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GEOLOGIC AND GEOTECHNICAL INVESTIGATION FOR ENGINEERING DESIGN OF FOUNDATION SYSTEMS AT THE FEDERAL UNIVERSITY, OTUOKE, BAYELSA STATE, NIGERIA

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ABSTRACT

This study aims at assessing the sub-soil condition for design of foundation systems at the Federal University, Otuoke, Bayelsa State, Nigeria. A total of eighteen (18) soil borings employing the standard penetration testing (SPT) each to a depth of 30.0m and twenty nine (29) shallow borings (3.00 m deep) were made at pre-selected positions across the entire area of the Federal University, Otuoke, Bayelsa State. On the basis of field investigations and laboratory testing carried out on the soil samples obtained from the project site, it is observed that five (5) identifiable soil horizons are present and this are namely: Brownish clayey layer (CL) - [top soil], greyish organic silty clays (OL), greyish clayey silty sands (SM) and (SC-SM), yellowish to whitish silty sands (SM) and well-graded sands and gravels (SW). The obtained value for the bearing capacity for continuous strip footings to be used at the Project Site is about 153.35 + 1.483B [kPa] where B = width of the structure to be built. For a B = 5.00 meters, the bearing capacity was been found to be 160.76 kPa. The recommended depth of emplacement of continuous strip footings is 0.75 meters. This value represents the bearing capacity of the upper bearing lateritic clays and silty-clays at the project site. The range of values obtained for the bearing capacity for raft footings at the project site, based on the conventional SPT Method is between 76.55 and 208.86 kPa with an average of 122.85 kPa. The recommended depth of emplacement of raft footings is 1.50 meters. This value represents the bearing capacity of the upper bearing lateritic clays and silty-clays at the project site. Since the buildings at the University Campus may subjected to live loads from the movements of different numbers of students in a continuously day-to-day fashion over the years, the potentials of the silty soils becoming liquefied as a result of human traffic-induced vibration was also assessed during this study, since this is a permanent structure for ages to come. Soil dynamics analysis carried out indicate that there will be no possibility of Soil Liquefaction at the site as a result of vibration from the Gas Plant. This was found not to be possible even though the groundwater table was found near the ground surface because of the absence of totally silty soils beneath the ground surface.

KEYWORDS: *Subsoil, bearing capacity, settlement, foundation, sensitivity analysis, Otuoke, Bayelsa State.*

INTRODUCTION

The geotechnical evaluation of subsoil condition of a site is necessary in generating relevant data inputs for the design and construction of foundations for proposed structures (Oke & Amadi, 2008; Oke *et al*., 2009). Sub-soil geotechnical data are required for proper design and construction of civil engineering structures to prevent adverse environmental impact or structural failure/prevention of post construction problems (Amadi *et al*., 2012; Ngah & Nwankwoala, 2013; Oghenero *et al*, 2014). This is very important in view of the rapid urbanization, resulting in extensive infrastructural development. Geotechnical information are useful in ensuring that the effects of projects on the environment and natural resources are properly evaluated and mitigated where necessary.

The study site at the Federal University, Otuoke, Bayelsa State is situated approximately between Latitudes 04^{0} $47^{'}$ $27.91^{''}$North and 04^{0} $47^{'}$ $44.37^{''}$North of the Equator and Longitudes 006^{o} $19^{'}$ $19.4^{''}$ and 006^{o} $19^{'}$ $52.12^{''}$ East of the Greenwich Meridian. The Satellite Positions of the locations of the borings is as shown in (Fig.1). An aerial view of the main campus of the Federal University Otuoke is shown via satellite imageries. The general topography of the site is low-lying, relatively flat lying terrain and situated in an undeveloped area of Otuoke community in Ogbia Local Government Area of Bayelsa State. The vegetation around the general area consisted mostly of primary vegetation of tall trees underlain by an undergrowth of shrubs, grasses and other forms of secondary vegetal growths in places where the primary forest have been cleared for farming.

The study area falls within the Dahomey basin. The site sits astride the Benin Formation, which is often called the Coastal Plain Sands (Qp) of the lower Quaternary (Pliocene-Pleistocene) and Alluvium of upper Quaternary (Recent sediments) and consists of sands and gravels. The geological map of the area is as shown in Fig.2. It is within the Niger Delta region, which is made up of thick clastic sedimentary sequence with age ranging from Eocene to Recent. It consists in ascending order, of the Akata Formation, Agbada Formation and Benin Formation (Short and Stauble, 1967; Etu-Efeotor and Akpokodje, 1990). The site sits astride the clays, sand and the swampy mangrove of the Niger Delta.

