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SUBSURFACE CHARACTERIZATION USING GEOPHYSICAL TECHNIQUES FOR THE RECONSTRUCTION OF ST. FINBARR'S COLLEGE ROAD, SOUTHWESTERN NIGERIA

***[1]Anukwu, G. C., [2]Ifarajimi, W. T., [1]Okuzor, C. A. and [1]Abdulkadir, Z.**

[1]Department of Geosciences, University of Lagos, Akoka, Lagos, Nigeria
[2]Department of Geology, Federal University of Agriculture, Abeokuta, Nigeia

*Corresponding authors' email: ganukwu@unilag.edu.ng

ABSTRACT

The St. Finbarr's College Road connects a number of educational institutions, including the University of Lagos, Akoka, to the northern part of Lagos. Rehabilitation work on the road revealed the presence of peat and clay at some locations, prompting the need to define the extent of their occurrence. In this study, geophysical techniques consisting of the Multichannel Analysis of Surface Waves (MASW) and Electrical Resistivity measurements were conducted on six traverses established along the road to characterize the subsurface and identify zones of instability. The resistivity and shear wave velocity (Vs) values obtained vary along the traverses, suggesting heterogeneity in the soil composition of the area. Specifically, the top 2m is generally characterized by materials having a resistivity less than 50 ohm-m and Vs greater than 200 m/s, which has been interpreted as a relatively stiff clay. However, a small number of spots on traverses 1 and 2 have low Vs (> 200 m/s), which suggests less stiff material and possible weak zones. Although the Vs values suggest that the upper 2m of the subsurface is characterised by materials considered to be stiff soil, its clayey nature might pose a challenge to the stability of the pavement, as clay materials are generally considered to be a problematic engineering material. To prevent the failure of the road, the soil parameters obtained in this study should be taken into account during reconstruction.

Keywords: Shear wave, Resistivity, Rehabilitation, Road, Stiff, Akoka

INTRODUCTION

The incessant failure of roads in the country has taken on a worrisome dimension, given the importance of good roads in the economic development of any state. Most roads do not last up to the expected span of years and develop issues such as cracks, portholes, depression, etc. that hamper the smooth movement of vehicles. In constructing a road, efforts have been made to ensure that all the necessary factors and design specifications are observed; however, for our case, it is noted that this still does not reduce the incidence of road failure. It is therefore important to ensure that all factors that can affect the stability of a road are adequately considered. One of such factors is the subsurface geology, which, if not properly characterized, can result in pavement failure. In-depth engineering-geological surveys that include geophysical and geotechnical investigations are essential for characterizing the subsurface of complex geological settings.

Prominent research works emphasized the need for thorough knowledge of the characteristics and behaviour of the subgrade layer on which structures are built through geological, geotechnical and geophysical investigations (Okigbo, 2012; Ugwu and Ezema, 2013). Inadequate investigations of subgrade and other pavement materials prior to the commencement of road projects constitute pitfalls in road construction (Aizebeokhai and Oyeyemi, 2014; Odunfa et al., 2018). The incessant early road pavement failure in Nigeria could be a result of a lack of adequate standard practice during the road construction process (Adeyemo and Omosuyi, 2012; Sabinus et al., 2014; Adeyemo et al., 2020). Attempts by various researchers to investigate possible causes of road failure in Nigeria have identified that the underlying geologic materials, among other factors, play a significant role in determining the stability of the road (Momoh et al., 2008; Oladapo et al., 2008; Adiat et al., 2009; Ifarajimi et al., 2021). However, signs such as cracks, potholes, bulging, and depression are typical evidences that lead to road failures (Adlinge, 2010; Yakubu, et al., 2023)

Geophysical techniques such as resistivity, surface wave have been shown to be useful in charactering the soil for road design and construction (Anukwu et al., 2017; Mannir et al., 2018; Ademila, 2021). While the resistivity of the soil is a function of the soil composition, moisture content, presence of dissolved minerals, etc., the shear wave velocity gives an indication of the soil's stiffness. Several authors have reported that unstable sections of a road are characterized by materials with relatively low resistivity (Ademila, 2021; Okeniyi *et al.*, 2022). On the other hand, low shear wave velocity values are indicative of clay and clayey sand as such signifies a poor engineering material that is capable of undermining the stability of road structure (Ayolabi and Adegbola, 2014; Ifarajimi *et al.*, 2021,).

This research therefore utilizes Electrical Resistivity Imaging surveying method and surface wave methods to characterize the subsurface along the St. Finbarr's College Road, Southwestern Nigeria with the aim of providing information that can aid the ongoing road rehabilitation. The study area lies between the University of Lagos main gate and the Chemist bus stop in the Akoka-Bariga area of Lagos State, southwestern Nigeria (Figure 1.0). It falls within latitudes 6°31´14.34´´N and 6°31´40.59´´N and longitudes 3°23´7.78´´ and 3°23´12.43´´. The road is a major artery within the community that connects people coming from the northern part of the state to the university campus and vice versa. The elevation ranges from 4 m to 9 m above sea level, and it is characterized by a tropical savanna climate with well-distinguished wet and dry seasons. The annual average temperature and rainfall within the Lagos metropolis are 28.67°C and 1506.6 mm, respectively (Onyenokporo and Ochedi 2018). Water is the most significant topographical feature in Lagos State. Water and wetlands cover over 40% of the total land area within the state, and an additional 12% is subject to seasonal flooding (Iwugo et al., 2003).

