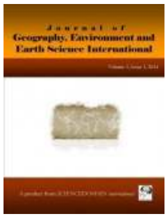

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Subsoil Competence Evaluation of Proposed Sites for Underground Utilities Using Non-destructive Integrated Geophysical Surveys and Geotechnical Method

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OOF and OEB designed the study, wrote the protocol. Author YA analyzed the data, wrote the manuscript. Author EGI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

One common cause of structural failure is inadequate soil analysis resulting in poor foundation. Therefore in order to prevent failure occurrence of a proposed communication mast and its accessories to be buried within the subsurface at a depth not less than 5 m at Isuada and Iyere towns of Ondo State, Nigeria integrated geophysical methods involving magnetic, very low frequency electromagnetic, and electrical resistivity methods were complemented with geotechnical laboratory tests adopting the British Standards methods, with the aim of evaluating the suitability of the subsoil within the chosen sites to harbour the structure. The % of fines (clay content) of the samples was generally greater than 20% with Low/Intermediate swelling potential. All the sampled soils exhibited low moisture content in their natural state (less than 10%). The geophysical results showed that the subsoil generally composed of sandy clay, clayey sand grading into laterite with

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thickness of 10 m and 5 m at locality 1 and 2 respectively. The results of the geotechnical analyses showed high shear strength, cohesion and compaction characteristics. Therefore considering the results of the investigation, the proposed structure can be constructed under VES 1 and 2 at locality 1 at a maximum depth of 10 m - 20 m, but fractured zone below VES 2 must be put into consideration during the design process of the proposed structure. At locality 2, construction of the structure under VES 4 could be possible provided the soil is stabilized with competent material to a depth of 15 m. Therefore geophysical investigations combine with the geotechnical results allow excellent geo-mechanical knowledge of the basement up to 10-20 m depth.

Keywords: Subsoil evaluation; shear strength; geotechnical; geophysical methods; competence.

1. INTRODUCTION

The general objective of a site investigation is to assess the suitability of a site for the proposed purpose. As such, it involves exploring the ground conditions at and below the surface [1]. It is a prequisite for the successful and economic design of engineering structures and earthworks. Accordingly, a site investigation also should attempt to oversee and provide against difficulties that may arise during construction because of ground and/or other local conditions. Indeed, investigation should not cease once construction begins. It is essential that the prediction of ground conditions that constitute the basic design assumption be checked as construction proceeds and designs modified accordingly if conditions are revealed to be different from those predicted.

The investigation of a site for an important structure requires exploration and sampling of strata likely to be significantly affected by structural load. Data appertaining to groundwater conditions, extent of weathering, and discontinuity pattern in rock masses are also important. However, the complexity of a site investigation depends upon the nature of the ground conditions and the type of engineering structure. More complicated ground conditions and sensitive large engineering structures require more rigorous investigation of the ground conditions. Although a site investigation usually consists of three stages, namely a desk study, a preliminary reconnaissance and a site exploration [2]. To this end, geophysical methods and geotechnical approaches are routinely used. The geophysical methods that suit such investigations are the electrical resistivity, gravity, magnetic, very low frequency electromagnetic and seismic refraction methods [3,4,5]. Geotechnical Subsoil strength investigation traditionally involves soil boring (auger or cone penetration), and soil sample testing for geotechnical properties such as grain size distribution, plasticity characteristics (index properties), bearing capacities and consolidation / compressibility characteristics determination [6].

On the basis of this, the electrical resistivity method, very low frequency electromagnetic and magnetic method, complemented with geotechnical soil tests such as mechanical test (specific gravity, compaction test, and undrained triaxial test); classification test (specific gravity, Atterberg limits and grain size analysis) were used to investigate the proposed sites for communication mast and its accessories meant to be buried at depth not less than 5 m below the ground surface at Iyere and Isuada towns of Owo Local Area of Ondo State. The objectives of the investigation were to delineate the subsurface sequence; determining the geoelectric parameters of the subsurface layers; mapping of subsurface structures (e.g. faults, joints, fractures, etc.); depth to the bedrock; and determine the geotechnical and engineering parameters of the proposed sites.

A combined geophysical and geotechnical investigations offer very useful approach for characterizing near surface earth and thus can help in preparation before engineering structures are constructed [7,6]. Also, they are often the most cost-effective and rapid means of obtaining subsurface information, especially over large study area [8,9,10].

2. DESCRIPTION OF THE PROJECT ENVIRONMENT

2.1 Geographic Location, Physiographic Features and Drainage

The studied sites are located in Isuada and Iyere towns of Owo local government area of Ondo State, Southwestern Nigeria. Both sites lie within Latitudes 07° 00' and 07° 30'N and Longitudes

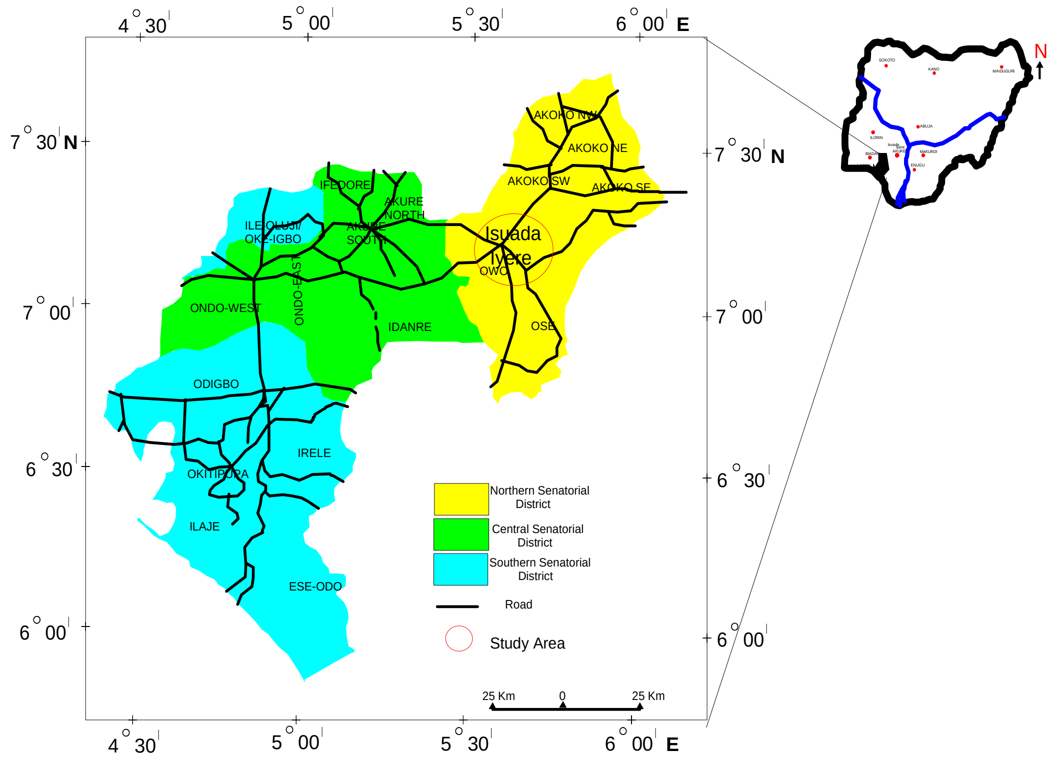


Fig. 1. Location map of the study area. Insert: Map of Nigeria

05°15' and 05°45'E (Northings 794510 – 800244 mN and Eastings 784621 – 788427 mE, UTM Minna Zone 31) (Fig. 1). The sites are accessible through the Benin-Ifon roadway, Abuja-Kabba highway and Ado-Akure highway. The area is located on a gently undulating terrain surrounded by low rising isolated hills. Topographic elevations varied between 940 and 1060 ft and drained by several streams and rivers like river Ogbese, river Eporo etc.