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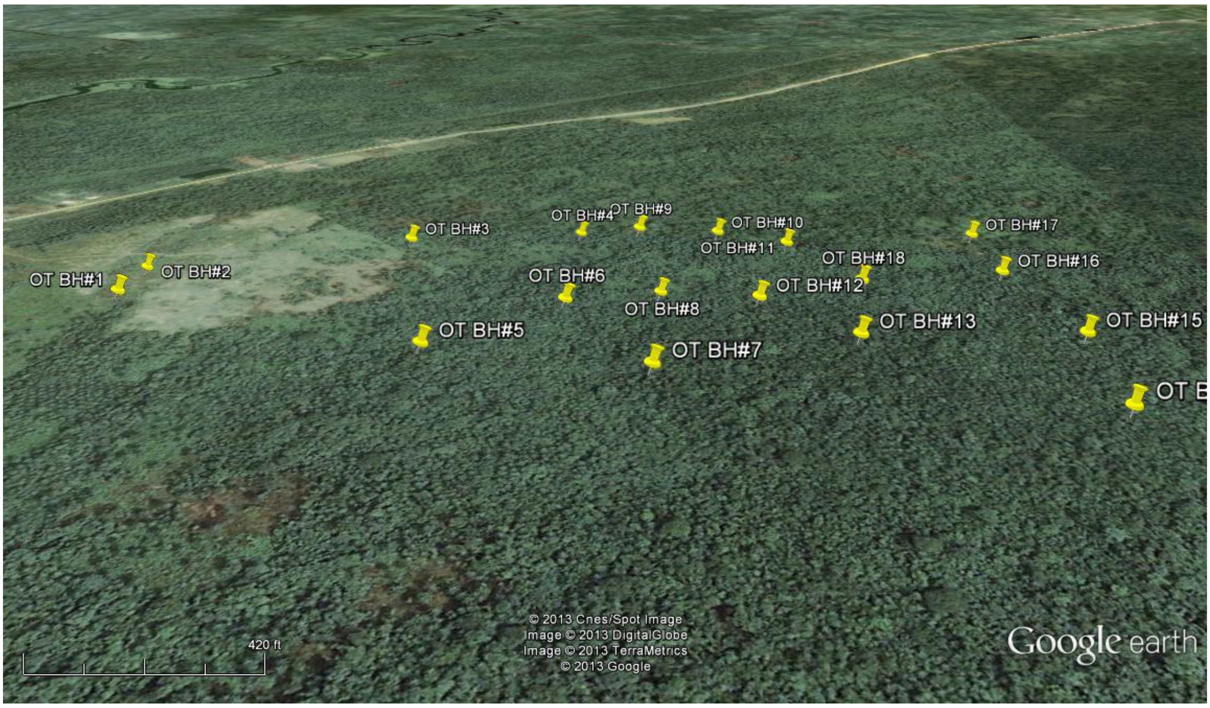
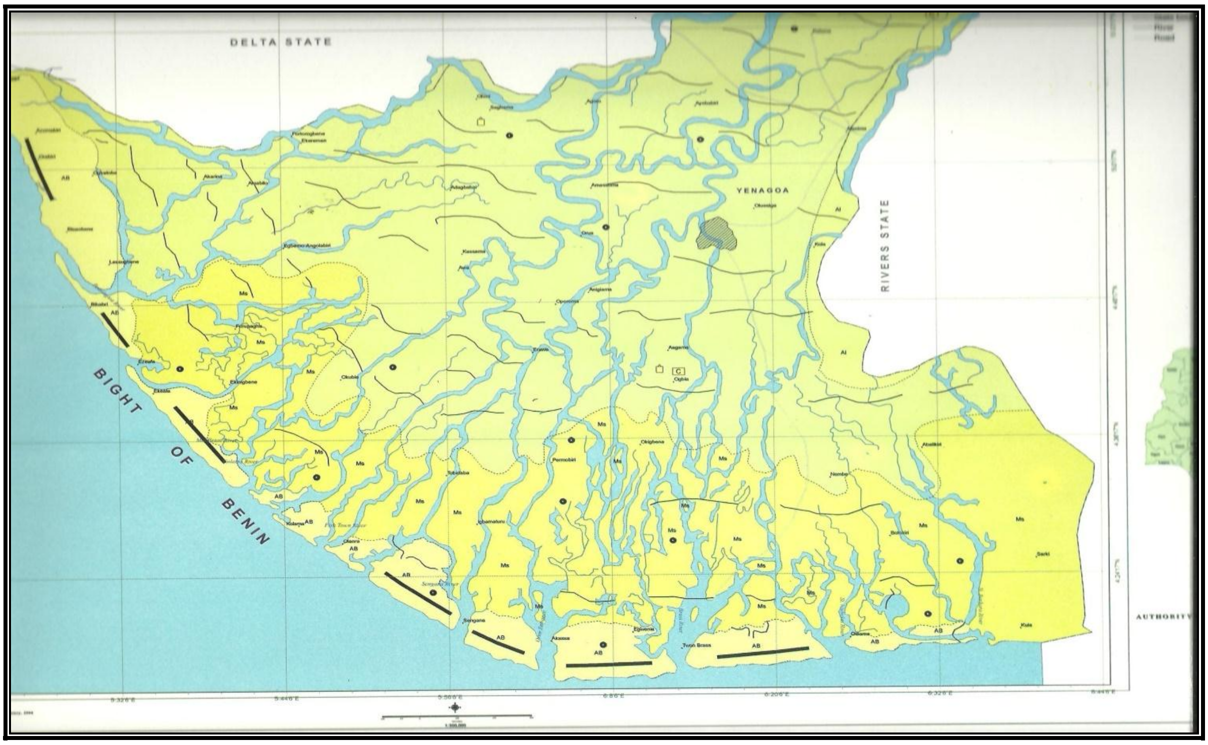


Fig. 1: Orthogonal view of the Satellite Imagery of Federal University Site, Otuoke Bayelsa State, showing the distribution of the Boring points.



