International Journal of Water Resources and Environmental Engineering Vol. 3(6), pp. 126-131, July 2011
Available online at http://www.academicjournals.org/ijwree
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Integration of very low-frequency electromagnetic (VLF-EM) and electrical resistivity methods in mapping subsurface geologic structures favourable to road failures

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Accepted 29 June, 2011

An integrated geophysical survey involving very low-frequency electromagnetic (VLF – EM) and the dipole-dipole electrical resistivity methods was carried out along the Auchi-Ibillo road in Igarra, Nigeria with a view to examining factors responsible for road failures in the area. Analysis of very low frequency electromagnetic current density sections and dipole-dipole pseudo-sections were made along three traverses. The (VLF–EM) revealed the presence of conductive zones and the dipole-dipole pseudo-sections delineated low resistivity clay enriched, water absorbing sections and a linear fracture zone or joint. The delineated clay section and the fracture zone are the major geologic factors responsible for road failures in the area.

Key words: Electromagnetic, resistivity, Igarra, Nigeria, geologic factor, road failure.

INTRODUCTION

Geological factors are rarely considered as precipitators of road failure even though the highway pavement is founded on the geology (Momoh et al, 2008). This is due to non-appreciation of the fact that proper design of highway requires adequate knowledge of subsurface conditions beneath the highway route. The non-recognition of this fact has led to loss of integrity of many highway routes and other engineering structures across the country as observed by Olorunfemi et al. 2000a, b). Some sections of major roads failed because their soil properties were not thoroughly investigated at the initial state. In fact, little or no consideration was given to the effect of clay mineralogy and the associated engineering soil behaviour, as highway foundation materials. The bearing capacity of rocks in relation to vehicular traffic is one the essential parameters to be reckoned with in road construction projects. Some major Nigerian highways are known to fail shortly after construction and well before their design ages. The factors responsible for road failures are traceable to lack of adequate geologic survey before commencement. Such preliminary studies are capable of delineating structures such as unconsolidated soil formations with varying resistivities and expansivities, naturally occurring underground water channels or logs etc which may expedite weathering and surface deformation. Degradation of many highway pavements are traceable to the surface water ingress through cracks and joints. These have resulted to frequent motor accidents leading to loss of lives and properties in Nigeria. Hence it is important to empirically investigate the study area at Igarra, Nigeria to ascertain the sub surface structures, their engineering properties and implications.