2.2 Geology and Structures

The major rocks types observed in the area were quartzite, migmatite and granite gneiss (Figs. 2 and 3). Quartzite was the most predominant in Isuada town, covered by topsoil in some areas which made their mapping difficult. However, road cuts exposed these rocks in parts of Owo.

The quartzite observed was highly weathered (Plate 1) which may be due to the Pan-African Orogeny that affected most parts of Africa. The observed mineralogy in hand sample showed that it was rich in quartz associated with muscovite and biotite. The major trends of the quartzite observed were NNW-SSE, WSW-ESE, NE-SW and NW-SE. The main structural features was fractures, mostly joints (Plate 2) filled in some places. The joints were oriented mostly in the NE-SW, ENE-WSW and NW-SE directions.

Migmatite and granite gneiss were the most common rock types in Iyere area of the study sites. The minerals observed in the rock were quartz, biotite, hornblende, plagioclase feldspar and orthoclase feldspar. Fractures and quartz intrusion (Plate 3) were commonly observed. Geologic structures common in the study area were fractures (especially joints), quartz intrusion and folds. Fracture on migmatite and gneiss in the study sites trend mostly in the NE-SW, NNE-SSW, ENE-WSW and E-W directions.

There were three major soil associations in the studied area (Fig. 4). These included Iwo, Ondo and Okemesi Associations [11]. The Okemesi soil type underlying the studied sites. The soil was composed of coarse textured, pale grayish brown to brown, usually sandy soils, often very shallow over quartz rubble. It was also associated with topography of steep sided elongated ridges. The sandy nature of this soil makes it competent for civil engineering foundation.

3. METHODOLOGY

The field layout at Isuada and Iyere sites showing geophysical traverse lines and geotechnical sampled points are shown in Fig. 5. Geophysical investigations involving the electrical resistivity method, magnetic method, and very low frequency electromagnetic were adopted for the study.

Magnetic method involves measurements of the earth magnetic field or its components at a series of different locations over an area of interest, usually with the objective of locating concentrations of magnetic material or determining depth to the magnetic basement. Magnetic measurements were made at 10 m interval along each of the traverses established at both sites with the GSM 8 Proton Precession Magnetometer (PPM). Two magnetic measurements with sensor height at 1.5 m were taken per station and the mean of the magnetic measurements adopted for each observed station. A set of readings was taken at an established base station close to each traverse before the commencement and immediately after data acquisition. The base station readings were used for diurnal and offset corrections. This was necessary to remove all causes of magnetic variation from observation other than those arising from magnetic effects of the subsurface The reduction carried out to the magnetometer measurements was the drift correction. Corrected magnetic data were plotted against station positions.

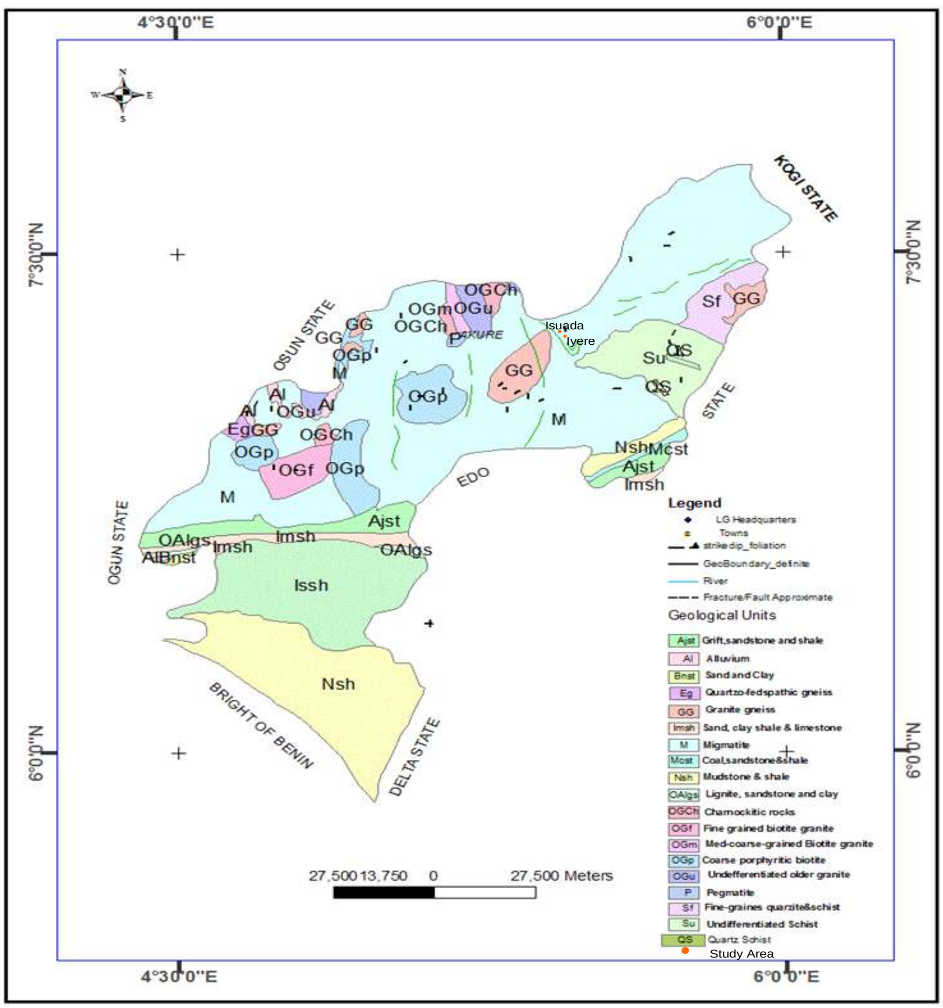


Fig. 2. Geology map of Ondo State showing the studied localities selected for the buried utilities

