Integration of Geoelectrical and Geotechnical Data for Soil Characterization in Parts of Owerri Metropolis Southeastern Nigeria

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***Abstract*:- The increasing rate of building and construction projects in Owerri Metropolis given the topographic nature has necessitated proper evaluation of the foundation beds in relation to elevation, to assess the suitability of the soil for engineering structures. Consequently, an integrated geoelectric and geotechnical approach of investigating soil characteristics was adopted. Ten Vertical Electrical Soundings (VES) were carried out using the OHMEGA-500 resistivity metre to acquire data which were analysed using the advanced Geosciences Incorporation (AGI) 1D Software package. At each VES location, elevation and coordinates were measured and soil samples collected to a depth of 2m were grouped to form three composite samples according to the elevation of the study area namely high, medium and low elevations. The samples were then subjected to laboratory tests for geotechnical parameters. The topsoil is composed of sand and laterite with resistivity ranging from 41.6Ωm to 7532Ωm and thickness of 3.2m. Elevation ranges from 140ft to 450ft. Geotechnical results revealed moisture content of 11.33 to 14.33%, liquid limit of 19.2 to 22.8 and plastic index (PI) of zero, showing none plastic soil. Grain size analysis revealed medium-dense sand with negligible gravel or silt. Compaction test result gave Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of 1.8 to 1.99 and 13 to 15% respectively. Triaxial test revealed the angle of internal friction of 18 to 27with cohesion values ranging from 20KN/m^{2}to 49KN/m^2 indicating high strength to shearing and high tendency to withstand load. All measured parameters fall within recommended standards in spite of variation in elevation.**

***Keywords*: Elevation, Resistivity, Geoelectric, Geotechnical, Compaction**

I. INTRODUCTION

The rapid growth in population and infrastructural development in Owerri and its environs require proper structural planning and development. Poor planning and the inability to carry out pre-development geophysical studies have resulted in lots of structural problems causing flood disasters (Ekwe*et al*., 2006), faulty road networks, water supply systems, sanitary and drainage systems, challenging mobility, dilapidation of buildings with conspicuous fracture and cracking on the walls, loss of properties and resources, sinking of buildings and total collapse of buildings which eventually leads to loss of properties and lives (Chendoand Obi, 2015).

Geoelectrical and geotechnical surveys are valuable techniques in the study of subsurface properties and characterization of soil for engineering structure foundation. Expansive soils in construction sites have significant influence on planning, structural design, construction, maintenance costs, performance and engineering life, especially for shallow foundation structures. Expansive soils are susceptible to considerable volume changes with response to fluctuations in groundwater table and moisture content following seasonal climatic changes. This property can cause severe damages to infrastructure unless proper measures are taken in the design and construction phases (Chen, 1988). Identification of expansive soils and characterization of their anticipated behaviour is thus important for all civil engineering structures (Nibret, 2011).

In the process of characterization, different techniques and procedures are applied for interpretation of sub grade soil condition. These interpretation techniques are often site specific and are influenced by geological, topographic, and climatic conditions. The data collected in the field, soil samples tested in the laboratory and results obtained determine the design of the structure as well as construction cost of the project. Hence, prior to construction, the sub grade soils on which the structure is to be constructed have to be sampled and investigated for the suitability of load bearing capacity. This indicates their response towards the application of load without significant failure of its plasticity nature and swelling ability.

The conventional methods for determination of soil engineering properties are invasive, costly and time-consuming. However, electrical resistivity survey is an attractive tool for delineating subsurface properties without soil evasion or destruction. Better still, it is cost effective (Fahad and Syed, 2012). Reliable correlations between electrical resistivity and other soil properties will enable the characterization of the subsurface soil without borehole sampling. This paper presents the results on soil investigations using; Vertical Electrical Sounding (VES) results and laboratory geotechnical measurements to assess the structural disposition of the foundation beds in the study area. From the data analysis, significant correlations are made between resistivity and moisture content and angle of internal friction.

A lot of studies have been done using the combined approach of geophysical and geotechnical methods. Abdul *et al*. (2016) correlated electrical resistivity of soil with geotechnical engineering parameters at Wattar area district Nowshera, Pakistan. Their result showed a strong correlation of Electrical resistivity with moisture content, lithologies and thickness of a layer. Ibeneme, *et al*.(2014) used geoelectrical and geotechnical data as veritable tools for feasibility study of the proposed Imo river dam site at Owerrinta, Southeastern Nigeria. The study revealed low to intermediate plasticity which implied that seepage is prominent. Hence, there is need for blanket material. The compaction test result showed that the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil is moderate. The best soil for foundation is the soil with high MDD at low OMC. Triaxial and bearing capacity results also revealed that angle of internal frictions his indicate high strength to shearing and high tendency to withstand load. The study concluded that the site was in a good condition for dam construction in the year 2014.