LEGEND

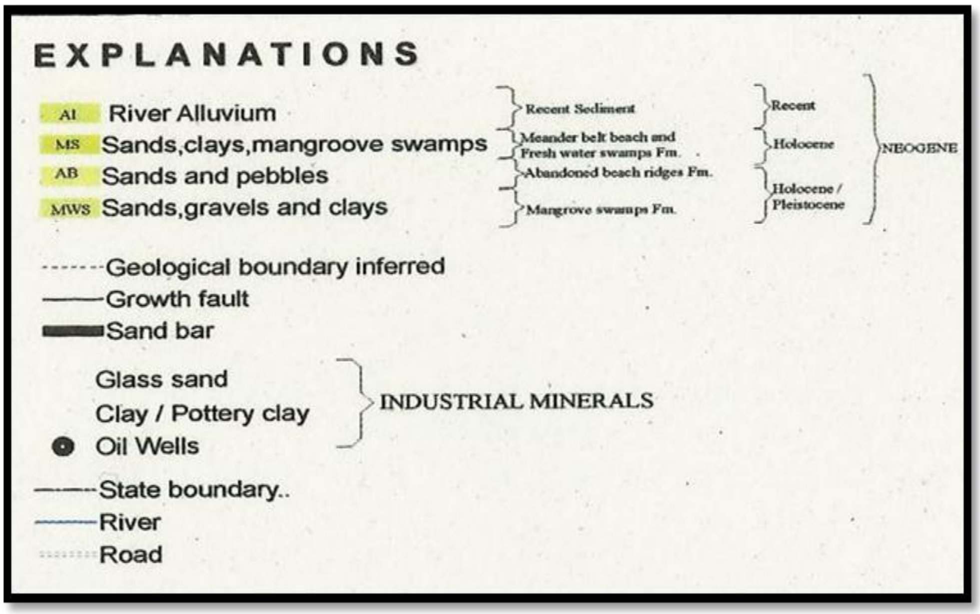


Fig. 2: The Geological Map of Bayelsa State.

METHODS OF STUDY

Samplings

In general, disturbed samples were obtained during the drilling activity using the Shell-and-Auger equipment. Within the zone of cohesive materials such as clays or sandy clays, undisturbed soil samples were obtained during the percussion drilling with the aid of splitspoons and U4-tubes. Disturbed soils taken during the drilling process are shown in Figure 4b above. Sampling intervals during the drilling were 1.50-meters apart down to the end of the boring. All the depths were in relation to ground level at the time of investigations.

The field survey involved boring, sounding and soil samplings. Three (6) borings were made to final depths of 20.00 meters. The boring employed the Shell-and-Auger Rig. The Standard Penetration Tests (SPT) was carried out at appropriate depth intervals of 1.50 meters or where a change in lithology was observed during the boring process. Both undisturbed samples (using Split Spoon Samplers and U-4 tubes) and slightly disturbed soil samples (using shelling augers) were obtained during the boring process. Table 1 shows the ground elevations and groundwater tables at boring locations while figure 3 shows the general outlay of the field boring locations.

The recovered soil samples were subjected to both field and laboratory visual examinations as well as detailed laboratory testing. The overall investigation is intended to provide a geologic- and geotechnical engineering investigation which will form the basis for sound engineering design of foundation systems for the Federal University, Otuoke, Bayelsa State, Nigeria.

Table 1: Ground Elevations and Ground water Tables at Boring locations at the Federal University, Otuoke.

ZONE	*BH #*	*Ground Elevation .m (asl)**	*Water Table (m) [bgl]* **	*Remarks*
A	**1**	5.30m	3.00m	Elevation effect [as at 04 /03/13]
	2	3.00m	3.10m	Elevation effect [as at 04 /03/13]
	3	4.00m	2.40m	Elevation effect [as at 04 /03/13]
	4	10.50m	2.50m	Elevation effect [as at 04 /03/13]
	5	3.00m	2.50m	Elevation effect [as at 04 /03/13]
	9	4.00m	3.50m	Elevation effect [as at 04 /03/13]
B	**6**	4.00m	2.40m	Elevation effect [as at 07 /03/13]
	7	5.30m	3.00m	Elevation effect [as at 07 /03/13]
	8	2.10m	3.1m	Elevation effect [as at 08

				/03/13]
	12	3.10m	3.20m	Elevation effect [as at 09 /03/13]
	13	3.00m	2.90m	Elevation effect [as at 04 /03/13]
C	**10**	3.60m	3.30m	Elevation effect [as at 04 /03/13]
	11	4.00m	3.10m	Elevation effect [as at 04 /03/13]
	14	3.00m	2.30m	Elevation effect [as at 04 /03/13]
	15	4.00m	2.70m	Elevation effect [as at 04 /03/13]
	16	0.80m	2.80m	Elevation effect [as at 04 /03/13]
	17	6.00m	2.50m	Elevation effect [as at 04 /03/13]
	18	3.00m	2.90m	Elevation effect [as at 04 /03/13]

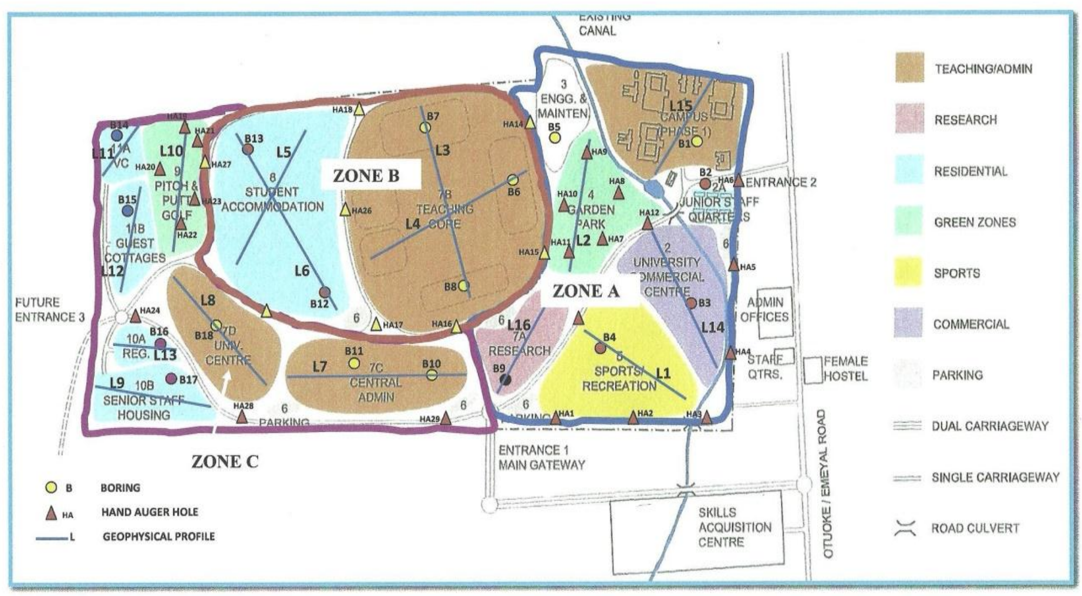


Figure 3: General Outlay of the Federal University, Otuoke, Bayelsa State showing Field Boring Locations.

