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Instrumentation for *in-situ* foundation investigation in Lagos, South West (SW) Nigeria

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In areas underlain by stratified rocks, it is difficult to obtain undisturbed samples at depth for satisfactory geotechnical results when analysed in the laboratory. Considering the complexity of its subsurface geology, a study on *in-situ* geotechnical exploration tool for foundation investigation in Lagos was conducted. Layer apparent resistivity (ρa) was measured with ABEM SAS 300 Terrameter using Schlumberger array at AB/2 ranging from 1.0 to 50.0 m. The resistivity curves were interpreted using the partial curve matching techniques, and computer iteration with RESIST software. Cone penetration test (CPT) was conducted with penetrometer unit of a cone apex angle 60° over an area of 10 cm^2. Winch and push rods were used to force the cone into the ground, while penetration resistance (q_c) was read from pressure gauge at 5 locations. Plots of q_c against depth of penetration were made in reverse order to obtain point resistance-depth curves. Allowable bearing capacity (ABC) of beds at depths of interest was estimated using Meyerhoff's formula in kN/m^2. The geological conditions to depth of about 13 m, from Shomolu to Ajah revealed a maximum of 5 layered soil types. Across the study area, the fourth layer of 0.5 to 1.1 m thickness range with minimum resistivity of 17 Ωm, constitutes the competent layer. Although, the resistivity value is characteristic of organic clay/coarse sand, the ABCs for shallow foundations, regardless of the width at depths of between 4.25 and 9.75 m are 288.9 and 675 kN/m^2, respectively. The geoelectric sections revealed broad composite nature of the underlying strata, while the CPT curves furnished information about the lithology variability of the underlying soils.

Key words: Geotechnical, resistivity, Lagos, foundations, penetration resistance.

INTRODUCTION

Apart from cost and difficulty of recovering undisturbed samples to provide satisfactory geotechnical information for site investigation in areas underlain by stratified rocks, instrumentation is another factor. For this particular reason, little or no attention has been paid to *in-situ* acquisition of accurate geotechnical information on the nature of subsurface conditions in such areas prior to construction project. The engineers also resolved that laboratory tests of undisturbed soil samples represent unconventional tests on a soil element, which happens to remain in the ground. It is obvious that result of tests on undisturbed samples cannot be scaled in any way to predict directly the behavior of a full scale construction (Carter and Bently, 1991).

Lagos metropolis is underlain by stratified sedimentary deposits with a high degree of lithologic variability (Onwuka, 1990). This factor as emphasized by Abam and George (1997) and Abam and Okogbue (1997), made the

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depth to foundation in such areas to remain unclarified. This paper presents the use of geoelectrical measurement and *in-situ* penetrometer as instrumentation for establishing soil profile, and predicting foundation conditions in a circumstance of an area underlain by stratified rocks. By these methods, surfacial geological mapping and identification of underlying rocks in the area are no longer required due to rapidity in urban development.

Research work on foundation investigation for structures, which made use of undisturbed samples or indirectly determined ground conditions for instance, Olorunfemi and Mesida (1987), Olorunfemi et al. (2000) e.t.c., were carried out in areas underlain by basement rocks. Olayinka and Oyedele (2001) employed electrical resistivity method only to assess ground conditions in a proposed Ibadan-Ilorin dual carriageway. This is definitely inadequate as geotechnical testing of samples either on the field or laboratory was not involved. Adebisi and Oloruntola (2005) showed much reliable results for recommendations on foundation design for a building underlain by basement rocks. In the study, vertical electrical sounding (VES) and horizontal resistivity profiling (HRP) were combined with cone penetrometer test (CPT) data in defining appropriate ground conditions.

Oyedele and Olorode (2010) revealed differential settlement of various degrees in several buildings at Medina Estate, Gbagada, and Lagos State. The site under investigation was found to be underlain by clay occurring from the ground level to over 20 m in many parts of the site. Although, sand bed of appreciable thickness occur at depth range of 14 to 25 m and above in some parts of the site, soils at shallow depths consist of extensive layer of extremely low shear strength formation and a corresponding high volume of compressibility potential. Oyedele and Okoh (2011) correlated geophysical and geotechnical data to define subsoils at Magodo Phase II Lagos, Nigeria. The generated geo-electric layers showed that the subsurface comprises topsoil, sandy clay (14.33 to 37.3 m), sand (3.35 to over 70 m), clay (22.4 to 43.89 m) and sand (27.64 to 55.89 m). However, plots of the penetration resistance versus depth showed competent layers at 14 and 18 m.

