	14	14	15
6.75	15	20	16	18	14	16	15
7.00	14	16	14	14	16	14	22
7.25	20	16	18	16	22	16	15
7.50	24	15	15	16	22	14	15
7.75	50	16	16	24	38	18	15
8.00	55	20	22	28	46	22	22
8.25	60	40	36	32	52	28	32
8.50	65	50	46	38	56	32	42
8.75	76	56	48	44	66	38	50
9.00	80	60	55	56	78	48	54
9.25	86	64	60	62	80	52	60
9.50	104	74	68	66	82	58	66
9.75	116	90	78	72	88	62	82
10.00	120	100	90	86	94	68	90
10.25	126	106	98	90	102	78	94
10.50	144	120	110	98	140	86	102
10.75	166	130	124	102	144	94	116
11.00	-	140	135	126	148	106	132
11.25	-	150	140	136	150	112	144
11.50	-	160	-	140	-	122	150
11.75	-	-	-	156	-	-	154
12.00	-	-	-	-	-	-	172

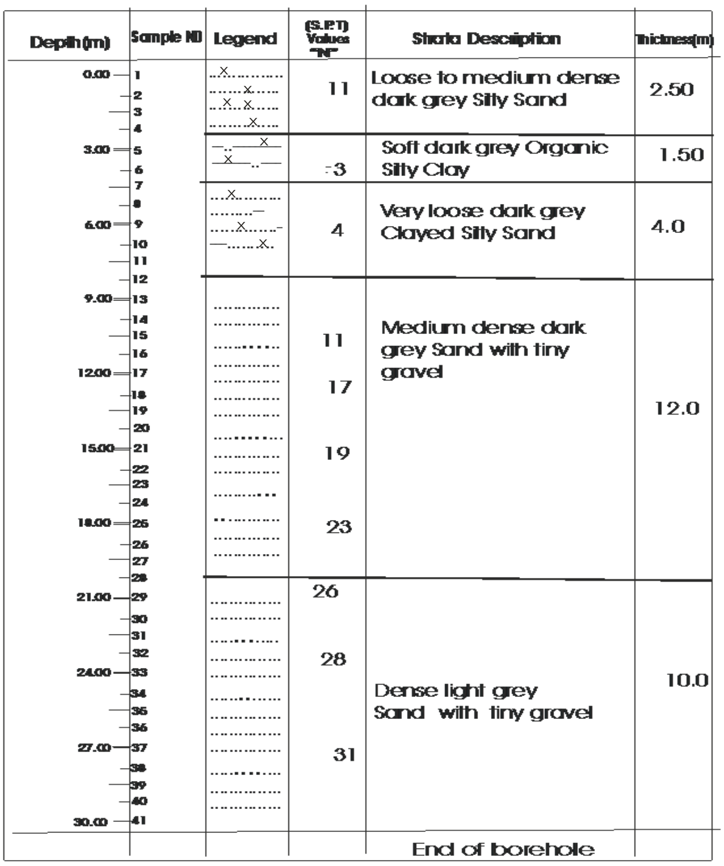

Figure 2: Log of borehole 1

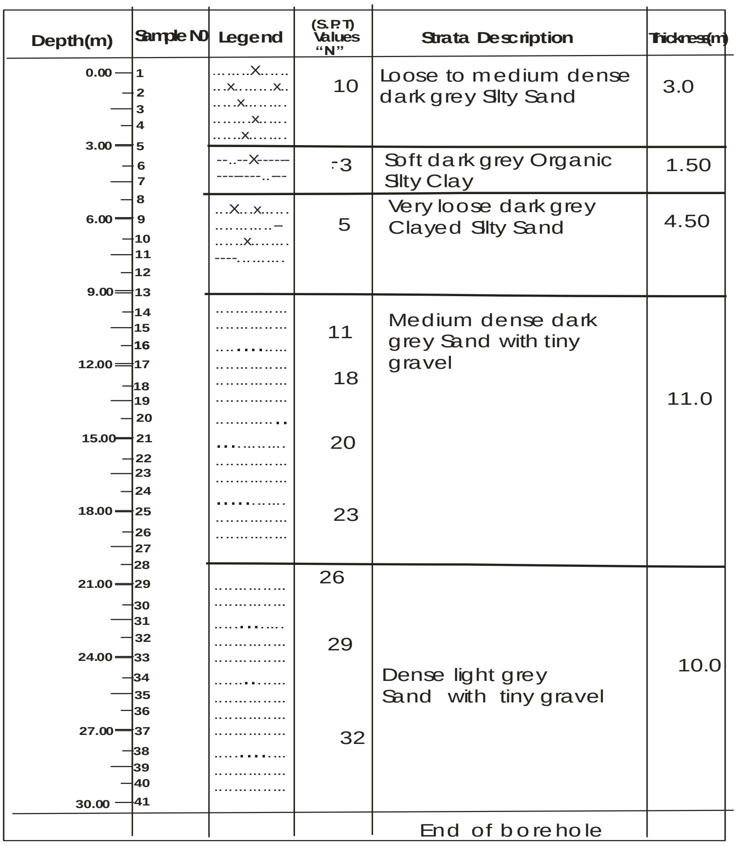

Figure. 3: Log of borehole 2

Table 2: Grain size distribution results parameters

Serial No	Sample Designation	Depth (m)	Effective size (d_{10})	Effective size (d_{30})	Effective size (d_{60})	Coefficient of Uniformity (C_u)	Coefficient of Curvature (C_c)	Remark
1	Lek 1	0.75	0.09	0.16	0.27	3.0	1.05	SP
2	Lek 2	1.00	0.07	0.15	0.30	4.3	1.07	SP
3	Lek 3	1.50	0.10	0.15	0.30	3.0	0.75	SP
4	Lek 4	4.50	0.16	0.26	0.40	2.5	1.06	SP
5	Lek 5	6.00	0.18	0.30	0.42	2.3	1.20	SP
6	Lek 6	15.00	0.19	0.26	0.37	1.9	0.98	SP
7	Lek 7	16.50	0.20	0.25	0.40	2.0	0.78	SP
8	Lek 8	18.00	0.20	0.28	0.40	2.0	0.98	SP
9	Lek 9	21.00	0.20	0.28	0.40	2.0	0.98	SP
10	Lek 10	24.75	0.18	0.28	0.42	2.3	1.04	SP
11	Lek 11	26.00	0.20	0.30	0.40	2.0	1.13	SP
12	Lek 12	29.00	0.20	0.28	0.44	2.2	0.89	SP

Table 3: Atterberg Limit Test Results

S/N	Sample No	Depth (m)	Natural Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Liquidity Index (%)
1	Lek 13	2.50	90	70	22	48	1.41
2	Lek 14	3.00	89	72	20	52	1.33
3	Lek 15	3.50	92	68	19	50	1.46
4	Lek 16	4.00	88	70	20	50	1.36

Table 4: Summary of Engineering Properties

Stratum Depth Range(m)	Thickness(m	Geotechnical Engineering Parameters								
		Type of Soil	Average CPT Value (kg/cm^2)	Average SPT Value	Void Ratio	Cohesion (kN/m^2)	Unit Weight(kN/m^3)	Angle of Internal Friction(^{0})	Estimated modu Elasticity(kN/m^2)	Poisson Ratio
0.0 – 3.0	3.0	Loose to medium dense silty sand	45	11	0.50	-	18.50	32	11,023	0.30
3.0 – 4.50	1.50	Soft silty clay	23	4	1.14	24.0	15.50	28	4,412	0.50
4.50 – 9.0	4.50	Very loose clayed sand	18	5	0.55	-	18.50	30	3,922	0.30
9.0 – 20.0	11.0	Medium dense sand	>90	20	0.45	-	19.50	33	22,064	0.30
20.0 – 30.0	10.0	Dense sand	-	31	0.40	-	20.50	34	29,419	0.30

Table 5: Pile Safe Working Load

Pile Type		Driven Pile		Bored Pile	
Diameter (mm)	Founding Depth (m)	Ultimate Pile Capacity (KN)	Safe Working Load (KN)	Ultimate Pile Capacity (KN)	Safe Working Load (KN)
