# INTEGRATED GEOPHYSICAL AND GEOTECHNICAL INVESTIGATION OF LATERITIC SOIL AS SUBGRADE MATERIALS IN AKURE, SOUTHWESTERN NIGERIA

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**Abstract**

An integrated geophysical and geotechnical investigation of the sub-soil was carried out to determine the suitability of the soil as sub-grade materials. Ten vertical electrical sounding points and two horizontal profiles of 100m each were carried out using a dipole-dipole configuration. Six soil samples were collected from three dug pits at 0.5m and 1.0m for laboratory analyses which included specific gravity, moisture content, compaction, grain size, and Atterberg limits. The result from the VES showed the sub-surface layer was made up of lateritic topsoil, clay, and sandy clay while the horizontal profile carried out also shows three continuous lithological units namely lateritic topsoil, clay, and sandy clay. The average resistivity values for the lateritic topsoil, clay, and sandy clay were 49 Ωm, 30 Ωm, and 95 Ωm respectively while the thicknesses for the three geo-electrical units are 1.5m, 10m and 9m respectively. The geotechnical results show that the MDD of the samples ranged from 1410 kg/$m^3$ to 1460 Kg/$m^3$ at 1m while the OMC ranged from 15-18% at 1m depth. The soils are silty clay with medium plasticity. Soil samples obtained here are fair to poor subgrade materials. The percentage of materials passing sieve no 200 for samples obtained in pits 1, 2, and 3 are 0%, 0%, and 63.6% respectively. The liquid limits values range from 35-41% while the plasticity indices range from 14 to 18%. In conclusion, soil samples are not good as subgrade materials, stabilization is necessary to improve their geotechnical properties.

**Keywords:** Subgrade, Geotechnical properties, Resistivity, Superstructure, Stabilization

## *1.1 Introduction*

The suitability of soils for engineering purposes depends mainly on their ability to remain in place or support either permanent or transient loads that may be placed on them [1]. A sub-structure is an integral part of a civil engineering structure that transmits the weight of the super- structure to the soil underneath it. It is good to investigate the geotechnical properties of the soil below to determine their ability to support structures emplaced on them [2,[3]. Laterite which is a residual soil is rich in iron and aluminium and is commonly considered to have been formed in hot and tropical areas. According to Alexander and Caly [4]], laterite is a highly weathered material rich in secondary oxides of Iron and Aluminium. Lateritic soil may be used as subgrade or base - course material [5, 6]. Sub-grade according to Head [7] is a natural soil or embankment construction prepared and compacted to support a pavement. Head [7], also defined pavement as a constructed layer of durable material of specified thickness, usually of concrete, asphalt or bituminous materials designed to carry wheeled vehicles. The performance of lateritic soils as the foundations for structure is varied and appears to depend on the nature of the soil, the degree of the weathering, topography, the drainage condition and more importantly, the type of foundation and the number of loads imposed [8]. In lateritic deposits, it may be possible to build ordinary structures on suitable design footings located a few feet below the surface of the ground. However, heavier structures may have to be based on firm layers, which are determined by sub-soil investigations. The mineralogical composition of the lateritic soil has an influence on the geotechnical parameters such as specific gravity, shear strength, atteberg limits, bearing ratio and petrographic properties [9]. Salter [10] pointed out that the performance of a highway pavement is influenced to a very considerable extent by the sub-grade material. Therefore, a good understanding of the basement soil on which highways and other transportation facilities are constructed is very important.Omotoso [11], worked on lateritic soil in connection with the construction of roads, highways, and airfields; and engineering problems associated with lateritic soil. Balogoun, [12] reported that the addition of lime to the soil increases its optimum moisture content, liquid limit, and California bearing ratio, among others

*2 .1 Location and physiography of the Study Area*

The study area is situated within the Ijapo-Extension in Akure, Ondo State. Akure lies within longitude 7˚13′N and 7˚17N and latitude 5˚7′E and 5˚14′E. The study area lies within longitude 7˚15′14′′N and 7˚17̕50′′N and latitude 5˚15′01′′E and 5˚13′ 2′′E.The area is a construction site made up of highly weathered laterite. The climate of the study area is Tropical rainforest, with distinct wet and dry seasons between November and March. In the Northern part of the state, the mean monthly temperature and its range are about $30^0$C and $6^0$C respectively. The mean monthly relative humidity is less than 70%. The study area experiences sufficientrainfall throughout the year; however,November, December, and January may be relatively dryseasons.The mean annual total rainfall exceeds 2000mm.Olarenwaju [13] had attempted the classification of the geology of Akure into migmatite gneiss, porphyritic granite gneiss, charnockite, Quartzite, Pelitic Schist (Figure 1). The Ijapo area of Akure is underlain by two main petrologic units; which include migmatite Gneiss and Granite Gneiss [14].

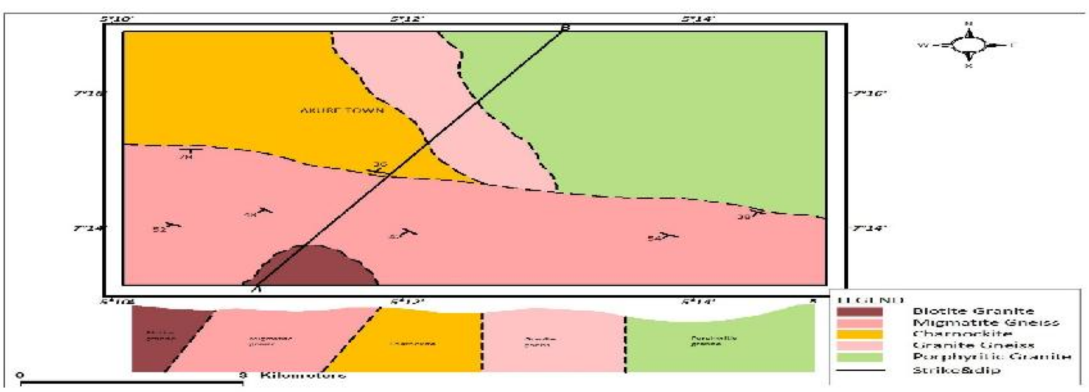



Figure 1: Geological map of Akure [14].