Approach to site investigation for structures using *in-situ* testing methods, has not been sufficiently employed in areas underlain by sedimentary rocks.The aim of this study is to employ *in-situ* means of information acquisition regarding subsoil conditions for foundation design instead of expensive and time-consuming sampling, which normally yield unreliable results. Careful interpretation geoelectrical data, and its correlation with penetration resistance – depth curves is expected to provide better subsurface picture capable of revealing heterogeneity and anisotropic nature of the formation. Furthermore, estimation of allowable bearing pressures is very possible, under circumstances beyond the capabilities of laboratory methods using Meryerhof's formula.

Physical setting and geology of the study area

Lagos area is located in Southwestern part of Nigeria within approximately between latitudes 6° 22'N – 6° 52'N and longitudes 2° 42'E - 3° 42'E (Figure 1). According to Odumosu (1992), the southern boundary of Lagos is formed by the 180 km Atlantic Coastline, while its northern and eastern boundaries are sheared with Ijebu towns and villages in the tropical region. On the western side, it is bounded by the Republic of Benin. Ojo (1990) noted that the relief and drainage patterns of Lagos, generally, influence the coastal location of the study area. The coastal lowlands which dominate the Lagos landscape form part of a wider stretch of the coastal zone of southern Nigeria (Abegunde, 1976). According to Akanni and Ojo (1990), the mode of landform evaluation in Lagos has been largely influenced physico-climatic characteristics, which include; rainfall amount, intensity and distribution character of vegetation. They exert dominant influence upon the dynamics of coastal landform processes in the area. In understanding the landform types of Lagos, vegetation and soil types have served as important indications of the spatial pattern of the landform (Figure 2).

Geologically, Lagos area is situated on a series of stratified sedimentary rocks in the Dahomey Miogeosynclinal Basin of Southwestern Nigeria. These rocks comprise silt, clay, peat or coal and sands of various sizes and composition. Onwuka (1990) identified two broad geological formations in Lagos area, which are Ilaro Formation and Coastal Plain sands. The Quarternary Formation of the Coastal Plain sands is more widely spread over the study area (Figure 3).

METHODS

Geophysical and geotechnical methods were employed in this study covering some selected areas of Lagos based on the challenges posed by the nature of their subsurface formation. The geophysical equipment used is ABEM Terammeter SAS 300 model. Data acquisition involved VES, which made use of the Schlumberger array with AB/2 varying from 1.0 to 50.0 m (that is, total current electrode spread of 100.0 m). Data processing began with plots of apparent resistivity (σ_a) on the y-axis against electrode spacing (AB/2) on the x-axis in a log-log paper to obtain resistivity curves. These curves were interpreted using the partial curve matching techniques of Orellana and Mooney (1966); Mooney (1980) and Velpen (1988) with computer iteration using RESIST software.

Cone penetration test (CPT) were carried out at 5 locations in those selected areas, which include, Shomolu, Ebute Metta, Ikoyi, Eleko, Gbagada and Ajah. The penetrometer unit consists of a cone having an apex angle of 60°and area of 10 cm^2 with a winch as well as push rods for pushing cone into the ground, and pressure gauge that indicates penetration resistance in Kg/cm^2.

