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# GEOPHYSICAL INVESTIGATION OF THE CAUSES OF HIGHWAY FAILURES IN NIGER DELTA SEDIMENTARY BASIN (A CASE STUDY OF THE EASTERN PART OF EAST- WEST ROAD), NIGERIA.

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## ABSTRACT

*The causes of the East-West highway failure in the Niger Delta Sedimentary basin have been investigated. The Vertical Electrical Sounding using the Schlumberger techniques was utilized. The aim of the investigation was to delineate the geoelectric and geologic parameters of the subsurface as a means of determining the causes of the highway failure. The survey was carried out in three failed and three stable portions of the highway. Five geo-electric layers were obtained from the interpretation. The subsurface layers are topsoil, clay to sandy-silt, fine sand, medium sand, medium-coarse sand and coarse sand. The resistivities of the top to the forth geoelectric layer for the failed segments ranges from 28.8-164Ω-m, 108.1-120.5Ω-m, 237.5-442.6Ω-m and 418.3-884.9Ωm. Similarly, the resistivities of the stable segments for the first four layers ranges between 209.6-348.47 Ω-m, 372.8-1247.8 Ω-m, 567-2977 Ω-m and 562-1419.04* Ω*-m. Comparison of the resistivity of corresponding layers show that the stable portions of the road are more resistive than the failed segments. The low resistivities of the sub-grade in failed segments have been attributed to the presence of high moisture clay in the subsurface. The failures in the road arise from the differential settlement of the sub- grade clay. Other factors also attributed to the road failure from walkover survey are floods, buried channels, poor design and specification, poor workmanship and lack of drainage system. It is hereby recommended that the clay zones be replaced with more competent sands. The road should be built to specification with high quality materials and also drainage be included in the ongoing expansion and construction work.*

***Keywords**: Highway, Geophysical Survey, Failed portion, Stable portion, Geological Factors.*

## INTRODUCTION

Major Nigerian highways are known to fail shortly after construction and well before their design age. Road failures could be defined as a discontinuity in a road network resulting in cracks, potholes, bulges and depressions. A road network is supposed to be a continuous stretch of asphalt lay for a smooth ride or drive. Visible cracks, potholes, bulges and depressions may punctuate such smooth ride. The punctuation in smooth ride is generally regarded as road failure (Aigbedion, 2007).

The East-West road is a major Federal highway in Nigeria which traverses about seven states (Lagos, Ogun, Edo, Delta, Bayelsa, Rivers and Akwa- Ibom) as shown in Figure 1. The highway is very important to Nigeria economically because it is the only major highway connecting the oil producing states in the south –south of the country to Lagos state (former capital of the country but now a commercial city). The spate of failure of the highway has been of major concern to the Federal and state governments and all stakeholders in the usage.

Rehabilitation of the roadway has constituted some financial burden to the various tiers of government until the recent move by the Federal government to expand and fully reconstruct it.

Though the contract has been awarded and the work is already on, it is imperative that adequate consideration be given to the causes of the failure so as to ensure that sufficient safeguards are incorporated in the ongoing reconstruction.

The causes of roads failure in Nigeria have been traced to several factors. These include poor construction materials, poor design and specification, road usage, poor drainage,