Location and geology of study area

The study area lies along the Auchi-Ibillo, Okpe and

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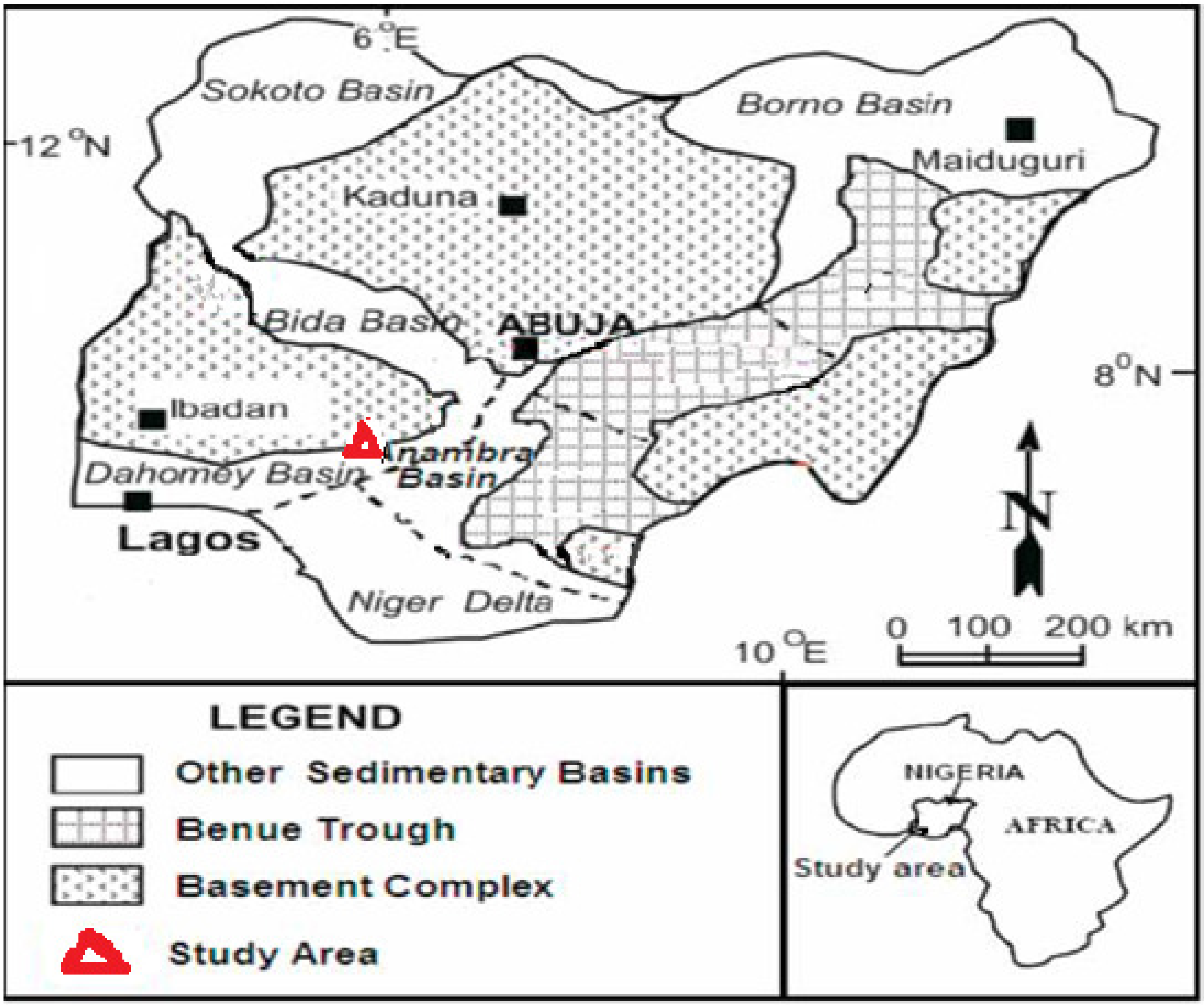

Figure 1. Showing the geological map of Nigeria and location of the study area.

Onwa in Igarra Edo State, Nigeria (Figure 1). It is located on 7°17′0″N, 6°6′0″E (Figure 1) as obtained from a reliable Thuraya field geographical positioning system (GPS) meter. The study site is bounded on the West by the Auchi-Ibillo road and on the South by the Comprehensive College road at Igarra Southwestern Nigeria. Its climate is predominantly rainforest characterized by two seasons-the wet season (between April-October) and the dry season (between October-March) with a mean annual rainfall of 1250 mm and a temperature range of 18 to 33°C. The topography is generally undulating with Eastward highlands of granitic origin. The study area is characterized by Precambrian Basement, complex rocks, consisting mostly of the meta-conglomerates, granites, quartzite complex, schist, gneisses complex, vein quartz, marbles/limestone complex among others. In the immediate vicinity of the site are evidences of meta-conglomerate outcrops and quartzite with sedimentary depression characteristic of a transition zone (Kogbe, 1989).

METHODOLOGY

The very low frequency - electromagnetic (VLF-EM) and the electrical resistivity (dipole-dipole array) methods of geophysical survey were used in S – N direction in Igarra. Five traverses with inter- traverse separations of 50 m were mapped out; Traverses 1 and 2 have a length of 165 m each, while transverses 3, 4 and 5 have lengths of 200 m each for convenience of space limitation. The VLF-EM data were acquired using the ABEM- WADI VLF equipment along the five traverses at a mean separation of 15 m with signal strength of 22.2 KHz. The Omega resistivity meter was used in acquiring the electrical resistivity data using the dipole-dipole configuration. The dipole-dipole data were acquired at an electrode spacing of 10 m on all the traverses with an expansion factor ‘n’ ranging from 1 – 5. The VLF-EM data were interpreted using the Karous-Hjelt filter and applying 2-D inversion software to generate current density sections and the dipole-dipole pseudo-sections from the “DIPROFWIN” version 4.0 software.