Adejumo *et al*.(2015) integrated geophysical and geotechnical technique to evaluate the proposed site of Vocational Skill and Entrepreneurship Centre at the Polytechnic Ibadan, Southwest Nigeria. Ibenemeet *al*., (2013) carried out a foundation study at a proposed building site located at about 3km east of Owerri, Nigeria. Based on high bearing capacity and other parameters obtained both studies rated the subsoil as competent as foundation material. On the other hand the study by Mundherand Nsaif(2016) which evaluated a proposed site for civil engineering structure showed that the topsoil is generally geotechnically less competent and may not serve as a good foundation material. Hence shallow foundation may not be feasible in studied area and for engineering structure to be erected on such soil, and so recommended soil improvement or pilling to the sand layer.

This study therefore aimed at investigating soil characteristics acrossOwerri Metropolis using electrical resistivity and geotechnical methods to forestall the hazards listed above.

The study area is located between latitudes 5º23'N to 5º33'N and longitudes 6º57'E to 7º08'E (Figure.1). Owerri lies entirely within Coastal Plain Sandstones (Benin Formation) which has a thickness of about 800 m (IbeandNjamanze, 1998). The Benin Formation extends from the west across the Niger Delta and southward beyond the present coastline. It is over 90 percent sandstone with minor shale intercalations in some places. It is coarse grained, gravely, locally fine grained, poorly sorted, sub-angular to well-rounded, and bears lignite streaks and wood fragments. Benin Formation is therefore partly marine, lagoonal, estuarine and also partly. deltaic and fluviolacustrine in origin (Reyment, 1976). Its age ranges from Miocene to Recent. The study area is drained by two rivers, namely the Otamiri and Nworie (Figure 2). The annual discharge of the Otamiri is about 1.7 x $108m^3$, and 22 percent of this (3.74 x $l07m^3$) comesfrom directly from runoff of rainwater and constitutes the safe yield of the river (Egboka and Uma, 1985). The aquifers have reasonable thickness and are extensive.

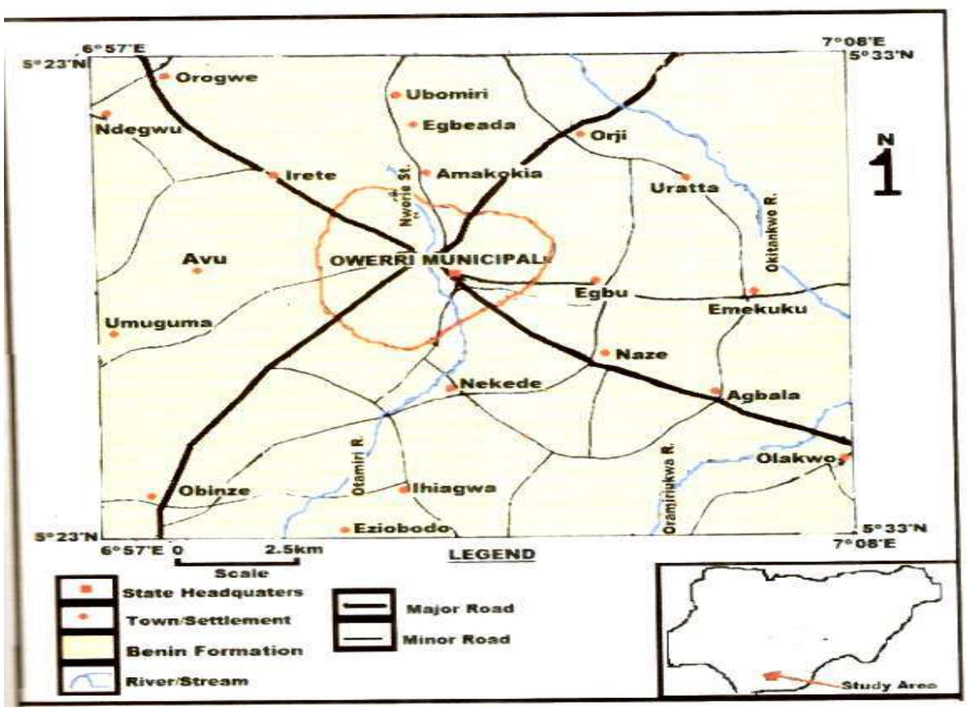

Figure 1.Location map of the study area.(Nwachukwu*et al.* , 2010).