## 3.0Materials and Methods

Site investigation was carried out in the study area using the geophysical and geotechnical methods.

*3.1 Geophysical Investigation*: Two transverses were established across the study area and ten Vertical Electrical Sounding (VES) stations were carried out along the transverses of the Schlumberger configuration. The electrode spacing (AB/2) was varied from 1m to 150m on average. The apparent resistivity values were plotted against electrode spacing (AB/2) on a bi-logarithmic graph sheet to generate depth-sounding curves. The field curves were then inspected visually for identification of the curve type. Partial curve matching was carried out on the field curves. The interpretation results (layer resistivity and thickness) were fed into the computer for 1-D computer-assisted interpretation involving Resist version 1.0 software. The final interpreted results were used for the preparation of geo-electric sections, histograms, and maps. The electrical resistivity method of subsurface exploration is based on the fact that different materials offer different resistance to the passage of an electrical current. Thus, by the determination of vertical and lateral variations in the resistance, it is possible, within certain limitations, to infer the stratification and the lateral extent of subsurface deposits.

***3.2*** *Geotechnical analyses*: Six disturbed soil samples were collected at three locations at depths 0.5m and 1.0m within the site. These samples collected from the field were preserved in polythene bags and transported to the laboratory within 24 hours after collection to determine theirnatural moisture content and soil samples were air-dried for a week before other tests were carried out using BS. 1377[15] ) methods of testing soils for engineering the tests carried out include moisture content, specific gravity, Atterberg limits, compaction, and grain size analysis.

*4.0 Results and Discussion*

*4.1Geophysical Results*

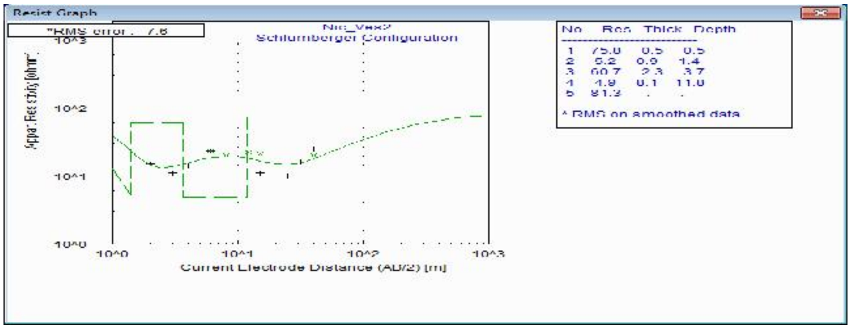
. From this investigation, three different subsurface lithological units were identified namely: Lateritic top soil, followed by clay which is underlain by sandy-clay. A correlation table was drawn to determine and compare the lateral continuity of the different lithological units, the correlation table belowpresents the summary of the different inferred subsurface layers as revealed by the sounding curves (Figs. 2 to.6)

Table 1: Correlation Table

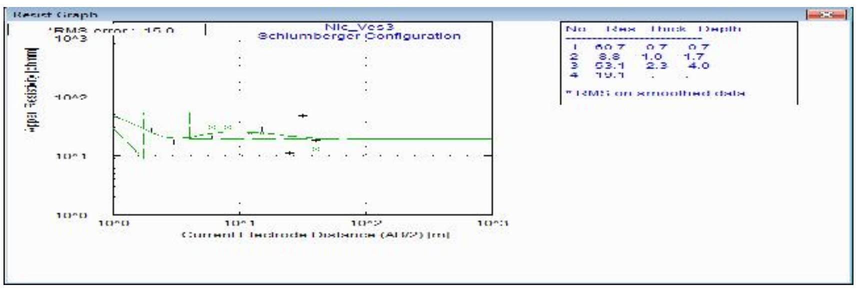
| LITHOLOGY | VES point | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Curve type | | H | HKH | HK | HK | H | H | K | HA | HA | HA |
| | Topsoil | Top | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Base | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 |
| | | Thk | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 |
| | | Ωm | 31 | 76 | 61 | 49 | 135 | 56 | 46 | 14 | 10 | 11 |
| | Clay | Top | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 |
| | | Base | - | 12 | - | - | - | - | - | 12 | 3 | 10 |
| | | Thk | - | 11 | - | - | - | - | - | 9 | 2 | 9 |
| | | Ωm | 43 | 61 | 53 | 45 | 22 | 25 | 47 | 5 | 1 | 5 |
| | Sandy clay | Top | - | 12 | - | - | - | - | - | 12 | 3 | 10 |
| | | Base | - | - | - | - | - | - | - | - | - | - |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ωm | - | 81 | - | - | - | - | - | 86 | 160 | 54 |

Geo-electric sections were generated to give a pictorial view of the lateral continuity of the different units (Tab. 1 and Figure 7a –c respectively). The depths to the top of the various lithological units were determined and the thickness of the various units and the average thickness units were all determined

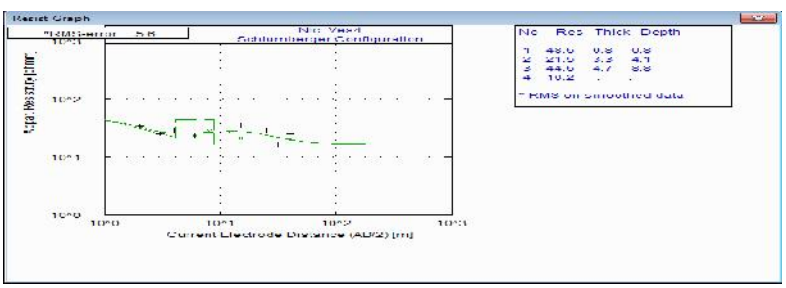



(a)

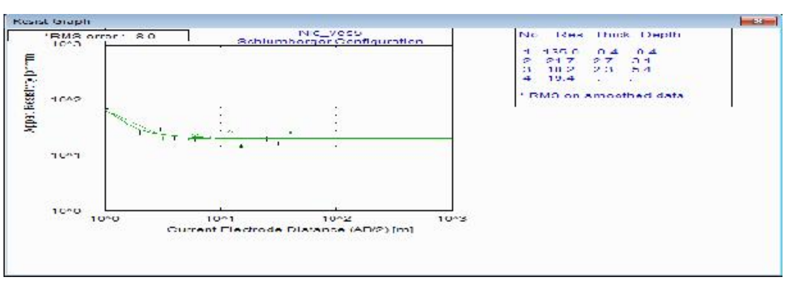



(b)

Figure 2a& b: Depth sounding curves from VES 2 & 3.