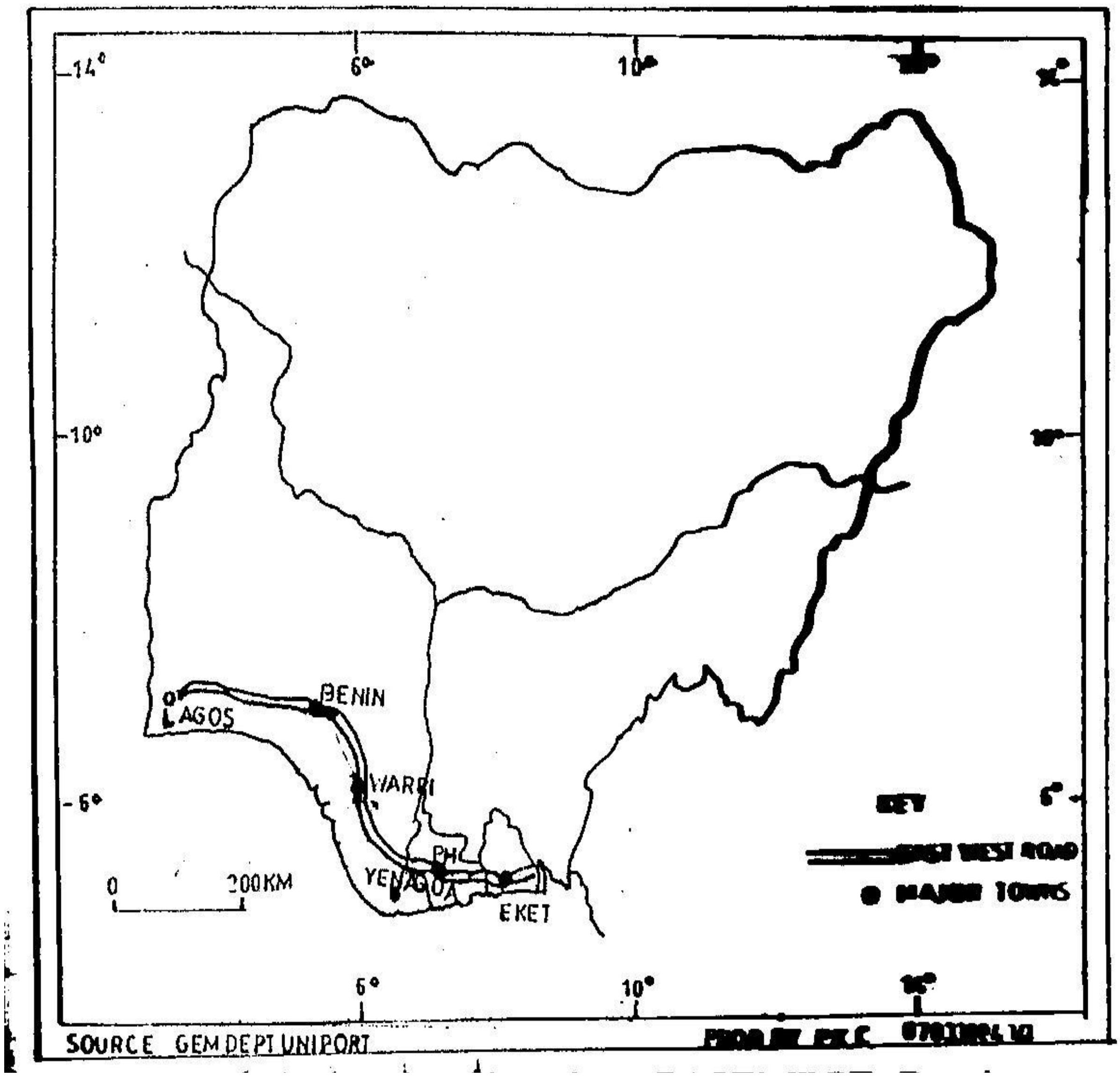


Fig. 1: Map of Nigeria showing the east-west highway

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geological and geotechnical factors (Ajayi, 1987; Abam et al. 2005a, b). Geological factors are rarely considered as precipitators of road failure even though the highway pavement is founded on the geology. This is due to non-appreciation of the fact that proper design of highway requires adequate knowledge of subsurface conditions beneath the highway route. Previous studies have revealed that the integrity of the highway pavement can be undermined by the existence of geological features and/or engineering characteristics of the underlying geologic/geoelectric sequences (Adeleye, 2005; Oladapo et al., 2008). The non-recognition of this fact has led to loss of integrity of many highway routes and other engineering structures across the country (Okogbue and Aghamelu, 2011; Momoh et al., 2008; Oladapo et al., 2008).

Conventional methods used for characterizing subsurface conditions that affect the stability of various transportation infrastructures are expensive, time consuming, and not fully effective. Geophysical data, when properly constrained with carefully supervised borehole lithologic logs, can provide critical information about the physical properties of the subsurface or structure being investigated. Current state-of-the-art geophysical technology in no way eliminates the need for the use of conventional methods; however, it represents a means of expediting the investigative process, reducing overall costs, and improving reliability of the final product. Although geophysical methods are enhancement to conventional methods, geotechnical engineers do not readily use them because of lack of experience and knowledge in their applications to highway problems. In the present study, the electrical resistivity method of geophysics has been used to investigate the causes of the East-West highway failure within the Niger Delta sedimentary basin portion of the road.

