# INTEGRATED GEOPHYSICAL AND GEOTECHNICAL INVESTIGATION OF A BRIDGE SITE - A CASE STUDY OF A SWAMP/CREEK ENVIRONMENT IN SOUTH EAST LAGOS, NIGERIA

**Salami, B. M.*, Falebita, D. E.*, Fatoba, J.O**, and Ajala, M.O*****
* Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria
** Department of Earth Science, Olabisi Onabanjo University, Ago- Iwoye, Nigeria
*** Row-Dot Ltd, Lagos
Corresponding Author: salamibm@yahoo.com
(Received: 4th Nov., 2011; Accepted: 23rd May, 2012)

## ABSTRACT

Integrated geophysical and geotechnical investigation was carried out at a bridge site within a creek and swamp environment in parts of Agbowa, South East Lagos. This was with a view to delineating the subsoil sequence and determining the engineering properties. The investigation involved three shell and auger boring and seven Vertical Electrical Soundings (VES) using the Schlumberger electrode array. Analysis of results of the boring lithological logs indicates occurrence of four major layers composed of clay, organic clay, silty sandy clay and sandy deposits to about 40 m depth. Results of the in-situ and laboratory tests reveal that the silty-sandy soils are characterized by low N-values that range from 5 to 15, while the clayey soils are characterized by high void ratio of 1.73 and low Cu values of 22 $kN/m^2$ with $4^0$ indicating the poor strength and highly compressible nature of the subsoil sequence. The electrical resistivity survey results show good correlation with boring logs and further indicated occurrence of a highly resistive (>1000 ohm-m) basal sandy deposit beyond the boring probe to appreciable depth of over 80 m. The generalized subsoil sequence indicates occurrence of old erosional channel cuts through the basal sand and subsequently filled by deposits of thick organic clay/peat. Based on the geotechnical and geoelectrial parameters, the heterogeneous deposits of soft clay, loose silty sand, clayey sandy and organic clay/peat overlying the basal sand within the creek/swamp section are incompetent foundation soil. The highly resistive superficial sandy deposits in the upland section and the basal sand constitute the competent foundation soils in the area.

**Keywords:** Bridge Investigation, Swamp/Creek Environment, Poor Subsoils, Deep Foundations

## INTRODUCTION

Lagos State with population of over 10 million and land mass of about 500 sq.km is the most densely populated State in Nigeria. Due to high rate of development within the State, several suburb of the Lagos metropolis are also being rapidly developed. Being a Coastal State, substantial part of its landmass occurs within the relatively flat and flood-prone swamp and creek environment. The shallow foundation soils within such geomorphic units are recent sediments composed of soft clays and loose sands that are generally incompetent to support heavy structures. There is therefore in many cases the need for deep subsoil probing to explore for competent foundation soils. The method commonly adopted for such investigations by engineers in most part of Nigeria is the traditional shell and auger exploratory borings without consideration for the use of geophysical methods which can be utilized to delineate the subsoil sequence as part of preliminary investigation prior to the execution of the traditional shell and auger boring.

Geophysical methods especially the seismic refraction and the electrical methods are regularly used as an integral part of site investigation programme for dam construction, pipeline route selection, site characterization for planning and design (Adeduro, et al., 1987; Barker, 1997; Olorunfemi et al., 2000 a&b; Ajayi et al., 2004). The methods are occasionally used in routine site investigation for building, road and bridge constructions in Nigeria (Olorunfemi and Mesida, 1987, Adewunmi and Olorunfemi, 2005, Akintorinwa et al., 2011). Although various studies have shown that the geophysical methods, especially the electrical resistivity methods are very useful for pre and post construction investigations of such projects (Olorunfemi and Mesida, 1987; Ako, 1989; Olorunfemi et al., 2004a; Olorunfemi et al., 2005; Idornigie et al.,2006a), the vertical electrical sounding (VES) technique may be particularly useful in swampy terrains that commonly have thick accumulation of soft foundation soils, but poor accessibility for heavy geotechnical equipments required for deep probing.