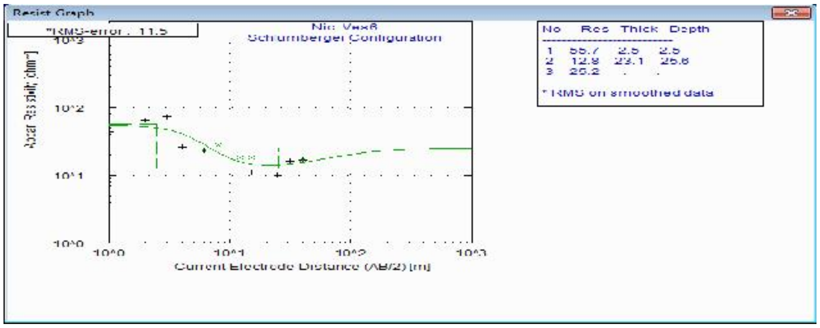



(a)

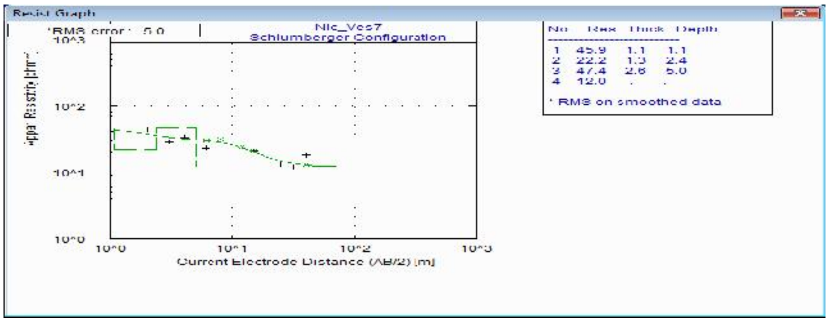



(b)

Figure 3 a &b: Depth sounding curves from VES 4 & 5.

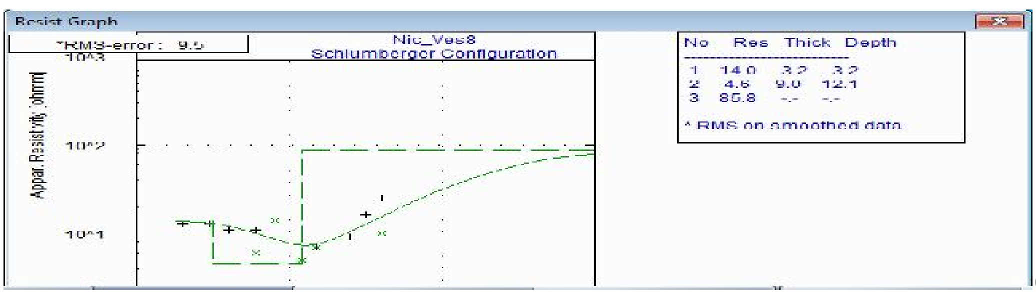


(a)



(b)

Figure 4 a & b: Depth sounding curves from VES 6 & 7.



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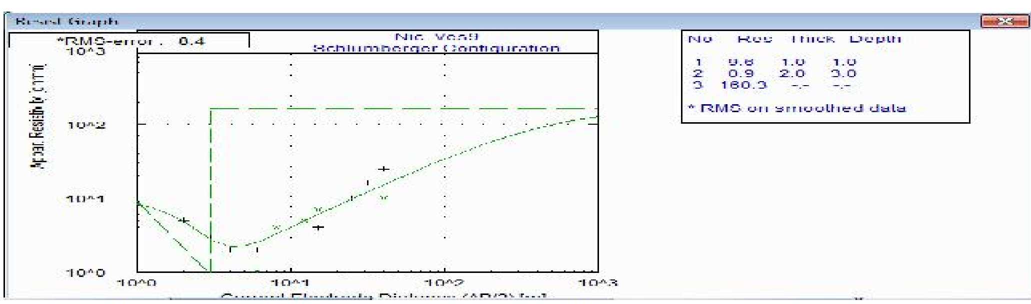

(b)

Figure 5 a & b: Depth sounding curves from VES 8 & 9

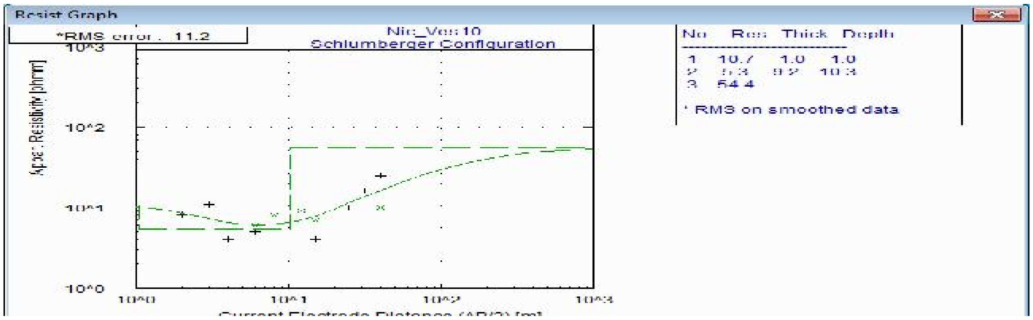


Figure 6: Depth-sounding curves from VES 10

The geo-electric sections (Figures 7 a, band c) show the variations of resistivity and thickness values of layers within the depth penetrated in the study area. Three subsurface layers were revealed: Lateritic-Topsoil, clay and sandy clay.

**Lateritic-Topsoil:** The Lateritic-topsoil is relatively thin along the study area. The average resistivity and thickness values for the topsoil are 49Ωm and 1.5m respectively.

**Clay:** Clay was encountered in all the locations and the average resistivity and thickness values of the clay are 30Ωm and 10.0m respectively.