The geology of the study area falls within the Dahomey Sedimentary Basin, and it is characterized by deposits of recent alluvium to coastal plain sand formation, which comprises loose sediments ranging from silt, organic clay/peat, and granular sand deposits (Olabode, 2006; Omatsola and Adegoke, 1981; Billman, 1976). Given the general climatic and geological conditions of the study area, it is important that adequate information about the nature of the subsurface is well understood in this locality prior to any road construction.

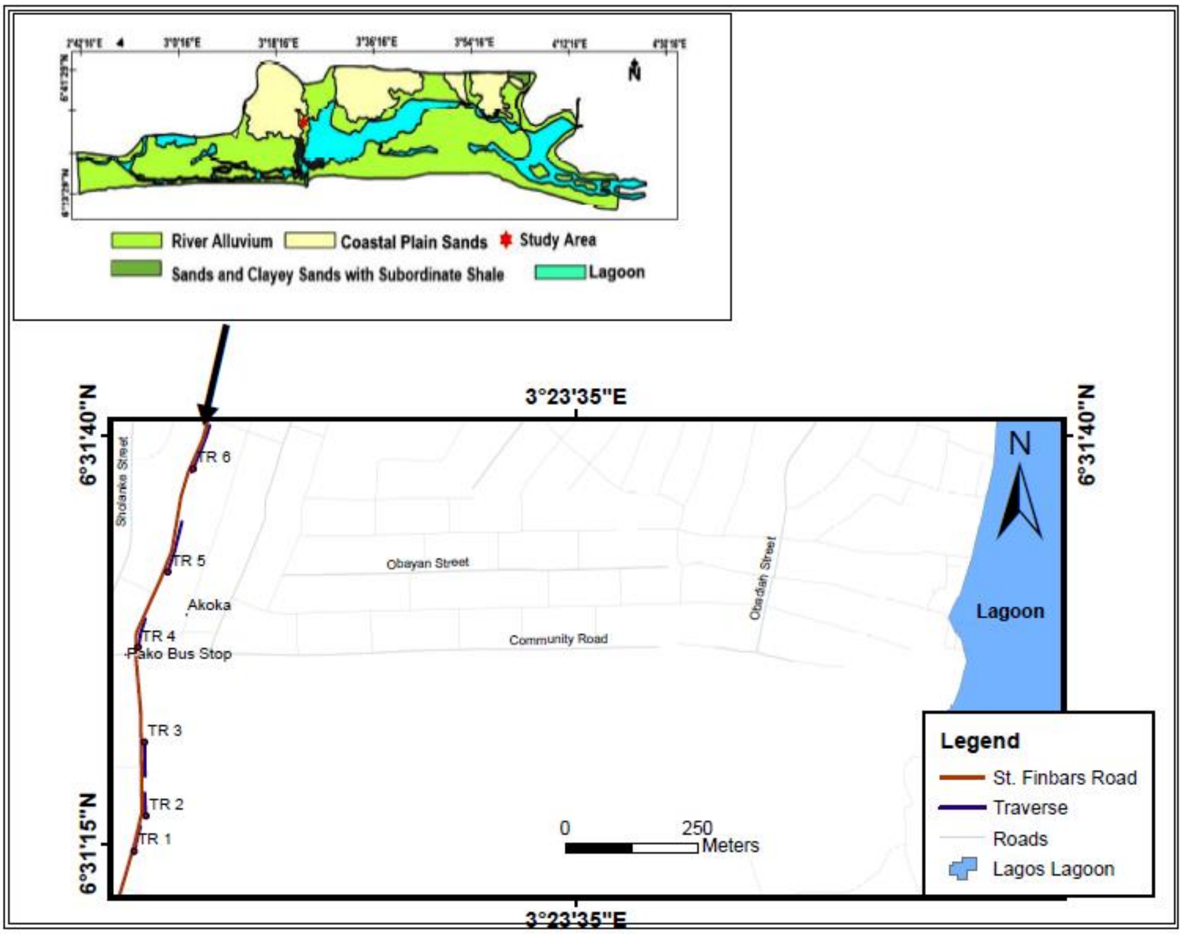


Figure 1: Geological map of Lagos showing the survey location and the basemap highlighting the ERT and MASW traverses