Agbowa, a suburb of Lagos metropolis, is a typical example of town occurring within the Coastal

Swamps and Lagoon environment with possible accumulation of thick soft soils. The town is being rapidly developed necessitating the need to provide various municipal infrastructural facilities such as roads for effective linkage to various parts of metropolitan Lagos. Part of the area earmarked for a possible bridge site along a proposed road route in the area was investigated using the traditional shell and auger boring that was constraint by the swampy environment. The VES technique was used as a complementary tool to delineate the subsoil sequence and derive the engineering properties of the sub-soils within the swampy portion of proposed road route.

## DESCRIPTION OF THE STUDY AREA

Geologically, Lagos State lies within the Nigerian part of the extensive Dahomey Basin. Stratigraphic descriptions of this basin (Omatshola and Adegoke, 1981, Nton, 2001) put the oldest unit as Late Cretaceous predominantly sandy strata of the Abeokuta group. Overlying these strata are the Tertiary strata that include: limestone, shale, shale/mudstone and sand of the Ewekoro, Akinbo, Oshoshun and Ilaro Formations respectively. These Tertiary strata are in turn overlain by the Late Tertiary to Recent deposits of the Benin Formation (also termed the Coastal Plain Sands) that is composed of poorly sorted sands with lenses of clays.

The study area is located between Agbowa and Okelisa area of Ikorodu Local Government, Lagos State. It is bounded by Latitudes 6° 36' N; 6° 38' N and Longitudes 3° 40' and 3° 42' 30" E. The area falls within the Coastal Swamp and Lagoon geomorphic unit and is generally low-lying with elevation varying from 1 m to 8 m above the sea level. Notable rivers and streams in the area include: Berre, Solodo, Losewe and their tributaries (Fig. 1). Recent alluvial littoral and lagoon deposits composed mainly of soft clays/silts and loose sands directly underlie the area. Beneath these Recent deposits are the sandy deposits of the Coastal Plain Sands. These lithologic units constitute the foundation soils in most parts of Lagos State.

## METHODS OF STUDY

### Geotechnical Investigation

The geotechnical investigation involved drilling of three exploratory holes using the shell and auger boring technique. However, accessibility, for field operational vehicles, personnel and equipment was hindered by excessive flooding of site. Consequently, the manually operated light cable tool percussion rig was used for two exploratory borings (Bh1 and Bh2) to shallow depth of about 22 m within the highly flooded creek and swamps section of the area (Fig 1), while the motorized heavier Pilcon Wayfarer type cable rig was used for the third exploratory boring (Bh3) at only one location in the slightly elevated location near Oke Lisa to appreciable depth of 40 m. During the boring operations, ordinary disturbed samples were collected at regular intervals for strata identification purposes, through visual inspection and classification tests. Standard Penetration Test (SPT) was carried out at necessary depth to determine penetration resistance in sandy strata.