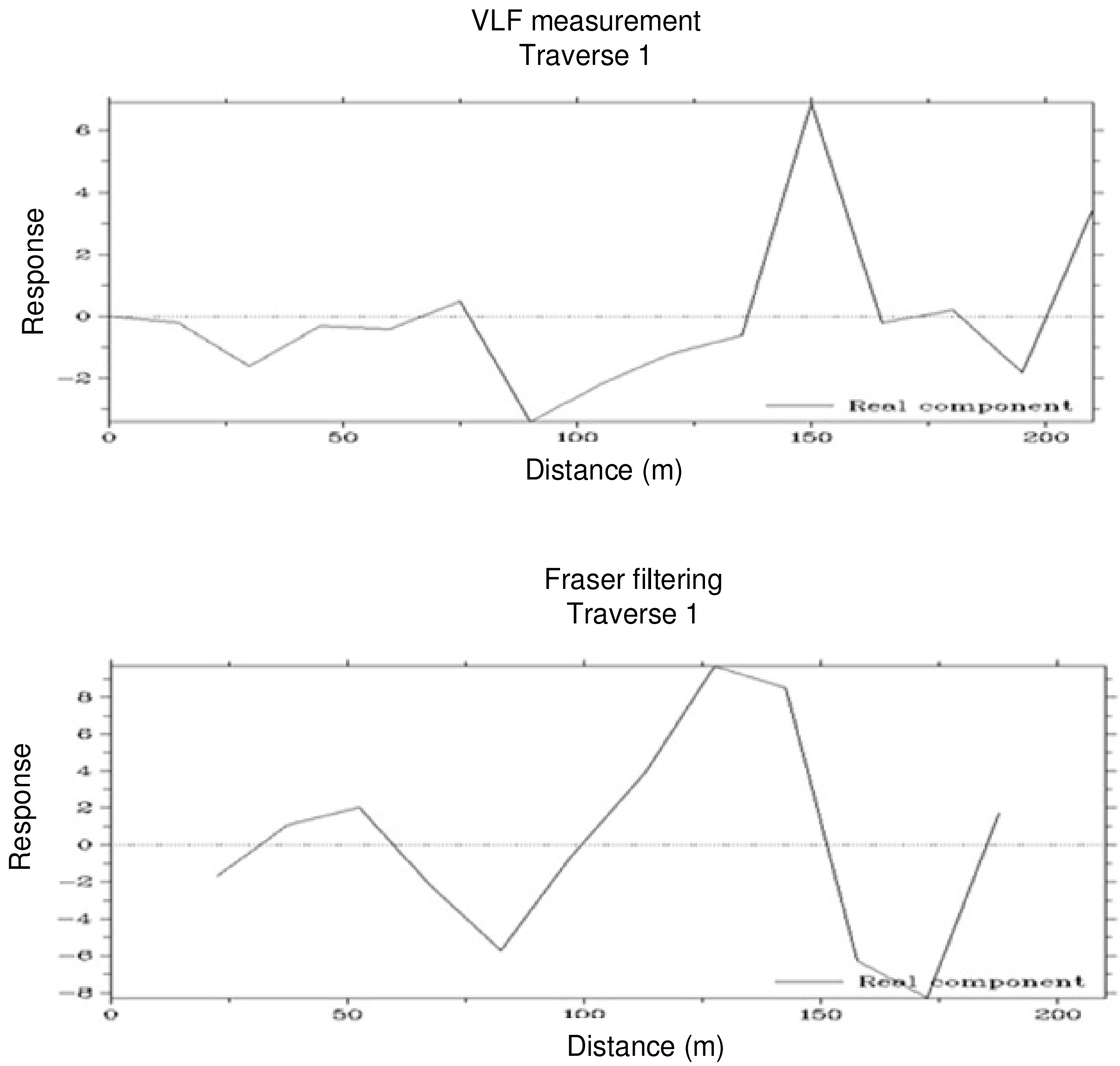

Figure 2a. Sample Karous-Hjelt filter 2-D inversion current density sections (Traverses 1).