Computations of the Bearing Capacities

In computing the bearing capacities of the soils at the various boring sites, several classical computational methods have been used. These methods include the following:-

a) SPT Method

b) Terzaghi's Method
c) Meyerhof's Method
d) Bowles Method
e) Brinch Hansen's Method

RESULTS AND DISCUSSION

The values of the bearing capacity based on Raft type (at foundation bearing level of 1.50 meters) for the Federal University Otuoke, Bayelsa State Foundation based on the various classical geotechnical computation methods are as given in Table 2 below, for purposes of comparison and analysis. These values are however, below the upper values for bearing capacity (380 to 470 kPa) cautioned for use by Bowles (1977). Settlement considerations are by the virtue of the inherent use of these equations limited to 25.4 mm. The use of the Factor of safety of 3.0 takes care of any unexpected high settlement values that may likely be obtained for this site. From the above, it could be observed that the range of Soil Bearing Capacity values useable at the site are based on a foundation depth (D_f) of 1.50 meters for a B value = 5.00 meters = 76.549 to 208.86 kPa with an average of 139.47 kPa. The above values of bearing capacity are based on the empirical methods of Bowles (1988), Meyerhof (1974), Terzaghi and Peck (1967); Hansen (1968) and proven field methods using the SPT techniques (Peck, et al., 1974; Vickers, 1978; B.S, 1990). The soil profiles are quite homogeneous as shown in the Fence diagrams given in Figures 5b; 5c; and 5d, respectively. A Sensitivity Analysis of the Bearing Capacity of the soils for both Isolated and Raft Footings for depths ranging from 0.50m; 1.00m; 1.50m; 2.00m and 2.50 meters was carried out and the results are as shown in Table 2. Table 3 is the sensitivity analysis of bearing capacities of project site soils for isolated and raft foundations. Table 4 shows the final average values of Bearing Capacity for Isolated and Raft Foundations at different foundation depths.

Table 2: Bearing Capacity Values for the Federal University, Otuoke, Bayelsa State [D_f = 1.50m] (Based on F.S = 3.0).

SPT N-value	Bearing Capacity Computational Methods (kPa)						Field Methods (kPa)	Average Values (kPa)
	Foundation Type Options							
	Isolated Footings	*Continuous Strip Footings*	*RAFT FOUNDATIONS*					
			Meyerhof (1974)	*Bowles (1988)*	*Terzaghi & Peck*	*Brinch Hansen*	*SPT*	

					(1967)	*(1968)*		
	Depth of Foundation (m)							
	1.50m	*0.75m*	*1.50m*					
17	*201.284*	*160.76*	*76.55*	*87.63*	*107.44*	*208.86*	*133.77*	*139.47*
OK		*OK*	*OK*	*OK*	*OK*	*On the High side*	*OK*	*Acceptable*

Table 3: A Sensitivity Analysis of Bearing Capacities of Project site soils for Isolated and Raft Foundations, Federal University Otuoke, Bayelsa State.

S/No.	**Foundation Depth (m)**	**Bearing Capacity Values for Foundation Types [kPa]**					**Remarks**
		Foundation Types					
		Isolated Footings	RAFT FOUNDATION				
		Analytical Methods adopted					
			Meyerhof's (1974)	Bowles' (1988)	Terzaghi & Peck (1967)	Brinch Hansen's (1968)	
1.	0.50	192.38	76.55	82.37	92.01	161.83	There is an increase of bearing capacity with depth except the Meyerhof's Method
2.	1.00	196.83	76.55	85.00	99.43	168.83	
3.	1.50	201.28	76.55	87.63	106.84	175.83	
4.	2.00	205.73	76.55	90.26	114.26	182.83	
5.	2.50	210.18	76.55	92.89	121.68	189.83	

Table 4: The Final Average Values of Bearing Capacity for Isolated and Raft Foundations at Different Foundation Depths.

S/No.	***Foundation Depth (m)***	***Final Average Bearing Capacity Values [kPa]***		***Remarks***
		Foundation Types		
		Isolated Footing	Raft Foundations	
1.	0.50	192.38	103.20	The values of the Final Average Bearing Capacity for the Raft Foundations are the averages for the Four (4) types of Foundation designs utilized
2.	1.00	196.83	107.45	
3.	1.50	201.28	111.72	
4.	2.00	205.73	115.98	
5.	2.50	210.18	120.24	

Settlements and Rates of Settlements

Settlement considerations are by the virtue of the inherent use of these equations limited to 25.4 mm. The use of the Factor of safety of 3.0 takes care of any unexpected high settlement values that may likely be obtained for this site. The likely settlement that may arise as a result of loading on the various structures was computed taking into account the dimensions of the structure and the subsurface lithology beneath the applied Foundations structures. It should be known that the Final settlement of foundation footings is the sum total of immediate settlement during construction phase and the Long-term settlement after T_{90} i.e 90% of consolidation. Table 5 is the summary of computed settlements at the project site while Table 6 shows the ummary of the computed rates of settlements.

Table 5: Summary of computed settlements at the Project Site.