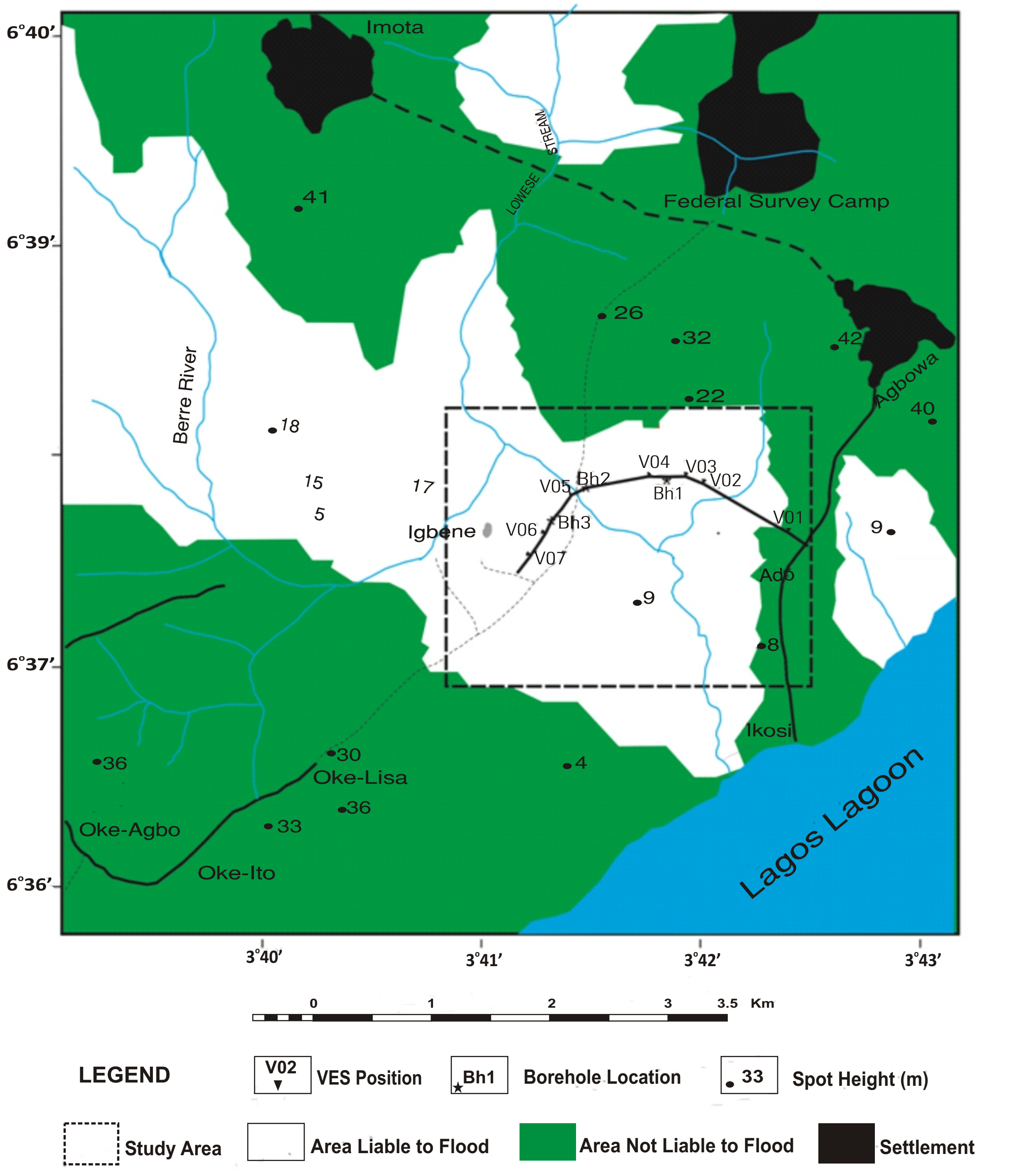


Figure 1: Map of part of Lagos State showing the Study Area

The test involved obtaining the number of blows (N-values) producing the last 300 mm of penetration, in connection with an overall 450 mm penetration tests, by a 63.4 kg hammer having free fall through 760 mm. Moreover, selected soil samples resulting from the above sampling procedure were subjected to laboratory geotechnical tests to determine moisture content, bulk density, sieve analysis, Atterberg indices, consolidation and shear strength.

**Geophysical Survey**

The geophysical investigation was conducted to supplement the geotechnical investigation with a major aim of delineating the sub-surface layers at depths beyond the depth of probe of the test drilling operation. The electrical resistivity method involving the VES technique was adopted. The resistivity survey was conducted with a digital ABEM (SAS 300C) Resistivity Meter using the Schlumberger array. Seven resistivity sounding stations were occupied in the area, four within the flooded swamp/creek section and three within the slightly elevated positions (Fig 1). Within the swamp/creek section, the VES was executed with the aid of local canoes and usage of electrodes of about 2 m length. The half current electrode spacing (AB) was varied between 1.5 m and 300 m within the dry slightly higher elevated area with corresponding spacing of 100 m within the swamp/creek section. The acquired VES data were interpreted by the partial curve matching technique. The interpreted geoelectric parameters were used as starting model in the 1-D forward modeling using the Winglink software package.

## RESULTS AND DISCUSSION

### a ) Lithologic log

Results of the shell and auger boring are presented as borehole lithologic logs along with the standard penetration (SPT) results (Fig 2) while the laboratory tests results are summarized in Table I. Analysis of the results indicates occurrence of four major lithologic layers from ground surface to about 40 m depth. These are composed of clay, organic clay, silty sandy clay and sandy deposits from ground surface to about 40 m depths. These deposits are typical alluvial sediments of swamp and creek environment.