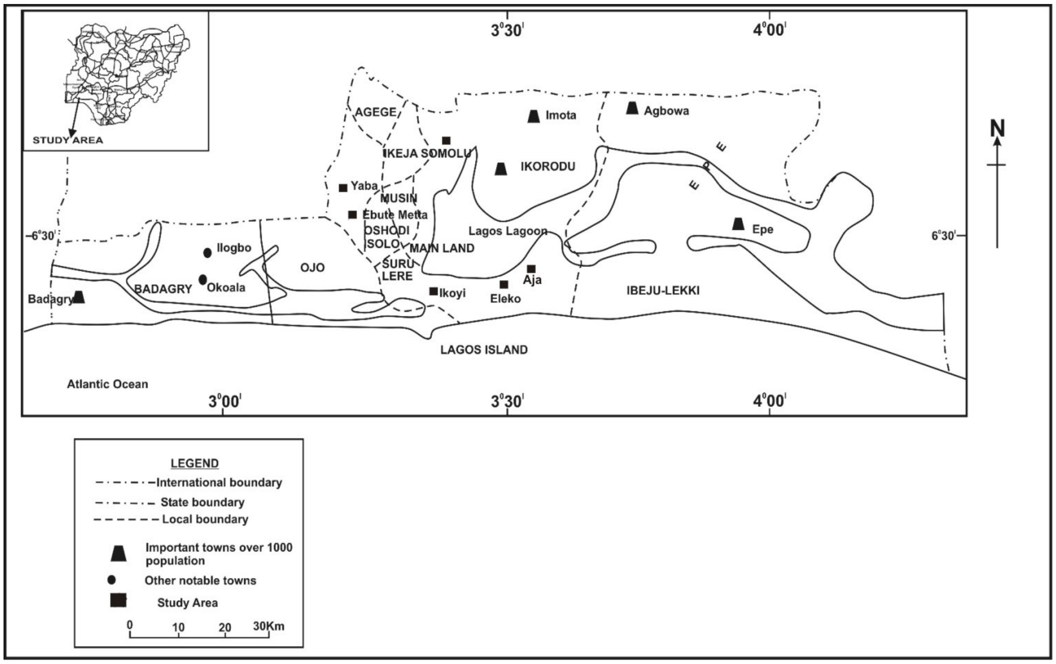

Figure 1. Generalised map of Lagos.

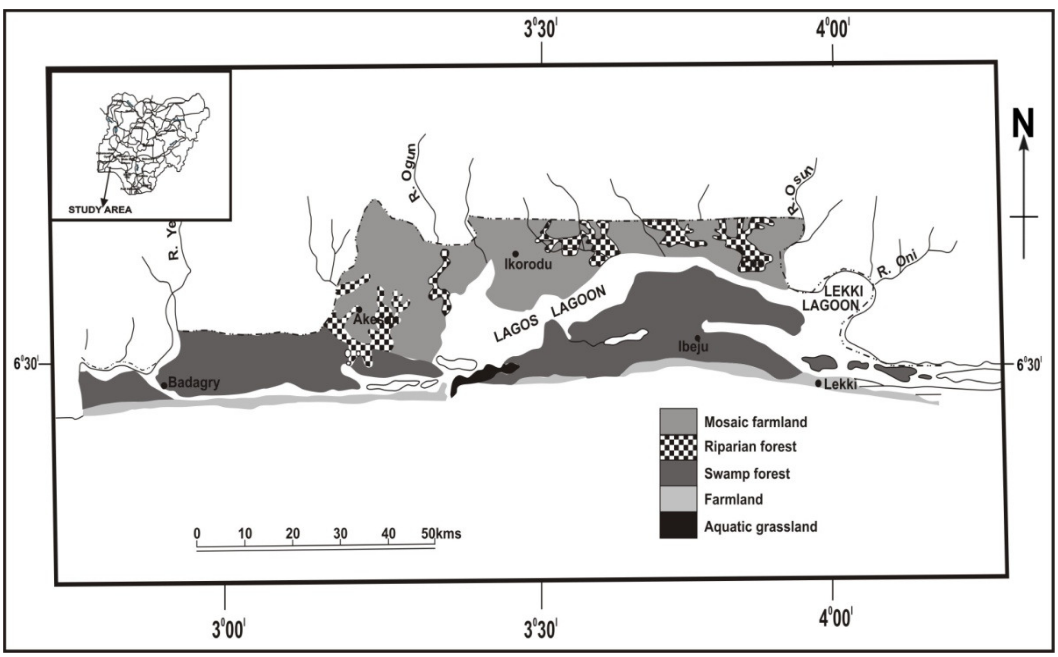

Figure 2. Map of vegetation distribution and drainage pattern of Lagos.