Project Site	***Computed Settlements (cm)***			***Remarks***
	Immediate settlement **(ρ_i)**	***Long-term Settlement*** **(ΔH_f)**	***Total Settlement*** **(ρ_{total})**	
Federal University, Otuoke, Bayelsa State.	0.000132T *m*	{ 0.520} $\log_{10}$ {1 + 0.01498T }m	0.000132T + { 0.520} $\log_{10}$ {1 + 0.01498T }m	Compressible layer beneath foundation level = *7.50 m*

Table 6: Summary of the computed rates of settlements.

Project Site	***Rates of Settlement (years)***		***Remarks***
	T_{50}	***T_{90}***	
FEDERAL UNIVERSITY, OTUOKE, BAYELSA STATE.	3.700	15.728	Over a compressive layer of 7.50m beneath foundation level

Factor of Safety of the Pile Foundation

The factor of safety (FS) of pile foundation is defined as the ratio of the imposed Load on the pile to the mobilized bearing capacity of the soil (equal to the sum of base resistance and skin resistance).

i.e,

$$F.S = Q_u' / Q \quad \text{--- --- --- --- --- --} \quad (1)$$

For the recommended pile under consideration, the Ultimate Carrying Capacity, Qu, can be assessed using equation (1) above as follows:-

For a Steel Pipe diameter of 400mm and a Factor of Safety (F.S) of 3.0.

Imposed load on the piles = Wt. of super-structure + Wt. of sub-structural pad overlying the pile cap.

Assuming the total load of the superstructure, = (T) Tons, and Area of each Pier = ($As_)$), then the Total imposed Net soil pressure (q_{net}) is:

$$.q_{net} = D_c(\gamma_c - \gamma_s) + (h_f)(\gamma') + T/A_s \quad --- \quad --- \quad --- \quad --- \quad (2)$$

$$= \{(1.50m)(2.96 - 2.78)\ kN/m^2 + (24.00m)(2.78 - 1.00)\}/1000 + \{(T \times 9.964)/(2\pi \times 300.00^2 \times 15)\}/1000\ MN/m^2$$

.where:

T = Weight of Super structure.

$$= (42.99 + 7.34 \times 10^{-7}\ T)$$

For stability of the Foundation, $q_{net} \leq q_{allow}$ … … … (3)

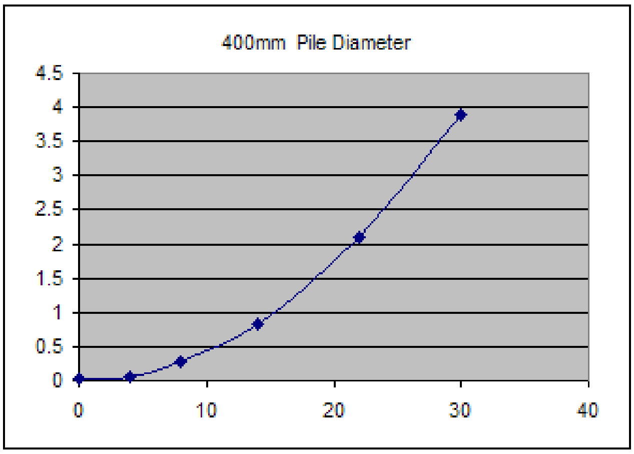


Fig. 4: Typical Plot of Pile Load vs Depth for Pile Diameters of 400mm.

Summary of Soil Profiles

Within the Project site tested, there are five (5) basic types of soil profiles namely:

(i) Brownish Clay Layer (CL) – Top Soil

(ii) Greyish Organic silty Clays (OL)

(iii)Yellowish Clayey Sands (SC)

(iv)Greyish Silty- Sands (SM) and

(v) Well-graded Gravelly-Sands (SW)

These basic soil types are found in these three Zones used in this study, as shown in the Fence Diagrams of each Zone (Figures 5a, b and c). Table 7 is the summary of bearing capacity values from field SPT soundings. Table 8 is the consolidation, bearing and drainage characteristics of materials in the area while Table 9 is the summary of pile bearing capacities at different pile diameters in each zone. Table 10 shows the summary of results on soil liquefaction potentials at the Federal University site, Otuoke, Bayelsa State.