The first lithologic layer is a mixture of peat, organic clay and silty sandy deposits with thickness of about 2 m. The underlying second layer is composed of sandy silty clay with thickness that ranges from about 6 m within the swamp/creek section to about 22 m towards Oke-Lisa upland section (Bh3). The N - blow values of between 2 and 10 recorded for this layer portrays its poor strength characteristics. The third layer is a clayey deposit composed of organic clay mixed with silt that is soft to firm as portrayed by its un-drained cohesion of 22 $kN/m^2$ and $4^0$ angle of internal friction. The high initial void ratio of 1.73 and low bulk density of 1.55 $Mg/m^3$ recorded for the layer is also indicative of its high compressibility. The layer thickness ranges from 4 m to about 12 m.

The fourth layer is heterogeneous in nature. The layer within swamp/creek section is composed of silty clayey sand deposit to the 22 m terminal depth of Bh1 and Bh2, but composed of fibrous peat, organic clay and silty clayey sand in the upland section towards Okelisa flank to the 40 m terminal depth of Bh 3. The silty clayey sand portray moderately strong strength characteristic based on the N blows values of between 10 and 15 recorded for it. On the other hand, the fibrous peat/organic clay deposit is very weak in term of strength characteristic due to its extremely soft nature which made collection of its undisturbed sample impossible. It is pertinent to note that none of these strata is competent as foundation soils for heavy structure.