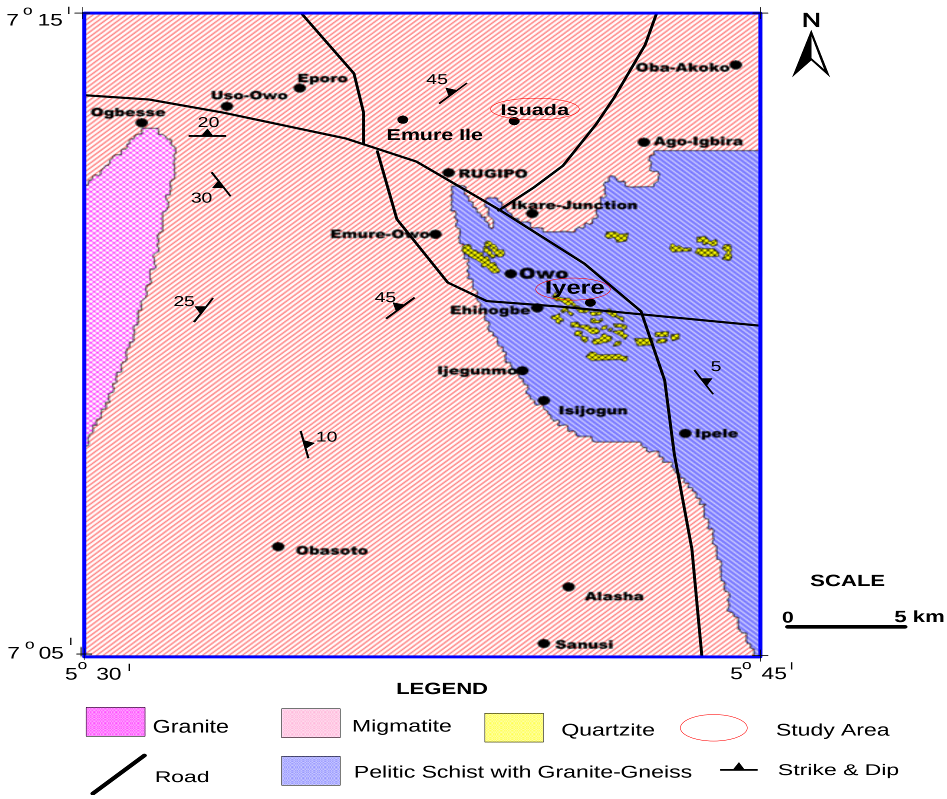


Fig. 3. Geology map of the study area showing Isuada and Iyere sites located on migmatite and granite gneiss respectively

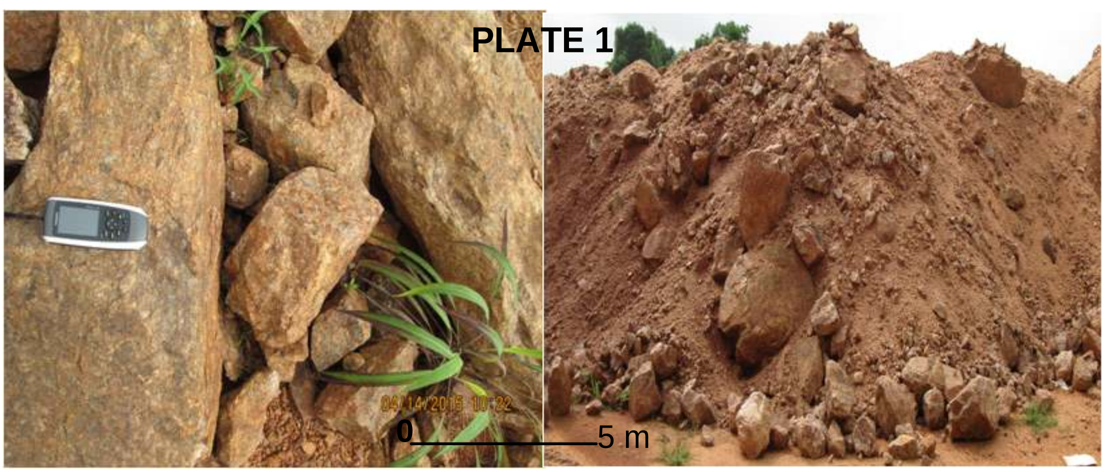


Plate 1. Highly weathered exposed quartzite rock observed at Isuada site

The Very Low Frequency Electromagnetic (VLF – EM) method is passive electromagnetic method that aims at detecting conductive or resistive bodies located at depths of a few tens meters. It uses the electromagnetic carrier waves produced by military navigation radio transmitters to communicate with submarines. These waves called primary fields in the VLF method have frequency of 15 to 30 KHz and are propagated between the surface of the earth and the ionosphere. The inline profiling technique was utilized for the study. VLF-EM measurements were taken at 5 m interval along each traverse. The real and quadrature components of the vertical/horizontal magnetic field ratio were recorded at each observation station. The receiver unit was tuned to Rugby in Great Britain. The real and filtered real [12] components were plotted against station positions using 'KHFFILT' software version 1.1. A 2-D inversion of the real component data was carried out using the same software.

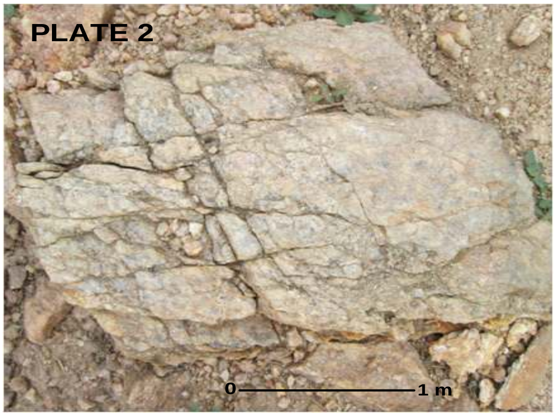


Plate 2. Joints observed on the quartzite at Isuada site

The electrical resistivity method involves the passage of electric current into the subsurface through two current electrodes while the potential difference is measured at the surface between another pair of electrodes which may or may not be located within the current electrode depending on the electrode configuration. The resistivity of the medium is obtained as the product of the quotient of the values potential difference and current and the geometric factors of the electrode configuration engaged. The resistivity of a geologic unit or target is measured in ohm-meters, and is a function of porosity, permeability, water saturation and the concentration of dissolved solids in pore fluids within the subsurface.

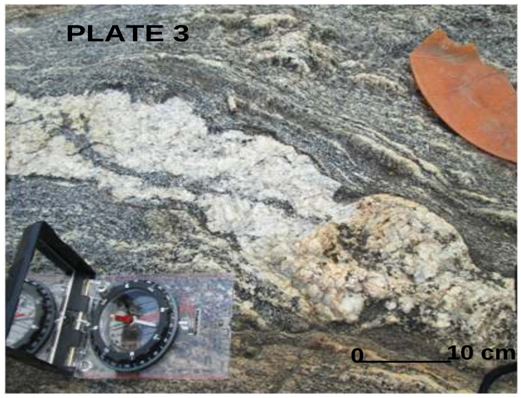


Plate 3. Quartz vein observed on granite gneiss in Iyere site

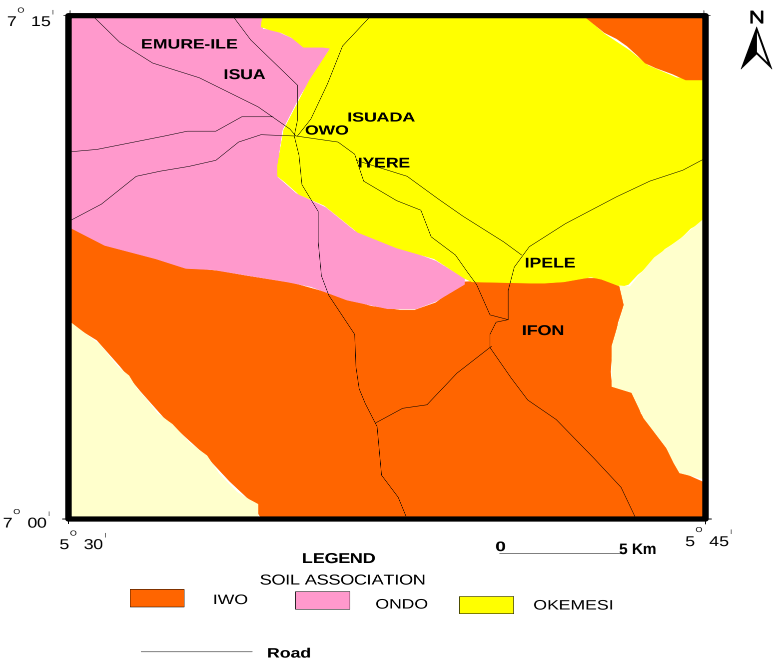


Fig. 4. Soil Map of the studied area (Extracted from [11])

