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Full Length Research Paper

Subsoil investigation using integrated methods at Lagos, Nigeria

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The application of geophysical and geotechnical methods in subsoil investigation at Magodo phase II Lagos, Nigeria has revealed the presence of five subsurface geo-electric layers. This consists of topsoil, sandy clay, sand, clay and sand. The sand ranges in thickness from 14.33 to 37.3 m while the depth to the sand body varies from 3.35 to over 70 m. The clay layer ranges in depth from 22.4 to 43.89 m while its thickness varies from 27.64 to 55.89 m. The 2-D resistivity profiles revealed the lateral variation of the subsurface litho-logy with depth. Also the cone penetrometer test (CPT) shows competent values for penetrative resistance at 14 to over 18 m. The study shows that shallow foundation is feasible in some part of the study area. The results of the two methods correlate well with each other.

Key words: Pseudo-section, geo-electric section, resistivity, cone resistance, expansive clay.

INTRODUCTION

In recent time, the statistics of failures of engineering structures such as roads, buildings, and bridges throughout the nation has increased geometrically. Several probable reasons speculated to have been responsible for this ugly incidence have been highlighted by the engineering community. These include inadequate supervision, poor construction materials, non compliance to specifications etc. Unfortunately, one particular and or /major point that has always not been given serious attention in this part of the world is the lack of adequate information on the nature of subsurface conditions prior to construction exercise. However, since every engineering structure is seated on geological earth materials, it is imperative to conduct pre-construction investigation of the subsurface of the proposed site in order to ascertain the strength and the fitness of the host earth materials as well as the timed post-construction monitoring of such structure to ensure its integrity. The need for pre - foundation studies has therefore become necessary so as to prevent loss of valuable lives and properties that always accompany such failures.

In many coastal areas of the world, Lagos as an example, the near surface soil is of expansive clay (Coertz, 1996). Expansive clay behaves differently than sandy soil. Sandy soil does not expand when it gets wet instead the water fills the air space between the grains of sand. Because of this, the soil volume does not change and there is little movement of structures supported by the soil when the soil moisture conditions alternate between wet and dry. Expansive clay soil expands when it absorbs water. Water becomes bound to the clay particles. As the soil goes through wet and dry periods, the soil expands and contracts. Structures sitting on top of the clay soil rise and fall with the soil. If this happened uniformly across the structures, damage to the foundation and finishes from soil movement would be limited. Unfortunately, uniform shrinking and swelling does not usually happen. The result is “differential” foundation movement, which causes cracking and distress. In view of the above, an integrated geophysical and geotechnical methods were employed to investigate the subsoil conditions at Magodo area of Lagos as an aid to engineering construction exercise.

For geophysical studies, electrical resistivity method is the most common technique used for such purpose (Gowd, 2004; Neil and Ahmed, 2006; Susan, 2004; Olorunfemi and Meshida, 1987; Dahlin, 1996). This is because the method is reliable, efficient and cost effective. Information such as thickness of the

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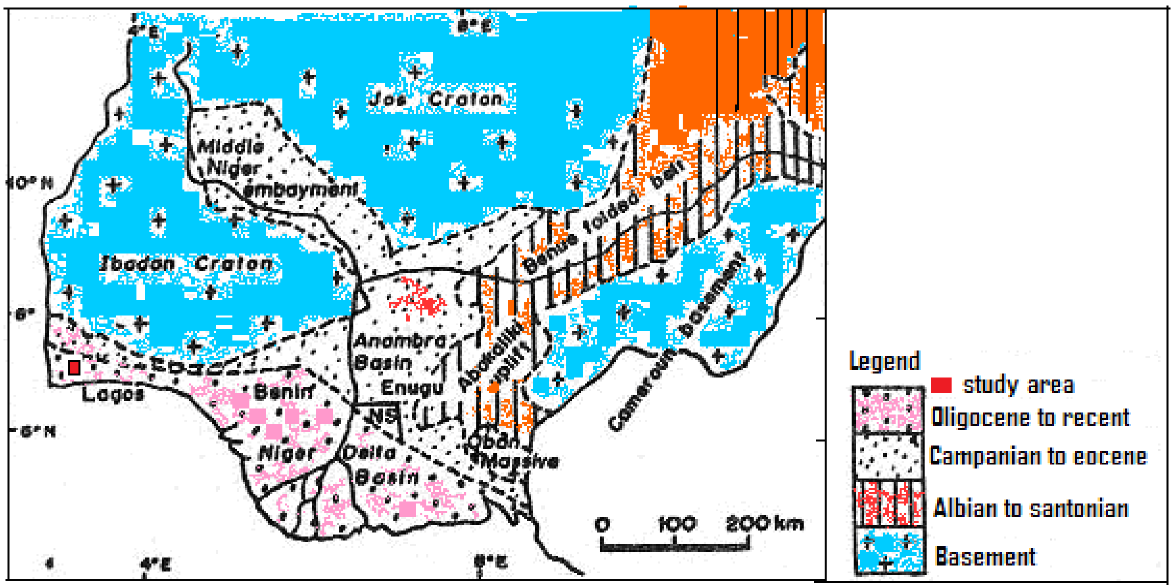

Figure 1. Part of the geologic map of Nigeria showing the study area.

geological layers, depth to geological beds, depth to water table, depth to buried metals, delineation of contaminant plumes etc can be determined. On the other hand, Cone penetrometre test (CPT) has been the most widely used method amongst geotechnical techniques (Baldi et al., 1995; Lunne et al., 1997; Coerts, 1996; Eslaamizand and Robertson, 1998). Cost, efficiency, speed, simplicity, reliability and the ability to provide continuous information on the soil properties with depth are the important reasons for the increasing popularity of CPT.