Plots of cone resistance against depth of penetration in metres were made to obtain point resistance-depth curves, while bearing values in kN/m^2 at depths of interest were estimated using Meyerhoff's formula $q_a = 2.7.q_c$. Where qa is the allowable bearing capacity expressed in kN/m^2, and qc is the cone resistance in Kg/cm^2.

RESULTS

The VES reveals that the geological conditions from Shomolu to Ajah are 2 to 5 layered soil types, and are summarized in Table 1. The first layer which has

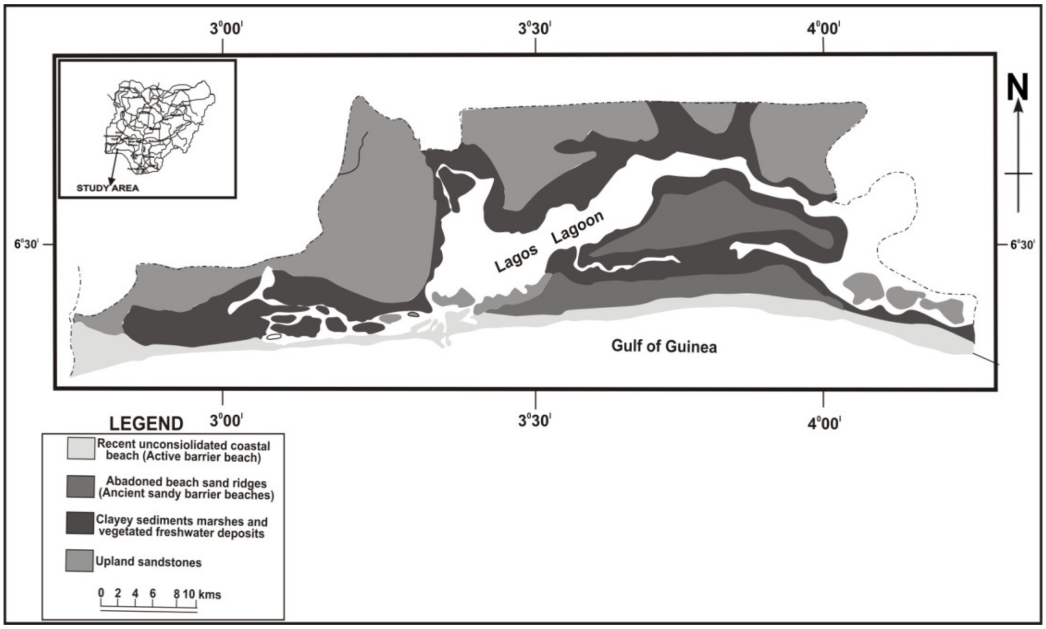

Figure 3. Map of surface geology and morphology of Lagos.

Table 1. Resistivity and layer thickness from VES data.

Location	Layers	Thickness (m)	Resistivity (Ωm)	Interpretation
Shomolu	1	0.94	41-163	Clay/Sandy Clay
	2	1.5	1711	Sand
	3	4.7	41	Organic Clay
	4	-	78333	Coarse Sand
Ebute Metta	1	0.6	200	Sand
	2	0.2	8	Organic Clay
	3	2.2	76	Clay
	4	-	206	Sand
Ikoyi	1	1.8	39-84	Clay/Inorganic Clay
	2	1.11	425	Sand
	3	4.7	46	Organic Clay
	4	0.5	1328	Coarse Sand
	5	-	100	Sandy Clay
Eleko	1	0.16	127	Sandy Clay
	2	4.3	294	Sand
	3	6.5	32	Organic Clay
	4	-	2302	Coarse Sand
Ajah	1	1.5	203-1084	Clayey sand
	2	-	169	

resistivity values ranging between 82 to 492 Ωm corresponds to the top soil, comprising clayey sand. Its thickness ranges from 0.1 to 1.26 m throughout the study area. The second layer reflects deposition of recent sediment. It is made up of sand and organic clay, with resistivity range of 294 to 1084 Ωm in Ajah and Eleko, as well as resistivity range of 8 to 41 Ωm in other places. The third layer is mainly organic clay of 2.2 to 7.1 m

Table 2. Generalised strata description of the study area from CPT data.