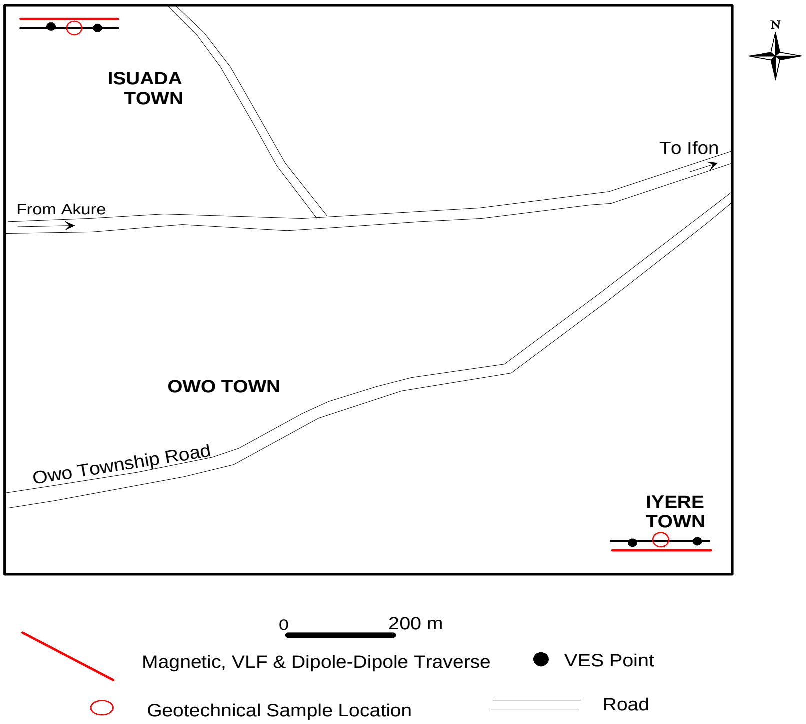


Fig. 5. Typical field layout of the study showing geophysical traverse lines and geotechnical sampled points

For this study, the electrical resistivity utilized two field techniques - Vertical Electrical Sounding (VES) technique involving Schlumberger array and 2-D electrical imaging using dipole-dipole configuration. Vertical Electrical Soundings provide information of different geological section and vertical variations of different earth material. In this survey Schlumberger array was used because of its data acquisition and interpretations are less labor intensive and economical [13]. In the Schlumberger configuration the electrodes were collinearly arranged i.e. arranged along a straight line with two outer current electrodes and two inner potential electrodes. Four electrodes C_1, P_1, P_2 and C_2 were placed at the surface and current electrode are spread much further apart than the potential electrodes as shown in Fig. 6. Four sounding stations were occupied along the two traverses established. The current electrode spacing (AB/2) was varied from 1 m to 275 m. The apparent resistivity measurements were plotted against electrode spacing on bi-logarithmic graph sheet. Resistivity data can be interpreted both qualitatively and quantitatively [13]. Partial curve matching was carried out for quantitative interpretation of the sounding curves. The results of the curve matching (layer restivities and thicknesses) were used as starting model parameters for I-D forward modeling using RESIST version 1.0 [14]. The VES interpretation results were used to prepare the geoelectric sections along the two traverses.

The 2-D electrical imaging measures the apparent resistivity along horizontal and vertical directions. The arrays commonly used include the dipole-dipole and pole-dipole. The Dipole-Dipole configuration is used in measuring the lateral and vertical variations in the ground apparent resistivity values. The Electrodes were also collinearly arranged. The two (pair of) current electrodes came before the two potential electrodes and the distance between the two pair of the electrodes was 'a' and the distance between the current and potential electrode pair was 'na' as shown in Fig. 7. The inter-electrode spacing of 5 m was adopted while inter-dipole expansion factor (n) was varied from 1 to 5. The measured apparent resistivity values were plotted against the intersection of two lines inclined at 45° from the midpoint of the current and presented as pseudo-sections. 2-D inversion of the dipole-dipole data was carried out using the DIPRO for Windows software [15].

Two soil samples were collected from the proposed sites i.e. Isuada (locality 1) and Iyere (locality 2); along the two traverses established in the area (Fig. 5). The samples were taken at depth not less than 3 m and analyzed for liquid and plastic limits, plasticity index, linear shrinkage and percentage clay content, Compaction test and Undrained triaxial test. All the tests were conducted using standard equipments in accordance to British Standards methods.

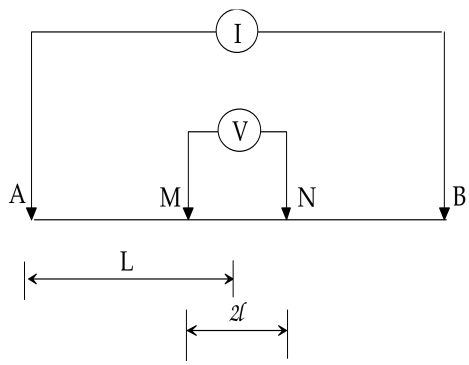


Fig. 6. Sketch diagram-m of schlumberger configuration array, A & B are current electrodes and M & N are potential electrodes

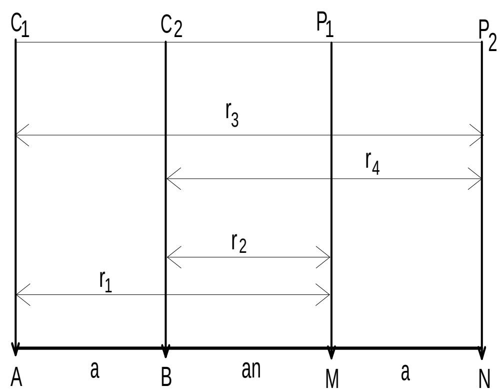


Fig. 7. Sketch diagram of dipole-dipole configuration array, A & B are current electrodes and M & N are potential electrodes

4. RESULTS AND DISCUSSION

4.1 Geophysical Results

Figs. 8 and 9 displayed the magnetic profiles obtained along traverses 1 and 2 at Isuada and Iyere sites respectively. These traverses were characterized by noisy magnetic anomaly, indicative of subsurface inhomogeneity. However, traverse 2 showed a relatively flat anomaly between distances 0 to 40 m and 60 to 150 m, which can be considered as magnetically homogeneous except for minor intrusions or thin dyke of alternating positive and negative amplitude at the eastern part. Moreover but traverses at both sites were characterized by high anomaly intensity signifying a resistive bedrock.