**Summary of the Geology of the Niger Delta**

The East-West highway passes through a basement complex in the west to a sedimentary basin in the east. The study was carried out in Port Harcourt, Rivers state in the eastern portion of the highway (Fig. 2). The geology of the area is that of the Niger Delta Sedimentary Basin. Generally, the Niger Delta was formed during the Tertiary period as a result of the interplay between subsidence and deposition arising from a succession of transgressions and regressions of the area. Its development began after the Eocene tectonic phase. Up to 12km of deltaic and shallow marine sediments have been accumulated in the basin. The Niger and Benue Rivers are the main supplier of sediments (Kulke, 1995; Reijers et al., 1997). Three lithostratigraphic units are distinguished in the Tertiary Niger Delta. These units are Akata, Agbada and Benin Formations, from the base to the top.

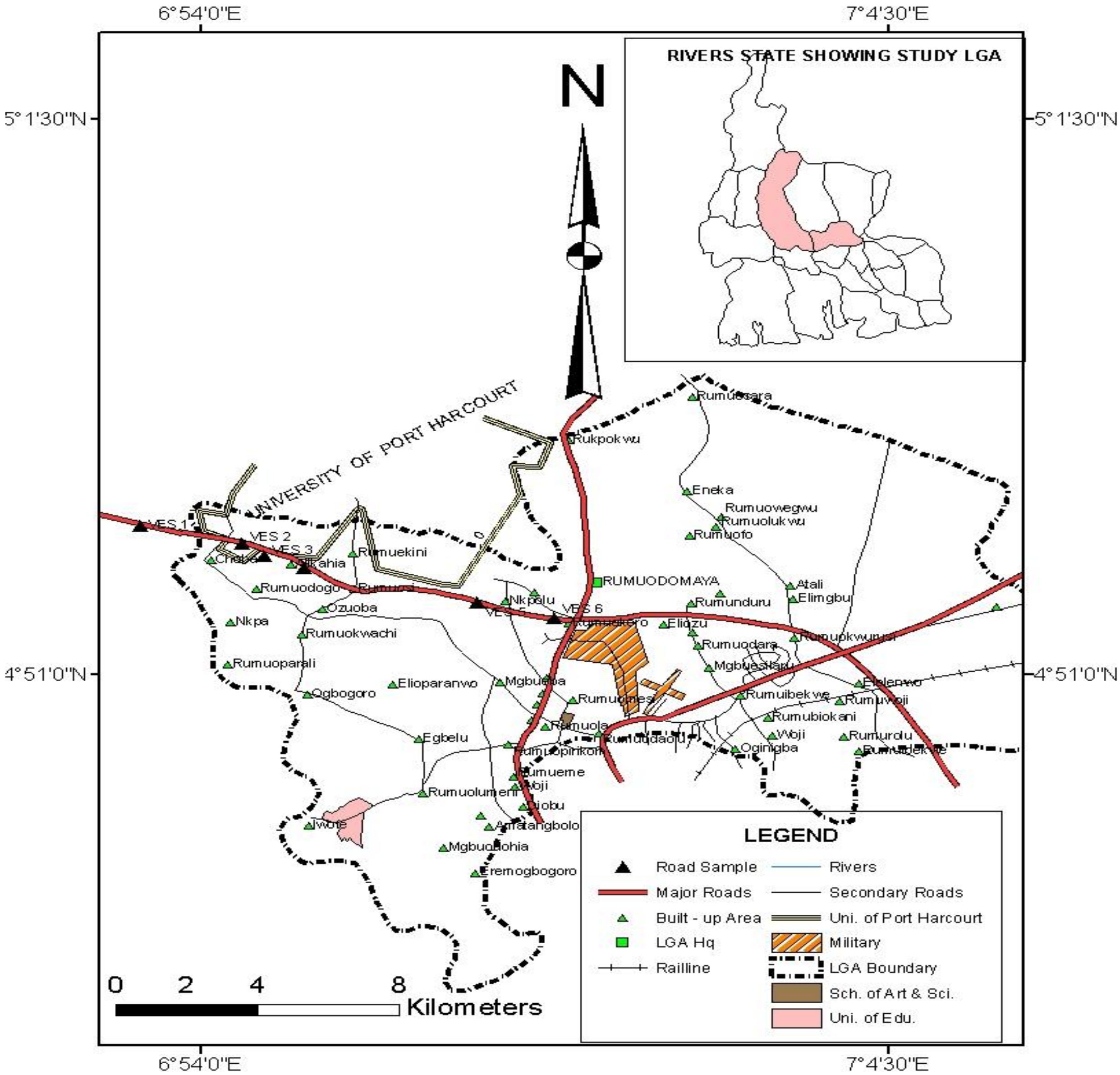


Fig. 2: Map of Obio/Akpor local government area, Rivers State showing the sounding points. Insert is a map of Rivers state.