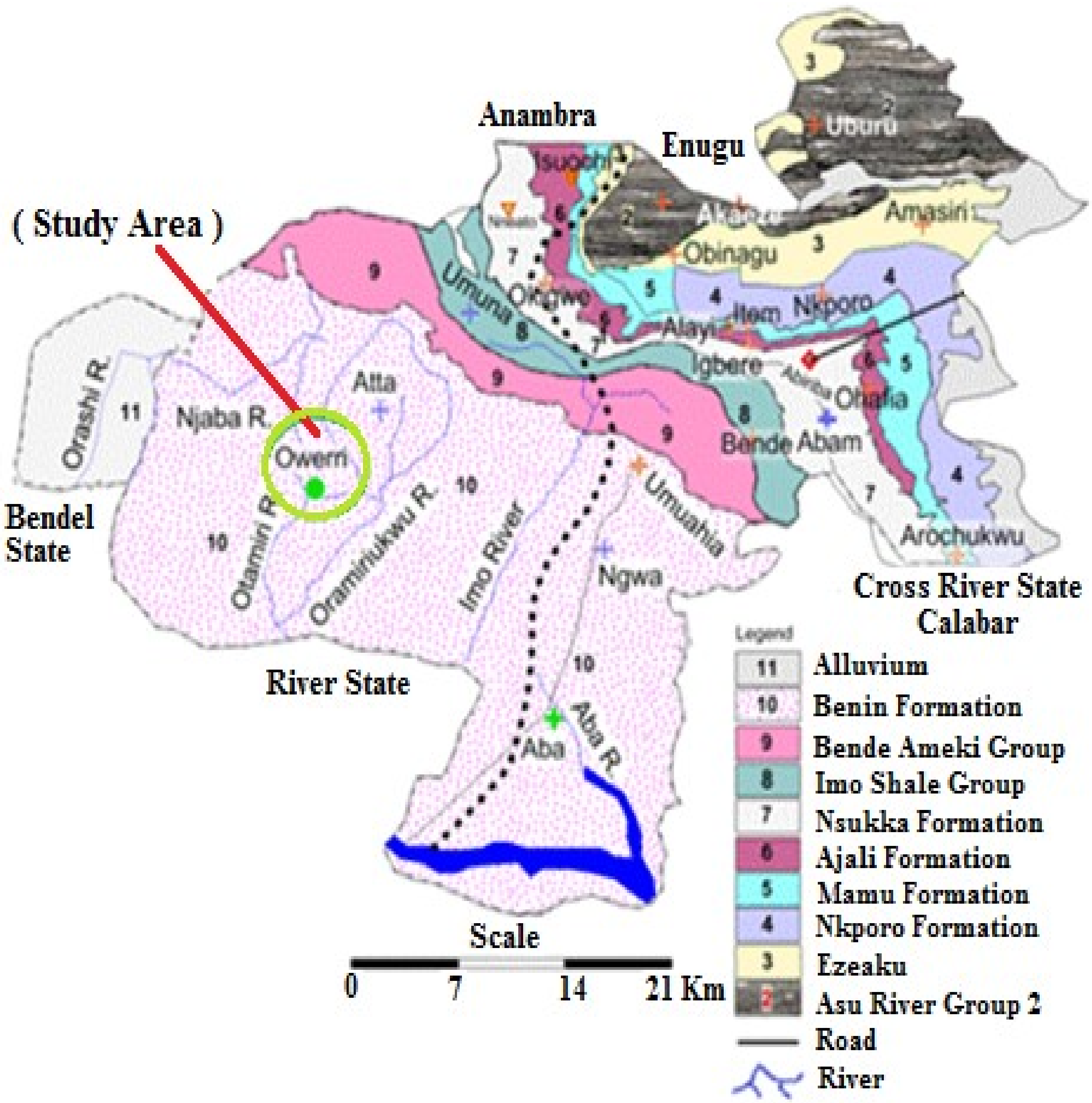

Figure 2: Geologic Map of Imo River basin, showing the Study Area (after Nwachukwu, 2010)

II. MATERIALS AND METHODS

In Geoelectrical survey, Vertical Electrical Sounding (VES) using Schlumberger electrode array and maximum electrode spread of 500m was employed for ten (10) stations distributed cross the study area. The theory and method of Vertical Electrical sounding (VES) is available in literature. Reference can be made to Dobrin and Servit (1985). The instrumentation consists of AAGLTerrameter (the Allied Associate Geophysical limited manufacturer of the Allied Ohmega instrument). The terrameter is powered by 12Volts battery. The elevations and coordinates of the study areas were measured using the E-trex GPS.The current electrodes were expanded systematically from the station point keeping the potential electrode spacing constant until it became necessary to increase it. With this procedure called electric drilling the properties of the subsurface is explored. After initial manual computation, the apparent resistivity values were then applied in the Advanced Geosciences Incorporation (AGI) 1D automatic analysis version to obtain the modelcurves.

In the geotechnical phase of the study, soil samples from seven locations within the study area were collected. These locations were grouped to fall into chosen elevations (Table 1). A hand auger was used to collect the samples at depth between one and two meters. The samples were carefully packaged in airtight polythene bags to retain the moisture content and transported to the laboratory where the following tests: natural moisture content, grain size analysis, atterberg limits, triaxial, density and compaction were carried out. The seven samples were mixed to give three composite samples.

Table 1: Composite sample grouping according to elevations and locations of collection points.

Sample Number	Elevations and location of collection
Sample 1	Elevations 165ft (Nworie) to 175 ft (Obinze)
Sample 2	Elevations 225ft (EgbuNaze) to 226 ft (Aladinma)
Sample 3	Elevations 413 ft (Orji), 418 ft (Toronto) to 450 ft (Awaka).