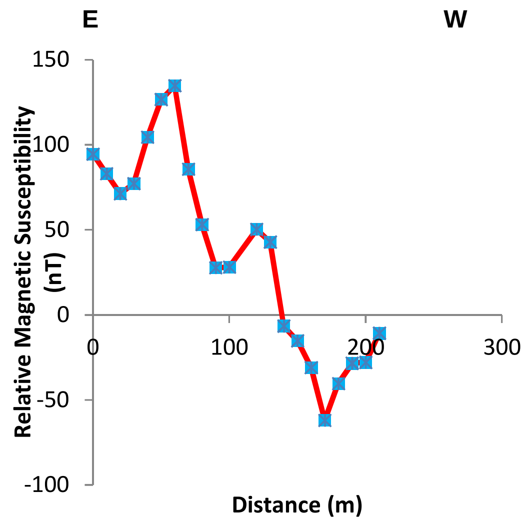


Fig. 8. Magnetic profile obtained along Traverse 1 (Isuada site)

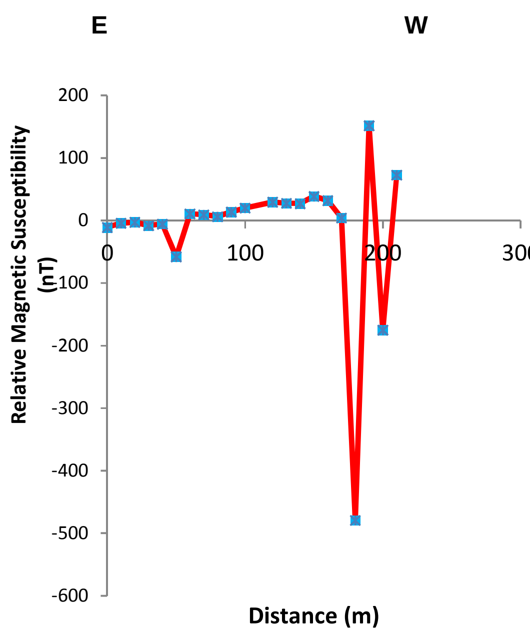


Fig. 9. Magnetic profile obtained along Traverse 2 (Iyere site)

The VLF –EM 2-D models for traverses 1 and 2 were presented in Figs. 10 and 11. The 2-D structure identified resistive zone at depth not less than 10 m but greater than 30 m along traverse 1. This target was well represented by a magnetic high anomaly at distances between 0 and 140 m along traverse 1 (Fig. 10) suspected to be a near surface outcropping basement. However, 2-D models showed some conductive zones along both traverses which were suspected to be clayey material, while a geological water filled formation within the basement was delineated along traverse 1 at distance 75 m and 120 m. Subsequently the proposed buried utilities could be constructed in areas devoid of geological structures and conductive zones.

The resistivity curve types recorded from the survey were KHKH, H, and KQ signatures (Fig. 12). The 2-D geoelectric sections along the two traverses (Figs. 13 and 14) indicated four distinct subsurface geologic layers. The layers comprised the topsoil, the weathered layer, the fractured basement, and the basement. The topsoil which was underlain by laterite has resistivity values that varied from 105 to 1264 ohm-m, and thicknesses of between 0.1 and 2 m. It was composed of sandy clay, clayey sand, sand, and laterite. The weathered layer was characterized by resistivity values ranging from 46 to 765 ohm-m and thicknesses varying from 2.2 to 16 m. The low resistivity values (< 100 ohm-m) under VES 3 and 4 were symptomatic of clay, but sandy under VES 1 and 2. The fractured basement has resistivity values that varied between 65 and 443 ohm-m, and thicknesses that varied from 9 m and greater than 35 m under VES 4. The depth to bedrock was 9.2 m with resistivity values that varied from 828 to 943 ohm-m.

Subsequently, the geo-material (weathered layer) along traverse 1 (VES 1) showed significant thickness with resistivity within the threshold of clayey-sand and sand, which makes it competent and suitable to host the proposed structure; while VES 4 showed a promising signature if stabilized or reworked by competent material, however the fractured zone underneath must be put into consideration. Basement depression could serves as groundwater collecting zone, therefore it’s better the proposed structure be constructed on relatively flat (even) topography in order to prevent unnecessary convergence of water which might destroy or weakens the foundation of the structure with time. Consequently distances between 30 m and 70 m, and 80 m to 120 m should be avoided along traverses 1 and 2 respectively.

The 2-D resistivity structure along traverses 1 and 2 were presented in Figs. 15 and 16 respectively. The resistivity structure delineated three major subsurface layers namely, the topsoil, weathered layer, and fresh basement. The topsoil composed of clayey sand and laterite with a significant thickness of 10 m along traverse 1 but 2 m thick along traverse 2. The weathered layer was characterized by clayey sand and sandy clay. Suspected linear features within basement rock observed at distance between 70 and 120 m along traverse 1 and 165 m and 200 m along traverse 2 correlated with suspected fractured zone on the VLF-EM model (Fig. 10). Subsequently the subsoil material along both traverses on the 2-D resistivity structure favours the construction of the proposed structure in the upper 10 m along traverse 1, and 5 m depth along traverse 2.

4.2 Geotechnical Results

Table 1 showed the summary geotechnical results of the sampled soils. The natural moisture content gives information on the condition of the soil. The natural moisture content of the soils from both sites varied from 6.2% to 7.8% signifying low moisture content in their natural state. The tested soils have percentage finer (percentage passing 0.075 mm) ranged between 31.5% and 38.9% indicating high clay/silt content. The liquid limit and plastic limit of the soil samples ranged from 23.9% to 39.9% and 18.6% to 25.8% respectively. The plasticity index ranged from 5.3% to 12.1%. A good subsoil materials must among other significant criteria be of low plasticity such that its resistance to swelling, total expansion and linear shrinkage should be minimal. The high plasticity index and liquid limit values are indicative of poor engineering and geological properties of subsoil soils [16]. However, sample I (representing Isuada site) showed more suitability on the basis of plasticity index.

Plotted in the Casangrade plasticity chart (Table 1; Fig. 17) showed that sample 1 and 2 fall within CL group and CI group respectively. This implied that the soil sample I contained clay fractions of low plasticity (low swelling potential) while sample II exhibits intermediate swelling potential. However both samples fall above the A-line, indicating that they composed of clayey inorganic material [16]. The soils were generally of fine-grained which corroborated with geophysical results which showed that the topsoil/subsoil was generally clayey. The specific gravity correlates well with the mechanical strength of the subsoil. The tested soils from both sites showed moderate values of specific gravity between 2.63 and 2.64. These values were moderately low, indicating a fine grained soil.