The basal Akata Formation which is predominantly marine prodelta shale is overlain by the paralic sand/shale sequence of the Agbada Formation. The Benin Formation is a stratigraphic unit that was laid down during the end of the Tertiary and early Quatenary period (Doust and Omatsola, 1990). The Benin Formation is predominantly sandy with minor intercalations of clays and mudstones. The sands and sandstone are coarse grained, commonly very granular pebbly to very fine grained. The sands are also unconsolidated, poorly sorted and highly porous and permeable. The Benin Formation is overlain by a considerable thickness of lateritic red earth formed by weathering and subsequent ferruginization of

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the weathered older sequences. The high permeability of the Benin Formation, the overlying lateritic earth, and the underlying clay-shale member of the Bende-Ameki series provide the good hydrologic condition in the area. High annual rainfall ensures adequate ground water recharge.

The Niger delta has a tropical rain forest climate with distinct wet (April-October) and dry (November-March) seasons. The daily relative humidity values ranged from 55.5 percent in the dry season to 96 percent in the rainy season. The mean annual rainfall ranges from 2000mm (in land) to over 4000mm at the coastal areas. Temperature varies uniformly and ranges from $21^0$C at night to $30^0$C during the day. The high humidity and long wet season (about 7-9 months) ensures adequate supply of water and the presence of moisture in the air promote the growth of perennial trees and shrubs. This high humidity can be attributed to a large scale of mist and fogs generated by the reaction between the equatorial high temperature and the Atlantic Ocean (Gobo, 1998).

## MATERIALS AND METHODS

The study was carried out in two phases; walkover and geophysical surveys.