The tests on geotechnical properties of soils were carried out as stipulated in British Standards B.S 1377 (1990) and American Society for Testing and Materials (ASTM) Standards. The geotechnical soil analyses carried out are;Atterberg Limits which includes both liquid and plastic limit, the difference between both gives the plasticity index.

Compaction test using the proctor compaction test method of determining the Optimal Moisture Content (OMC) at which a given soil type will become dense and achieve its Maximum Dry Density (MDD) was also measured. Following standard procedure and ensuring necessary precaution, the average water content was computed. Graph of moisture content against dry density was plotted to obtain the compaction curve. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) were deducted from the graph.

In Triaxial test, the shear strength of a soil is its maximum resistivity to shearing stresses giving by;

$$\tau = \acute{C} + \sigma \tan \Phi \quad (1)$$

Where

$\acute{C}$ = effective cohesion

σ= effective stress

Φ = effective angle of shearing resistance.

III. RESULTS

The results of the geoelectrical were obtained bygeoelectricalmodelling.Typical modelled VES results representing the 3 elevation zones of the study area are shown in Figures 3 to 5 and Tables 2 to 4 revealing multi geoelectric layers. The summary of the modelled results is shown in Table 5.

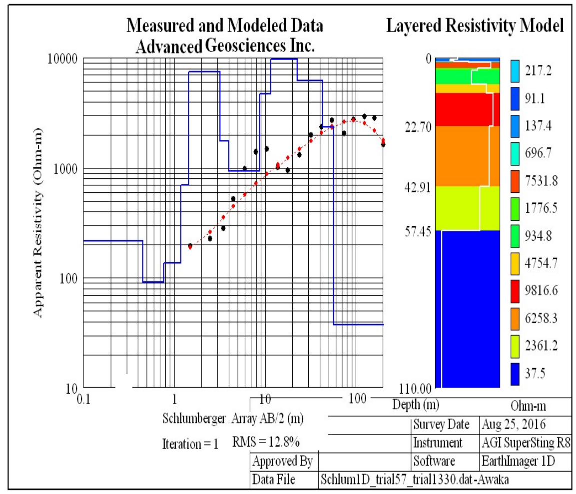

Figure. 3: VES model result forAwaka

Table 2: AwakaVES analytical result in constrained geo-electric sub-layers

LAYER	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	3.195	7531.8	Topsoil	Red
2	8.7	934.8	Sandy soil	Green
3	11.56	4754.7	Sandy soil	Yellow
4	22.7	9816.6	Sandstone	Red
5	42.91	6258.3	Siltstone	Orange
6	57.45	2361.2	Sand	Green
7	110.00	37.5	Sand (aquifer)	blue

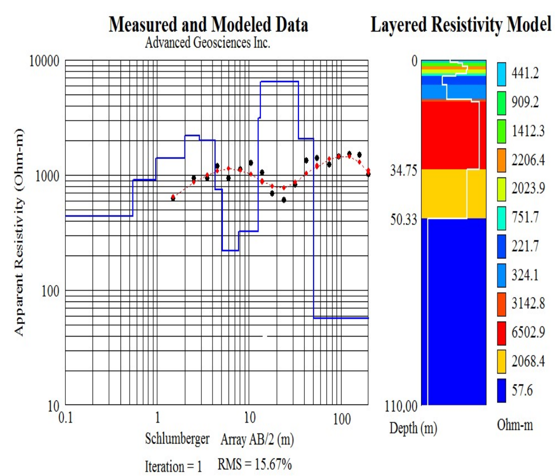

Figure 4: VES model result of EgbuNaze

Table 3: EgbuNazeVES analytical result in constrained geoelectric sub-layers

	DEPTH (m)	RESISTIVITY (Ohm-m)	LITHOLOGY	COLOR
1	2.0	1412	Topsoil	Green
2	5.1	751	Lacteric Sand	Light Blue
3	12.5	324	Sandy clay	Mixed blue

4	13.3	3142	Sand/Gravel	Red
5	34.7	6502	Sandstone	Red
6	50.3	2068	Siltstone	Yellow
7	110	57.6	Sand (Saturated aquifer)	Blue

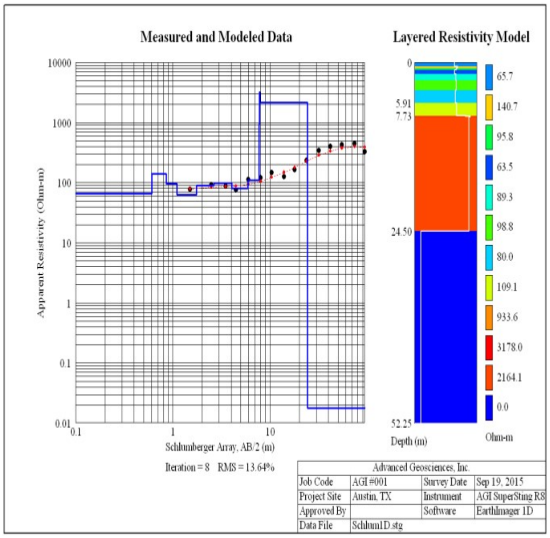

Fig.5: VES model result of Obinze

Table 4: ObinzeVES analytical result in constrained geo-electric sub-layers

LAYER	DEPTH (m)	RESISTIVITY	LITHOLOGY	COLOR
1	1.2	140.7	Topsoil	yellow
2	3.0	89.3	Sand	Mixed blue
3	4.4	98.8	Sandy clay	Green
4	5.91	80.0	Sand	Light blue
5	7.73	109.1	Silty sand	Light green
6	24.50	3178.0	Sand/Gravel	Red
7	52.25	0	Sand (Aquifer)	Blue