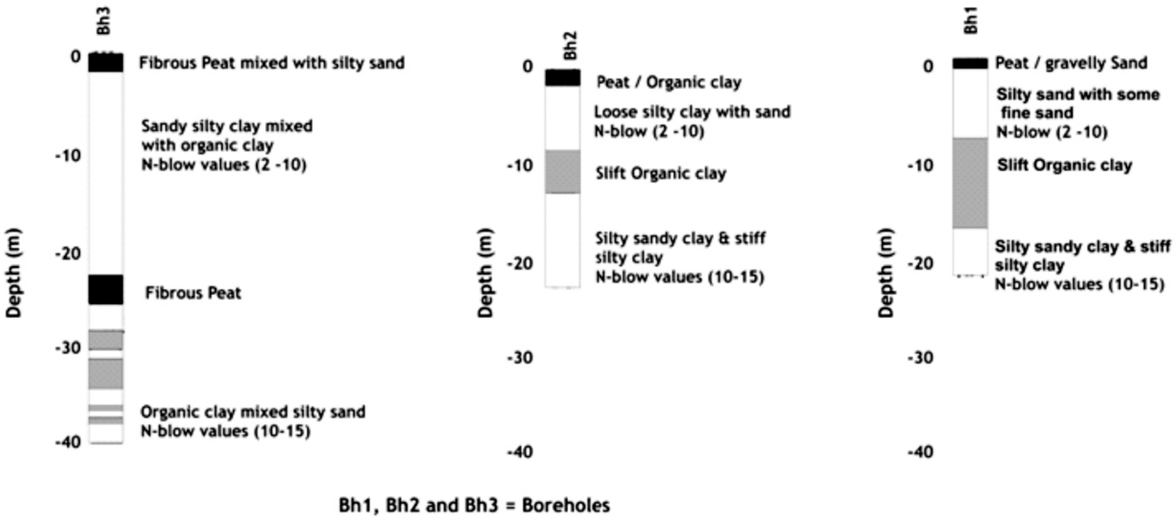


Figure 2: Borehole Lithologic logs with Standard Penetration Test Results

**Table I:** Summary of Laboratory Test Results

| Borehole & Sample Depth (m) | Soil Description | Bulk Density $Mg/m^3$ | Cohesion Cu | Internal Friction Angle | Comp. Index Cc | Press. Range kN/m | | Coeff of Cons. Cv (m /yr) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Min | Max | |
| **BH1/2** | Fibrous Peat | 1.22 | 8 | 0 | - | - | | - |
| **BH1/17** | Organic Clay | 1.55 | 38 | 3 | - | - | | - |
| **BH1/21** | Silty Clay | 1.89 | 93 | 9 | 0.080 | 12<br>25<br>50<br>100<br>200 | 25<br>50<br>100<br>200<br>400 | 1.11<br>1.08<br>0.75<br>0.71 |
| **BH2/17** | Sandy/Silty Clay | 2.06 | 68 | 5 | 0.067 | 12.5<br>25.0<br>50.0<br>100<br>200 | 25<br>50<br>100<br>200<br>400 | 6.23<br>2.87<br>1.96<br>1.57<br>0.872 |
| **BH3/9** | Stiff/ Organic Clay | 1.58 | 43 | 7 | 1.2 | - | | - |

**b) Geo-electric Section**

Figure 3 shows the observed depth sounding curves while Figure 4 displays the geo-electric section along the bridge path. Four major geo electric layers were delineated from ground surface to about 80 m depth. Four major geo electric layers were delineated from ground surface to about 80 m depth.

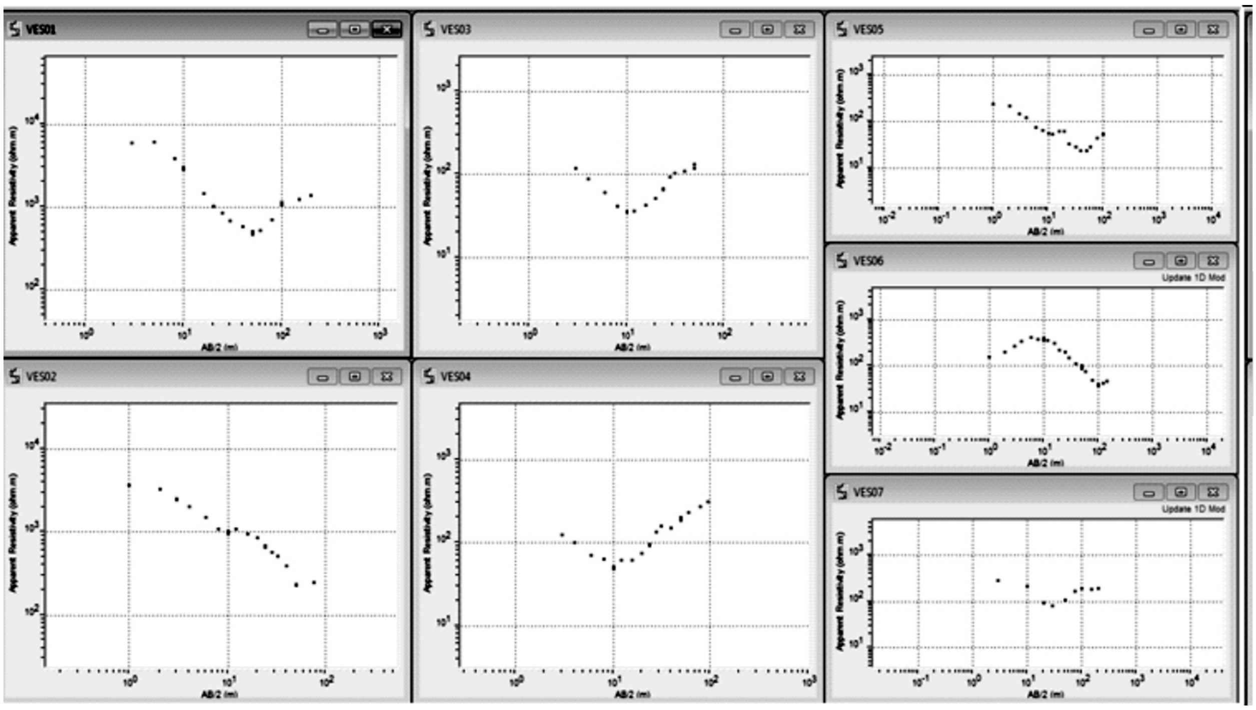


Figure 3: The VES Curves from the Study Area

The first layer with thickness of between 2 m and 5 m has highly variable resistivity values to portray its heterogeneous nature. Portion of the layer within the upland sections of Agbowa flank characterized by high resistivity values that range from 1047 ohm-m to 5000 ohm-m (VES 1&2) suggests occurrence of dry and dense sandy deposits; whereas, the other portions of the area characterized by resistivity values of 147 ohm-m to 220 ohm-m (VES 3- VES 7) is composed of silty sand mixed with clay.