MATERIALS AND METHODS

Geological setting

The study area lies within the Dahomey sedimentary basin. The basin extends from the eastern part of Ghana through Togo and Benin Republic to the western magin of the Niger Delta (Figure 1). The base of the basin consists of unfossiliferous sandstones and gravels weathered from underlying Precambrian basement. On top of these are marine shales, sand stones of Albian to Santonian ages deposited prior to the Santonian tectonic episode (Omatsola and Adegoke, 1981). The Quaternary geology of the study area comprises the Benin Formation (Miocene to Recent), recent lithoral alluvium and lagoon/coastal plain sand deposits (Durotoye, 1975; Longel et al., 1987). The alluvial deposits consists mainly of sands with clay intercalations; litholoral and lagoon sediments formed between two barrier beaches and coastal plain sands (Adeyemi, 1972).

Field technique

The vertical electrical sounding (VES) using Schlumberger array system and horizontal profiling (HP) using dipole-dipole array system were conducted along three traverse lines. Terrameter SAS 1000 system was employed in data collection. SAS stands for Signal Averaging System, a method whereby consecutive readings are taken automatically and the results averaged continuously. SAS results are more reliable than those obtained using single-shot systems. A total of 16 VES points and 3 HP lines were covered (Figure 2). Also two (2) cone penetrometer test (CPT) were conducted. The VES data obtained were processed using WingLink software. A WingLink data-base contains the data for all surveys carried out in the area of interest. Information on the central meridian, the projection used for the station coordinates, and the linear units used for distances and depths are stored in the database properties. By this technique, minor errors due to manual interpretation are eliminated.

The cone penetrometer test (CPT) was carried out at 3 locations on each traverse lines by forcing a hardened steel cone with a base area of 1000 mm^2 at an apex angle of 60° continuously into the ground and measuring its resistance to penetration. The 2 ½ ton equipment is a manually operated unit furnished with a single cone that can measure the end resistance, q_c only. The cone was advanced at regular intervals of 25 cm and the corresponding pressure required to advance it is transmitted to a gauge which in turn records this pressure value. This procedure was repeated until the required depth is either reached or the total resistance to

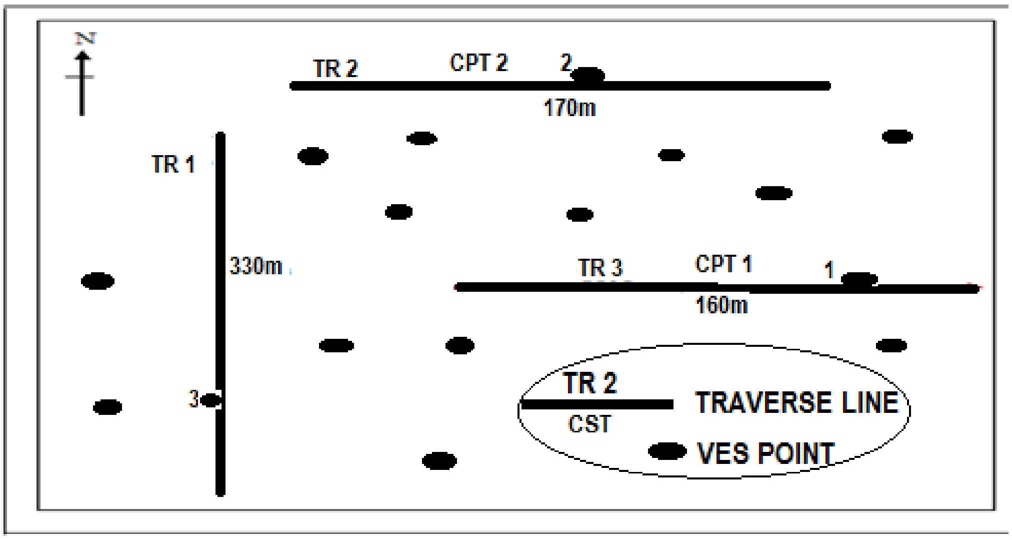

Figure 2. Base map of the study area showing the data points.

