

Application of Geophysical and Geotechnical Methods to Site Characterization for Construction Purposes at Ikoyi, Lagos, Nigeria

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Abstract

An integrated geophysical and geotechnical survey was carried out in a proposed engineering site at Ikoyi, Lagos, Nigeria. The survey aimed to image shallow subsurface with a view to evaluate the stratigraphy and competency of the shallow formation as foundation materials. Geotechnical investigation involving Cone Penetration Testing (CPT) and Standard Penetration Testing (SPT) were carried out on the site. Geophysical technique involving Vertical Electrical Sounding (VES) was also implemented and the data were processed, inverted and interpreted. Geophysical and geotechnical tests showed good agreement. Four to five subsurface layers were delineated within the study area: the topsoil loose sand, peat/clay, sandy clay, sand and clay. This indicates good correlation with the soil layers in bore logs. The existence of loose sand, peat and clay near at the surface is capable of being inimical to building structures. The subsurface layers up to the depth of 16 m are mechanically unstable with low penetration resistance value which may not serve as good foundation materials. Shallow foundation is

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considered unsuitable for the intended building. In view of unsuitability of shallow foundation in this area, structures in this area should be safely founded in competent and mechanically stable coarse sand through piling.

Keywords: Geophysics, SPT, CPT, VES, Resistivity, foundations

1 Introduction

The figures of failures of buildings throughout the nation have increased in recent times. The necessity for site characterization for construction purposes has therefore become very vital so as to prevent loss of valuable lives and properties that always accompany such failure. Some general reasons why buildings may be susceptible to collapse have been advanced, which include poor quality of building materials, salinity, and old age of buildings. Less frequently mention is the subsurface conditions of the ground on which the buildings are sited. The design of a structure which is safe, durable and has low maintenance costs depends upon an adequate understanding of the nature of the ground on which such building is located.

Site characterization usually provides subsurface information that assists civil engineers in the design of foundation of civil engineering structures. The primary purpose of all site investigations is to obtain the data needed for analysis and design. The most challenging part of these investigations is to collect only those data needed with the least amount of money and in the least amount of time.

The proposed Site is located at Ikoyi in the south-western part of Lagos State, south west Nigeria, lying between latitudes $6^{\circ} 25' 00''$ and $6^{\circ} 27' 11''$ North; $3^{\circ} 25' 00''$ and $3^{\circ} 26' 8''$ East (Figure. 1). It is a zone of coastal creeks and lagoons which is almost encompassed by the Lagos lagoon system. Ikoyi area of Lagos is located near the eastern margin of the Nigerian sector of the Benin-basin, within

the Western Nigeria coastal zone which consists largely of coastal creeks and lagoons developed by barrier beaches associated with sand deposition underlain by recent deposits which vary from the littoral and lagoon sediments to the coastal belt and alluvial deposits of the major rivers (Adeyemi, 1972). Sub-soil investigations involving geophysical and geotechnical methods have been carried out in the study area. The non-destructive mode of stratigraphy determination of geophysical methods made them necessary and adequate while the geotechnical investigation is essential to have an adequate knowledge of the engineering properties of the subsoil materials that would have direct interaction with the proposed structure on the site. In the last decade, the involvement of geophysics and geotechnical methods in civil engineering has become a promising approach (Adepelumi *et al* 2009; Adepelumi, A. A. and Olorunfemi, M. O. (2000)). The Cone Penetration Test (CPT) which allows for the soil type to be determined from the measured values of cone resistance and sleeve friction was employed to provide valuable and continuous information regarding the soil strength with depth. The resistance parameters were used to classify soil strata and to estimate strength. The Standard Penetration Test (SPT) identified the soil stratification and engineering properties of soil layers. Due to the soft nature of soil deposits in Ikoyi, the CPT is considered a perfect tool for subsurface investigation and site characterization.

This investigation will be useful in determining the nature and engineering properties of the proposed site for proper foundation design for the proposed structure. This study therefore employed geophysical investigation in conjunction with in-situ soil testing to provide information on the subsurface sequence, competence and structural disposition with a view to capture geo-engineering information of the subsurface that are inimical to engineering projects.