RESULTS AND DISCUSSION

The VLF-EM representative results

The VLF-EM representative results of the Fraser model filtered data plots as well as Karous-Hjelt filter 2-D inversion current density plots for profiles 1-5 are presented in Figures 2a and b. The 2-D inversion shows variation of apparent current density with change in conductivity with depth (conductivity gradient). High positive values indicate presence of conductive subsurface structures while low or negative values are indicative of resistive formations, (Sharma and Baranwal, 2005) Figure 2a. The cross-section of the apparent current density of: Transverse 1 reveals the presence of anomalies between 15 to 60 m and between 90 to 155 m along the profile having slightly high current density indicative of potential subsurface fracture systems. Transverse 3 reveals a number of conductive anomalies between 15 to 68 m and 80 to 130 m indicating the presence of conductive subsurface structural trends of inferred fractures. Transverse 5 reveals a number of conductive anomalies at 50 to 65 m, 80 to 95 m and 105 to 155 m indicating the presence of conductive subsurface structural trend of fractures Figure 2b. The transverses show development of conductive zones with slightly high apparent current densities which is indicative of a combination of non-dipping and slightly North-dipping

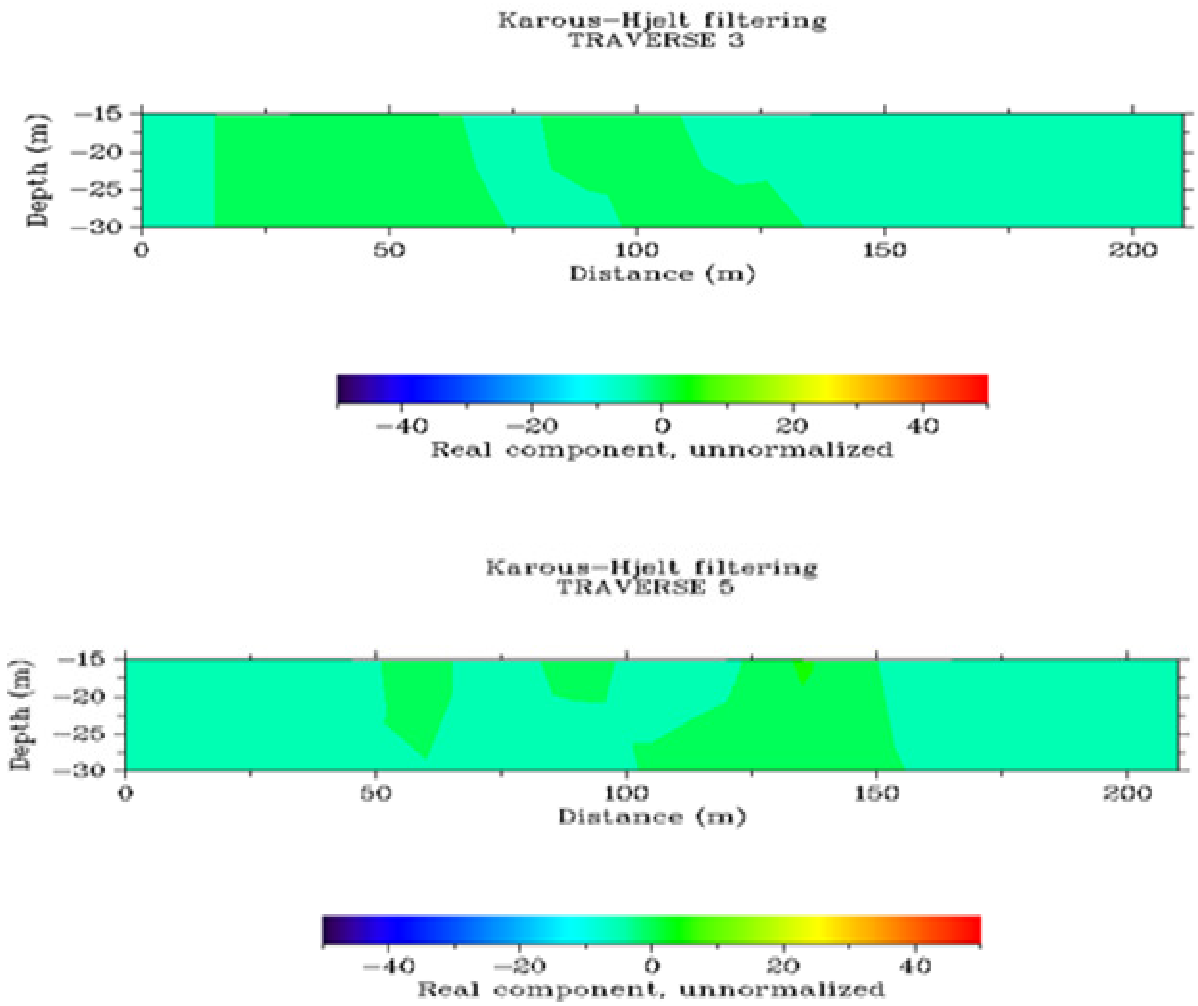

Figure 2b. Sample Karous-Hjelt filter 2-D inversion current density sections (Traverses1, 3 and 5).

profiles resulting in subsurface structural fractures.

Dipole-dipole pseudo-sections