**Sandy-Clay:** Sandy-Clay was encountered in 3 locations and the average resistivity value and depth of the Sandy-Clay are 95Ωm and 9m respectively.

**Overburden:**The overburden is assumed to include all materials above the Sandy-Clay. The depth to the top of the Sandy-Clay 9.0m (Table 1 and Figures 7 a, b & c).Overburden thickness was established in only 3 of the locations and the thickness value is 9.0m.

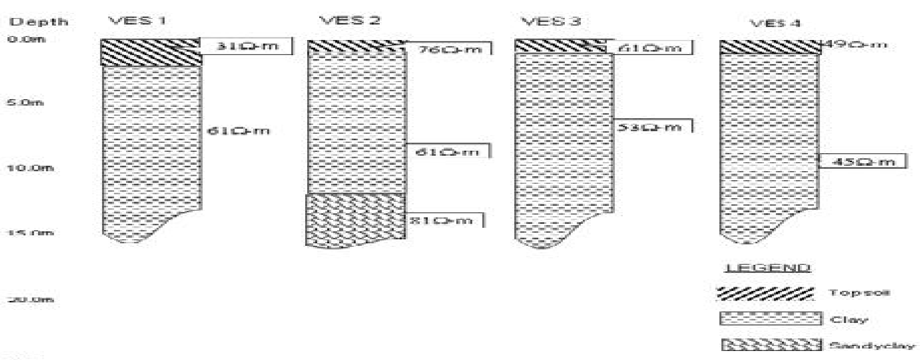


Figure 7a: The Geo-electric section obtained from VES 1, 2, 3 &4

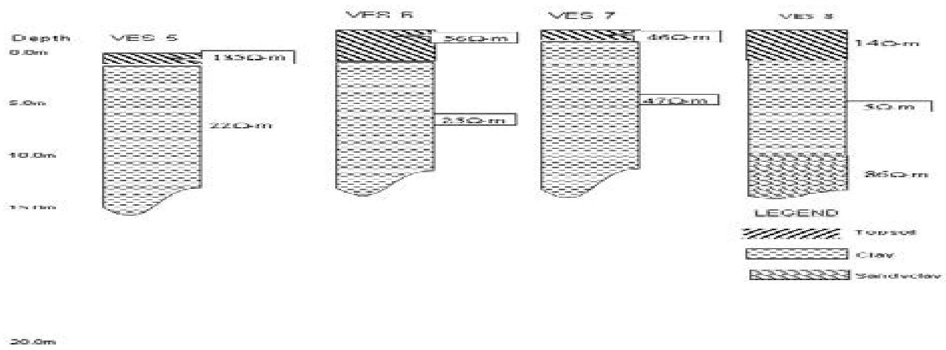


Figure 7b: The Geo-electric section obtained from VES 5,6,7 and 8

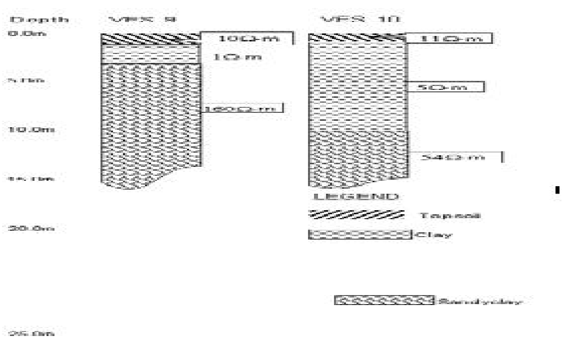


Figure 7c: The Geo-electric section obtained from VES 9 & 10

*Horizontal Profiling*

The results of the two profiles carried out are presented in the sections below. The traverses are 100 meters long each. Three continuous subsurface lithological units namely; Lateritic topsoil (blue), clay (green), and sandy-clay (reddish purple) were established by the profile sections. The results are presented in the form of field, theoretical data, and 2-D resistivity structures (Fig 8 a, b & c and Fig 9: a, b & c).