300	12.0	709	284	475	190
400	12.0	1158	463	793	317
500	12.0	1712	685	1190	476
600	12.0	2377	951	1477	591

5. Discussion:

The summary of geotechnical engineering parameters estimated from the field and laboratory data is as shown in table 4. The borehole logs (fig. 2 and 3) indicate occurrence of five geotechnical strata from ground surface to about 30.0 m depth. The uppermost layer of silty sand (0.0 – 3.0m) with an angle of internal friction of 31^0, q_c of 45kg/m^2 and SPT-N value of 11 is considered a moderate foundation material. The second layer of soft silty clay (3.0 – 4.50m) with low cohesion value of 24.0KN/m^2, SPT-N of 4, q_c value of 23, unit weight of 15.50KN/m^3 and high natural water content of 88 – 92% as well as void ratio of 1.14 is undesirable in engineering construction particularly in foundation applications. It is pertinent to mention that the presence of the highly sensitive soft clay layer beneath the upper silty sandy stratum render it technically unsuitable as foundation material since even a thin sensitive clay layer can lead to amplification in compressibility and reduction in the strength of an otherwise good material [30]. Therefore, the two upper layers are considered unsuitable for foundation construction. The third layer of very loose clayed sandy layer (4.50 – 9.0m) with low friction angle of 30^0, q_c of 23 and SPT-N of 4 is also incompetent as foundation material. The fourth layer of medium dense sand (9.0 – 20.0m) with friction angle of 33^0, q_c >90, SPT-N of 20 and low void ratio of 0.45 will mobilize appreciable foundation pressure under imposed load. Furthermore, the fifth layer of dense sand (20.0 – 30.0m) is highly resistive with relatively high average friction angle of 34^0, average SPT-N value of 31 and low void ratio of 0.40 is considered the most competent foundation layer and will mobilize the highest pressure under load. The relatively resistive sandy deposits encountered at depth beyond 20.0m with an average SPT-N value of 31 is comparable to the sandy deposits reported as occurring from 35.0 – 60.0m in several parts of Southwest Lagos by [31, 32, 33, 34, 11] as medium coarse grained in texture, characterized by SPT-N values of 25 to 50 indicating its competence as foundation soils. For engineering consideration, the medium – dense sandy layers encountered at depths 9.0 – 30.0m should be concentrated on for founding of foundation of structures in the area, this is consistent with [30] which established the present of mechanically stable layer at depth of 16.0m in Ikoyi district in the western part of the study area.