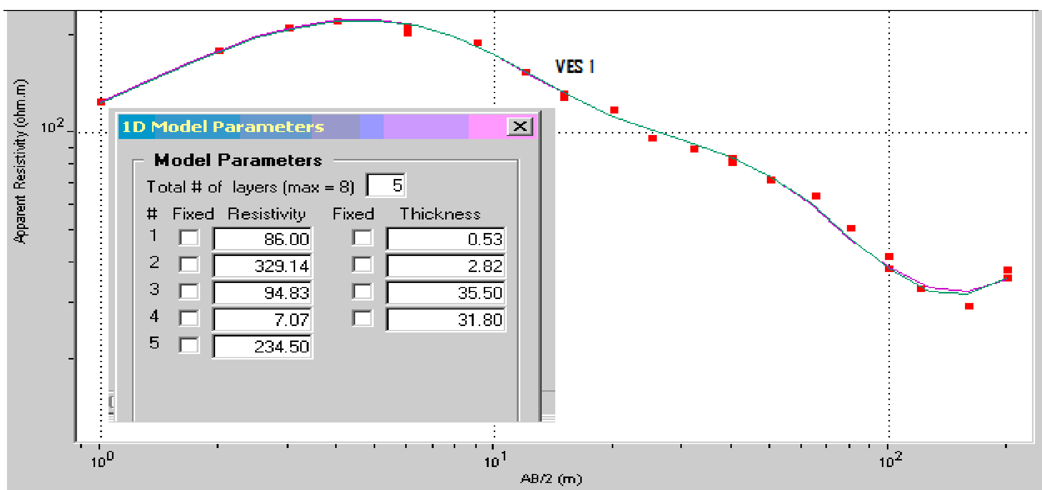

Figure 3a. Sample of computer iterated field curve.

penetration of the tubes and cone reaches the capacity of the machine. Successive cone resistance readings were plotted against depth to form a resistance profile which indicates the strata sequence penetrated (Figure 10).

RESULTS

Presentation of results

The interpreted results were presented in the form of curves, geo-electric sections, contoured maps, pseudo-sections, graphs and tables (Figures 3 to 10 and Tables 1 and 2).

DISCUSSION OF RESULTS

Curves and geo-electric sections

The one dimensional resistivity curves (Figure 3) is made up of four layers. The qualitative interpretation shows one QQH and two KQH curves. The quantitative interpretation was achieved using inversion software called WinGLink. The geo-electric section AA' (Figure 4) gives visual representation of the litho-logic units identified. The result shows that the area has five geo-electric layers namely topsoil, sandy clay, sand and clay. The topsoil constitutes the first geo-electric layer with thickness that ranges from 0.53 to 1.07 m and resistivity value that varies between

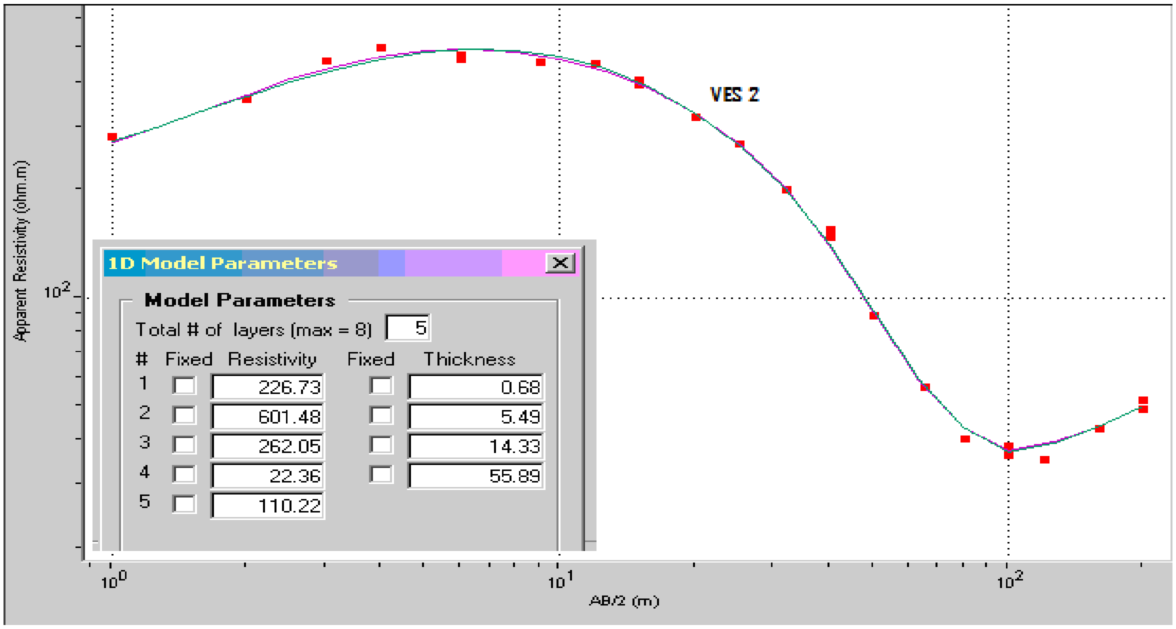

Figure 3b. Sample of computer iterated field curve.