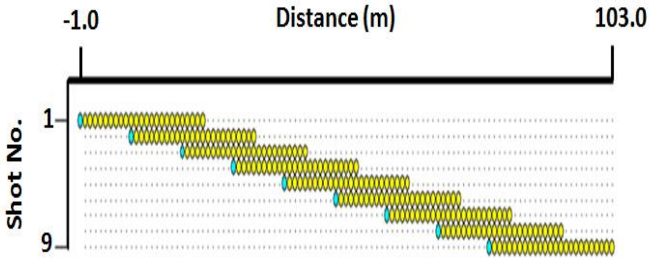
MATERIALS AND METHODS

The data collection exercise consisted of the 2-D Electrical Resistivity Imaging (ERI), Vertical Electric Sounding (VES) and Multichannel Analysis of Surface Waves (MASW) techniques to infer the subsurface materials at the selected segments of the study road, which comprised both stable and failed sections along Saint Finbarr’s Road, Akoka, Lagos, Southwestern Nigeria, as shown in Figure 1.

Data Acquisition

2D Electrical resistivity imaging was done using the Ohmega Resistivity meter and adopting the Wenner array electrode configuration along six profiles (Figure 1.0). Measurements were made at sequences of electrodes at 2m, 4m, 6m, 8m and 10m interval using four (4) electrodes for all traverses (except for traverse 6, which stopped at 8m). Apart from the 2D ERI measurements, Five (5) Vertical Electrical Sounding Stations were acquired at different points along the first three traverses. The Schlumberger electrode configuration was acquired using an electrode separation (AB) that varied from a minimum of 2.0 m to a maximum ranging from about 130 m at the VES locations. The VES measurements were adopted to provide information on the resistivity variation at greater depths.

The Multichannel analysis of surface waves (MASW) technique was conducted using the ABEM Terraloc MK6 seismograph, twenty-four 4.5Hz geophones, with geophone spacing of 1m and a 12kg hammer as the energy source. The measurements were made using a roll along technique and an average array length of 100 m was achieved for most traverses (Figure 2).



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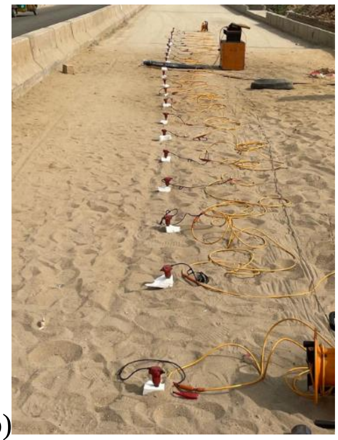


(a)

Figure 2: (a) The schematic of the roll-along technique of the MASW measurements adopted in this study. In this case, for traverse 1. (b) The linear array arrangement of the geophones on the paved surface. Styrofoam was adopted to allow for contact between the ground and the geophone

Data Processing

The electrical resistivity data acquired was processed using the RES2INV software to generate a 2-dimensional resistivity model of the subsurface. The software utilizes the least-squares inversion optimization routine to achieve this. On inputting the data into the software, bad data points are edited, and the forward model is generated using the finite-difference method.

The VES data was processed first by utilizing the partial curve matching technique (Bhattacharya and Patra, 1968). In order to do this, the VES data were plotted on a transparent overlay. The partial curve matching technique involved the use of a standard two-layer master curve and four (4) auxiliary-type curves (H, K, A, and Q). This procedure required segment-by-segment curve matching, starting from the position with shorter electrode spacing and moving towards those with longer spacing. The results obtained from the partial curve matching were then used to constrain the interpretation by the computer using iteration software known as WINRESIST. This procedure improves the accuracy of the final inverted model, which gives the geoelectric parameters: resistivity, thickness, and depth.

For the MASW process, cross-correlation analysis was adopted, as it has been shown to achieve a better two-dimension resolution of the subsurface (Hayashi and Suzuki, 2004; Mahdavi and Siahkoohi, 2009). To achieve this, the common mid-point cross correlation (CMPCC) of the shot gathers for offsets of either 1m or 5m acquired for each array along the traverse was calculated using a bin size of 10m. Subsequently, a phase velocity-frequency transform is applied to each CMPCC gather from which the dispersion curves were extracted (Figure 3). The dispersion curves for all shot gathers were then used to obtain a 1D Vs model; the 1D Vs models were subsequently interpolated to yield the 2D shear velocity image of the traverse.