Depth range (m)	Strata description	Cone resistance (Kg/cm^2)
0.25 - 1.75	Clay/inorganic clay/Clayey sand	1.0 - 50.0
2.0 - 4.25	Organic clay/Sand	2.0 - 107.0
4.5 - 9.75	Organic clay/Clay/Clayey sand	12.0 - 250.0
10.0 - 13.75	Organic clay/Coarse sand	10.0 - 160.0

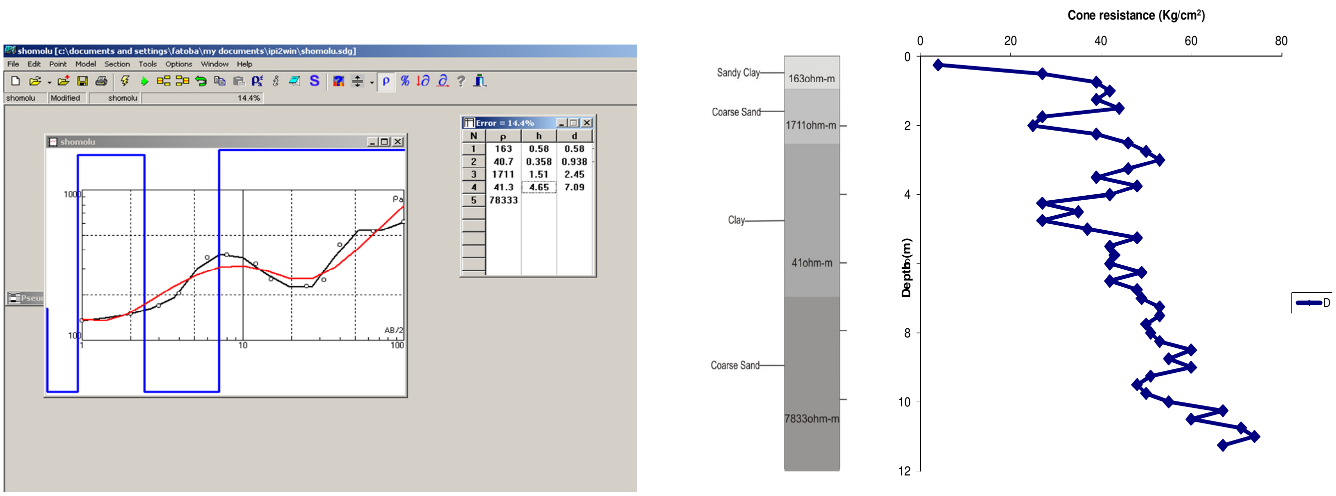

Figure 4. Resistivity curve, geoelectric section and penetration resistance at Shomolu.

thickness with resistivity range of 26 to 76 Ωm. The fourth layer has resistivity range of 17 to 78333 Ωm is organic clay/coarse sand with thickness ranging between 0.5 and 1.1 m. Results of penetrometer test are summarized in Table 2. On the basis of penetration resistance values, the strata compositions of the subsurface contain clayey sand with the exception of the formation below the depth of 10 m which contain coarse sand in addition. From CPT data, the first layer is 1.75 m thick with penetration resistance range of 1.0 to 50.0 Kg/cm^2 where inorganic clay/clayey sand are inferred. The second and third layers are made up largely of organic clay and sand having maximum cone resistance of 107.0 to 250.0 Kg/cm^2, form depth of 2.0 to 4.25 m, respectively.

DISCUSSION

Discussion of results for this study is limited to depth of 13.75 m, which is adequate for foundation investigation as corroborated by Adeyemi and Osammor (2001). The VES curves generated so far are characteristic of an area underlain by stratified rocks. On the basis of resistivity values, various soil types that make up every layer in the subsurface formation are defined. The subsoils to a depth of about 13 m, revealed 4 major geoelectric layers. The soil types range from sandy clay to organic clay. Throughout the study area, only Eleko recorded 6.5 m thickness, while Shomolu and Ikoyi recorded the maximum thickness of 4.7 m.