6. Conclusions

Boring and penetration tests test have revealed that the study area is underlain predominantly by superficial heterogeneous deposits of loose – medium dense silty sand, soft clay, very loose clayed sand and medium – dense sand constituting five geotechnical layers delineated. The first three layers are highly compressible or loose and are regarded as poor engineering material that is incompetent in withstanding load from higher loading structures while the two lower layers of medium – dense sandy deposits is considered suitable pilling layers. It is important to mention that both Standard and Cone Penetration Tests revealed that the soil at depths from the ground surface to approximately 9.0m within the study area is heterogeneous in nature and exhibit low resistance typical of poor foundation material. Also, the high q_c value range of 172kg/cm^2 and average SPT-N value of 20 at depth 12.0m is considered appropriate for foundation of heavy structure. The good correlation between Standard and Cone Penetration Tests is indicative of the near accuracy of both methods in characterizing the shallow subsurface for geo-engineering applications. Therefore, deep foundation in form of Piles installed within the medium dense sandy layer at assumed depth of 12.0m (table 5) could mobilize anticipated safe working loads of 284.0kN – 951.0kN and 190.0kN – 591.0kN under driven and bored piles respectively at assumed diameters of 300.0 – 600.0mm. If the loading requirements of structures to be sited in the area are above these values, piles of higher diameters and depths should be considered based on the geotechnical parameters presented in this work.

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References:

[1] O.E. Faseki, O.A. Olatinpo and O.B. Taiwo, “Ground Investigation of an Engineering Site at Point Road, Apapa, Lagos, Nigeria”, Journal of Engineering and Energy Research, vol 6. No 1., pp 1 – 20., 2016.

[2] M.A. Olorunniwo, S. Malomo and O. Ogunsanwo, “Engineering Geological Mapping in Terrains of Tropical Weathering: An Example from Abuja, Nigeria”, Engineering geology, vol 19, pp 133-148., 1983.

[3] A.N. Amadi, C.J. Eze, C.O. Igwe, I.A. Okunlola and N.O. Okoye, “Architect’s and geologist’s view on the causes of building failures in Nigeria”, Modern Applied Science, vol 6. no 6., pp 31 – 38., 2012.

[4] P.O. Youdeowei and H.O. Nwankwoala, “Suitability of soils as bearing media at a freshwater swamp terrain in the Niger Delta”, Journal of Geology and Mining Research, vol 5, no 3., pp 58 – 64., 2013.

[5] S.A. Ngah and H.O. Nwankwoala, “Evaluation of Geotechnical Properties of the Sub-soil for Shallow Foundation Design in Onne, Rivers State, Nigeria”, The Journal of Engineering and Science, vol 2, no 11., pp 8 – 16., 2013.

[6] K.F. Oyedele, L. Adeoti, S. Oladele and A. Kamil, “Investigation of a Proposed Four

Storey Building Sites using Geophysical and Laboratory Engineering Testing Methods in Lagos, Nigeria", International Journal of Scientific Research in Knowledge, vol 2, no 2., pp 83-91., 2014.

[7] A.E. Oghenero, E.G. Akpokodje and A.C. Tse, "Geotechnical Properties of Subsurface Soils in Warri, Western Niger Delta, Nigeria", Journal of Earth Sciences and Geotechnical Engineering, vol 4, no 1., pp 89 – 102., 2014.

[8] M.O. Onwuka, "Ground water resources of Lagos", M.Sc. dissertation, Department of Geology, Universiy of Ibadan, 144 p., 1990.

[9] A.A. Adepelumi and M.O. Olorunfemi, "Engineering geological and geophysical investigation of the reclaimed Lekki, Peninsula, Lagos, Southwest Nigeria", Bulletin of Engineering Geology and the Environment, vol 58, pp 125-132., 2000.