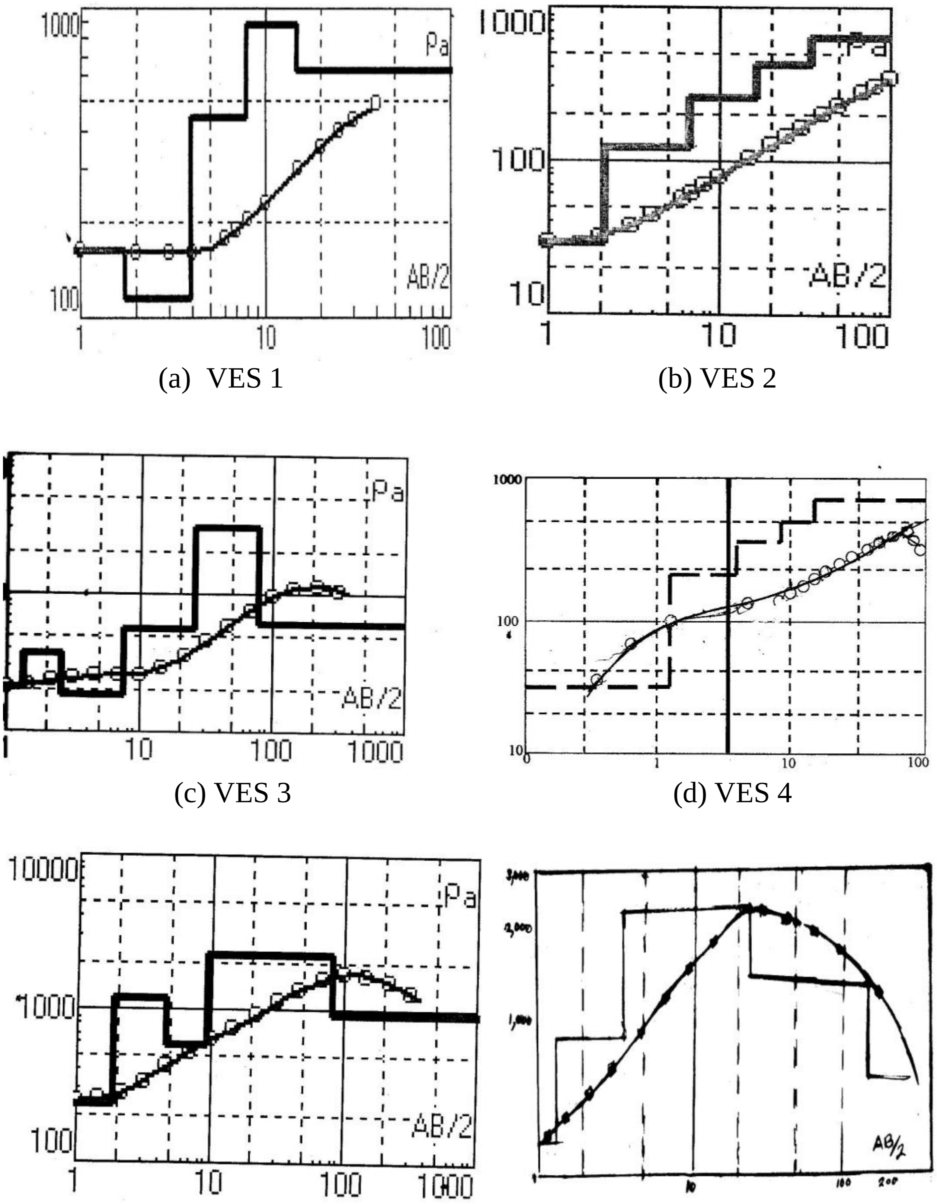
Geophysical investigation involving Vertical Electrical Sounding (VES) was carried out along both failed and stable segments of the roadway at six locations. Three vertical electrical soundings VES 1 (located between Emuoha and Choba), VES 2( Opposite Choba main park), and VES4 (located between Elekahia and Rumuosi) were carried out at three different failed portions of the highway. The other three vertical electrical soundings VES 3(opposite Choba police station), VES5 (near Jeptha Secondary School) VES6 (near Rumuokoro junction) were carried out at three stable portions of the road. The traverses were established parallel to the road pavement at each locality. The traverse length ranges between 80 and 200 metres.

The Electrical resistivity survey was carried out with ABEM Terrameter SAS 1000. The electric current was introduced into the subsurface by means of two current electrodes, arranged on a straight line with the potential electrodes placed between them and symmetrically moved with respect to the centre of the configuration. The apparent resistivity measurements at each station were plotted against electrode spacing (AB/2) on bi-logarithmic graph sheets. The curves were examined to obtain the number and nature of the layering. Partial curve matching was carried out for the quantitative interpretation of the curves.

The results of the curve matching (layer resistivity and thickness) were fed into the computer as a starting model in an iterative forward modelling technique using RESIST Version 1.0 (Vander Velper, 1988). The final layer resistivity and thicknesses were obtained from the modelling.

## RESULTS

The results of the study are presented as depth sounding curves, table and geoelectric section. The curves types identified ranges from HAK, AAA and AKQ. The AAA curve type dominates. The VES curves obtained in the area are shown in Figure 3a-f. These curves are modelled into five geoelectric layers. The interpreted parameters of the subsurface layers are listed in Table 1. The correlation of the geoelectric parameters (resistivity and thickness) of the resulting layers with the geological succession from nearby boreholes (Fig.4a and b) led to the identification of five layers. The horizontal and vertical distributions of the layers are illustrated as geoelectrical cross section in Figure 5. The succession of the geoelectric layers from the ground surface is as follows:




(a) VES 1 (b) VES 2

(c) VES 3 (d) VES 4

(e) VES 5 (f) VES 6

Fig. 3 a-f: Interpreted Vertical Electrical Sounding Curves of the Study Area.