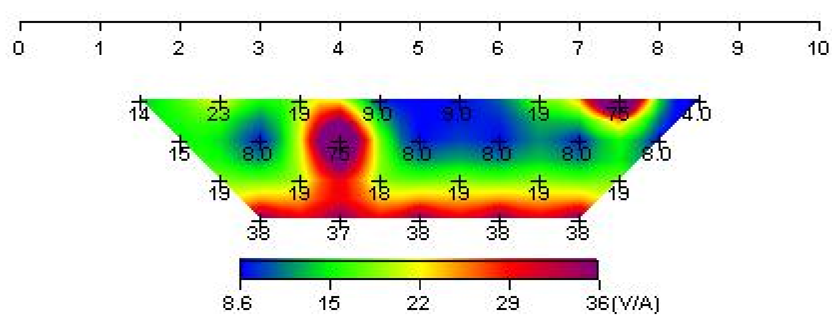


Figure 8a: Field Data Pseudosection of Traverse 1

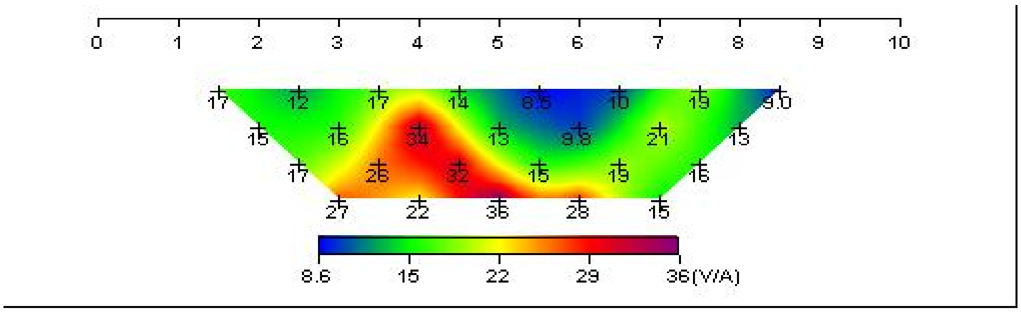


Figure. 8b: Theoretical Data Pseudosection of Traverse 1

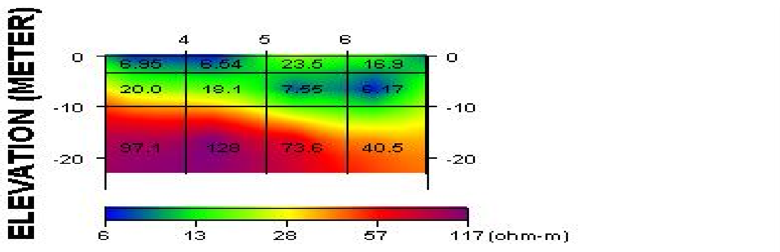


Figure 8c: 2-D Resistivity Structure of Traverse 1

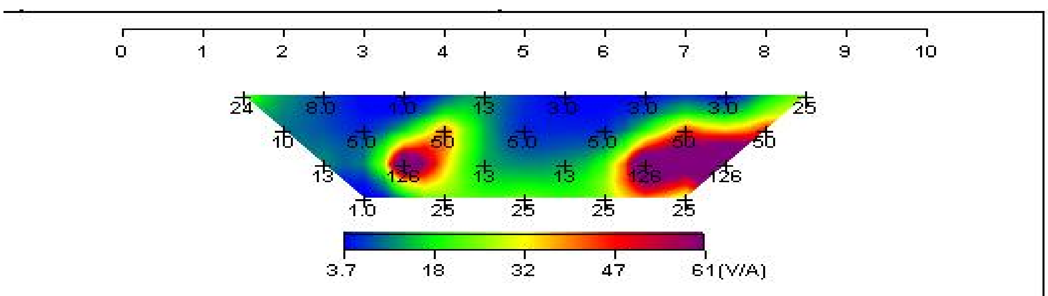


Figure 9a: Field Data Pseudosection of Traverse 2

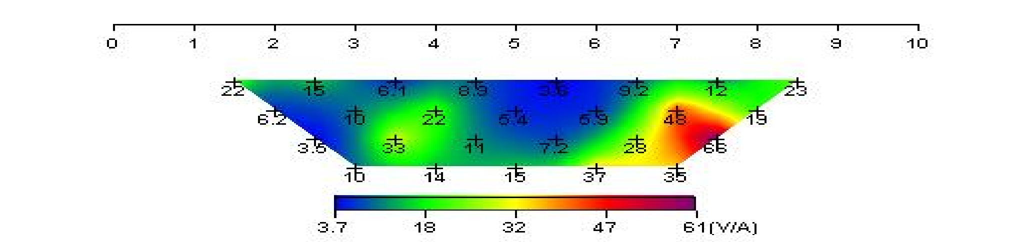


Figure. 9b: Theoretical Data Pseudosection of Traverse 2

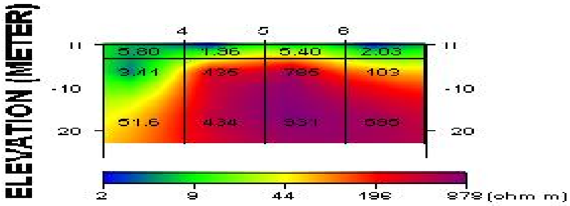


Figure 9c: 2- D Resistivity Structure of Traverse 2

## 4.2 Geotechnical Results

### Moisture Content

The moisture content of subsoil materials collected from pit 1 to pit 3 ranged from 18.0 to 35.0%. Pit 1 at a depth of 1.0m has the highest moisture content 35.0%. The Federal Ministry of Works and Housing [16] classified soils into 4 types based on their moisture content sand (6 to 10%), sandy silt (8 to 12%), silt (12 to 16%), and clay (14 to 20%).  From the table below, the moisture content of the soilfalls between 18.0 to 35.0%, thereby making it clay.

### Specific Gravity

Specific gravity is the ratio of the mass of a unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a standard temperature. The specific gravity for the soil samples ranges from 2.23 to 2.8, with an average of 2.5. According to AASHTO specifications, good lateritic soil should have a specific gravity ranging from 2.5 to 2.75, based on the specification. Pits 1 and 3 of the soil samples collected are within the acceptable limits.According to Das [17] most clay minerals have a specific gravity that falls within the range of 1.6-2.9. Values of the specific gravity outside the range of values given may occasionally be encountered in soils derived from parent materials that contained either unusually light or unusually heavy minerals.

### Atterberg's Limits Test

The liquid limits ranged from 35 - 41%, plastic limits ranged from 20 - 23%, and the plasticity index ranged from 14 – 18% (Table 2). Federal Ministry for Works and Housing [16]  for road works recommended liquid limits of 50% maximum for sub-base and base materials. All three soil samples collected fall within this specification thereby making them suitable for sub-base and base material. Also according to Wright [18], the liquid limit values of 40% and above are assumed high in pavement construction, and using this specification, only samples 5 and 6 have values higher than 40% thus making them unsuitable for road construction [19]. Adeyemi and Oyeyemi [20] gave the maximum value of 8% as linear shrinkage for highway sub-base materials and a maximum of 10% was specified for sub-grade materials. Linear shrinkage ranges from 24 -28% falling above the range of the maximum value of 8% for the requirements of highway sub-base material.

Table **2:** Atterberg limit of the study area

| Sample location | Depth (m) | Liquid limit (%) | Plastic limit (%) | Linear Shrinkage (%) | Plasticity index (%) | Description |
|---|---|---|---|---|---|---|
| Pit 1 | 0.5 | 41 | 23 | 24 | 18 | Medium plastic |
| | 1.0 | 38 | 22 | 25 | 16 | Medium plastic |
| Pit 2 | 0.5 | 37 | 20 | 24 | 17 | Medium plastic |
| | 1.0 | 37 | 23 | 25 | 14 | Medium plastic |
| Pit 3 | 0.5 | 35 | 21 | 28 | 14 | Medium plastic |
| | 1.0 | 35 | 21 | 28 | 14 | Medium plastic |

Table **3:** Description of soil type based on the plasticity of soil

| Plasticity index | Description |
|---|---|
| 0 | Non plastic |
| 1-5 | Slightly plastic |
| 5-10 | Low plasticity |
| 10-20 | Medium plasticity |
| 20-40 | High plasticity |
| >40 | Very high plasticity |

The plasticity chart (Figure 10) was used to classify the soil. Plasticity chart depicts that all the samples obtained from all the pits are above the A-line indicating that the samples were all clay.