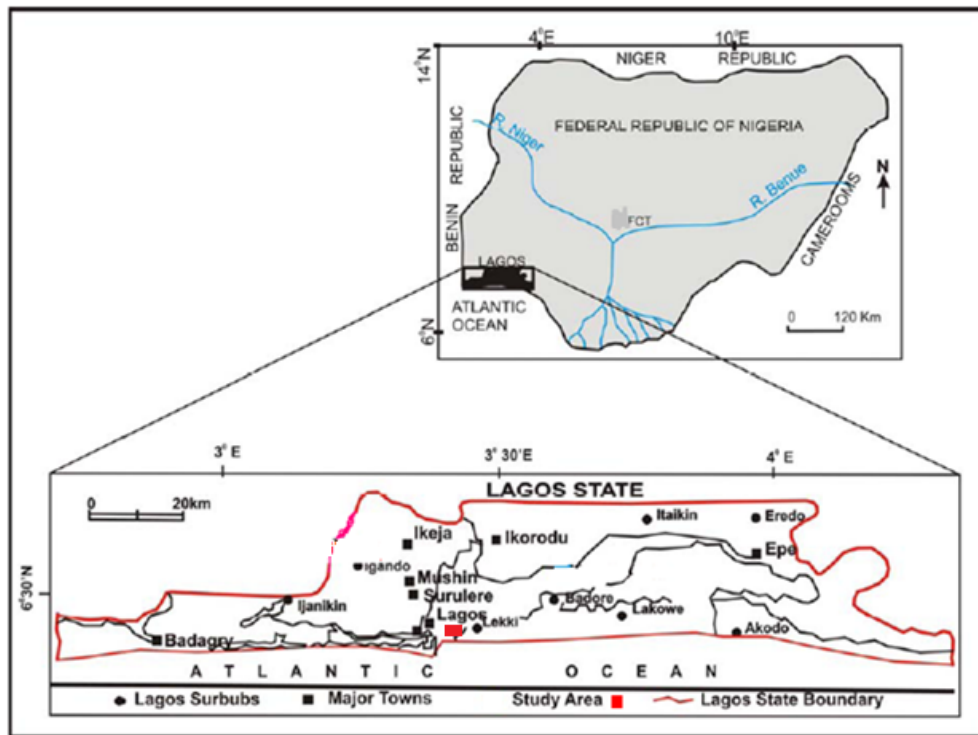


Figure 1: Map of the study area showing locations of data acquisition

2 Geology of the study area

The Lagos metropolis is the area of land around the only inlet of the sea into the extensive lagoon system. Stratigraphically, the basin is divided into Abeokuta Formation, Ilaro Formation, Coastal Plain Sands and Recent Alluvium sediments (Jones and Hockey, 1964). Deposition of Cretaceous sequence in the eastern Dahomey basin began with the Abeokuta Group, consisting of the Ise, Afowo and Araromi Formations (Omatsola and Adegoke 1981). 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 eastern Dahomey basin (Omatsola and Adegoke, 1981). 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 (Ogbe, 1972). 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 (Durotoye 1975) and consists of poorly sorted sands with lenses of clays. The sands are in parts crossbedded and show transitional to continental characteristics. The age is from Oligocene to Recent.

3 Methodology

3.1 Geophysical survey

Data from four Vertical Electrical Soundings (VES) were acquired on the proposed site with Syscal Junior Terameter using Schlumberger array with electrode spread varying between 1-200 m. (Figure1). The field resistivity data was interpreted using the 1-D inversion program of Kim (2005). The interpretation of the resistivity curves was based on a number of layers depicted on the observed curves and models that are geologically plausible and produce acceptable fit. The geoelectric parameters of different layers are obtained after a number of iterations with minimal RMS error. Typical resistivity soundings results obtained after the processing earlier explained are shown in Figure 2. Engineering competence of the soil can be qualitatively evaluated from layer resistivity. The higher the layer resistivity value, the higher the competence of a layer.

3.2 Geotechnical survey

3.2.1 Cone penetration testing

Cone penetration testing can be utilized for a wide range of geotechnical engineering applications. Sanglerat (1972) and De Ruiter (1981) reviewed the application of the method in geotechnical practice. The Cone Penetration Test is a means of ascertaining the resistance of the soil. Four CPT tests, coinciding with VES locations were carried out to 18.50m depth. The tests were performed using a 10-Ton nominal capacity manually powered CPT machine. Penetration resistance (q_c), sleeve friction (f_s) and the depth of penetration were recorded at each station and processed into plots (figure 3). 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