Table 5: Summary of Methods VES Results

VES	Station Location	Elevation (FT)	Coordinates N (Degree)	Coordinates E (Degree)	Resistivity of top soil (Ωm)	Thickness of topsoil (m)	Depth to water table
1	Awaka	450	$05^0$28.584/	$07^0$05.185/	7532.0	3.20	57.45
2	Foundation Road	226	$05^0$29.545/	$07^0$02.916/	296.0	1.23	16.80
3	Orji	413	$05^0$7.987/	$07^0$08.239/	865.0	1.95	43.00
4	Toronto junction	418	$05^0$29.527/	$07^0$05.101/	733.0	1.12	43.00
5	EgbuNaze	225	$05^0$27.71/	$07^0$03.769/	1412.0	2.00	50.30
6	Obinze	175	$05^0$24.032/	$06^0$57.855/	140.7	1.20	24.50
7	Nekede	225	$05^0$26.750/	$07^0$01.067/	911.0	1.80	47.80
8	Nworie River Bank	165	$05^0$29.338/	$07^0$01.348/	41.6	1.80	26.20
9	New Owerri	140	$05^0$29.344/	$07^0$00.839/	240.0	2.40	25.94
10	FUTO Ihiagwa	213	05023.092/	06059.618/	1028.0	0.44	56.3

IV. DISCUSSION

The topsoil constitutes the layer within which normal Civil Engineering foundation is founded. The layer is composed of laterite and sandy materials. The topsoil thickness ranged from 0.44 to 3.20meters. Akintorinwa, and Adeusi, (2009), observed that the higher the layer resistivity value, the higher the competence of the delineated topsoil units. Generally, the topsoil resistivity is greater than 240Ωm except Obinze and Nworie with 140 Ωm and 41.6 Ωm respectively. Hence both areas are not suitable as engineering materials and will have to be filled to required depth with a more suitable material. This low resistivity can be attributed to the high moisture content, hence high conductivity and also the low elevation (Table 5). The water table in the areas where VES was carried out was also delineated. About 80% of the overburden in the study area has relatively high value of electrical resistivity. This indicates high degree of consolidation which is favorable for citing engineering structures (Nwosu*et al,* 2017).

The elevation contour map (Fig. 7) shows areas around Owerri North such as Awaka, Toronto and Orji have high elevation. Nworie river bank lies between topographic high areas and corresponds to Nworie river valley. Topographic low areas include Obinze, Nekede and Futo in Owerri west. Otamiri river drains this low elevation areas from EgbuNaze, Nekede, Ihiagwa and Obinze.The topsoil resistivity contour map (Fig. 8) shows that very high resistivities (blue) are observed around Awaka in Owerri North, medium resistivity (Yellow) was observed in Orji and EgbuNaze in Owerri North and also Nekede and Futo in Owerri West. Very low resistivity (red) was recorded in Nworie, new Owerri and Foundation road which is likely as a result of Nworie River. The topsoil Isopach map (Fig. 9) shows high soil thickness is recorded at Awaka and EgbuNaze in Owerri North. Medium topsoil thickness is recorded at Nekede, Toronto, Obinze and Nworie. Very low topsoil thickness is recorded at Foundation Road.