[10] E.A. Ayolabi, I.J.E. Enoh and A.F. Folorunsho, "Engineering site characterisation using 2-D and 3-D tomography", Earth Science Research, vol 2, pp 133-142., 2012.

[11] O.O. Adewoyin, E.O. Joshua and M.L. Akinyemi, "Geophysical and Geotechnical Characterization of a Reclaimed Land For Construction Purposes in Lagos Nigeria: A Case Study", Sci.Int.(Lahore), vol 28, no 2., pp 945-950., 2016.

[12] H.T. Durgunoglu, and E. Togrol, "Penetration Testing in Turkey: State of the Art Report", In: Proceedings of the 1st International Symposium on Penetration Testing, Stockholm, 137., 1974.

[13] P.K. Robertson, Guide to In-Situ Testing, Gregg Drilling and Testing, Inc, 2006.

[14] N.G. Obaje, "Geology and Mineral resources of Nigeria", Lecture Notes in Earth Sciences, pp 96- 103., 2009.

[15] M.E. Brownfield and R.R. Charpentier, Geology and total petroleum systems of the West Central Coastal Province , W/Africa, U.S. Geological Survey Bulletin, 2207, 52p., 2006.

[16] H.A. Jones and R.D. Hockey, "The geology of part of Southwestern Nigeria", Geological Survey of Nigeria Bull, 1964.

[17] M.E. Omatsola and O.S. Adegoke, "Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin", Journal of Mining Geology, vol 18, no 1, pp 130-137., 1981.

[18] A.B. Durotoye, Quaternary sediments in Nigeria, Geology of Nigeria, Elizabeth Press, Lagos, 1975.

[19] BS1377, Method of test for soils for civil engineering purposes, British Standards Institution, London, pp 8 – 200., 1990.

[20] B. Vickers, Laboratory Work in Soil Mechanics, 2nd Edition, 1978.

[21] M. J. Tomlinson, Foundation Design and Construction, 6th Edition, Longman, 536 p., 1999.

[22] V.N.S. Murthy, Soil Mechanics and Foundation Engineering, Dhanpart Rah and Sons, India, 763 p., 1984.

[23] J.E. Bowles, Foundation Analysis and Design, 5th Edition, McGraw-Hill, USA, 1997.

[24] [24] G. Sanglerat, The penetrometer and soil exploration, Elsevier, Amsterdam, 1972.

[25] G.G. Meyerhof, "Shallow foundations", Journal of the Soil Mechanics and Foundations Division, ASCE, vol 91, no 2., pp 21-31., 1965.

[26] G.G. Meyerhof, "Bearing capacity and settlement of pile foundation", J.of the Geotechnical Engineering division, ASCE, vol 102, pp 196 – 228., 1976.

[27] A.A. Wagner, "The use of the Unified Soil Classification System by the Bureau of Reclamation", Proc. Fourth Intern. Conf. Soil Mech. Found. Engs. 1, London, 1957.

[28] A.W. Casagrande, "Classification and Identification soils", Trans ASCE, vol 113, pp 901-903., 1959.

[29] R.D. Holtz and W.D. Cubbs, Introduction to geotechnical engineering properties of soil, Prentice-Hall, Inc. Eagle wood cliffs, New Jersey, 1956.

[30] K.F. Oyedele, S. Oladele, and O. Adedoyin, "Application of Geophysical and Geotechnical Methods to Site Characterization for Construction Purposes at Ikoyi, Lagos, Nigeria", Journal of Earth Sciences and Geotechnical Engineering, vol 1, no 1, PP 87-100., 2011.

[31] L.A. Ajayi, "Geotechnical Properties of a deep organic clay stratum underlying Lagos area of Nigeria", Proceedings: 7th Regional Conference for Africa on Soil Mechanics and Foundation Enginnering, Accra, PP 75, 82., 1980.

[32] L.A. Ajayi, R.J.Epps, P. Farrington and A.D. Robinson, "Deposition and engineering properties of sediments in the Lagos area and their influence on recent developments", Quarterly Journal of Engineering Geology, London, vol 16, PP 231, 239., 1983.

[33] B.M. Salami and E.A. Meshida, "Stratigraphic Influence on Some Engineering Properties of Foundation Soils in Parts of South West of Lagos Metropolis", Global Journal of Geological Sciences, Calabar, vol 4 no 2., PP 65, 71., 2006.

[34] B.M. Salami, D.E. Falebita, J.O. Fatoba and M.O. Ajala, "Integrated Geophysical and Geotechnical Investigation of a Bridge Site - A Case Study of a Swamp/Creek Environment in South East Lagos, Nigeria, Ife Journal of Science, vol 14, no 1., PP 75 – 82., 2012.