Linear shrinkage is an important parameter in the evaluation of subsoil materials civil engineering construction. The values of the linear shrinkage (LS) test range from 12.1% and 10.9%. The values were still within 12% maximum recommended subsoil materials [17]. The importance of compaction test is to improve the desirable load bearing capacity properties of a soil for civil engineering construction purposes. The Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) obtained from the tested soils ranges from 10.6 to 18.6% and 2066 - 1738 Kg/m³ respectively. The degree of compaction is sensitive to moisture content, thus the higher the value of MDD and the lower OMC, the more suitable the soil material to sustain any load imposed. Therefore both soil samples have high MDD at low OMC with sample 1 showing better compaction characteristics.

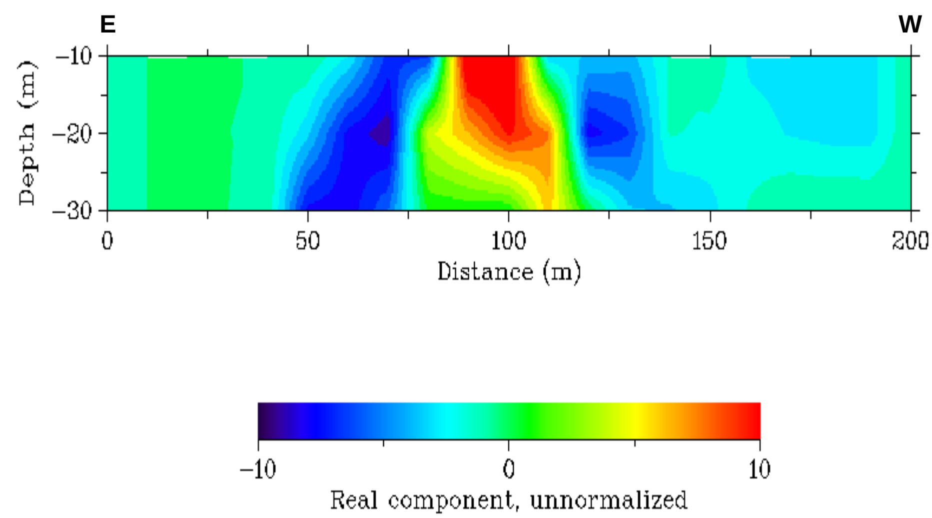


Fig. 10. VLF – EM 2 – D model for traverse 1 (Isuada site)

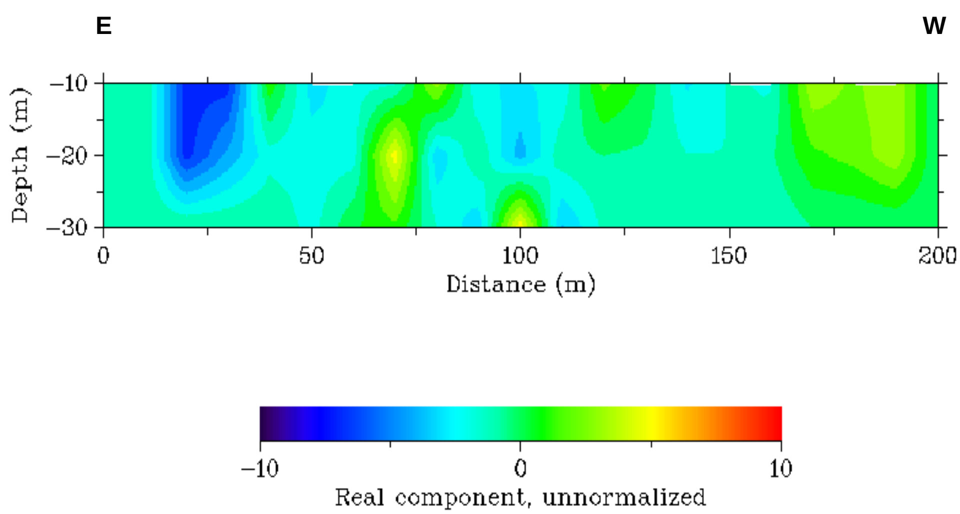
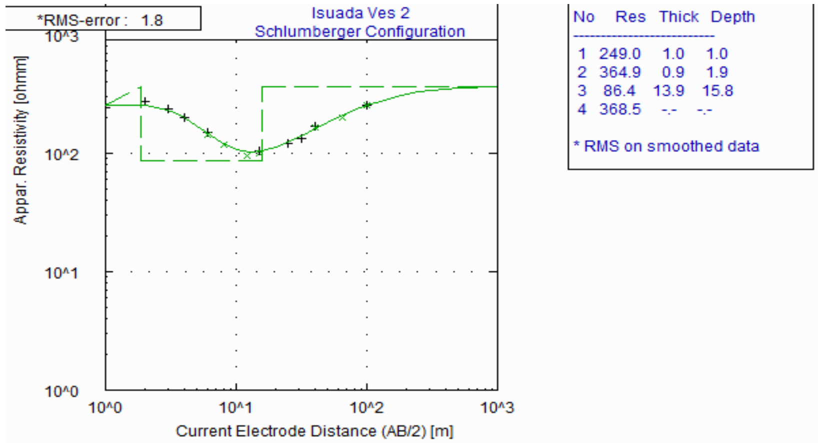
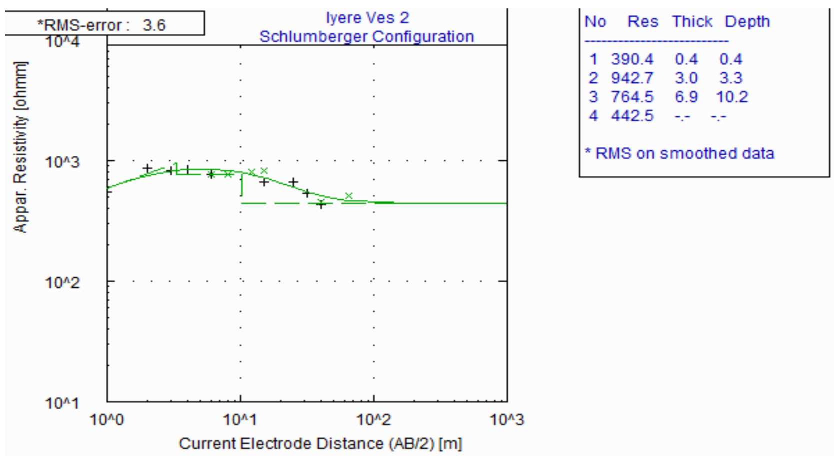


Fig. 11. VLF – EM 2 – D model for traverse 2 (Iyere site)



(a)



(b)