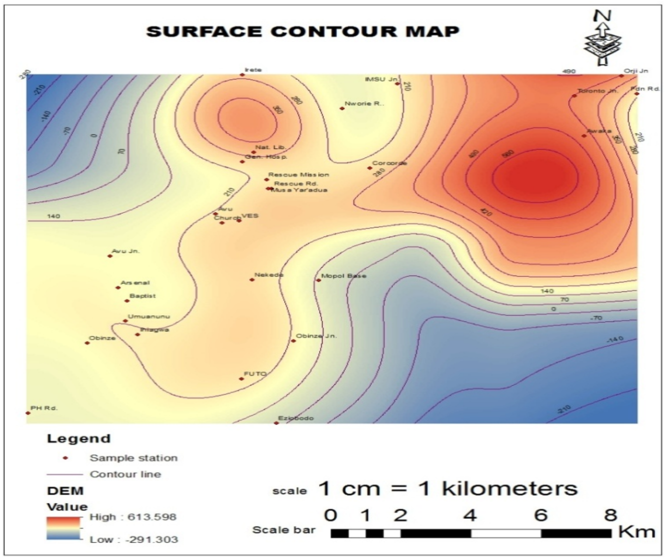

Figure 7: Elevation contour map

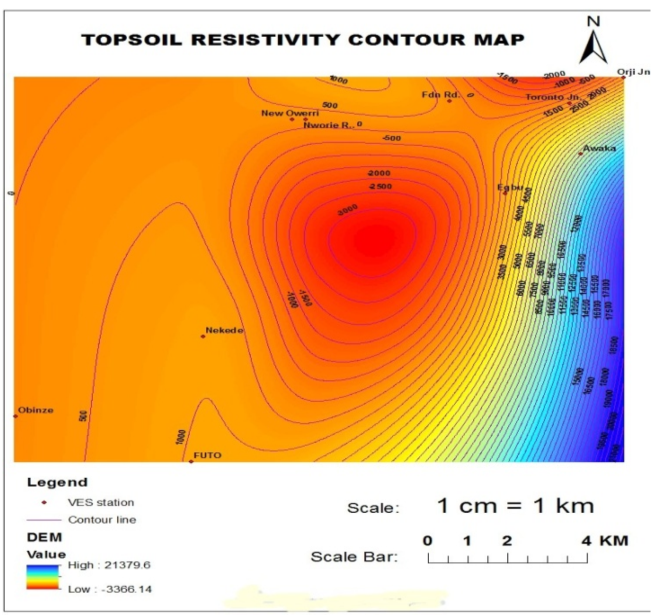

Figure 8: Topsoil resistivity contour map

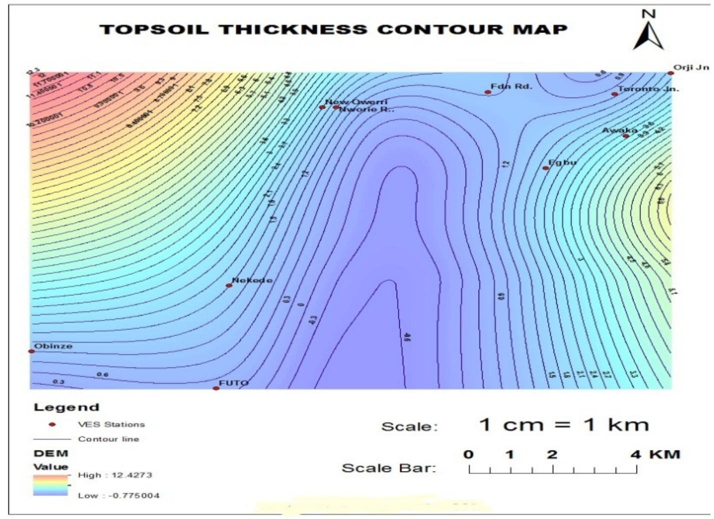

Fig. 9: Topsoil Isopach map

Geotechnical Data

The summary of geotechnical result is shown in Table 6. The natural moisture contents of the samples are 14%, 13% and 11% for sample 1, 2 and 3 respectively. Results obtained are within the same range (10 to14%) of previous research in same area (Ibeneme, *at al.*, 2014). This shows that the moisture content of the soil in the area is relatively low at its natural state. Sample one (Table 7a and b) which is from an area of lower elevation and shallow water table have higher natural moisture content of 14.33% than sample three with moisture content of 11.33% from a higher elevation and deeper water table. This has always been an assumption and this research has support it. Moisture variation is generally determined by intensity of rain, depth of collection of sample, soil texture, nature of plasticity, low permeability and high ability to retain water (Jegede, 2000). Electrical resistivity decreased with increasing moisture content in soils (Fig. 10). This agrees with previous studies as reported in various literatures (Cosenza *et al.,* 2006; Pozdnyakova et al., 2001; Ozcep et al., 2010; Giao*et al.,* 2010.

Grain size analysis results are within the Federal Ministry of Works and Housing (F.M.W& H) Specification Requirement that for a sample to be used as both subgrade/fill and base. The percentage by weight passing the No.200 sieve (75µm) shall be less than but not greater than 35% for a Lateritic base course is greater than 35%, no need for further tests and material rejected (Habeeb, *et al.,* 2012). Hence all three samples can be used as base materials safely as negligible grains were able to perceive No. 200 obtained using the Standard Proctor Compaction test for maximum dry densities of the soils ranged from 1.86 to 1.99 Mg/m^3 and optimum moisture content 12 to 15 %. Both fall within the acceptable standard recommended by Federal Ministry of Works and Housing (FMWH) 1972 for a foundation material. (Okunade, 2007) working on the geotechnical properties of soils of parts of Imo state including around the study area, reported MDD between 1.7 to $2.1Mg/m^3$ and OMC between 9 to 24%.

Okunade's work justifies our findings with respect to OMC and MDD. Therefore, it should be noted that for any engineering construction within the area, the soil should be compacted to calculated OMC and MDD as to achieve maximum strength (Onunkwo, Uzoije, &Onyekuru 2014).