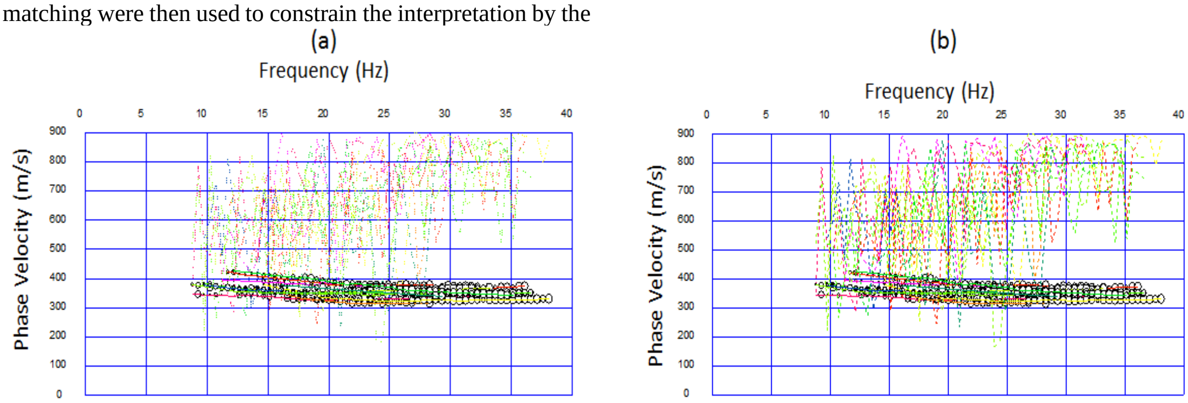


Figure 3: Extracted dispersion curves from the CMPCC shot gathers for (a) Traverse 3 (b) Traverse 6

RESULTS AND DISCUSSION

Resistivity

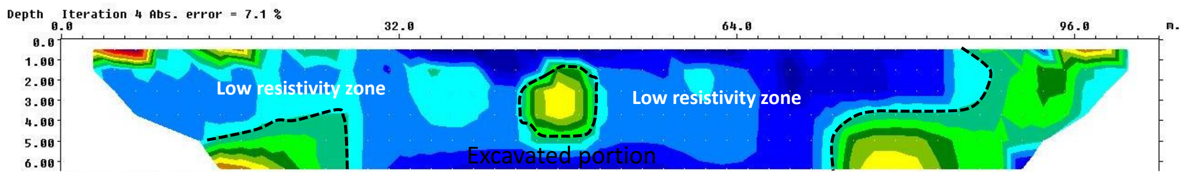
The 2D resistivity results for all the traverses are shown in figure 4. The model shows variation in the resistivity of the subsurface to a depth of about 6 m and a resistivity value that ranges from about 20 ohm-m to 120 ohm-m. The resistivity value obtained indicates a possible lithology of clay, clayey sand/sand down to a depth of 6m. In general, the lithology of all the traverses shows a similar trend of a low resistivity zone, followed by a slightly higher resistivity zone (> 50ohm-m). However, it is observed that for Traverse 1, the resistivity values showed a complex pattern due to ongoing excavation at the time of data acquisition. A region of peat was observed during the construction of the road, which led to the excavation and refilling of the area (Figure 5). The result for traverse 1 indicates that the low velocity zone extends to greater depths (> 5 m), from line position 28 m to 76 m, and it is suggestive of a problematic section of the road. The results of traverses 2 and 3 show that the low resistivity zone, which is most probably clayey in nature, extends to a depth of 2 m, except from line position 80 m on traverse 3, where it extends to a depth of 4 m. This trend of low resistivity zones is also observed on traverses 4, 5, and 6.

The lithology after the low resistivity zone has a resistivity value that varies from about 50 ohm-m to 120 ohm–m. The trend of this unit (below the low resistivity zone) is observed not to be uniform across the study area, as regions having a resistivity value greater than 100 ohm-m are observed on traverses 2, 3, 5, and 6. While traverses 1 and 4 do not have resistivity values that are up to 100 ohm-m.

Although there are no available borehole logs along the road section investigated, borehole logs from a nearby location, the University of Lagos, as reported by Allo et al. (2019), reveal that the top 4m are characterized by materials such as topsoil and silty clay. Below this depth, the subsurface is characterized by sand, sandstone, sandy clay, and clayey sand. Correlating the borehole data with the resistivity data obtained in this study, it can be inferred that the lithology of the subsurface along the area investigated is composed of the following: a first layer characterized by topsoil or clay material, and a second layer made up of sand or clayey sand.

Samples of the VES curves obtained are presented in Figure 6. While the maximum depth probed by the ERI is 6m, the VES probes to an average depth of about 18m. The resistivity value obtained also indicates a maximum value of less than 120 ohm –m down to the depth probe, which correlates quite well with the 2D – ERI data. Visualizing the data as a geoelectric section (Figure 7), it is observed that the first two layers (topsoil and layer 2), corresponds to the low resistivity zone as seen on the ERI results, and the zone is observed to vary along the section, reaching a depth of about 6m in VES 2 (along traverse 1). The sandy/clayey sand region (layer 3) is observed to be underlain by a relatively low resistivity layer (suggestive of clay), from a depth of about 15m.