Fig. 12. Resistivity curve types recorded from the studied sites : (a) KQ (b) H

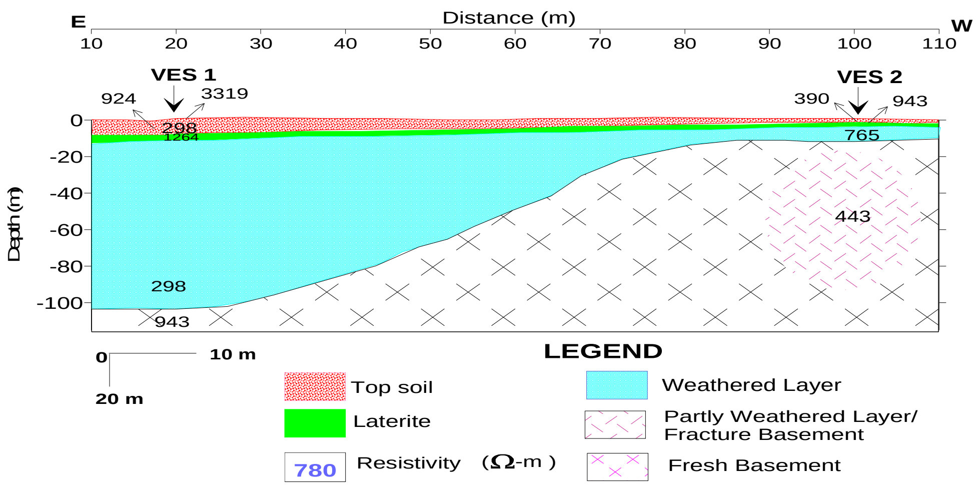


Fig. 13. Geoelectric section along traverse 1 (Isuada site)

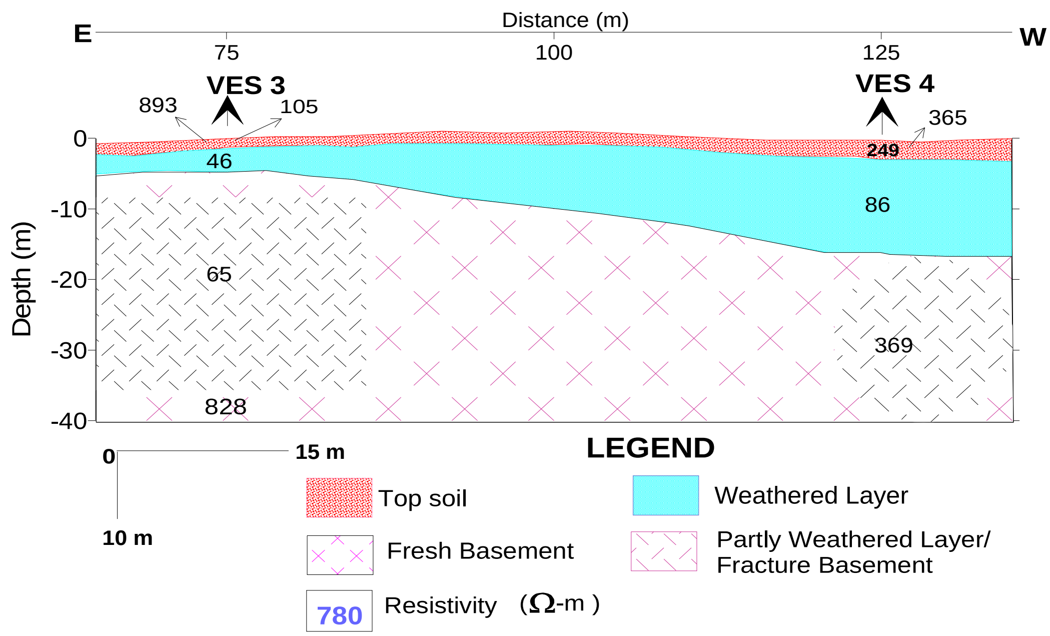


Fig. 14. Geoelectric section along traverse 2 (Iyere site)

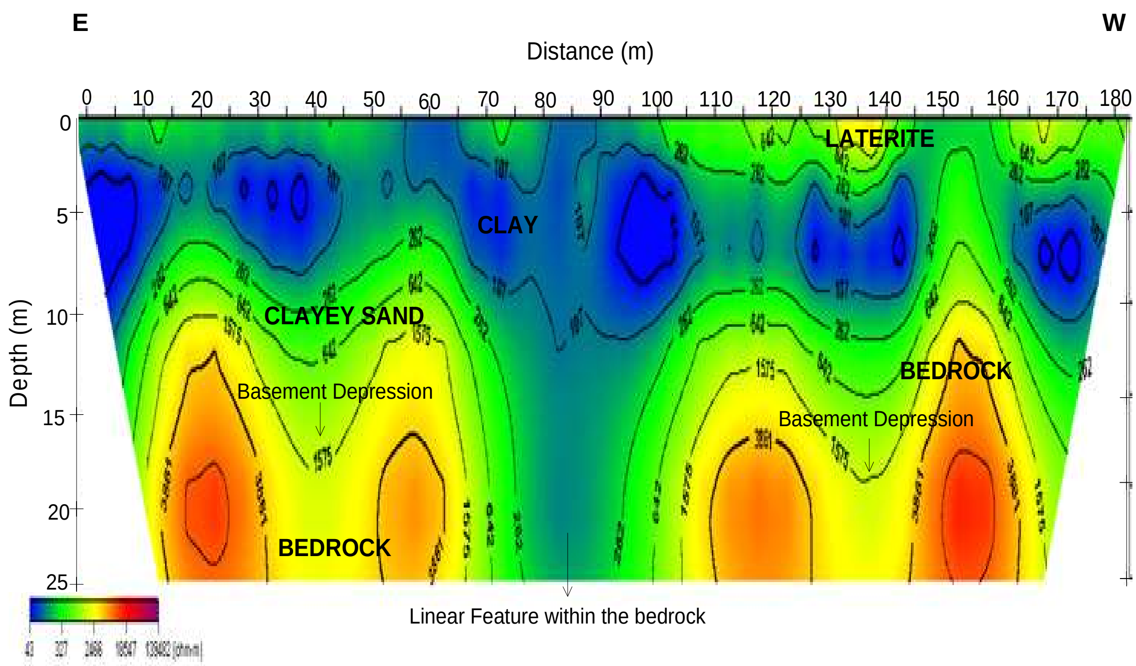


Fig. 15. 2-D resistivity structure along traverse 1 (Isuada site)

The cohesion, angle of friction, and shear strength of the samples obtained from the triaxial test conducted showed a range between 102.1 Kpa to 84.2 Kpa, 20.4° to 28.6°, and 124.3 Kpa to 116.9 Kpa respectively. Therefore both samples showed good cohesive property and shear strength, but sample I has higher shear strength which corroborated the compaction result.