The second geoelectric layer with thickness of between 8 m and 23 m is also heterogeneous in nature as portrayed by its highly variable resistivities. Within the upland sections towards Agbowa and Oke-Lisa flanks, the layer has high resistivity values that range from 900 ohm-m to 1400 ohm-m suggesting sandy deposits. On the other hand, within the swamp/creek section, the layer resistivity value ranging from 30 ohm-m to 641 ohm-m indicate a stratum composed of clayey and sandy materials and corresponds to the sandy silty clay obtained within the boreholes.

The third geoelectric layer is also a mixture of silty sandy materials and organic clay/peat. The organic clay/peat deposits characterized by resistivity values raging from < 10 ohm-m to 33 ohm-m was delineated towards the Okelisa flank, while the silty sand deposits with clays characterized by resistivity value ranging from 78 ohm-m to 349 ohm-m occurs towards the Agbowa flank. The fourth layer is a coarse sand deposit with resistivity value of between 1120 ohm-m and 2008 ohm-m. This layer, delineated at depth range of 15 m to 120 m is regarded as the main competent layer at the site.

### c) Generalized Subsoil Sequence and Competence Evaluation

The geologic/geoelectric section (Fig.4) indicates occurrence of four main strata from ground surface to about 80 m depth. The uppermost two layers are deposits of loose silty sand and clayey sandy occurring from ground surface to about 20 m depth. The third layer is a deposit of organic clay/peat and clay/silty clays occurring from about 15 m to about 60 m depth. The underlying fourth layer is a highly resistive sandy deposits occurring to over 80 m.

The thick organic clay/peat (VES 5 & 6, Bh 3) and the clay/silty clay (VES 2, Bh 2) constituting the third layer is regarded as in-filling of old erosion channels cut through the highly resistive sandy deposits. Similar old erosion channels with comparable in-filling of thick soft clayey deposit have been reported for related geomorphic environments in parts of Southwest Lagos (Farrington, 1961, Ajayi, 1980 and Ajayi et al. 1983). In addition, the highly resistive sandy deposits is also comparable to the sandy deposits reported by Ajayi et al, (1980 &1983) as occurring from 35 m to 60 m in several parts of Southwest Lagos and which have been shown (Ajayi, 1980; Ajayi et al. 1983, Salami and Meshida, 2006) as medium coarse grained in texture, characterized by N values of 25 to 50 indicating its competence as foundation soils.