**Table 1:** Results of the Interpretation of 1-D Vertical Electrical Sounding Points.

| Ves No. | Resistivity (Ω-M) | | | | | Thickness (M) | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\rho_1$ | $\rho_2$ | $\rho_3$ | $\rho_4$ | $\rho_5$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ | |
| 1 | 164.5 | 115.3 | 442.6 | 884.9 | 625.8 | 1.75 | 3.93 | 7.79 | 14.7 | Failed Portion |
| 2 | 28.8 | 120.5 | 257.3 | 421.7 | 636.2 | 2.11 | 6.62 | 12.3 | 34.7 | Failed Portion |
| 3 | 209.6 | 372.8 | 562.3 | 1220.8 | 610.5 | 1.34 | 2.57 | 7.46 | 25.8 | Stable Portion |
| 4 | 43.9 | 108.1 | 237.5 | 418.3 | 511.3 | 1.64 | 3.0 | 6.15 | 8.57 | Failed Portion |
| 5 | 237.1 | 1170.1 | 586.0 | 1362.1 | 921 | 1.85 | 4.57 | 9.21 | 81.6 | Stable Portion |
| 6 | 348.5 | 1247.9 | 2977. | 1419.0 | 195.0 | 1.01 | 1.88 | 16.2 | 119 | Stable Portion |

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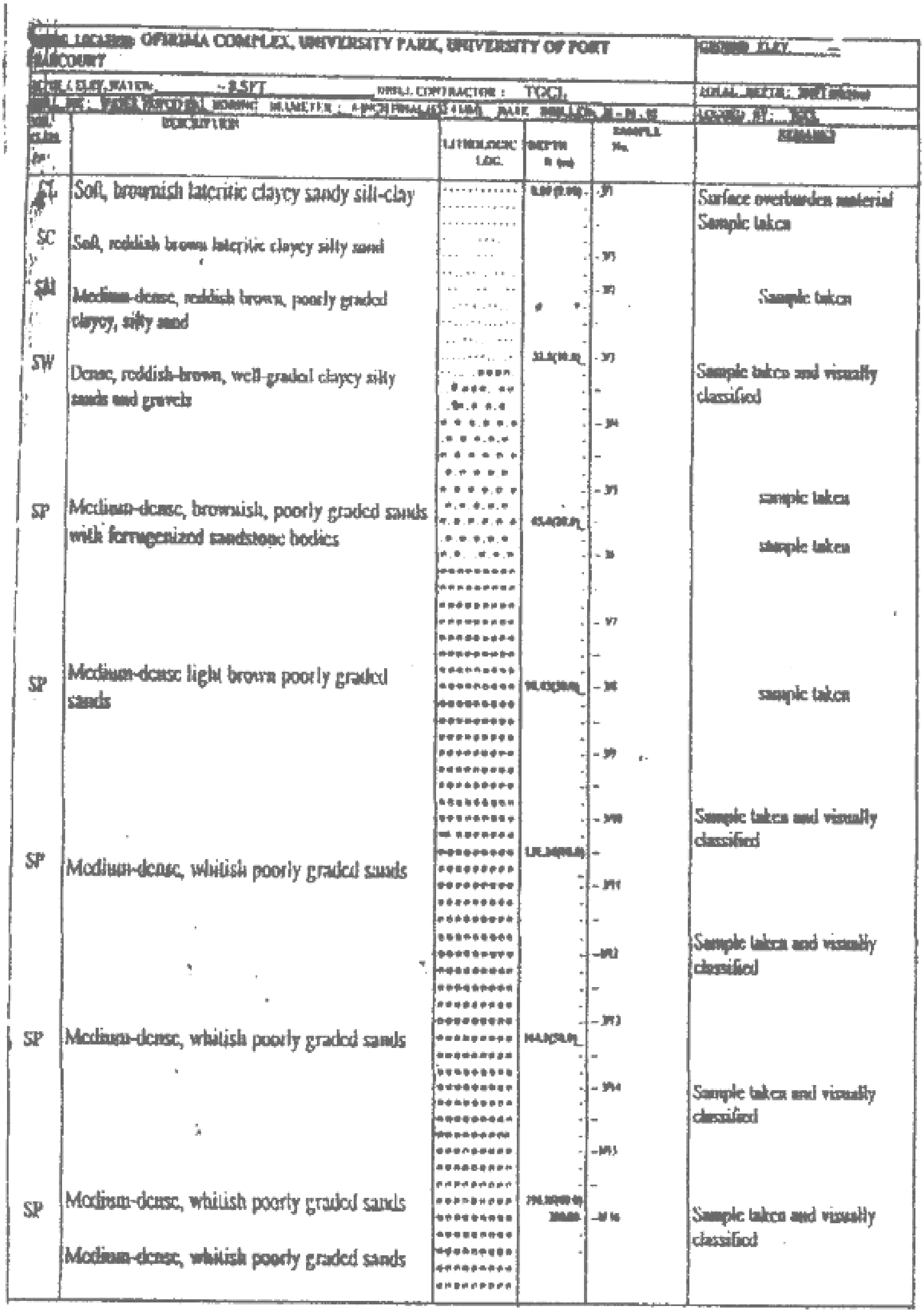
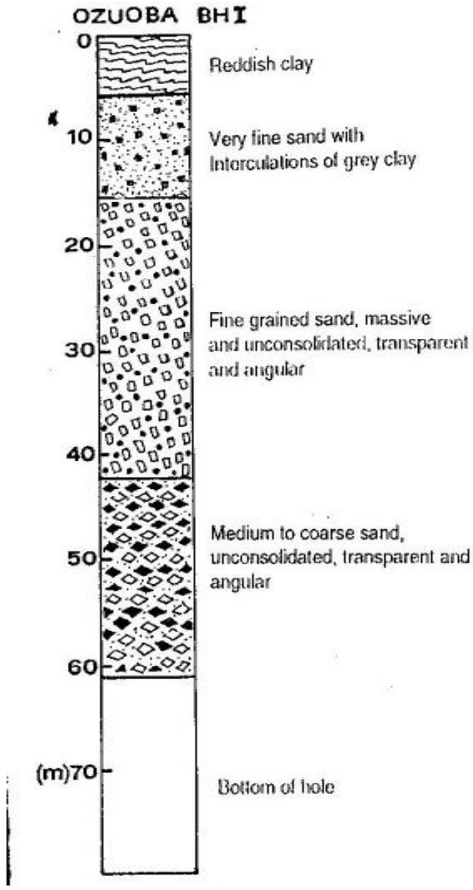