(a)



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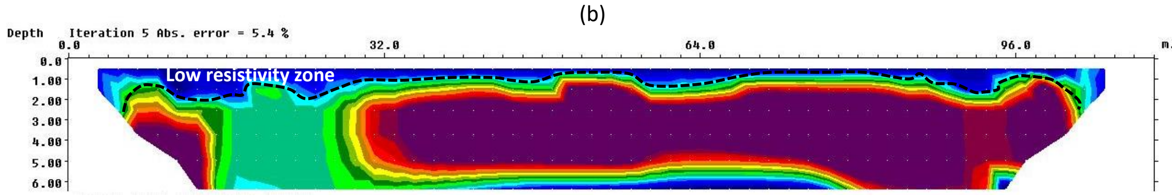

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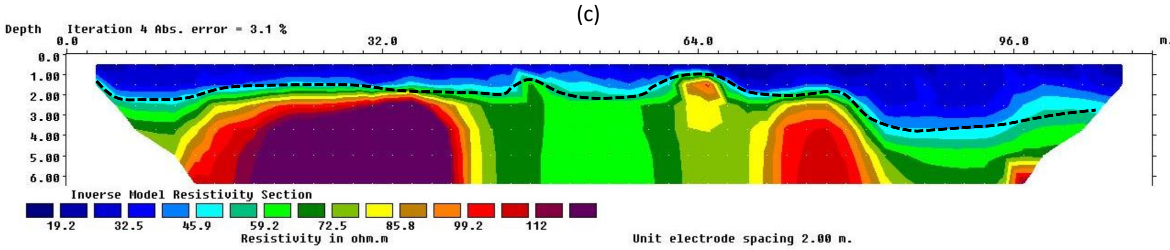

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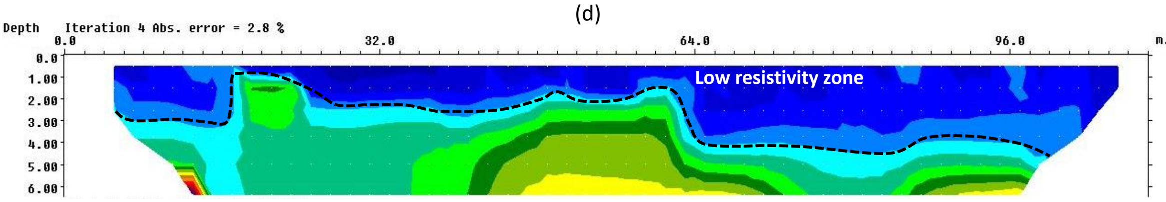

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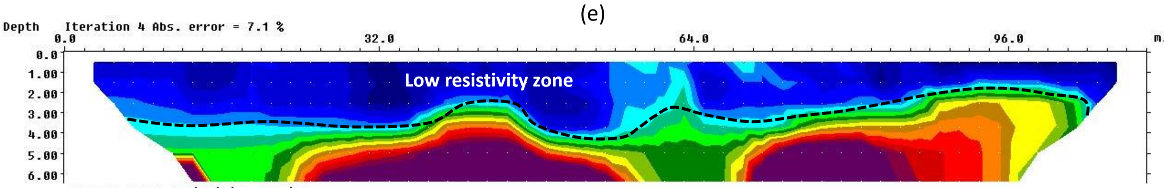

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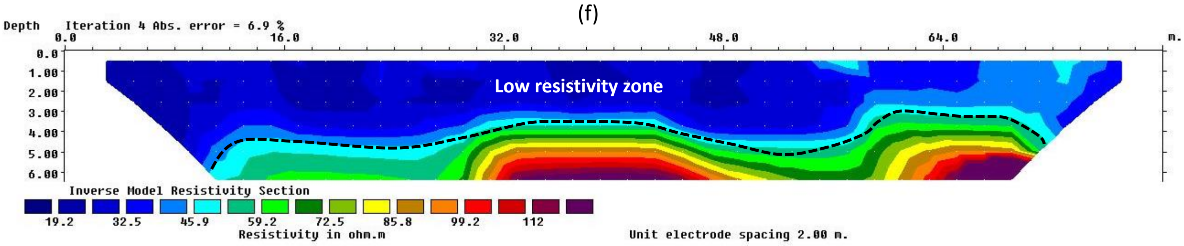


Figure 4: 2D Electrical resistivity along (a) Traverse 1 (b) Traverse 2 (c) Traverse 3 (d) Traverse 4 (e) Traverse 5 (f) Traverse 6. The topsoil is characterized by a low resistivity zone that can pose a threat to the stability of road pavement

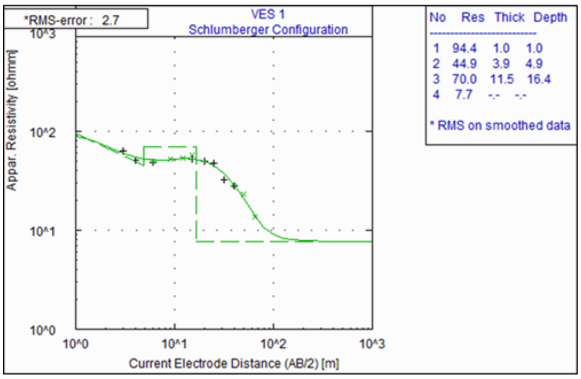
(a)