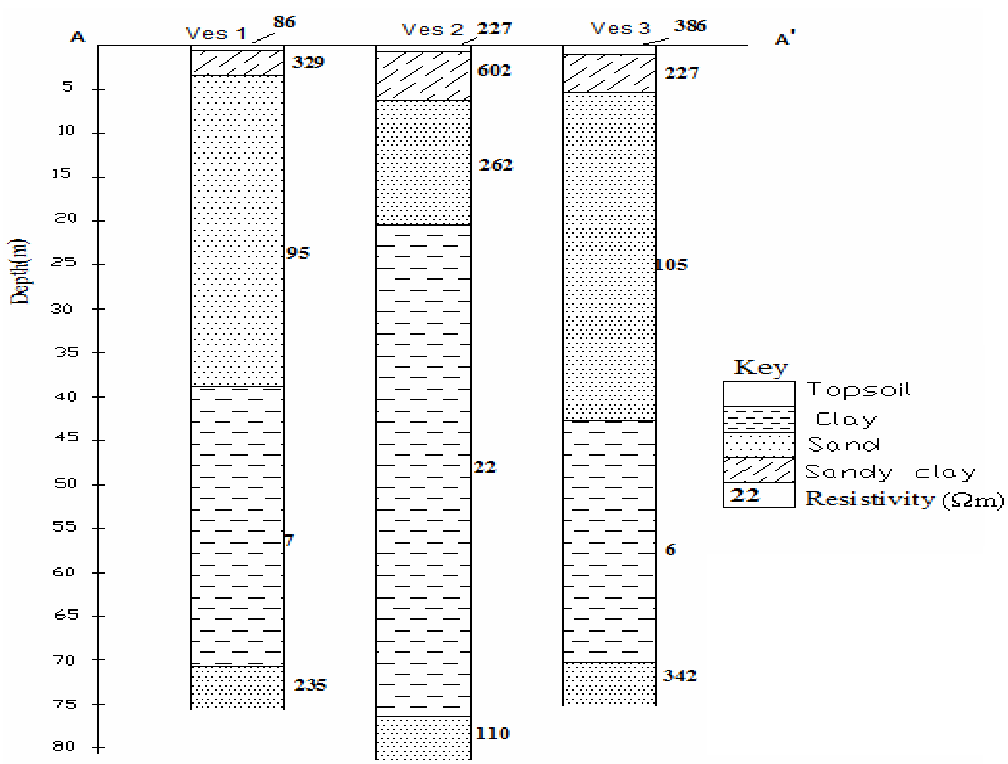

Figure 4. Geoelectric section along traverse AA'.

86 and 386 Ωm. The second layer is made up of sandy clay with resistivity value that varies between 227 and 602 Ωm and thickness value that ranges from 2.82 to 5.49 m. The third geo-electric layer consists of sand with resistivity value that ranges from 95 and 262 Ωm and thickness values that varies from 14.33 to 37.3 m. The

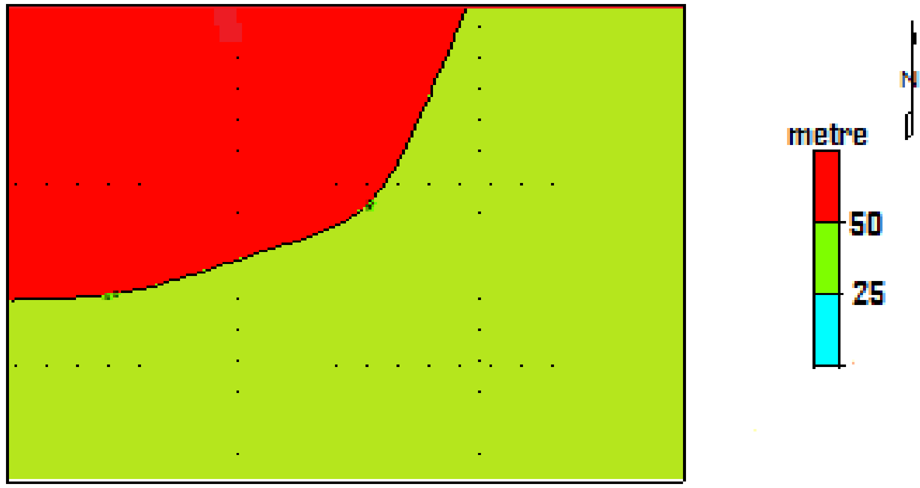

Figure 5. Isopach map of clay layers.

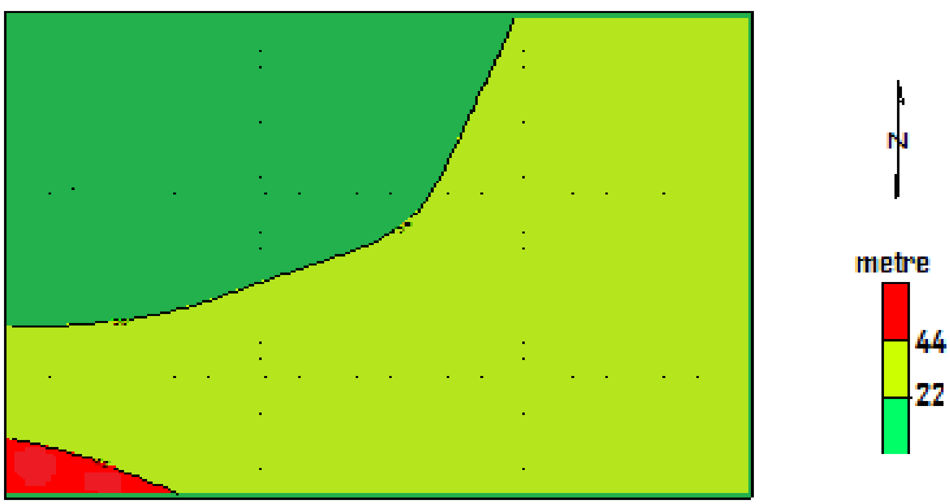

Figure 6. Contoured map of depth to clay layers.

forth geo-electric layer is made up of clay with resistivity value that varies from 110 and 342 Ωm and thickness values that vary from 27.6 to 55.9 m. The fifth layer consists of sand with infinite thickness because of the termination of current at this layer.