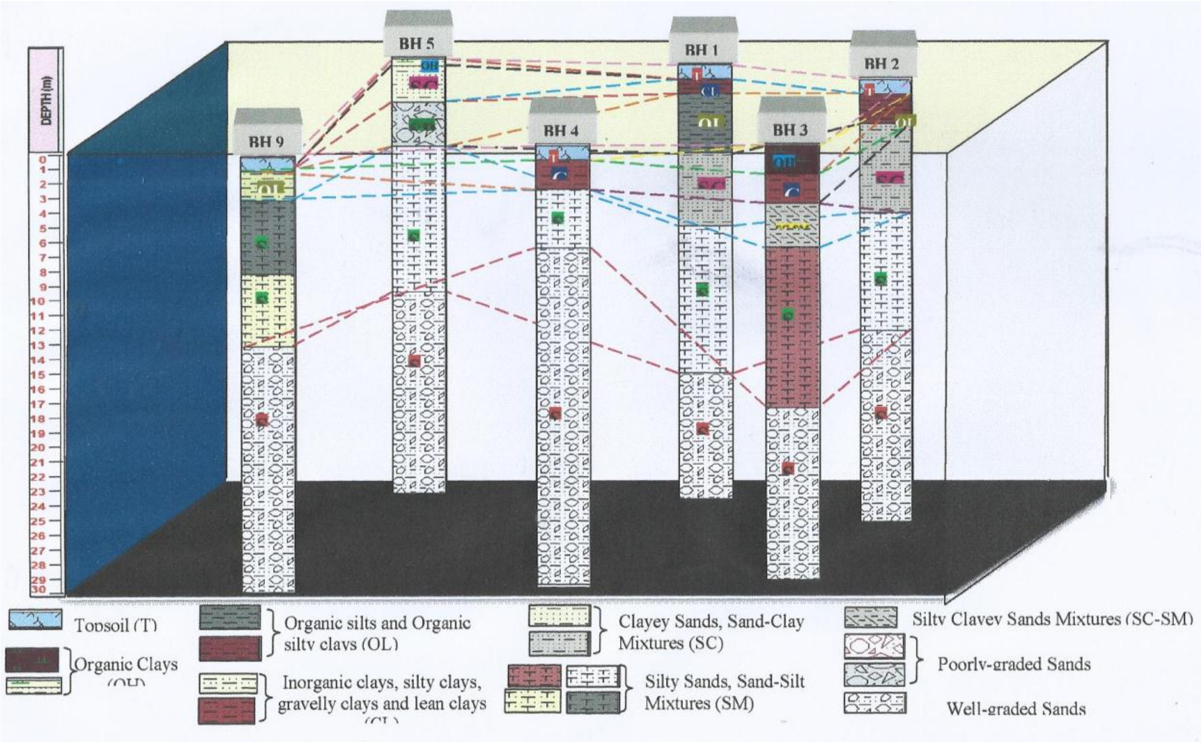


Figure 5a: Schematic Fence Diagram showing the Borings in Zone A.

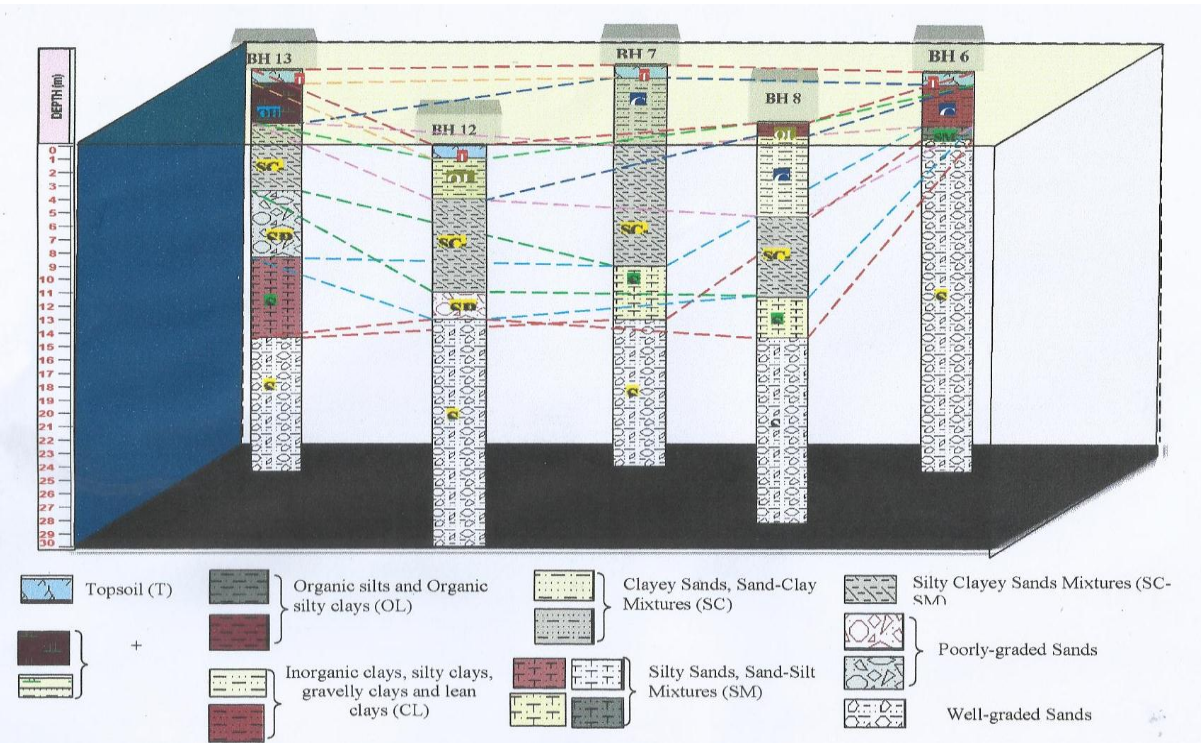


Figure 5b: Schematic Fence Diagram showing the Borings in Zone B.