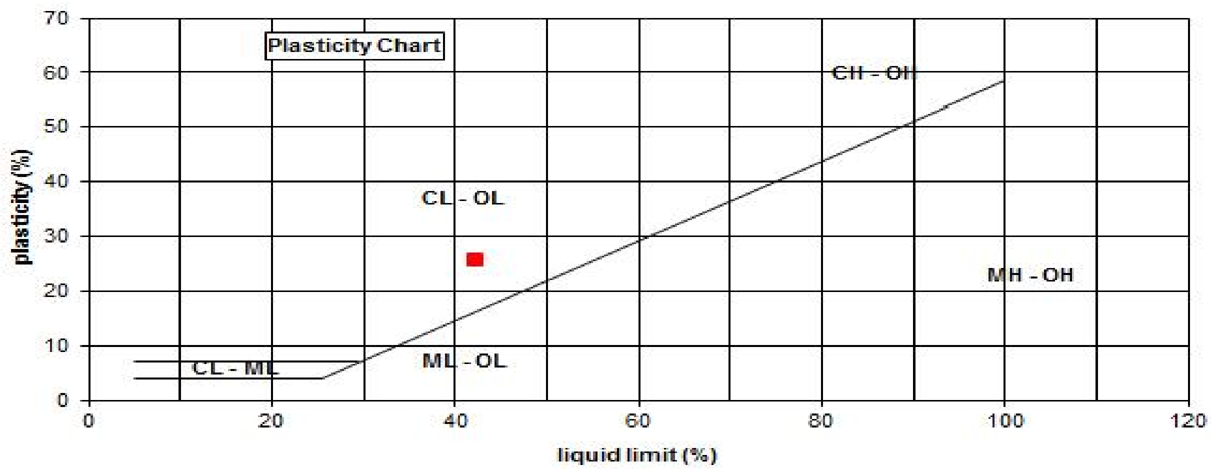


Figure 10: Cassagrande Plasticity Chart

Table 4: Nigerian standard of soil classification for roads and bridges

| Sample location | Pit 1 | | Pit 2 | | Pit 3 | |
|---|---|---|---|---|---|---|
| Sample depth (m) | 0.5 | 1.0 | 0.5 | 1.0 | 0.5 | 1.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| L.L (≤30%) (sub-grade/fill material) | 41 Fail | 38 Fail | 37 Fail | 37 Fail | 35 Fail | 35 Fail |
| L.L (≤50%) (Sub-base material) | 41 Pass | 38 Pass | 37 Pass | 37 Pass | 35 Pass | 35 Pass |
| P.I (≤12%) | 18 Fail | 16 Fail | 17 Fail | 14 Fail | 14 Fail | 14 Fail |

The results of the geotechnical and geophysical parameters measured in the research were correlated using the least square regression method. The plot of resistivity against liquid limit shows a good regression co-efficient $R^2$= 0.57 while the plot of resistivity against plasticity index shows a mild regression as shown in figure 11.. These findings reveal that soil with low plasticity has tendencies of higher resistivity values and vice versa. These findings also agree with Oyediran and Falae [21] who concluded that soil samples with a high amount of clay (more than 20%) will have a corresponding medium plasticity.

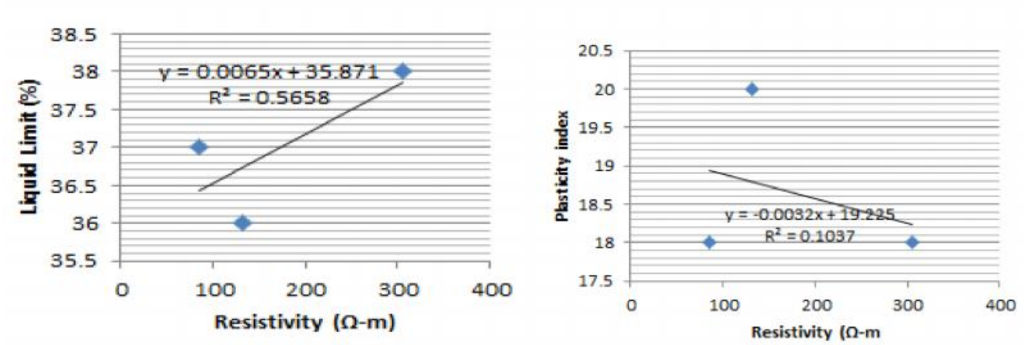


Figure 11: Showing graphs of resistivity vs liquid limit and plasticity index

### *Grain Size Analysis*

This test is performed to determine the percentage of different grain sizes contained within a soil. It is one of the criteria used in determining the suitability of soil for most civil engineering structures. Generally, a soil with high percentage of fines is not suitable for construction purposes as it is susceptible to volume change with time.The sieve analysis was performed to determine the distribution of the coarser-sized particles. The distribution of different grain sizes affects the engineering properties of soil. The soils that are largely made up of fine particles are likely to have poor geotechnical properties as sub-base and sub-grade materials than soils that are largely made up of coarse particles. Information obtained from grain size analysis can be used to predict soil water movement.

According to the specification requirement of the Federal Ministry of Works and Housing (FMWH), for a sample to be used as both sub-grade and sub-base material, the percentage by weight passing sieve no. 200 (0.063mm) should be less than but not greater than 35% and if the percentage passing sieve no. 200 for a lateritic base course is greater than 35%, there is no need for further tests and the material should be rejected. Pit 1 and Pit2 are within the specification, while Pit3 is above the specification. In the plotting of the graph, it was seen that the soil sample collected at the three dug holes fell into a composition of sand. According to clause 6201 of the Federal Ministry of Works and Housing [16] (FMWH, 1997) specification requirement; for a sample to be used for construction base, the percentage by weight passing the 0.063mm sieve size should be less than but not greater than 35%. If it is greater than 35%, then there is no need for further tests and materials should be rejected. From the data presented below, pit 1 (0.5 &

1.0m) and pit 2 (0.5 & 1.0m) are within the specification while pit 3 (0.5 & 1.0m) exceeds the standard making it unsuitable as sub-grade material.