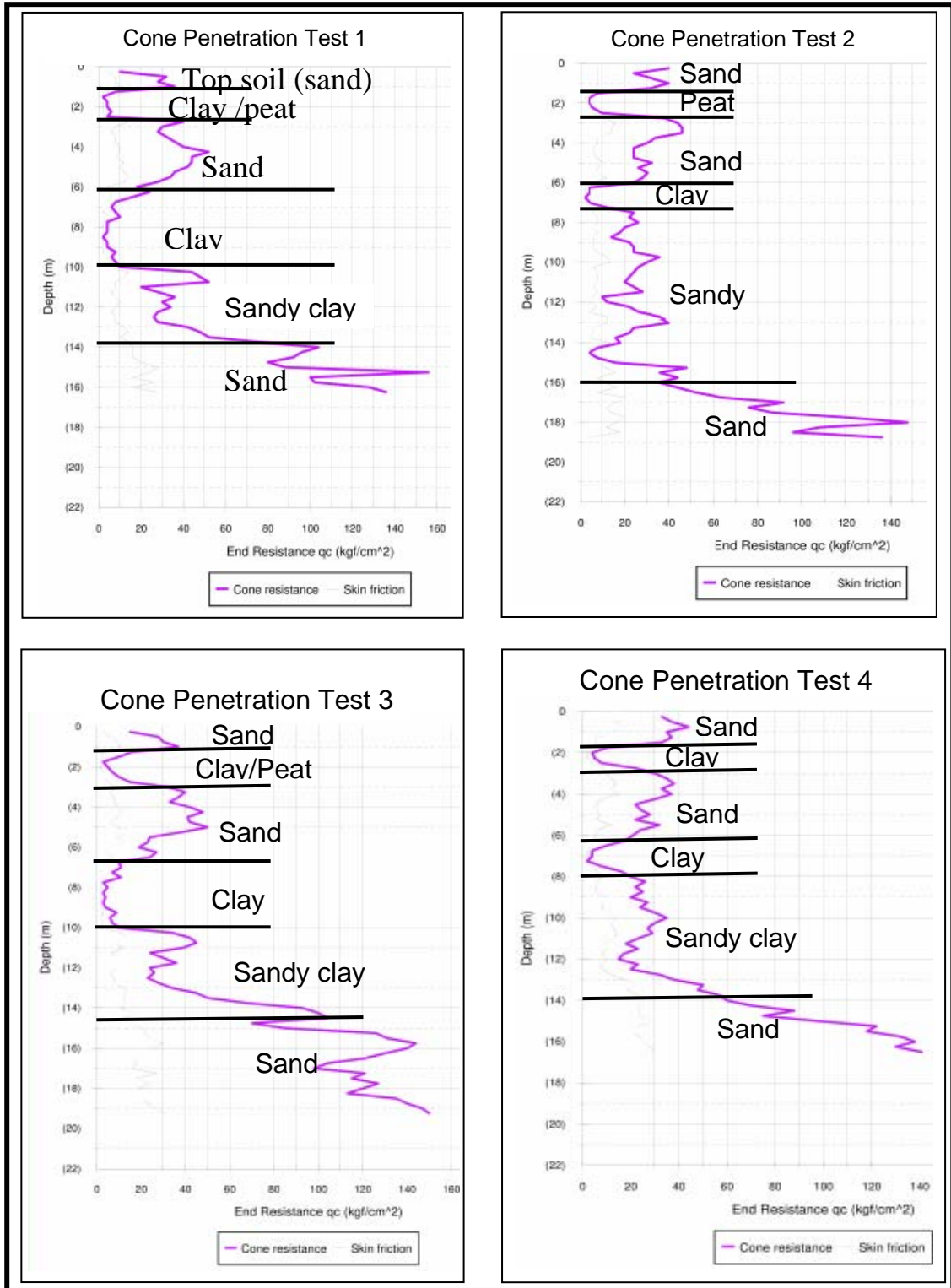


Figure 3: Cone Penetration Test (CPT) curves 1-4

3.2.2 Standard penetration testing

Since CPT does not serve as the exclusive site investigation tool, soil sampling is still required. To this effect, two boreholes were drilled down to 30m depth with 250mm, 200mm and 150mm diameter steel casings. The borings were conducted using a Percussion motorised Shell and Auger rig employing light cable percussion boring techniques. In the cohesion less materials, Standard Penetration Test (SPT) was carried out at 1.5m intervals and disturbed samples were recovered from the SPT sampling tool. 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 (N-value) required obtaining a 300mm penetration below an initial 150mm penetration. The N-values and all pertinent borehole data, penetration resistance, and sample data are recorded on the boring log data sheet (Figures 4a &b). In boreholes, SPT results are routinely used to provide an estimate of density. The N value is assumed to be dependent on relative density in granular soils, and undrained shear strength in cohesive soils. The purpose of the Standard Penetration Test is to identify the soil stratification and engineering properties of soil layers.