Figures 4 to 8 show correlations of geoelectric sections at each location with the corresponding penetration resistance in the study area. Although, both methods provided information about the soil types in the area however, the geoelectric sections revealed broad composite nature of the underlying strata, while the CPT curves furnished information about the lithology variability of the underlying soils. VES data obtained from this study, describing the stratified subsurface is consistent with findings of Koefoed (1979). Throughout the study area depths of 4.25 and 9.75 m displayed considerably high cone resistance. The allowable bearing capacities for foundations, irrespective of the width at those depths will be 288.9 and 675 kN/m^2 in the organic clayey sand - clayey coarse sandy formation. These values were estimated from Meyerhof's (1956) approximate formula.

Patterns displayed by both geoelectric section and the penetration-depth curves strongly defined the variation of the subsurface lithology in the study area. The portions of the underlying strata that are sandy show greater resistivity, and cone resistance than the portions of the strata that are clayey. Sand is known to be associated with high angle of internal friction and limited settlement,

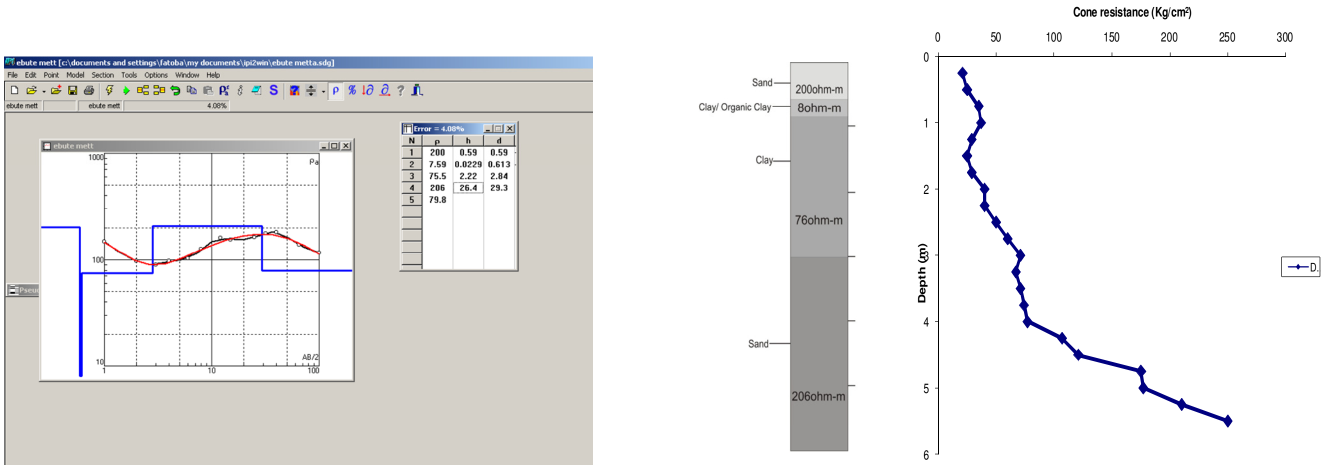

Figure 5. Resistivity curve, geoelectric section and penetration resistance at Ebute-Metta.