(b)

(c)

Figure 5: (a, b) Excavation of Clayey/Peat section along Traverse 1 during construction (c) A stable section of the road

(a)



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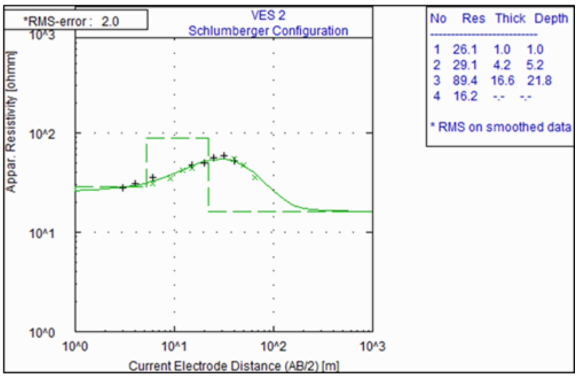

Figure 6: Samples of the Vertical Electrical Sounding Curves obtained in the area

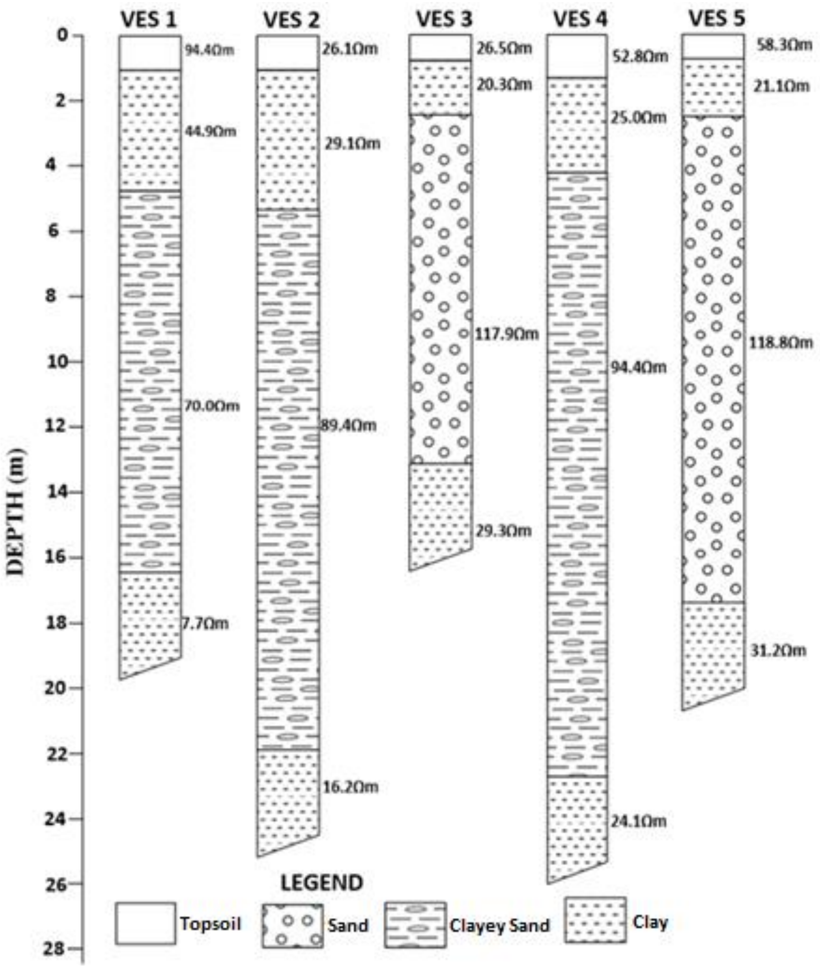

Figure 7: Geoelectric section showing the results obtained for VES 1 – 5

2D S-Wave Velocity Model

The resulting 2D shear wave velocity (Vs) models for all the traverses are presented in Figure 8.0. In general, the shear wave velocity for the area down to a depth of 15m is observed to range from about 200 m/s to 400 m/s, with a few locations on traverses 1 and 2 having Vs > 200 m/s (Fig. 8.0, blue colour). This shear wave range (>200 m/s) suggests that the study area in general is characterized by materials classified as stiff or medium soil (Worku, 2014; Sulistiawan et al., 2018). Also, traverses 1 and 2 show that a significant part of the traverse is characterized by materials with Vs > 240 m/s within the top 6m (Figure 8); this is not so in other traverses, which are characterized more by Vs > 240 m/s. This suggests that the soil for traverses 1 and 2 has lower shear strength when compared to other traverses. It is worthy of note that the challenging section of the road during the road construction (Figure 5.0) was observed along traverse 1. The MASW measurements were taken after the excavation and filling of traverse 1 were done, and the result still reveals low Vs values (> 200 m/s) at line positions 60–100 within the top 2m. This relatively low Vs zone suggests that this area is prone to deformation, which can result in road failure. Traverses 3 to 6 show a much higher Vs, within the top 6 m, with a Vs that is higher than 300 m/s, suggesting a stiffer material, less prone to deformation.