4 Results and Discussion

2-D view of the inverted 1-D resistivity models for the vertical electrical sounding (Figure 2) show that the shallow subsurface of the site (up to 30 meter depth) is composed of a relatively low resistivity formation, which is probably soft and saturated with water. The electro-stratigraphy of the area revealed the topsoil (26-108 Ω -m) ranging from 2-3.5m in thickness as loose coarse grained sand underlain by clay/peat formation (8-15 Ω -m) with thickness varying from 2- 3 metres. Clay (1-3 Ω -m) of thickness 2-9 metres represent the third geo-electric layer. The clay is in turn underlain by sand/ clayey sand layer (24-42 Ω -m) with

varying thickness (5-12 m). Current terminated in the lowermost clay layer. This model confirmed the cyclic nature of sand and clay typical of this geologic setting. These low resistivity and loose soil except the sand/clay sand are not suitable for use in shallow foundations. The sand/clayey sand layer is viewed as the only competent geo-material for the proposed engineering foundation while the clay and loose material are inimical to the foundation of any engineering structures sited within the study area.

Type of Boring:		Shell & Auger - Percussion Boring Method		Borehole No.:		BH 1																		
Diameter of Hole (mm):		200mm & 150mm																						
Depth (m):		30.00																						
Commenced on:		June 16, 2010																						
Completed on:		June 18, 2010																						
Water Struc. (m):		0.30		Borehole Location:		Ikoyi																		
DEPTH (m)	LEGEND	SAMPLE NO	SAMPLE TYPE	SPT				SOIL DESCRIPTION	SPT Curve															
				0 - 150mm	150 - 300mm	300 - 450mm	N		0	10	20	30	40	50	60	70	80							
0.00								0.00-1.50m Loose brownish grey fine to coarse SAND																
1.50		3	SPT	3	3	4	7	1.50-5.00m Very loose to loose brownish PEAT	◆	7														
3.00		5	SPT	3	3	4	7		◆	7														
4.50		7	SPT	2	2	3	5		◆	5														
6.00		9	SPT	2	2	3	5	5.00-19.50m Loose to medium dense brownish grey fine to coarse SAND	◆	5														
7.50		11	SPT	4	4	5	9		◆	9														
9.00		13	SPT	10	16	10	26				◆	26												
10.50		15	SPT	10	15	14	29				◆	29												
12.00		17	SPT	5	3	4	7				◆	7												
13.50		19	SPT	4	3	4	7				◆	7												
15.00		21	SPT	7	9	9	18				◆	18												
16.50		23	SPT	8	9	12	21				◆	21												
18.00		25	D																					
19.50		27	SPT	3	3	8	11	19.50-28.50m Firm light grey sandy CLAY	◆	11														
21.00		29	SPT	5	7	8	15	From 21.00 to 22.50, layer of sand			◆	15												
22.50		31	SPT	5	8	11	19				◆	19												
24.00		33	D																					
25.50		35	U4																					
27.00		37	U4																					
28.50		39	SPT	5	6	9	15	28.50-30.00m Medium dense brownish grey fine to coarse SAND	◆	15														
30.00		41	SPT	7	8	7	15				◆	15												
Borehole completed at 22.50m																								