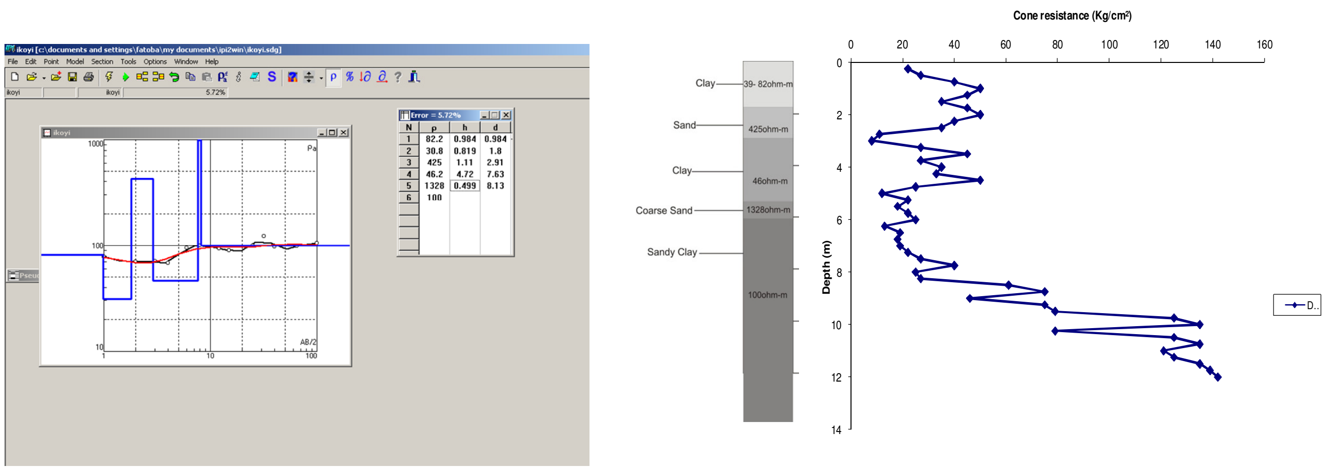

Figure 6. Resistivity curve, geoelectric section and penetration resistance at Ikoyi.

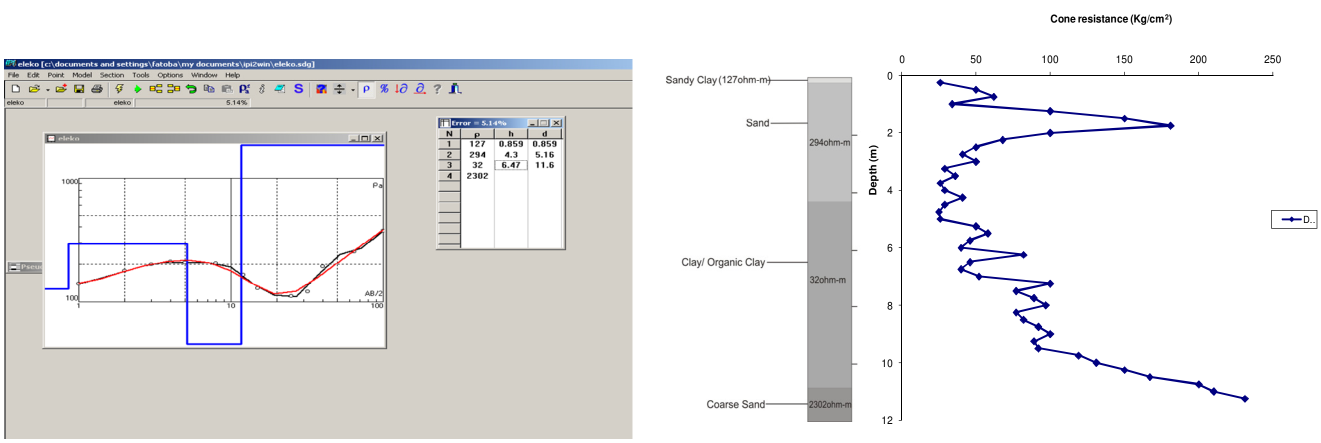

Figure 7. Resistivity curve, geoelectric section and penetration resistance at Eleko.