(a)




(b)

Fig.4: Lithologic logs of nearby boreholes (a) University of Port Harcourt (b) Ozuoba

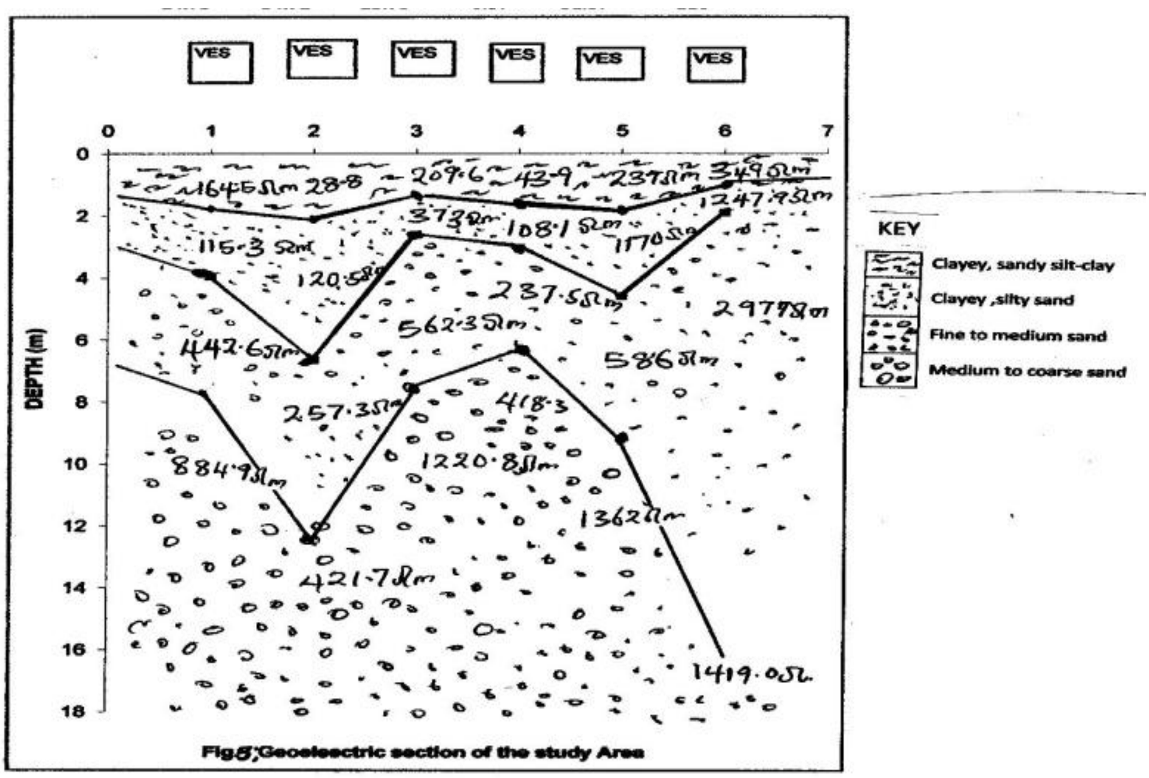



Fig. 5: Geoelectric Section of the Study Area.

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The first layer (Topsoil) comprise of clay to sandy-silt. The apparent resistivity value varies between 28.8Ω-m at VES2 (failed portion) and 348.47 Ω-m at VES6 (stable portion). The thickness varies between 1.01m at VES6 and 2.11m at VES2. The topsoil resistivities within the failed segments (28.8-164 Ω-m) are less than those obtained (209.6-348.47 Ω-m) within the stable zones.

The second layer which is made up of clay and silt-sand has resistivity which varies between 108.1 Ω-m at VES4 (Failed portion) and 1247.9 Ω-m at VES6.The thickness ranges from 1.88m at VES6 to 6.62 at VES2. The resistivities of the second layer within the failed segments (108.1-120.5 Ω-m) are also less than those obtained (372.8to1247.8 Ω-m) within the stable segments.

The third layer consists of fine to medium sand. The resistivity ranges from 237.5Ω-m at VES4 to 2977.2Ω-m at VES6. The thickness varies between 6.15m at VES4 and 16.18m at VES6.The resistivity values of the third layer within the failed portions (237.5-442.6 Ω-m) are far less than those obtained at the stable segments (567-2977.2 Ω-m).

The forth layer which consists of medium to coarse sand has resistivity which varies between 418 Ω-m and 1419.08 Ω-m. The thickness ranges from 8.57 to 118.97m.The resistivity of the failed segments (418.3-884.9 Ω-m) are lower than those obtained within the stable portions (562-1419.04 Ω-m). The fifth layer consists of coarse sand with resistivity which varies between 511.3 and 921.0 Ω-m.

## DISCUSSIONS

The results of the vertical Electrical Sounding survey revealed five geoeletrical layers comprising of topsoil, clay to sandy-silt, fine sand, medium sand, medium-coarse sand and coarse sand**.