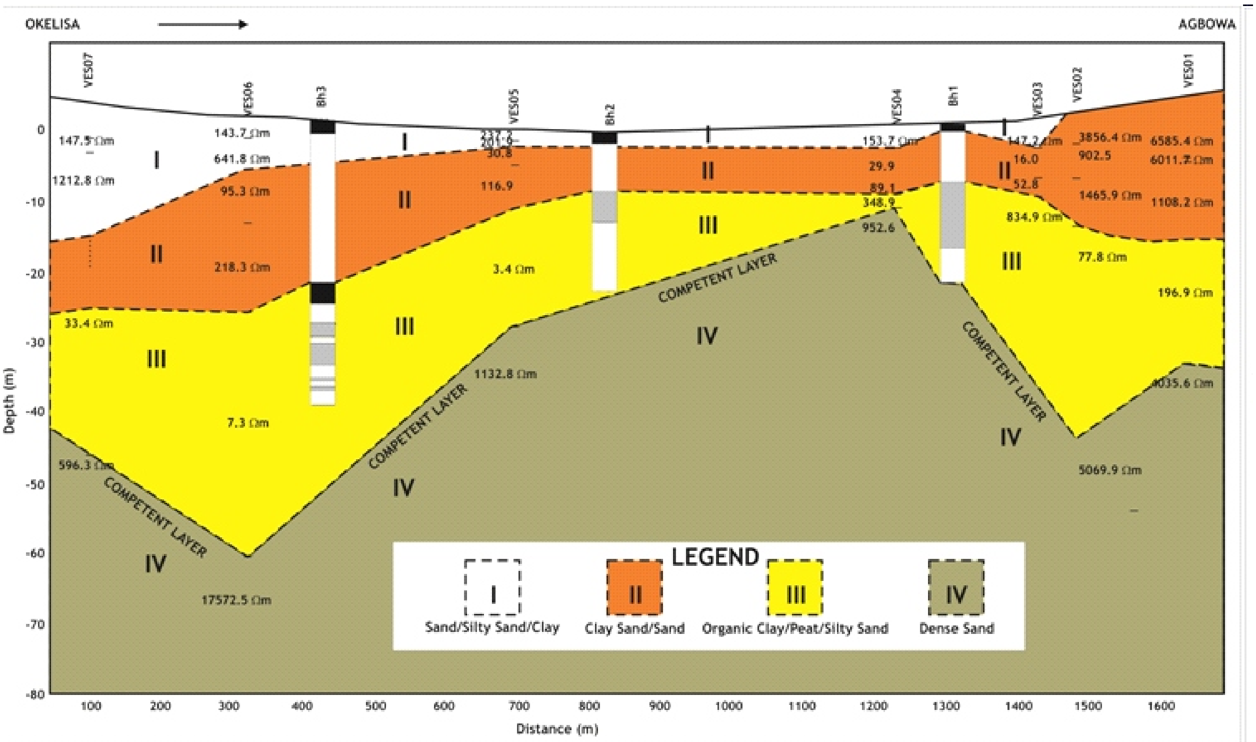


Figure 4: Geoelectric Section Along the Bridge Course with Superimposed Borehole Lithological Logs

Based on the geotechnical and geoelectrical parameters, the superficial heterogeneous deposits of soft clay, loose silty sand and clayey sandy constituting the first three layers within the creek and swamp section are highly compressible or loose and are therefore regarded incompetent soils for foundation of heavy structures such as bridge construction. However, the shallow sandy deposits portion of the first two layers in the upland parts towards Agbowa and Okelisa flanks and the deep coarse dense sandy deposit constituting the fourth geoelectric layer characterized by high resistivity > 1000 ohm-m are considered as being competent and may be used as foundation soils for heavy structures such as bridge abutments and deep foundations for bridge piers. Necessary densification of the shallow sandy deposits may be required for adequate soil strength improvements.

## CONCLUSIONS

Electrical resistivity survey was used as part of preliminary site investigation to complement the traditional shell and auger boring in creek and swamp environment in parts of Agbowa, South East Lagos along a proposed road route. The investigation involved three shell and auger boring and seven VES using the Schlumberger electrode array. The borehole logs indicate occurrence of four major lithologic layers, composed of clay, organic clay, silty sandy clay and sandy deposits from ground surface to about 40m depths. These layers are generally incompetent as foundation soils for heavy structure. The electrical resistivity survey delineated four major geo electric layers from ground surface to minimum of 80 m depth. These are composed of heterogeneous deposits of sand, silty sand, and clay in the uppermost part underlain by thick organic clay mixed with peas and silt. The basal layer is a highly resistive sandy deposit. The generalized geologic/geoelectric section indicates occurrence of old erosion channels cut through the basal sand and subsequently filled by deposits of the overlying thick organic clay/peat. Based on the geotechnical and geoelectrical parameters, the superficial heterogeneous deposits of soft clay, loose silty sand and clayey sandy constituting the first three layers are incompetent foundation soil. The highly resistive superficial sandy deposits in the upland section of the area and the basal sand constitute the competent foundation soils in the area.

## REFERENCES


Adeduro, A.D., Ako,B.D . and Meshida, E.A. 1987. Dam Site Investigation: An Experience in a Sedimentary Terrain in Bendel State, Nigeria. Journal of Mining and Geology,V.23 Nos. 1 & 2 pp 127 134.

Adegoke, O.S. 1977. Stratigraphy and Paleontology of the Ewekoro Formation (Paleocene) of Southwestern Nigeria. *Bulls. A Paleontol.*, Vol. 71, No. 295, 275pp.