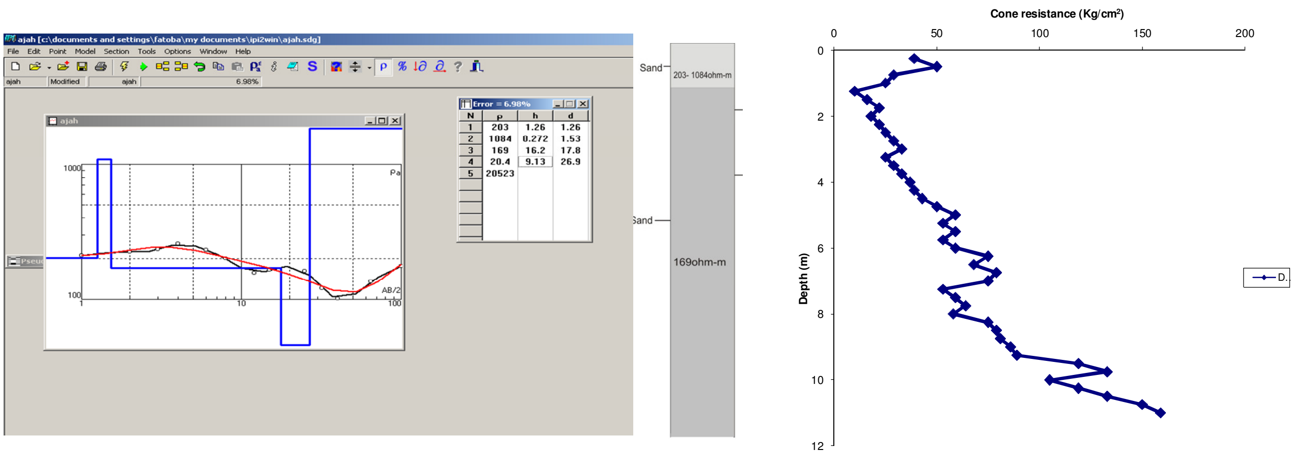

Figure 8. Resistivity curve, geoelectric section and penetration resistance in Ajah.

thus a shear failure is not likely occur at the specified depths.

Conclusions

The use of geophysical and geotechnical *in-situ* instruments made it possible to acquire information about the subsurface over a substantial area, and depth for near surface stratigraphy and in the determination of allowable bearing capacity at zones of interest to foundations. Method of cone penetrometer is of advantage over VES by revealing localized variations in the subsurface strata. Unlike the time-consuming laboratory methods which require boring of holes/pits, the equipment for *in-situ* methods are easily deployed and easily detect competent beds for structural loading.

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APPENDIX

Depth (m)	Eleko (CPT)	Ikoyi (CPT)	Shomolu (CPT)	Yaba (CPT)	Ebute metta (CPT)	Ajah (CPT)	Gbagada (CPT)
0.25	26	22	4	0	21	39	1
0.5	50	27	27	21	25	50	2
0.75	62	40	39	25	35	29	3
1	34	50	42	29	37	25	4
1.25	100	45	39	33	29	10	5
1.5	150	35	44	32	25	16	5
1.75	181	45	27	38	29	22	5
2	100	50	25	47	40	18	6
2.25	68	40	39	37	40	22	8
2.5	50	35	46	38	50	25	6
2.75	41	11	50	47	60	29	7
3	50	8	53	54	71	33	4
3.25	29	27	46	50	67	25	11
3.5	36	45	39	49	71	29	12
3.75	26	27	48	50	74	33	22
4	29	35	42	59	77	37	10
4.25	41	33	27	67	107	39	19
4.5	29	50	35	63	121	43	17
4.75	25	25	27	69	175	50	14
5	26	12	37	71	177	59	12
5.25	50	22	48	79	210	53	13
5.5	58	18	42	81	250	59	100
5.75	46	22	43	77		53	100
6	40	25	42	89		59	106
6.25	82	13	49	108		75	111
6.5	46	19	42	121		68	119
6.75	40	18	48	128		79	125
7	52	19	49	150		75	131
7.25	100	22	53	166		53	135
7.5	77	27	53	170		59	137
7.75	89	40	50	181		64	140
8	97	25	51			58	143
8.25	77	27	53			75	144
8.5	82	61	60			79	146
8.75	92	75	55			81	148
9	100	46	60			86	149
9.25	89	75	51			89	151
9.5	92	79	48			119	156
9.75	119	125	50			133	158
10	131	135	55			105	160
10.25	150	79	67			119	
10.5	167	125	60			133	
10.75	200	135	71			150	
11	210	121	74			159	
11.25	231	125	67				
11.5		135	69				
11.75		139	75				
12		142	78				
12.25			100				
12.5			101				

Appendix. Contd.

12.75	100
13	111
13.25	120
13.5	150