Traverse 1: The 2-D resistivity section here shows a high resistivity (>100, < 200 Ωm) zone between station 1-6 (10 to 35 m), to a depth of 3.3 m below the surface and another zone of high resistivity of over 200 Ωm extends from 3.3 m to an infinite depth below the surface. A low resistivity zone of 60 Ωm lies between stations 6 – 11 (35 to 60 m) with lowest resistivity between stations 6 – 8 (35 to 45 m) and extending to infinite depth below the surface Figure 3a. This low resistivity indicates the presence of clay in the subsurface (Okolie, 2010, 2011).

Traverse 3: This has low resistivity zone (<35 Ωm) between stations 1 – 2 (10 to15 m) reaching a depth of 3.5 m from the surface and between station 4 – 14 (25 to 75 m) reaching depths ranging from 3 to 8 m below surface. This suggests the existence of near surface clay and clayey soil within the subsurface structure. A relatively high resistivity zone of 161 Ωm lies between station 2 to 4 (15 to 25 m) reaching depths ranging from 6 to 8 m below the surface. This high resistivity zone also exists between stations 4 to17 (25 to 90 m) with depth ranging between 3 to10 m and extending to depth of 20 m below the surface between station 6.5 to 8 (38 to 45 m). A highly resistive zone greater than 200 Ωm is also obtained from depths (between 8 to 10 m) to infinity. The high resistivity zone is indicative of the occurrence of thick lateritic medium Figure 3b.

Traverse 5: This has low resistivity zone of 40 Ωm and above between station 6 to17 (33 to 90 m along the profile) with depths ranging from 2 to10 m below the surface. A relatively high resistivity zone of 100 Ωm exists below the low resistivity layer from depth of 10 to 21 m below the subsurface surface except between station 1