Adewunmi, I., and Olorunfemi, M. O. 2005. Using Geoinformatics in Construction Management. *Journal of Applied Sciences,* 5(4), pp. 761 767.

Ajayi, L.A. 1980. Geotechnical Properties of a deep organic clay stratum underlying Lagos area of Nigeria. Proceedings: 7th Regional Conference for Africa on Soil Mechanics and Foundation Enginnering, Accra, 75 82.

Ajayi, L.A., Epps, R. J., Farrington, P. and Robinson, A. D. 1983. Deposition and and engineering properties of sediments in the Lagos area and their influence on recent developments. Quarterly *Journal of Engineering Geology*, London, 16, 231 239.

Ajayi, O., Olorunfemi, M.O., Ojo, J.S., Adegoke Anthony, C.W., Chikwendu, K.K., Idornigie, M.I. and Akinluyi, F. 2004. Intergrated Geophysical and Geotechnical Investigation of a Dam Site on River Ini, Adamawa State, Northern Nigeria. Africa Geoscience Review, Vol. 12, No. 3, pp. 179 188

Akintorinwa, O. J., Ojo, J. S., and Olorunfemi, M. O., 2011. Appraisal of the Causes of Pavement Failure along the Ilesa-Akure Highway, Southwestern, Nigeria Using Remotely Sensed and Geotechnical Data. *Ife Journal of Science*, vol. 13, pp. 185 198.

Ako, B.D., 1989. Geophysical Prospecting for Groundwater in an Area without Adequate Geological Data Base. *Journal of Mining and Geology*, 18 (2), pp. 87-105.

Barker, R. 1997. A simple algorithm for electrical imaging of the subsurface. *First Break* 10, 53-62.

Enu, E.I. 1990. Aspect of Rock Evaluation Studies of the Maastrichtian Eocene Sediments. *Jour. Min and Geol.*, Vol 40(1), pp 29 40.

Farrington, 1960. Earthworks and foundations on recently deposited organic soils in Lagos area. Proceedings: 7th Regional Conference for Africa on Soil Mechanics and Foundation Enginnering, Accra, 253 259.

Nton, M.E., Ikhane,P.R. and Tijani, M.N. 2009. Aspects of Rock-Eval Studies of the Maastrichtian-Eocene Sediments from Subsurface in the Eastern Dahomey Basin, Southwestern Nigeria. *European Journal of Scientific Research* Vol. 25 No. 3 pp 417- 427

Jones, M.A. and Hockey, R.O. 1964. The Geology of Part of Southwestern Nigeria. *Nig. Geol. Surv, Bull.* No. 31, 101p.

Omatsola, M.E., and Adegoke O.S. 1981. Tectonic and Cretaceous stratigraphy of Dahomey Basin. *Journal of Min. Geol.* Vol. 54 pp. 65-87.

Ogbe, F.G.A. 1972. Stratigraphy of Strata Exposed in the Ewekoro Quarry, Southwestern Nigeria. *In: T.F.J. Dessauvagie and Whiteman (Eds) African Geology, University Press, Nigeria*, pp. 305

Olorunfemi, M.O. and Mesida, E. A. 1987. Engineering Geophysics and its Application in Engineering Site Investigation (Case Study from Ile Ife Area). The Nigerian Engineer, Vol. 22 (2), pp. 57 66.

Olorunfemi, M.O., Ojo, J.S., Sonuga, F.A., Ajayi, O. and Oladapo, M.I.2000a. Geophysical Investigation of Karkarku Earth Dam. *Global Journal of Pure and Applied Sciences*, Vol.7 (2) pp. 311 320.

Olorunfemi, M.O., Ojo, J.S., Sonuga, F.A., Ajayi, O. and Oladapo, M.I.2000b. Geoelectric and Electromagnetic Investigation of the Failed Koza and Nasarawa Erath Dams around Katsina, Northern Nigeria. *Journal of Mining and Geology*, Vol. 36 (1) , pp. . 51-65

Salami, B.M. and Meshida, E.A. 2006. Stratigraphic Influence on Some Engineering Properties of Foundation Soils in Parts of South West of Lagos Metropolis: *Global Journal of Geological Sciences,* Calabar, Vol 4 No. 2. pp 65 71.