Contoured maps

Four maps were produced, two each for sand and clay layers. Figures 5 and 6 show the isopach map for clay and depth to clay layer respectively. In Figure 5, it is seen that almost 65% of the area has clay thickness value in the neighborhood of 25 m while the remaining portion has clay thickness value of about 35%. On the other hand, Figure 6 shows that the depth to clay layer varies from less than 70 m in some parts to over 75 m in other parts of the area. Figure 7 shows the isopach map of sand layer. Here, it is shown that less than 20% of the area has sand thickness value that is less than 15 m while the remaining part has sand thickness value that is less than 30 m. In Figure 8, almost three-quarter part of the area show the depth to sand layer to be less than 2 m while the remaining portion show the depth to sand layer to be above 6 m.

Pseudo-sections

Figures 9 shows representative sample of the two dimensional resistivity pseudo-sections of the study area

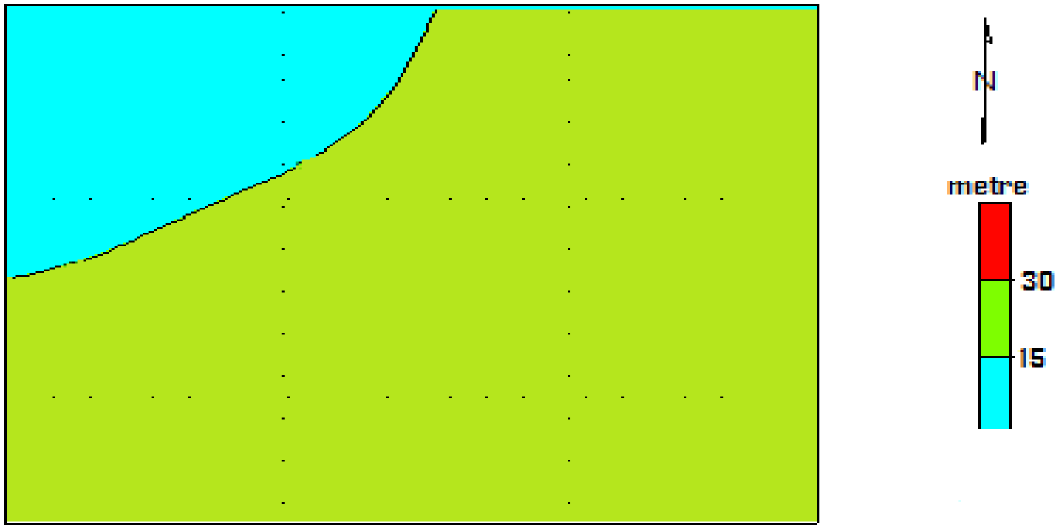

Figure 7. Isopach map of sand layers.

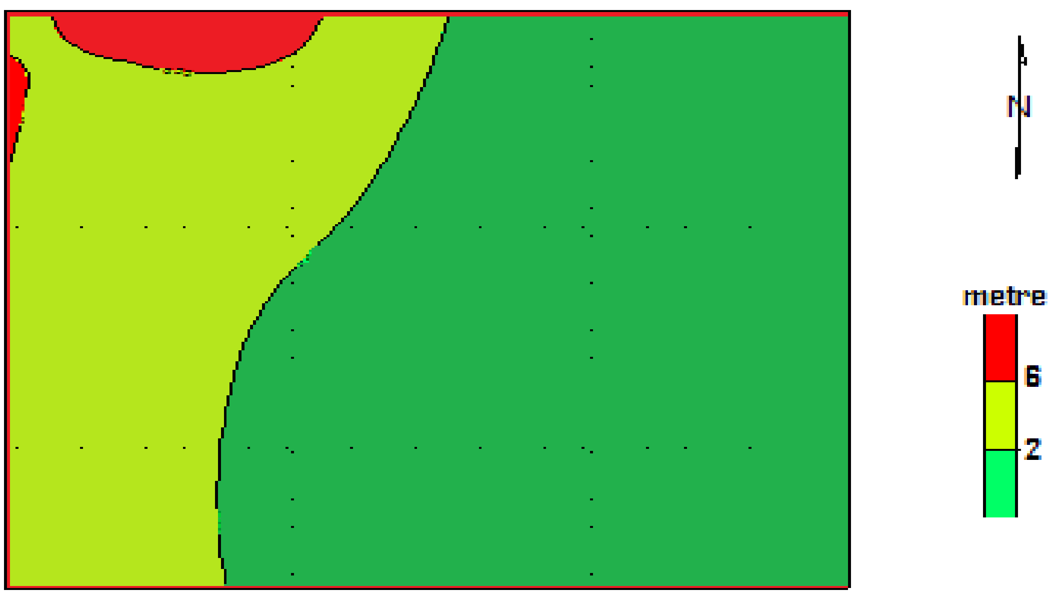

Figure 8. Contoured map of depth to sand layers.

showing the lateral variation of the subsurface litho-logy with depth. Traverse 1 is the longest of all the traverses (Figure 9a). It has a length of about 310 m. VES 3 was shot at 140 m on the traverse. Here the litho-stratigraphical variation along the horizontal axis bears close resemblance with that on the vertical axis (Figure 4). The second traverse has a length of 170 m and VES 2 was shot at 80 m. VES 1 was shot on the third traverse at 50 m. Also the lateral subsurface litho-logical variation bears close resemblance with the vertical variation. The main observable litho-logy consist of sandy clay, sand, clay and clayey sand occurring at various depths.