Table 6: Summary of Geotechnical results

Sample Source			**Percentage Passing of sand particles**			**Consistency limit**			**Compaction**				**Triaxial Test**	
Sample No	**Depth (Meters)**	**Moisture content (%)**	**Fine (%)**	**Medium (%)**	**Coarse (%)**	**LL**	**PL**	**PI**	**MDD Mg/m^3**	**OMC %**	**Bulk Unit Weight (KN/m^3)**	**Dry Unit Weight (KN/m^3)**	**Undrained Cohession Cu (KN/m^2)**	**Angle of Int. Friction Ø**
1	1-2m	14.33	8.4	47	44.6	19.3	Non plastic	0	1.99	14	19.3	17.6	20.0	27.0
2	1-2m	12.54	7.4	70	22.6	22.4	Non plastic	0	1.90	13	18.8	17.1	49.0	18.0
3	1-2m	11.33	0	74.6	25.4	22.8	Non plastic	0	1.86	15	18.9	17.0	35.0	25.0

Table 7a: COMPACTION TEST DATA TABLE (Sample 1)Water content Determination

Sample No	1		2		3		4		5		6	
Moisture Can No.	P5	E10	D1	D3	X3	Se	E8	9	O5	7	10	4
Mass of cup + wet Soil	49.2	45.4	54.0	53.2	61.6	51.7	46.7	56.6	55.3	50.1	62.7	56.7
Mass of wet soil	18	18.2	23	25.8	29	22	22.9	27.8	26.9	21.9	29.5	28.4
Mass of cup + dry Soil	47.7	43.6	51.1	49.9	57.2	48.3	42.8	51.8	50.5	46.2	57.3	51.5
Mass of dry soil	16.5	16.4	20.0	22.5	24.6	18.6	19.0	23.0	22.1	18.0	24.1	23.2
Mass of cup	31.2	27.2	31.0	27.4	32.6	29.7	23.8	28.8	28.4	28.2	33.2	28.3
Mass of water	1.5	1.8	3.0	3.3	4.4	3.4	3.9	4.8	4.8	3.9	5.4	5.2
Water Content, W%	9.09	10.98	15.0	14.7	17.89	18.28	20.53	20.87	21.72	21.67	22.41	22.41

Table 7b: COMPACTION TEST DATA TABLE (Sample 1), Density Determination

Test Number	1	2	3	4	5	6
Water content, W%	10.03	14.85	18.09	20.70	21.70	22.41
Mass of mold+ base plate	4.14	4.14	4.14	4.14	4.14	4.14
Mass of mold + base plate + soil	5.64	6.13	6.08	6.03	6.02	5.99
Mass of wet soil, M_{ws}	1.50	1.99	1.94	1.89	1.88	1.85
Volume of mold	937.5	937.5	937.5	937.5	937.5	937.5
Wet density, kgm^3	1600	2123	2069	2016	2005	1973
Moisture content (from above)	10.03	14.85	18.09	20.70	21.70	22.41
Dry density, Kg/m^3	1454	1848	1752	1670	1648	1612

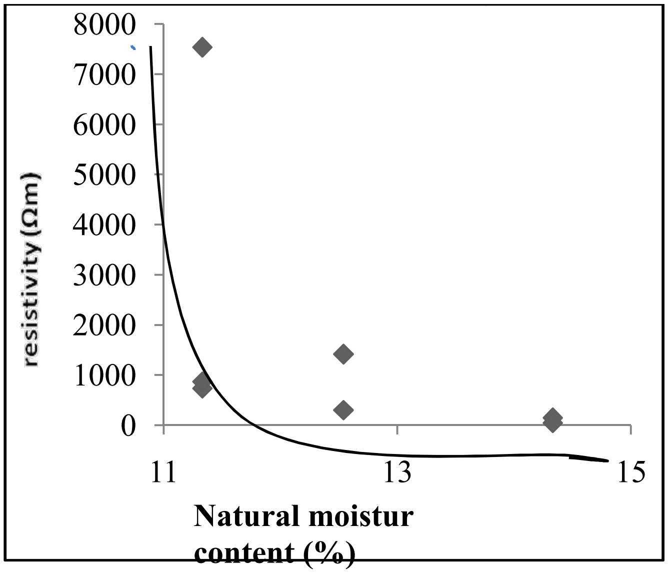

Fig. 10: Graph of variation between moisture content and resistivity

Atterberg limits resultsshows that the LL of the three samples was 19.33, 22.4 and 22.8% respectively (Fig. 11).The federal government of Nigeria specifies that values of plasticity index of the soil should be less than 20% and liquid limit should be less than 30% for the soil to be used in building foundation. The samples where non plastic, the plastic limits cannot be determined by standard procedure (Head 1984). The plasticity index value of zero from this study show that the soil has low swelling capacity and buildings set up in this environment is not likely to develop cracks. Since the soils are non-plastic, they are likely to have higher permeability (NwachukwuandOsoro, 2013). The low value of liquid limit of the soil is attributed to low amounts of fine fraction and indicates that the soil may change from one state of consistency to another with minimum change in water content (Akpokodje, 2001).