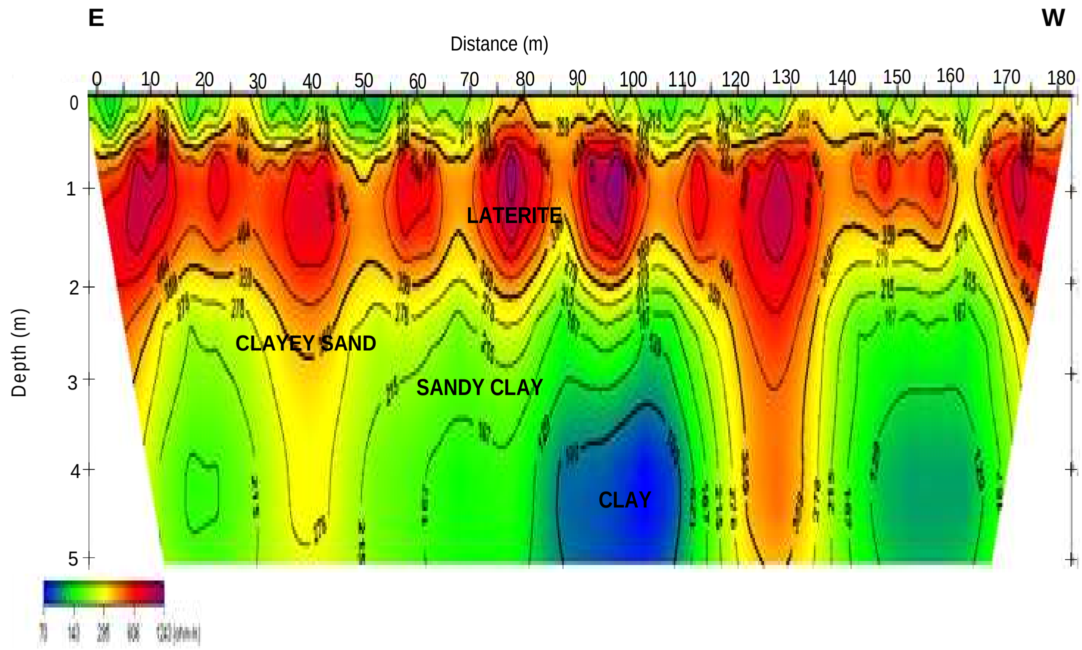


Fig. 16. 2-D resistivity structure along traverse 2 (Iyere site)

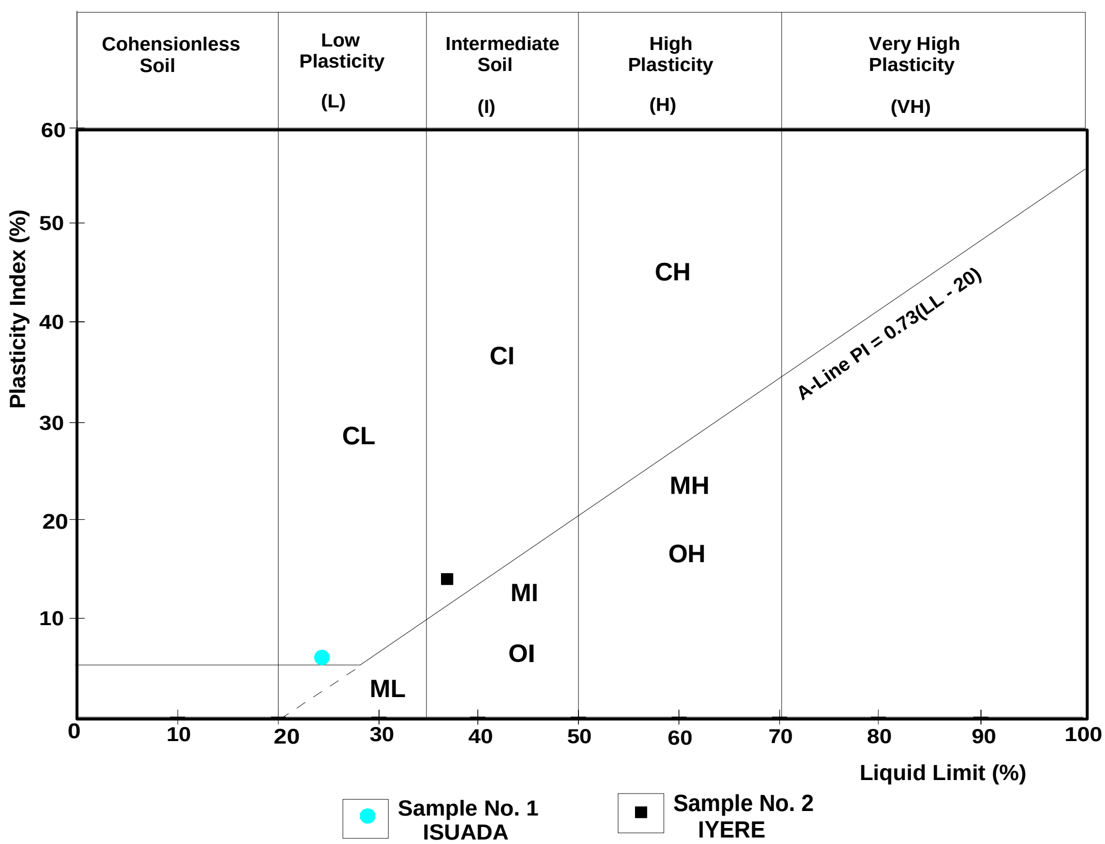


Fig. 17. Casangrade plasticity chart for the sampled soils

Table 1. Summary of the geotechnical results

Test		Sample no./Location	
		Sample 1	Sample 2
	Natural moisture content (%)	6.2	7.8
	% of fines (Silt/Clay content)	31.5	38.9
	Specific gravity	2.64	2.63
Consistency limits test	Liquid limit (%)	23.9	37.9
	Plastic limit (%)	18.6	25.8
	Plasticity index (%)	5.3	12.1
	Linear shrinkage (%)	12.1	10.9
Compaction test	MDD (Kg/m^3)	2066	1738
	OMC (%)	10.6	18.6
Undrained triaxial test	Cohesion (Kpa)	102.1	84.2
	Angle of friction (°)	20.4	28.6
	Shear strength (Kpa)	124.3	116.9
	USCS group symbol	CI	CL

5. CONCLUSION

Integrated geophysical surveys complemented with geotechnical method were used to evaluate the competence of the subsoil to host a proposed communication mast and its accessories in Isuada and Iyere towns of Ondo State. The Geophysical survey involved magnetic, very low frequency electromagnetic (VLF-EM), and electrical resistivity method using vertical electrical sounding and combined vertical electrical sounding and horizontal profiling field techniques (dipole-dipole). The geotechnical investigation involved analysis of soil samples taken at a depth not less than 3 m for grain size analysis, specific gravity, consistency limits test, compaction test, and undrained triaxial test.

The geoelectric section and the 2-D resistivity structure delineated three to four layers, namely the topsoil, weathered layer, fractured basement, and fresh basement. The resistivity of the topsoil indicated sandy clay, clayey sand, and laterite composition with a thickness of 10 m and 5 m along traverse 1 and 2 respectively. Basement depression was found along traverse 1 which was also delineated on the geoelectric section. The geophysical results showed a well correlated result by all the methods adopted for the study. The VLF-EM method delineated resistive zones and fractured zones which correlated with geoelectric sections and 2-D resistivity structure. The fractured zone was represented by low magnetic intensity on the magnetic profiles.

The results of the geotechnical analysis of the sampled soil showed that the subsoil at both sites possessed good geotechnical properties. However sample 1 taken from Isuada site was more competent than sample 2 representing Iyere site in terms of mechanical strength (ability to withstand the proposed load) and less % of fines soil with mild corrosive tendency of the proposed metallic utilities.

Therefore considering the results of the investigation, the proposed structure may be constructed under VES 1 and 2 i.e. along traverse 1 at a maximum depth of 10 m - 20 m but fractured zone below VES 2 must be put into consideration during the design process the proposed structure. Along traverse 2, VES 4 would be suitable provided the soil is stabilized with competent material to depth of 15 m.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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