Graphs

The data obtained from the CPT measurements was used to produce the plots of cone reading against the depth (Figure 10). Table 2 shows the data for CPT 1 and the calculated bearing capacity using Meyehorf equation.

$q_a = 2.7\ q_c\ kN/m^2$

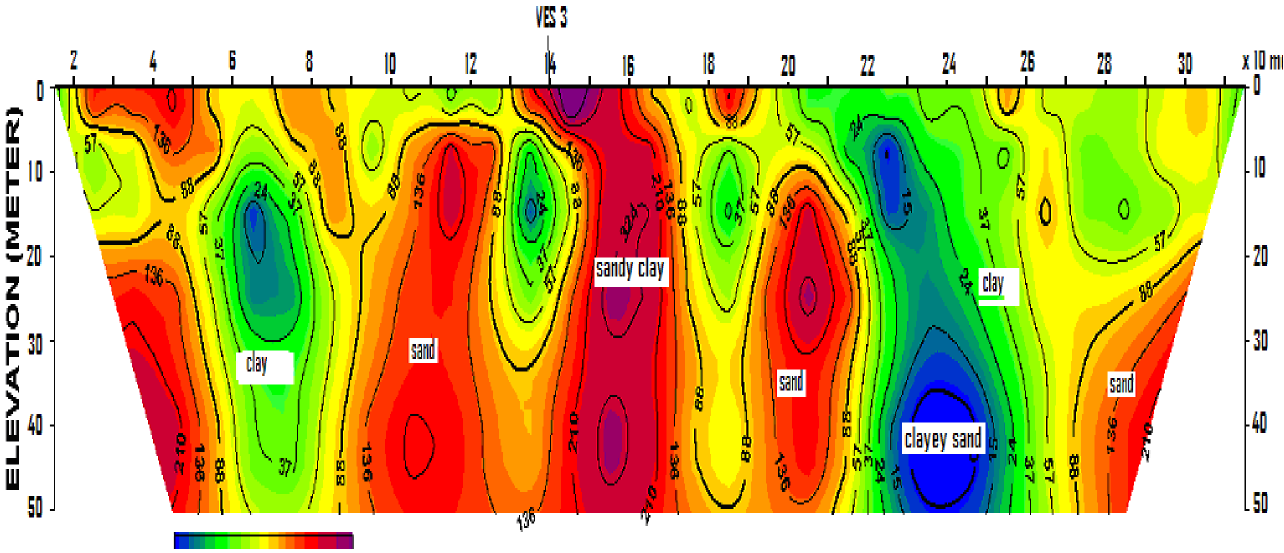

Figure 9a. 2-D pseudo-section for traverse 1.

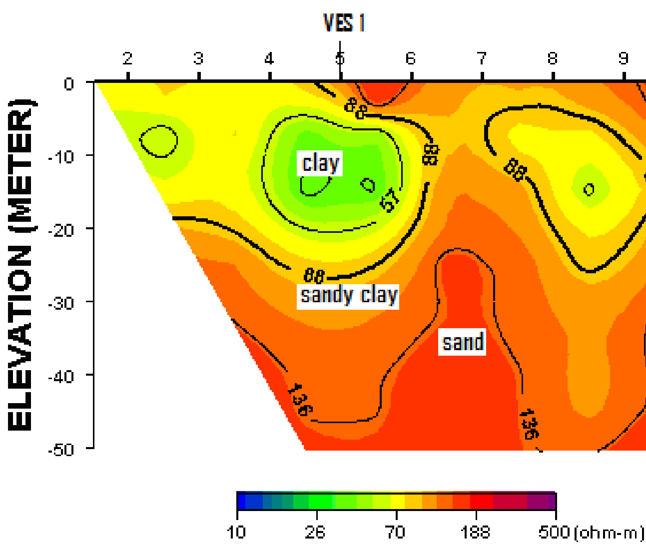

Figure 9b. 2-D pseudo-section for traverse 3.

Where q_a is the allowable bearing capacity; q_c is the cone resistance.