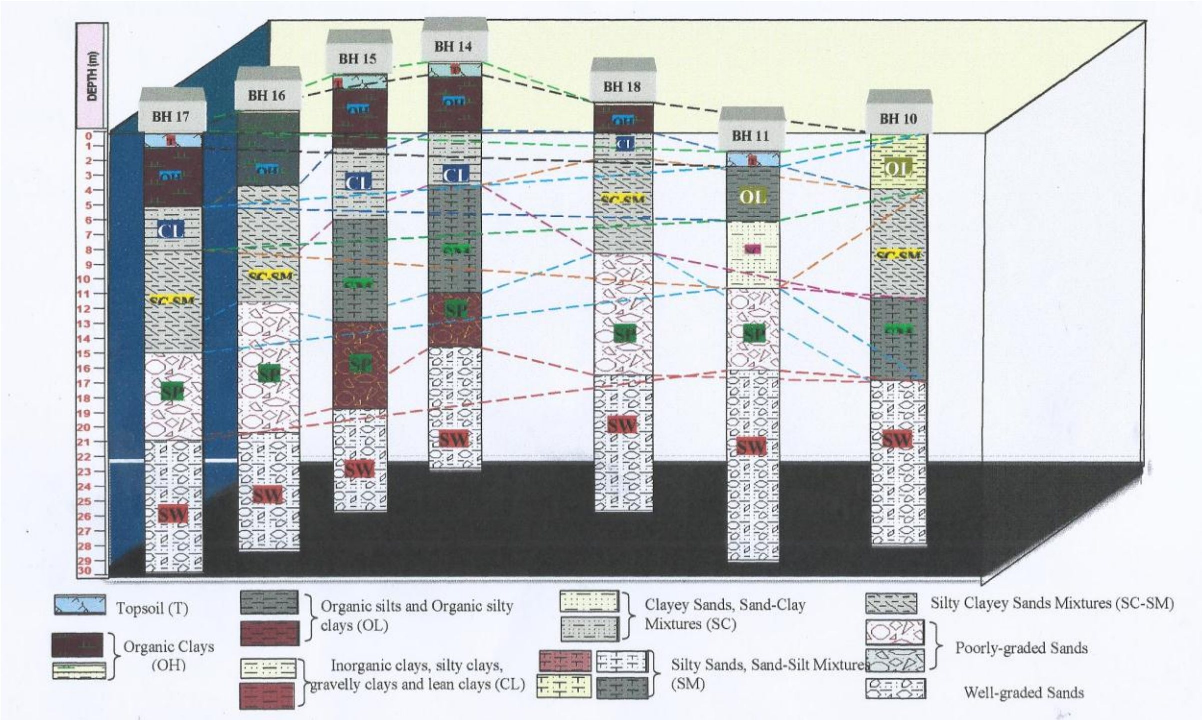


Figure 5c: Schematic Fence Diagram showing the Borings in Zone C.

Table 7: Summary of Bearing Capacity Values from Field SPT Soundings.

S/No.		BORINGS		GPS LOCATIONS		RANGE OF BEARING PRESSURES (kPa) [S.F. = 3.00]
		No. of Boring	Boring #	Northing	Easting	
1.	Campus (Phase 1) [Built-up Site]	1	# 1	N 04° 47' 33.45"	E 006° 19' 19.92"	110.16 – 275.40 kPa
2.	Engineering & Maintenance	1	# 5	N 04° 47' 30.04"	E 006° 19' 31.83"	291.14 – 377.70kPa
3.	Sports / Recreation	1	# 4	N 04° 47' 42.9"	E 006° 19' 34.8"	55.08 – 70.82 kPa
4.	Research Park	1	# 9	N 04° 47' 43.70"	E 006° 19' 37.13"	70.82 – 291.14 kPa
5.	Teaching Core	3	# 6, 7& 8	N 04° 47' 34.51"	E 006° 19' 35.54"	118.03 – 220.32 kPa 141.64 – 212.45 kPa 149.50 – 220.32 kPa
6.	Central Administration Area	2	# 10 & 11	N 04° 47' 43.61"	E 006° 19' 40.39"	141.64 – 267.53 kPa 86.56 - 354.09 kPa
7.	Student Accommodation	2	# 12 & 13	N 04° 47' 35.56"	E 006° 19' 42.08"	110.16 – 299.01 kPa 55.08 - 243.93 kPa
8.	University Centre	1	# 18	N 04° 47' 37.90"	E 006° 19' 45.71"	133.77 - 275.40 kPa
9.	Senior Staff Housing Area	1	# 17	N 04° 47' 44.37"	E 006° 19' 50.69"	141.64 – 314.75 kPa
10.	Junior Staff Quarters	1	#2	N 04° 47' 36.03"	E 006° 19' 19.04"	133.77 – 314.25 kPa
11.	Registrar's Residence	1	# 16	N 04° 47'	E 006°	133.78 – 314.75 kPa

	Area			39.35"	19'50.84"	
12.	Guest Cottages	1	# 15	N 04° 47' 33.30"	E 006° 19'52.12"	62.95 – 133.77 kPa
13.	Vice-Chancellor's Lodge	1	# 14	N 04° 47' 27.81"	E 006° 19'51.78"	86.56 – 204.59 kPa
14.	University Commercial Centre	1	# 3	N 04° 47' 41.04"	E 006° 19'28.13"	62.95 – 141.64 kPa
	Total No of Borings	.x18 No.	.x18 No.			

Table 8: Consolidation, Bearing and Drainage Characteristics of Materials in the Area.

Site	**ZONE #**	**Q_u Values from SPT N-Values [kPa]**	**Bearing Strength C / ϕ**	**Coefficient of Compress-ibility (M_v) m^2/MN**	**Coefficient of Consolidation (C_v) m^2/yr**	**Coefficient of Permeability (K) cm/sec**	**REMARKS**
Federal University, Otuoke, Otuoke, Bayelsa Site.	ZONE A BH #s 1,2,3,4,5 &9	55.08 *to* 377.70	0.00 – 52.80kPa / 4° – 25.40°	0.14 - 0.38	0.24 - 0.88	1.75×10^{-8}	Material strength adequate for Bungalows in all places but require rafts and piles for multiple storey buildings
Federal University, Otuoke, Otuoke, Bayelsa Site.	ZONE B BH #s 6,7,8,12 &13	55.08 *to* 299.01	0.0 kPa & 34° – 36°	0.14 - 0.38	0.24 - 0.88	1.25×10^{-2}	Material strength adequate for Bungalows in all places but require rafts and piles for multiple storey buildings
Federal University, Otuoke, Otuoke, Bayelsa Site.	ZONE C BH #s 10,11,14,15, 16, 17 &18	62.95 *.to* *354.09*	1.0 kPa & 34° – 36°	0.14 - 0.38	0.24 - 0.88	1.25×10^{-2}	Material strength adequate for Bungalows in all places but require rafts and piles for multiple storey buildings

Table 9: Summary of Pile Bearing Capacities at Different Pile Diameters in Each Zone.