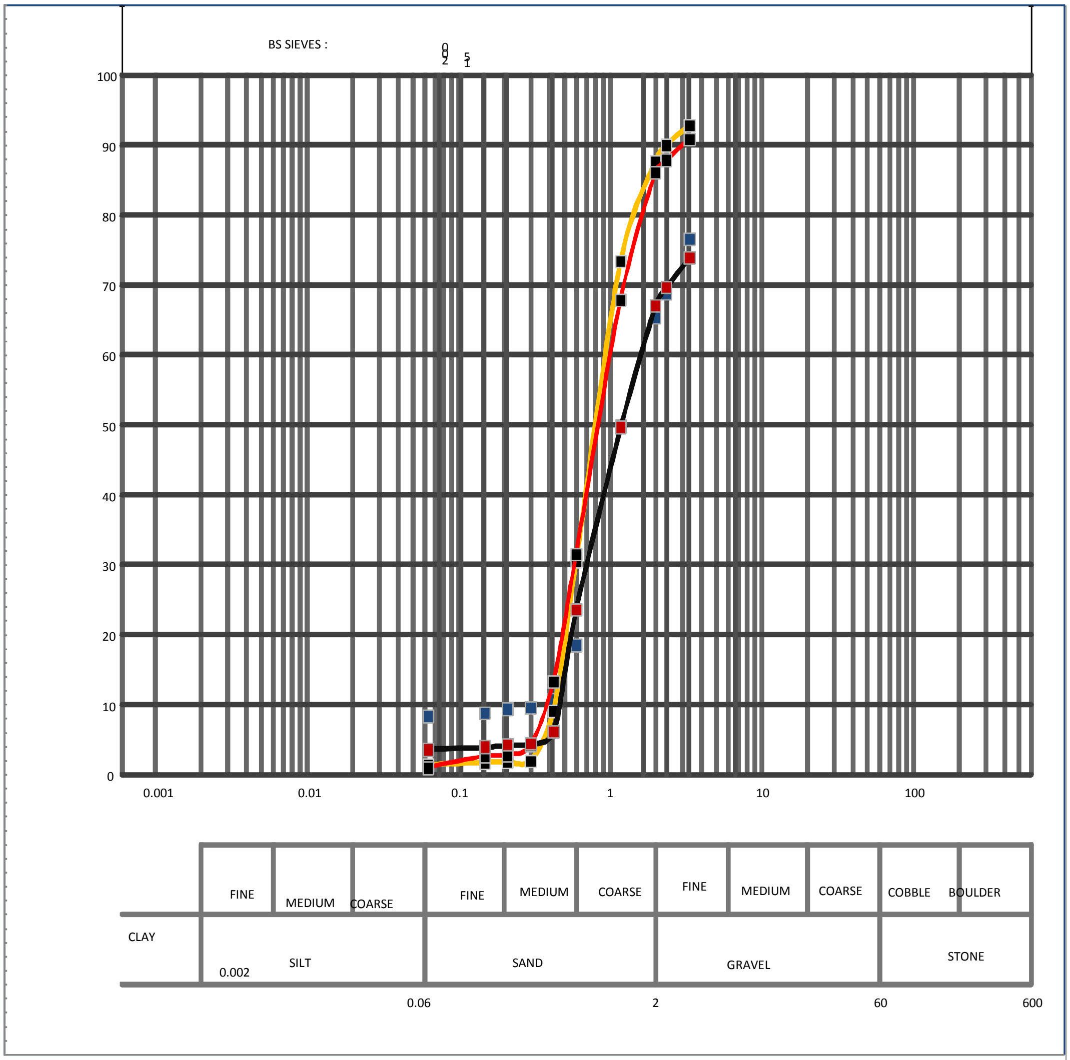


Figure 12: Sieve analysis of the study area

**Key:** Black: Pit1, Red: Pit 2, Yellow:Pit 3

| Group Classification | A-1 | | A-3 | A-2 | | | | A-4 | A-5 | A-6 | A-7 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A-1-a | A-1-b | | A-2-4 | A-2-5 | A-2-6 | A-2-7 | | | | A-7-5<br>A-7-6 |
| Sieve Analysis, % passing | | | | | | | | | | | |
| 2.00 mm (No. 10) | 50 max | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.425 (No. 40) | 30 max | 50 max | 51 min | ... | ... | ... | ... | ... | ... | ... | ... |
| 0.075 (No. 200) | 15 max | 25 max | 10 max | 35 max | 35 max | 35 max | 35 max | 36 min | 36 min | 36 min | 36 min |
| Characteristics of fraction passing 0.425 mm (No. 40) | | | | | | | | | | | |
| Liquid Limit | ... | | ... | 40 max | 41 min | 40 max | 41 min | 40 max | 41 min | 40 max | 41 min |
| Plasticity Index | 6 max | | N.P. | 10 max | 10 max | 11 min | 11 min | 10 max | 10 max | 11 min | 11 min |
| Usual types of significant constituent materials | stone fragments, gravel and sand | | fine sand | silty or clayey gravel and sand | | | | silty soils | | clayey soils | |
| General rating as a subgrade | excellent to good | | | | | | | fair to poor | | | |

**Note:** Plasticity index of A-7-5 subgroup is equal to or less than the LL - 30. Plasticity index of A-7-6 subgroup is greater than LL - 30

Figure 13: AASHTO Classification of subgrade materials.

Following the AASHTO Classification scheme for subgrade materials shown in figure 13. sample 1 to sample 4 which were obtained at 0.5m and 1m for borehole 1 and borehole 2 are good subgrade materials because the percentage of materials passing sieve no 200 (0.074mm) are 0.91 and 0.46% respectively for sample no 1-4 and also falls between the allowable liquid limits and plasticity the index for good subgrade materials while sample 5 and 6 are fair to poor subgrade materials because the percentage passing sieve No 200 for sample 5 and 6 are 63.6 and 63.6 respectively.