For the purpose of foundation construction, an average value for penetrative resistance for competent subsurface materials is taken as 100 kg/cm^2. The corresponding value for allowable bearing capacity (qa) is 26460 KN/m^2 while the value for the ultimate bearing capacity qu (KN/m^2) is given as 79380 KN/m^2. Table 2 shows the various parameters obtained from the penetrative resistance. These are the tip resistance in standard unit (KN/m^2) and the calculated allowable bearing capacity in KN/m^2. The plot for cone reading in CPT 1 (Figure 10a) shows values which vary from 0 to 194 kg/cm^2. From a depth of 0 – 14.5 m the cone reading ranged from 0 – 89 kg/cm^2. At 14.75 m the penetrative reading was 104 kg/cm^2 which is greater than 100 kg/cm^2, this implies competent material. However at 15.25 – 15.5 m and 16.25 – 16.5 m the cone reading showed values that vary between 70 – 74 kg/cm^2 which does not represent competent material. Beyond 16.5 m, that is, from 16.75 m to the point of termination, the cone reading ranges from

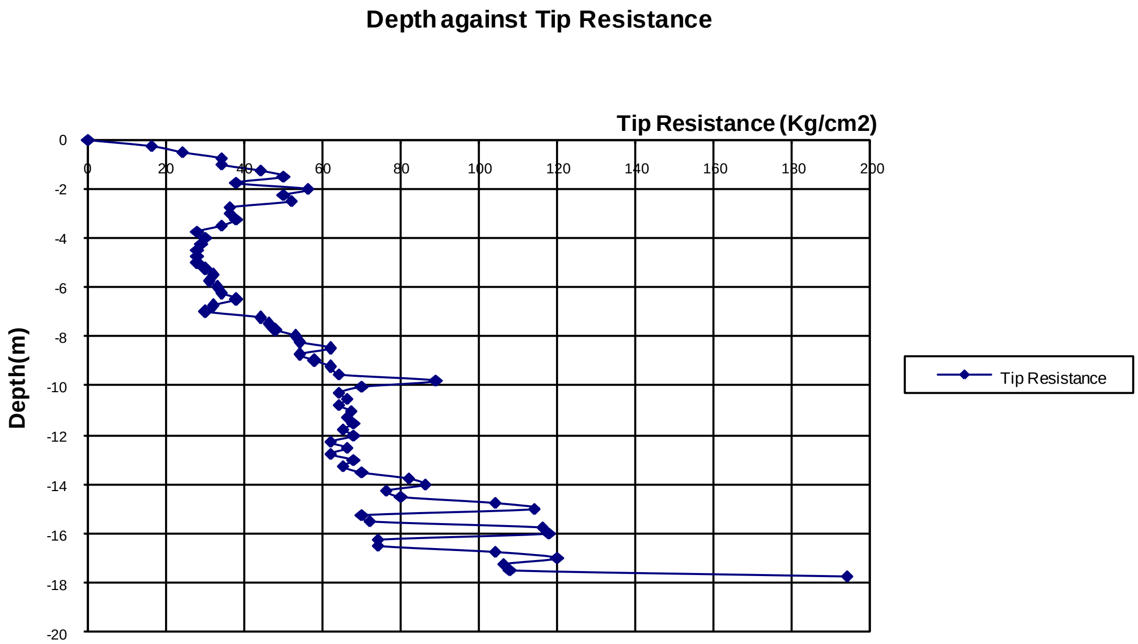

Figure 10a. Plot of cone reading (Kg/cm^2) versus depth (m) for CPT 1.

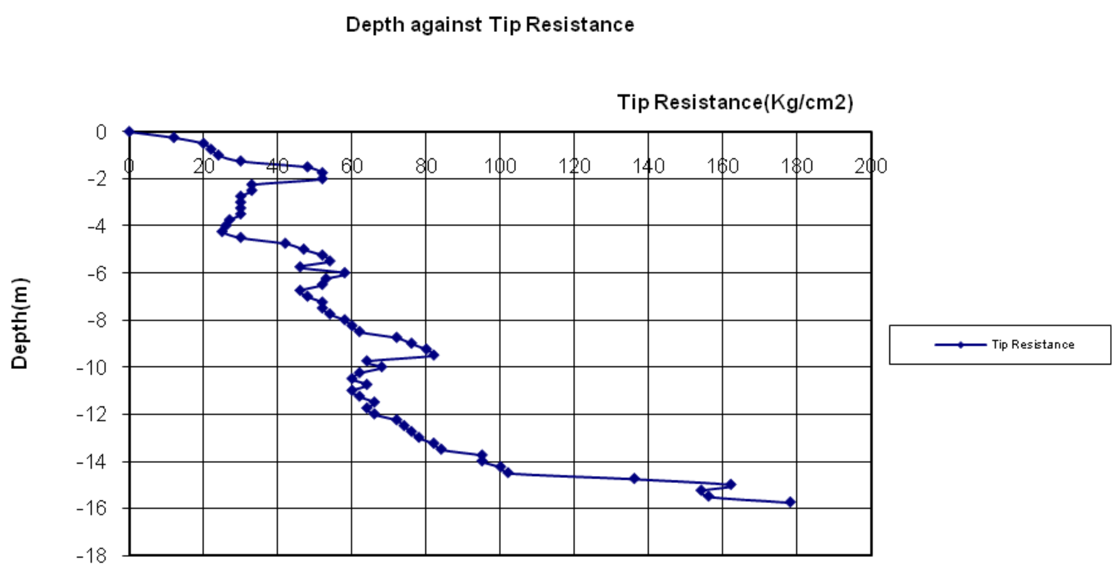

Figure 10b. Plot of cone reading (Kg/cm^2) versus depth (m) for CPT 2.