In general, from the Vs models for the study area, we can infer a two partitioning of the soil in the area. The top layer has a thickness that ranges from about 3 to 9 m, followed by material with higher Vs.

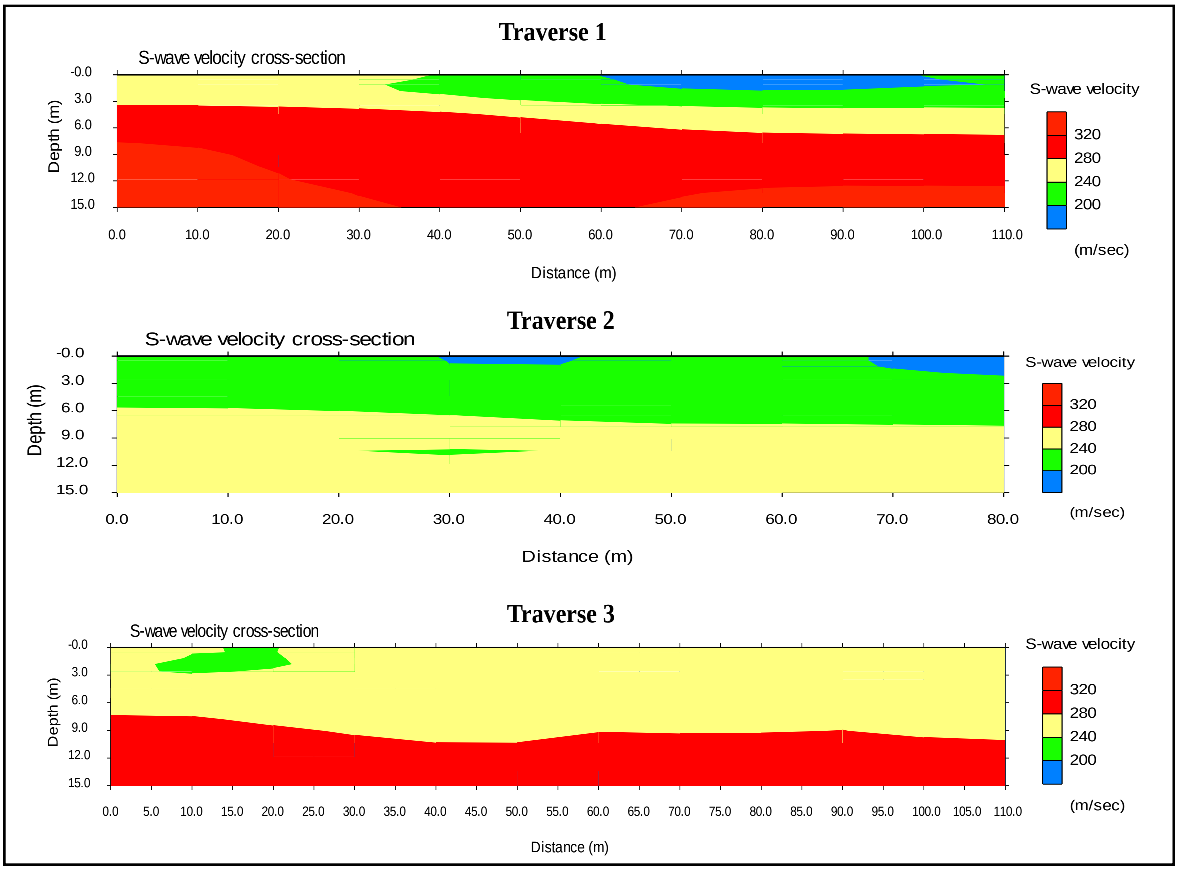

Figure 8: Shear wave velocity (Vs) model for traverses 1 to 3. Low velocity lenses are observed on traverse 1 and 2