*Compaction test*

The maximum peak point of the soil compaction is called the Maximum Dry Density value (MDD) and the water content that corresponds to this point is called the Optimum Moisture Content (OMC). From Figure 13 a-c, for pit 1, the maximum dry density was 1410.0Kg/m$^{3,}$ and the optimum moisture content, was 18%., for pit 2, the MDD was 1410.0Kg/m$^3$ with OMC of 18% and for pit 3, the MDD was 1460 Kg/m$^3$ and OMC was 15%. The OMC for Pit 1 and Pit 2 falls withinthe clay classification while Pit 3 falls within the silt classification.

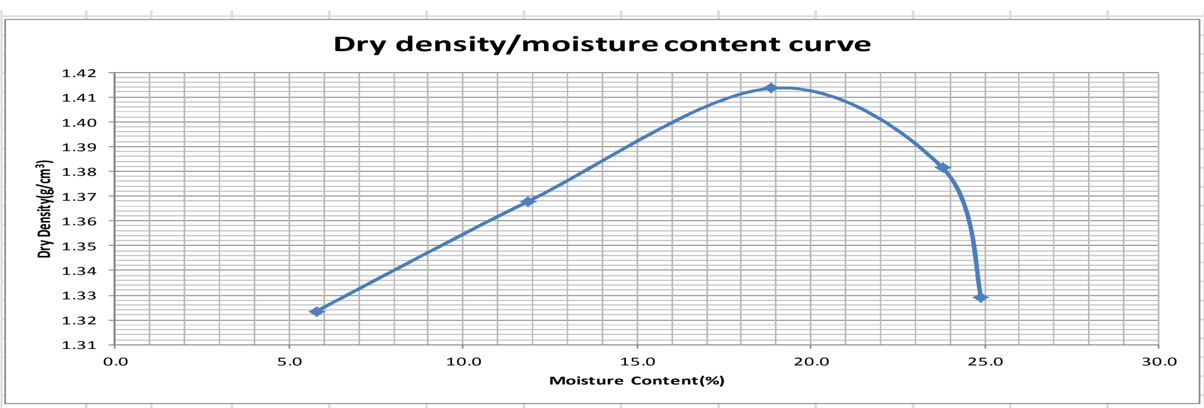


Figure 13a**:** Graph of dry density against moisture content for pit 1

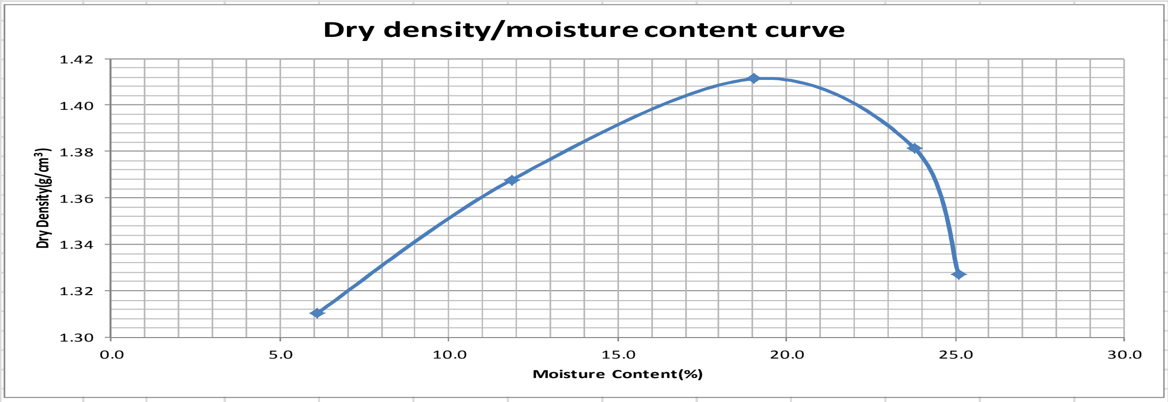


Figure 13b: Graph of dry density against moisture content for pit 2

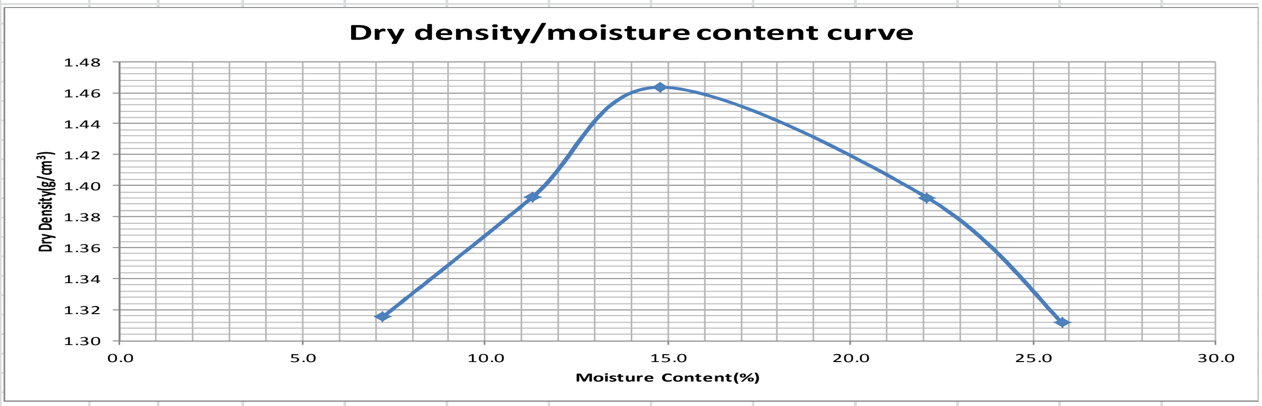


Figure 13c**:** Graph of dry density against moisture content for pit 3

## *5 Conclusions*

Geophysical results classified subsurface units intolateritic soil, clay, and sandy clay, and their resistivity and thickness as 49Ωm and 1.5m, 30Ωm and 10.0m, and 95Ωm and 9m respectively.
Geotechnical investigations showedthe value of linear shrinkage, liquid limits, and moisture contentwere higher than the specification for sub-base and sub-grade material, this may be due to the high clay content of the soil samples. The percentage of fines was also very high from the grain size distribution. Therefore, for soil samples to be used as subgrade or base course materials, soil samples must bestabilized to improve their geotechnical properties

## *6. Conflicts of Interest*

The authors declare that they have no conflict of interest**.**

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