104 to 194 kg/cm^2. For CPT 2 (Figure 10b), the penetrative resistance varies from 0 to 95 kg/cm^2 starting from the surface to a depth of 14 m. From 14.25 to 15.75 m, the cone reading varies from 100 to 178 kg/cm^2. In the nut shell, the results of the geotechnical analysis show the presence of competent materials at the depth range of 14 to over 18 m. This correlates well with the results of geophysical analysis as seen in (Figure 8).

Conclusion

The integrated geophysical and geotechnical investigations carried out at Magodo phase II Lagos has revealed the presence of five subsurface geo-electric layers. This consists of topsoil, sandy clay, sand, clay and sand. The sand ranges in thickness from 14.33 to 37.3 m while the depth to the sand body varies from 3.35

Table 1. Sample of interpreted VES data.

VES	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type
	1	86.00	0.53	0.53	Topsoil	
	2	329.14	2.82	3.35	Sandy clay	
1	3	94.83	35.5	38.85	sand	KQH
	4	7.07	31.8	70.65	Clay	
	5.	234.50			Sand	
	1	226.73	0.68	0.68	Topsoil	
	2	601.48	5.49	6.17	Sandy clay	
2	3	262.05	14.33	20.5	Sand	KQH
	"	22.36	55.89	76.39	Clay	
	5	110.22			Sand	
	1	385.92	1.07	1.07	Topsoil	
	2	227.10	4.28	5.35	Sandy clay	
3	3	105.29	37.3	42.65	Sand	QQH
	4	5.71	27.64	70.29	Clay	
	5	342.12			Sand	

Table 2. Cone penetrometer test (CPT 1) and the calculated bearing capacity.

Depth (m)	qc (Tip Resistance) kg/cm^2	Tip resistance (in standard unit) (KN/m^2)	qa calculated allowable bearing capacity (KN/m^2)
0.0000	0.0000	0	0
0.2500	16.0000	1568	4234
0.5000	24.0000	2352	6350
0.7500	34.0000	3332	8996
1.0000	34.0000	3332	8996
1.2500	44.0000	4312	11642
1.5000	50.0000	4900	13230
1.7500	36.0000	3528	9526
2.0000	56.0000	5488	14818
2.2500	50.0000	4900	13230
2.5000	52.0000	5096	13759
2.7500	36.0000	3528	9526
3.0000	36.0000	3528	9526
3.2500	36.0000	3528	9526
3.5000	34.0000	3332	8996
3.7500	28.0000	2744	7409
4.0000	30.0000	2940	7938
4.2500	29.0000	2842	7673
4.5000	28.0000	2744	7409
4.7500	28.0000	2744	7409
5.0000	28.0000	2744	7409
5.2500	30.0000	2940	7938
5.5000	32.0000	3136	8467
5.7500	31.0000	3038	8203
6.0000	33.0000	3234	8732
6.2500	34.0000	3332	8996
6.5000	36.0000	3528	9526

Table 2. Contd.

6.7500	32.0000	3136	8467
7.0000	30.0000	2940	7938
7.2500	44.0000	4312	11642
7.5000	46.0000	4508	12172
7.7500	48.0000	4704	12701
8.0000	53.0000	5194	14024
8.2500	54.0000	5292	14288
8.5000	62.0000	6076	16405
8.7500	54.0000	5292	14288
9.0000	58.0000	5684	15347
9.2500	62.0000	6076	16405
9.5000	64.0000	6272	16934
9.7500	69.0000	6762	18257
10.0000	70.0000	6860	18522
10.2500	64.0000	6272	16934
10.5000	66.0000	6468	17464
10.7500	64.0000	6272	16934
11.0000	67.0000	6566	17728
11.2500	66.0000	6468	17464
11.5000	68.0000	6664	17993
11.7500	65.0000	6370	17199
12.0000	68.0000	6664	17993
12.2500	62.0000	6076	16405
12.5000	66.0000	6468	17464
12.7500	62.0000	6076	16405
13.0000	68.0000	6664	17993
13.2500	65.0000	6370	17199
13.5000	70.0000	6860	18522
13.7500	82.0000	8036	21697
14.0000	86.0000	8428	22756
14.2500	76.0000	7448	20110
14.5000	80.0000	7840	21168
14.7500	104.0000	10192	27518
15.0000	114.0000	11172	30164
15.2500	70.0000	6860	18522
15.5000	72.0000	7056	19051
15.7500	116.0000	11368	30694
16.0000	118.0000	11564	31223
16.2500	74.0000	7252	19580
16.5000	74.0000	7252	19580
16.7500	104.0000	10192	27518
17.0000	120.0000	11760	31752
17.2500	106.0000	10388	28048
17.5000	108.0000	10584	28577
17.7500	194.0000	19012	51332
18.0000			
18.2500			
18.5000			
18.7500			

to over 70 m. The clay layer ranges in depth from 22.4 to 43.89 m while its thickness varies from 27.64 to 55.89 m. The 2-D resisstivity profiles revealed the lateral variation of the subsurface litho-logy with depth. Also the CPT shows competent values for penetrative resistance at 14 to over 18 m. The study shows that shallow foundation is feasible in some part of the study area.

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