Figure 4a: Boring log data sheet of BH 1

Type of Boring:		Shell & Auger - Percussion Boring Method															
Diameter of Hole (mm):		200mm & 150mm		Borehole No.:		BH 2											
Depth (m):		30.00															
Commenced on:		June 19, 2010															
Completed on:		June 21, 2010															
Water Struc. (m):		0.30		Borehole Location:		Ikoyi											
DEPTH (m)	LEGEND	SAMPLE NO	SAMPLE TYPE	SPT			N	SOIL DESCRIPTION	SPT Curve								
				0 - 150mm	150 - 300mm	300 - 450mm			1								
									0	10	20	30	40	50	60	70	80
0.00								0.00-1.50m Loose brownish grey fine to coarse SAND									
1.50		3	SPT	3	3	3	6	1.50-5.00m Very loose to loose brownish PEAT	◆	6							
3.00		5	SPT	1	1	1	2		◆	2							
4.50		7	SPT	1	1	1	2		◆	2							
6.00		9	SPT	5	7	10	17	5.00-19.50m Loose to medium dense brownish grey fine to coarse SAND	◆	17							
7.50		11	SPT	7	7	14	21		◆	21							
9.00		13	SPT	7	6	8	14		◆	14							
10.50		15	SPT	7	4	2	6		◆	6							
12.00		17	SPT	4	3	3	6		◆	6							
13.50		19	SPT	3	3	4	7		◆	7							
15.00		21	SPT	7	10	9	19		◆	19							
16.50		23	D														
18.00		25	D														
19.50		27	SPT	5	5	8	13	19.50-28.50m Firm light grey sandy CLAY	◆	3							
21.00		29	SPT	4	6	8	14		◆	14							
22.50		31	SPT	6	9	13	22		◆	22							
24.00		33	D														
25.50		35	U4														
27.00		37	U4														
28.50		39	SPT	8	10	9	19	28.50-30.00m Medium dense brownish grey fine to coarse SAND	◆	19							
30.00		41	SPT	6	8	9	17		◆	17							

Figure 4b: Boring log data sheet of BH 2

The cone penetration sounding curves of the study area (Figure 3) generally showed similar responses. They are essentially characterized by alternation of high and low magnitude of resistance responses. From the CPT signatures, the soil layering consists of loose and dry sand top soil of comparatively low resistance ($10\text{-}42\text{ kg/cm}^2$). The top soil is underlain by peat/clay horizon of very low resistance ($< 5\text{ kg/cm}^2$). Non uniform but relatively more compacted sand layer ($40\text{-}52\text{ kg/cm}^2$) underlies the peat/clay horizon. This sand is underlain by low resistance clay which in turn is underlain by clayey sand ($5\text{-}155\text{ kg/cm}^2$). The CPT reached point of anchor pulling in a sand horizon (up to 150 kg/cm^2) which indicates a mechanically stable layer. The bearing capacities calculated for the stable layer at 16m depth from CPT1, CPT2, CPT3 and CPT4 are given as 337.5Kg/cm^2 , 229.5Kg/cm^2 , 391.5Kg/cm^2 , 364.5Kg/cm^2 indicates higher load bearing values.

The Shell and Auger boring logs with SPT values are shown in figures 4a and 4b. The soil samples obtained indicate the presence of loose fine to coarse grained sand up to 1.5m depth. The presence of loose brownish peat with N-values is revealed beneath the top soil up to 5m depth. At 5 to 19.5m depth, medium dense brownish grey fine to coarse sand was encountered. Firm grey sandy clay was sampled between 19.5 to 28.5m. Below the depth of 28.5m medium dense brownish grey fine to coarse sand exists.

It is noteworthy that the three methods revealed similar soil layering consisting of loose sand, peat/clay layer, sandy clay and sand. The subsurface feature capable of being inimical to building structure discovered from the geotechnical and geophysical study of the site was the existence of loose sand, peat and clay at the near surface. While loose sand is cohesionless, peat and clay are more susceptible to subsidence and are also affected by environmental conditions such as temperature and moisture, which vary irregularly throughout the year (Soupios *et al* 2007). The presence of even a thin peat layer (an organic material) can lead to amplification in compressibility and reduction in the strength

of an otherwise good material. Continuous foundation footings should not be placed on soils consisting of loose sand and peat/clay layer because the differential settlements caused by such incompetent soils could deform the overlaid constructions severely. A mechanically stable coarse sand material indicates high load bearing capacity suitable for foundation of piles at 16m depth. In view of these incompetent shallow materials, deep foundation in which piles carry super-structural loads to competent soil at 16m depth is recommended for this site.

5 Conclusion

Geophysical and geotechnical study involving VES, CPT and SPT has revealed the presence of alternation of loose sand, clay/peat and sand layers in the shallow subsurface of the study area. The delineated clay and peat within the normal foundation depth exposed the presence of mechanically unstable soil formations which are considered inimical to the foundation of engineering structures that will be sited in the study area. Shallow foundation is therefore considered unsuitable for the intended building because of the presence of these incompetent materials. Coarse sand material of suitable competency was defined at 16m depth. In view of unsuitability of shallow foundation in this area, piling to a depth of 16m, which is in the coarse sand layer, would be suitable for the proposed structure. Foundations of large civil engineering structures within the study area should be safely founded on piles on the suggested depth of 16m. This study has showed the significance of combination of geotechnical and geophysical tools in engineering site characterization.

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