** Comparison of the results of the Vertical Electrical Sounding survey for the failed and stable portions of the highway sub-grade shows that the failed portions are highly associated with low resistivity values than the stable portions for the corresponding five layers. The low resistivity values of the failed portions are mainly due to the presence of high clay contents in the sub-grade at different depths. The clay minerals typically have lower electrical resistivity (higher conductivity) than silt, sand and gravel. However clay minerals also exhibit a wide range in electrical resistivity in particular, swelling clays have a higher capacity for ion exchange which results in much lower measured resistivity than non-swelling clays.

Furthermore, a qualitative comparison between VES data and the failed and stable portions of the highway also shows a good correlative between failed pavements and low resistivity values. Roads constructed over areas of clay are generally subjected to potential differential settlement due to volume changes caused by swell/shrink and low shear strength of the clay resulting from high moisture contents. The clayey sub-grade on which some parts of the road are founded have tendency of absorbing water which makes them to swell and collapse under wheel load stress which subsequently lead to the road failure. This unstable seasonal behaviour of the clay makes pavement to lose its integrity within a short time after road construction.

Other factors observed from Walkover survey of the highway that might also be responsible for the highway failure are; abandon river channels, high water table, water flooding and fallen tree trunks that were left and buried. The abandon river channels are filled with unconsolidated and incompetent materials of high moisture contents. These materials undergo subsidence when a load is applied to it. The flooding of the highway and high water table of the region are other major challenges affecting the integrity of the road. The tree trunks create void in the subsurface when they decayed.

It is hereby recommended that hydraulic sand fill should be used for the road embankments and for the replacement of the weak, incompetent and compressible clay materials. The ongoing construction work should be well supervised and monitored by competent government agencies in order to ensure that high standards and specification are maintained by the construction company. Proper drainage system should also be included to remove flood water from the road.

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