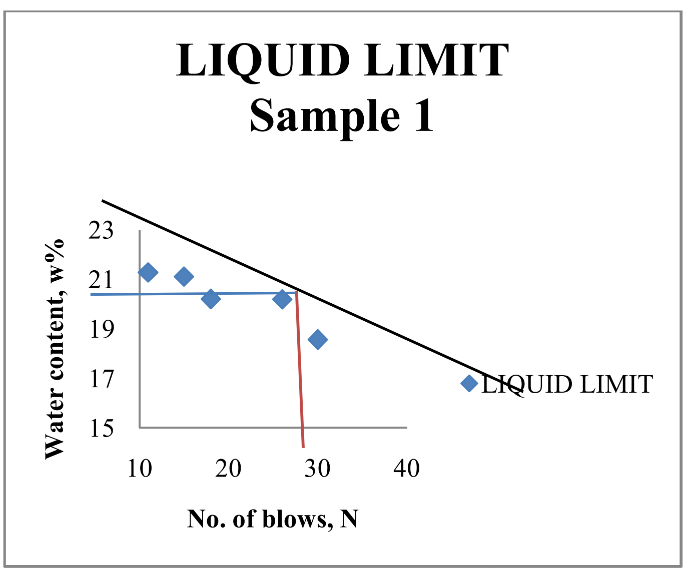

Figure 11: Graph of water content against number of blows (Sample 1)

Plasticity index = 3.54%

Liquid limit = 19.3%

Plastic limit= 15.76%

Mold dimensions: Diameter = 10.1cm, Height = 11.7cm, Vol = 937.5cm^3

Triaxial test results reveal that cohesion range of 20KN/m^2 to 49KN/m^2 was obtaind. This indicates high strength to shearing and also high tendency to withstand load (Ibeneme et al., 2013). The calculated angle of internal friction is 18 to 27%. The high angle of internal fraction and the resulting shear strength is an indication that the soil can withstand stress resulting from heavy structure. The soil due to its low plasticity index with no swelling characteristics and high shear strength is a good site for building foundations, but cannot be used in dam construction (Onunkwo*et al.,* 2014).

Figure 12, shows the relation between dry density and moisture content. The dry density increases with moisture content until it attained the maximum value of 1850 Kg/m^3 at water content of about 15 %. The dry density start decreasing with moisture content after its maximum value.

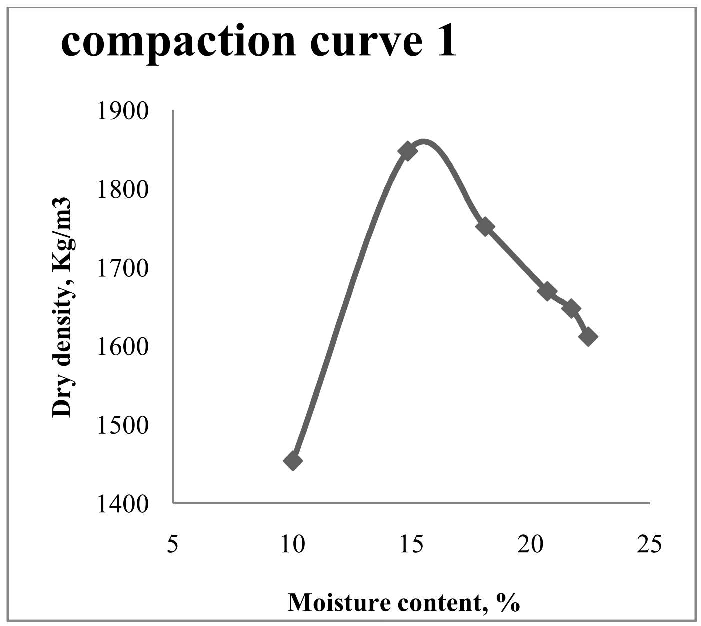

Fig.12: Graph of water content against number of blows(Sample 1)

V. CONCLUSIONS

Subsoil evaluation of Owerri metropolis using geoelectrical and geotechnical methods of investigation has been successfully carried out in this study. The investigation has provided information on the stratigraphy, nature, structural disposition and competence of the subsoil. The investigation delineated several geoelectric layers which were constrained to seven (7) layers for this study. They layers include the mostly sandy and lateritic top soil which was of focus in the study. 80% of the considered topsoil have resistivity greater than 240Ωm. The topsoil with thickness varying from 0.44 to

3.2m constitutes the layers within which normal civil engineering foundation is founded. All the determined geotechnical parameters of the subsoil fall within the specification recommended for foundation material. The results of this study show that soil sample between 0.0 to 2.0 meters (0-6.6 feet) are characterized by very high angle of internal friction of 18-27^o with cohesion values ranging from 20KN/m^2 to 49 KN/m^2. The deduction from the above is that, the topsoil Formation may be rated as relatively good as a foundation material. The foundation of the proposed civil structure can be hosted by this formation.

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