S/No.	ZONE	Pile diameter (mm)	Total Pile load (MN)	Areas in question
1.	A	400	0.7482	Campus Phase I; Engineering & Maintenance; Sports / Recreation Area; University Commercial Center
		600	1.3107	
		800	1.9984	
		1000	2.8134	
2.	B	400	0.2568	Teaching Core; Students' Accommodation;
		600	0.5736	
		800	1.3496	
		1000	1.5835	
3.	C	400	0.4528	University Centre; Senior Staff Housing; Registrar's Residence Area ;Guest Cottages; Vice-Chancellor's Lodge
		600	0.7981	
		800	1.0236	
		1000	1.2894	

Table 10: Summary of Results on Soil Liquefaction Potentials at the Federal University site, Otuoke, Bayelsa State.

(i) Earthquake Intensity M = 6.0

Depth (m)	τ_{av}*	τ_o*	$\tau_{av} > \tau_o$	*Remarks*
2.50	0.089	0.409	No	Liquefaction Not Possible
3.00	0.106	0.655	No	Liquefaction Not Possible
5.00	0.175	1.48	No	Liquefaction Not Possible
7.00	0.240	2.075	No	Liquefaction Not Possible
9.00	0.299	2.740	No	Liquefaction Not Possible
11.00	0.552	14.520	No	Liquefaction Not Possible

(ii) Earthquake Intensity M = 7.5

Depth (m)	τ_{av}*	τ_o*	$\tau_{av} > \tau_o$	*Remarks*
2.50	0.089	0.312	No	Liquefaction Not Possible

3.00	0.106	0.491	No	Liquefaction Not Possible
5.00	0.175	1.092	No	Liquefaction Not Possible
7.00	0.240	2.528	No	Liquefaction Not Possible
9.00	0.299	1.895	No	Liquefaction Not Possible
11.00	0.552	11.616	No	Liquefaction Not Possible

(iii) Earthquake Intensity M = 8.25

Depth (m)	τ_{av}*	τ_o*	$\tau_{av} > \tau_o$	*Remarks*
2.50	0.089	0.254	No	Liquefaction Not Possible
3.00	0.106	0.421	No	Liquefaction Not Possible
5.00	0.175	0.975	No	Liquefaction Not Possible
7.00	0.240	1.365	No	Liquefaction Not Possible
9.00	0.299	1.685	No	Liquefaction Not Possible
11.00	0.552	8.131	No	Liquefaction Not Possible

CONCLUSION AND RECOMMENDATIONS

The results of the study revealed soil properties at the various Zones of the University Complex and the Bearing Capacities of the Piles to maximum depths of 30.00 meters at different Pile diameters. At all intensities of Earthquake [M = 6.0; 7.50 and 8.25], there was little possibility of any liquefaction occurring in the area. This can be explained by the fact that the water table at site is about 3.00 meters below the ground surface. Most liquefaction occurs when water table is near ground surface.

On the basis of the computations carried out as revealed in this study, the following recommendations are hereby made:-

(1). The obtained value for the Bearing Capacity for Isolated Footings to be used at the Project Site is about 195.35 + 1.1867B [kPa] where B = Width of the Structure to be built. For a B = 5.00 meters, the Bearing Capacity has been found to be 201.284 kPa. The recommended depth of emplacement of isolated footings is 1.50 meters. This value represents the bearing capacity of the upper bearing lateritic clayey sands at the project site.

(2) The obtained value for the Bearing Capacity for Continuous Strip Footings to be used at the Project Site is about 153.35 + 1.483B [kPa] where B = Width of the Structure to be built. For a B = 5.00 meters, the Bearing Capacity has been found to be 160.76 kPa. The recommended depth of emplacement of Continuous Strip Footings is 0.75 meters. This value represents the bearing capacity of the upper bearing Lateritic Clays and Silty-Clays at the project site.

(3) The range of values obtained for the Bearing Capacity for Raft Footings at the project site, based on the methods of Meyerhof (1974); Bowles (1988); Terzaghi & Peck (1967); Brinch Hansen (1968) and the conventional SPT Method is between 76.55 and 208.86 kPa with an average of 122.85 kPa. The recommended depth of emplacement of Raft Footings is 1.50 meters. This value represents the bearing capacity of the upper bearing Lateritic Clays and Silty-Clays at the project site.

(4) A value of $q_{allowed} = [14.4] + [(9.964T)/(B \times L)]$ kN / m^2 can be used as the allowable Soil Pressure on the soil at the project site, since this value should be less than the average value of the allowable soil pressure (bearing capacity), $q_{(allow)}$ of the soils at site. [Note: B = breadth; L = Length of structures at site].

(5). The computed settlement data for the project area indicate that the Immediate Settlement values for the Project Site is estimated to be about $\rho_i = 0.0000132(T)(B)$ (meters) , where T = the Dead weight of the Buildings at site. This is the settlement expected to take place during the construction phase of the Buildings at the Project site.

(6). The computed settlement data for the project area indicate that the Long-Term Settlement value for the Buildings at the Site is estimated to be about 0.000132 T + {(0.520) Log 10 (1 +0.01498 T)} (meters), where T = the estimated Dead Weight of the Buildings. This is the settlement expected to take place long after the construction phase of the Buildings at the various zones at the Project sites.

(7). About 50% of the settlements must have taken place about 3.70 years after construction, while 90% of the settlement will take place after about 15.728 years after the completion of the Buildings at the University Complex.

(8). Since the buildings at the university Campus may subjected to Live Loads from the movements of different numbers of students in a continuously day-to-day fashion over the years, the potentials of the silty soils becoming liquefied as a result of human traffic-induced vibration was also assessed during this study, since this is a permanent structure for ages to come. Soil dynamics analysis carried out indicate that there will be no possibility of Soil Liquefaction at the site as a result of vibration from the Gas Plant. This was found not to be possible even though the groundwater table was found near the ground surface because of the absence of totally silty soils beneath the ground surface.

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