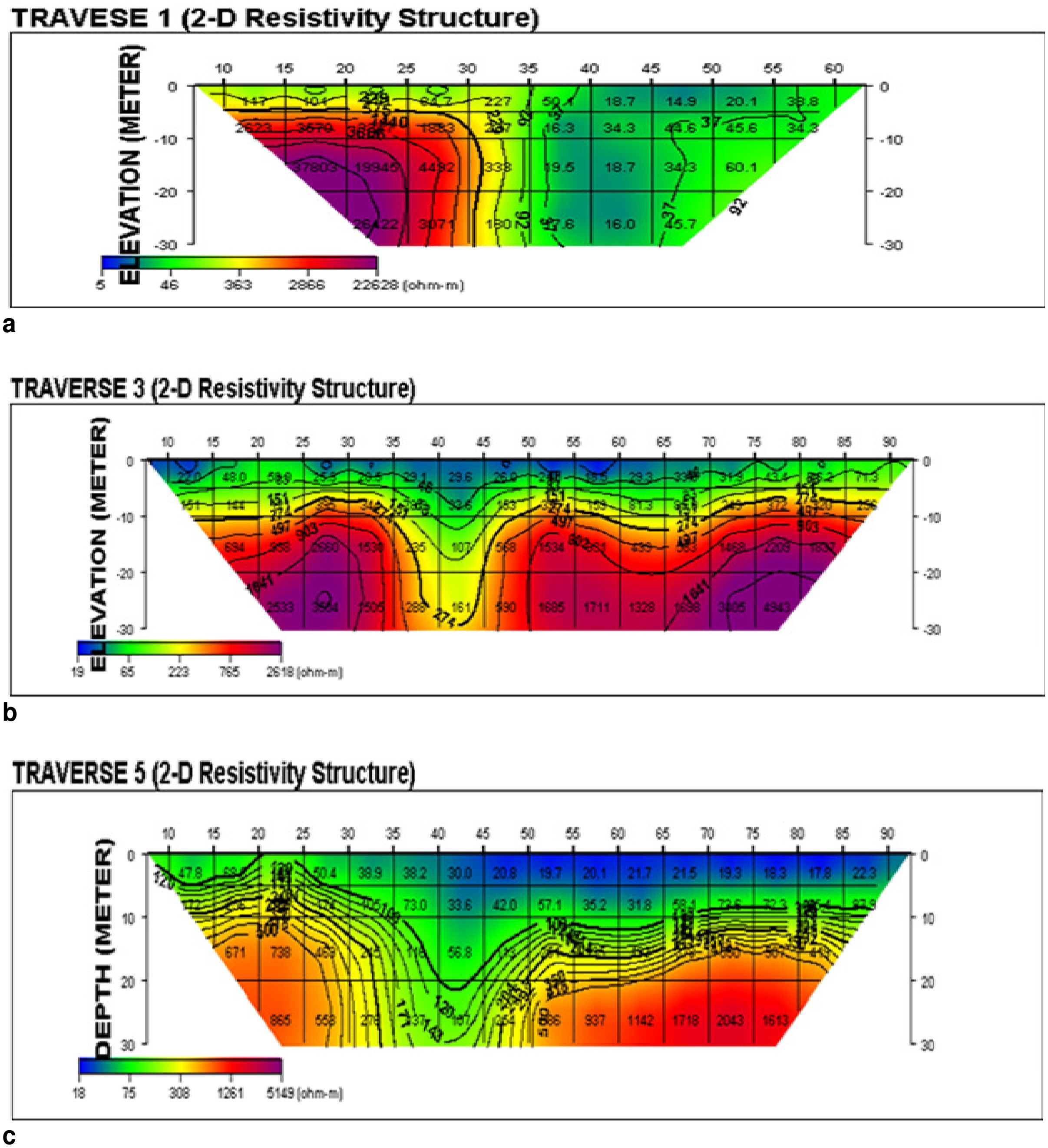

Figure 3. Samples of 2-D resistivity pseudo-sections acquired along traverses a) 1, b) 3 and c) 5.

to 5 (10 to 30 m) where it is exposed. A highly resistive zone of 200 Ωm and above lies between station 1 to 6 (10 to 35 m) and between station 9 to16 (47 to 85 m) to depths ranging from 10 m to infinity below the surface Figure 3c. The low resistivity of 60 Ωm from the pseudo-sections indicates the presence of clay mineralization in the subsurface. This is because clay is a relative good conducting earth material which can hold a significant amount of water. It has high porosity and deceasing shear strength which are responsible for is low resistivities. Hence, there is potential deformation due to volume changes of moisturized clay. Roads constructed over areas of such clay and clayey soil will result in poor pavement performing systems which subsequently results in subgrade failure and linear features suspected to be fracture zone, and joints along the sections which is visibly observed as pavement deformation over problem areas.

Conclusion

In conclusion, from the study the area contains near surface low resistive geologic structures such as clay along the transverses which are highly favorable to road failures. Therefore, appropriate measures such as deep earth excavation of clay and clayey materials from the subsurface and replacing them with compact lateritic substrate should be employed to prevent road failure in Igarra and similar areas where durable road construction or rehabilitation is required. Moreover, intensive empirical geophysical investigations should be carried out before embarking on road constructions.

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