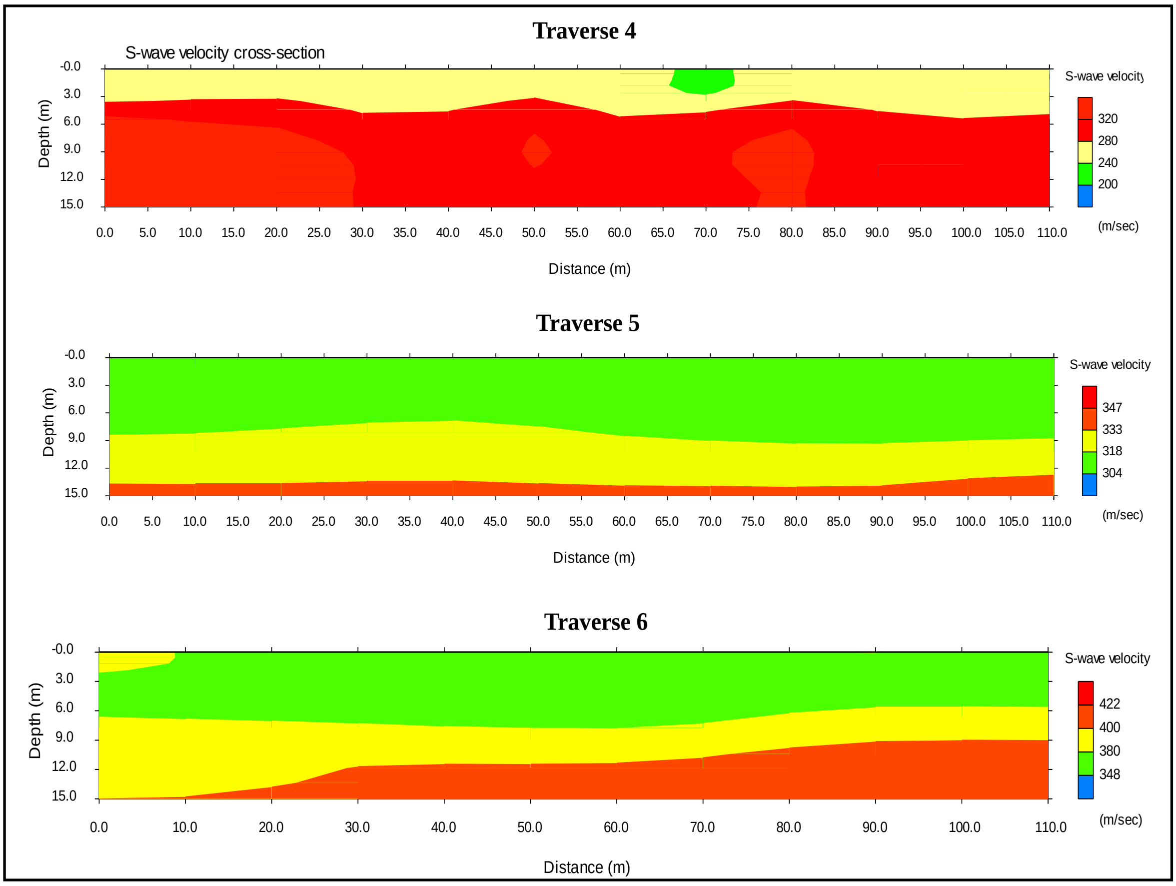

Figure 9: Shear wave velocity (Vs) model for traverses 4 to 6. The shear wave velocity of the soil can be categorized into two, a relatively high Vs top layer (thickness ranging from 3 – 9 m), followed by a layer with higher Vs, indicating a stiffer material

In general, whereas the resistivity of the top 2m which would form the subgrade for the proposed road pavement is characterized by low resistivity soil (< 50 ohm-m), a value that is suggestive of clay, which is generally considered a problematic engineering material (Ifarajimi et al., 2021), these materials within the same depth exhibit a Vs that is relatively high (200 m/s – 320 m/s/), especially for traverses 3 to 6. This implies that the clay is relatively stiff, with allowable bearing capacity that is in the range of 75 – 150 kN/m^2 (Ozebo, 2019). The variation in the stiffness of the top 2m, which has been inferred to be characterized by the topsoil and clay can be attributed to the variation in the properties of the clay materials, which basically can be water content, density, plasticity (Long and D'Ignazio, 2021).

To ensure the stability of the pavement, it is paramount that the subgrade must be able to support the load transmitted to it. While the MASW results indicates the area is characterized by relatively stiff material, the result of the 2D ERT indicates that the top 6m is generally characterized by resistivity value that is less than 50 ohm-m, which is typical of clayey material.

CONCLUSION

Geophysical techniques comprising of 2D Electrical Resistivity Tomography, Vertical Electrical Sounding and Multichannel Analysis of Surface Waves were integrated to characterize the subsoil for the purpose of providing information about the subgrade to aid the rehabilitation of the Unilag – Chemist Bus-stop section of the St. Finbarr's Road, Akoka, Lagos. The results of this study show that the study area is characterized by resistivity that ranges from about 20 to 120 ohm-m and Vs from 180 – 320 m/s; from the surface to a depth of about 6m. These values suggests that the lithology of subsurface to a depth of 6m is characterized by topsoil/clay, clayey sand and sand. In general, the topsoil lithology to a depth of about 2m is attributed with low resistivity (> 50 om-m), indicative of clay, however, the Vs range is high (200 – 320 m/s) which suggests a stiff clay.

The utilization of both the resistivity and shear wave velocity values have given a more comprehensive information on the nature of the soil that make up the study area. While the resistivity value is a function of moisture content, soil type amongst other factors, the Vs is a function of the stiffness of the material. As such, the study has revealed that top 2m is composed of a relatively stiff clay. The clayey nature of the top 2m can be a challenge to the stability of the road, and as such should be taken into consideration in the rehabilitation and/or construction of the pavement in the area.

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