INTEGRATED GEOPHYSICAL INVESTIGATION OF THE IGBARA-OKE – IGBARA-ODO ROAD PAVEMENT FAILURE IN ONDO/EKITI STATE, SOUTHWESTERN NIGERIA

Oni, A. G. and Olorunfemi, M. O.
Dept. of Geology, Obafemi Awolowo University, Ile-Ife. Osun State
(Corresponding Author: oniademakinwa@yahoo.com)

(Received: 30th Nov., 2015; Accepted: 21st Jan., 2016)

ABSTRACT

Integrated geophysical investigation, involving the electrical resistivity and magnetic methods was carried out along the Igbara-Oke – Igbara-Odo roadway in Ondo/Ekiti State. This was with a view to investigating the cause(s) of the persistent pavement failure recorded over the years along the road, in spite of repeated rehabilitation works. The resistivity survey utilized 1-D Vertical Electrical Sounding (VES) with the Schlumberger array and 2-D imaging with the dipole-dipole array while profiling technique was adopted for the magnetic survey. Two (2) stable and two (2) unstable segments were identified for the geophysical investigation. Total field magnetic data were acquired along the identified segments of the road at 5 m intervals. The data were corrected for diurnal variation and offset and presented as residual magnetic profiles. Both qualitative visual inspection and quantitative (2-D modeling) interpretations were applied to the resulting residual magnetic profiles. The 2-D dipole-dipole profiling data were acquired along the magnetic traverses. The 2-D data were inverted into 2-D resistivity structures and were used to constrain the location of the nineteen (19) VES stations. The VES curves were interpreted quantitatively and the results were used to generate geoelectric sections. The magnetic profiles, 2-D magnetic models, 2-D dipole-dipole images and the geoelectic sections along the stable segments were characterized generally by relatively high resistivity (> 151 Ωm) weathered layer; significantly thick (>1.5 m) lateritic subbase; A and KH type curves with increasing layer resistivity and hence competence with depth, within the upper two layers and a subsurface devoid of geological structures (faults, fracture or joints). Along the failed segments, relatively thin (< 1.5 m) or non existing lateritic subgrade; low resistivity weathered layer(< 151 ohm-m);H type curve starting with decreasing resistivity typical of incompetent substratum and subsurface geological structures suspected to be faults, fractures, joints or lithologic boundaries characterized these segments. This study concluded that failures along the investigated roadway were caused by clayey subsoils with relatively low resistivity (< 151 ohm-m); differential settlement on road segment cut into saprolite (decomposed rock rich in clay) and presence of geological structures such as lithologic boundaries, faults and fractured zones.

Keywords: Geophysical Investigation, Pavement Failure, Subsurface Competence, Roadway.

INTRODUCTION

Failures of flexible pavements (bituminous roads) are prevalent in developing countries (Mulei *et al.*, 2002). This trend is of great concern to both road users and authorities due to many fatal accidents, wearing down of vehicles, wastage of valuable time during traffic jams and the huge fund government expend on their rehabilitation and reconstruction.

Despite government efforts in rehabilitation and reconstruction of these failed roads, several segments still record perpetual failure. In this country today, such rehabilitations have become annual ritual with little or no effort made by government and road engineers to identify factor(s) responsible for the persistent pavement failures.

However, research by several authors showed that several factors are responsible for road failure and road pavement performance. These factors include geological, geomorphological, and geotechnical factors, road usage, construction practices and maintenance (Adegoke-Anthony and Agbada, 1980; Ajayi, 1987 and Akintorinwa, *et al.*, 2011). The nature of the subgrade soils on which roads are founded, the bearing capacity and/or hosting fitness of existing soil to bear engineering structures can also initiate pavement failure (Mesida, 1981 and Ajayi, 1987).

The fact that subsoils and rocks are characterized by varying porosity, moisture content, composition and structure with consequent variations in the physical properties (resistivity, magnetic susceptibilities etc.), make factors responsible for pavement failures amenable to geophysical delineation.

Segments of the Igbara-Oke - Igbara-Odo roadway in Ondo/Ekiti State, Southwest Nigeria, have witnessed persistent pavement failure over the years, in spite of repeated rehabilitation works. This study intends to use the electrical resistivity and the magnetic methods to investigate the cause(s) of the road failure.

Description of the Study Environment

The Igbara-Oke – Igbara-Odo roadway, cuts across Ondo and Ekiti States in the Southwestern part of Nigeria (Fig. 1). The about 12 km long road lies within Latitudes 7° 23' 52" and 7° 30' 08" and longitudes 5° 03' 14" and 5° 04' 01" , or between Northings 818129 mN and 829701 mN and Eastings 727319 mE and 728005mE of Zone 31 (Minna datum). The investigated roadway is underlain by the migmatite gneiss and biotite-muscovite granite of the Precambrian Basement Complex of Nigeria (Fig. 2). The predominant rock type is the migmatite gneiss that belongs to the Migmatite-Gneiss Complex classification by Rahaman (1976, 1988) with intrusion of granite. NE – SW striking lineaments predominate the study area (Fig. 3). However, an ENE – WSW lineament cuts across the investigated road.

The topography along the investigated road is gently undulating with surface elevations ranging between 338 m and 385 m. The tropical climatic condition prevails in the study area. It is characterized by short dry season (November - March) and a long wet season (April – October) with mean annual rainfall ranging between 1000 and 1500 mm (Iloeje, 1981). The annual mean temperature is between 22°C (wet season average) and 31°C (dry season average) with relatively high humidity that ranges from about 60%-85% from November to March, and about 80%-90% around August (Adeleke and Leong, 1978; Federal Survey, 1978; NIMET, 2007).The vegetation is the evergreen thick forest type with varieties of hardwood timbers, broad-leave tress and grasses.

MATERIALS AND METHOD OF STUDY

The GARMIN 12 channel personal navigator (GPS) unit was used to acquire the coordinates of the segments of the investigated roadway.

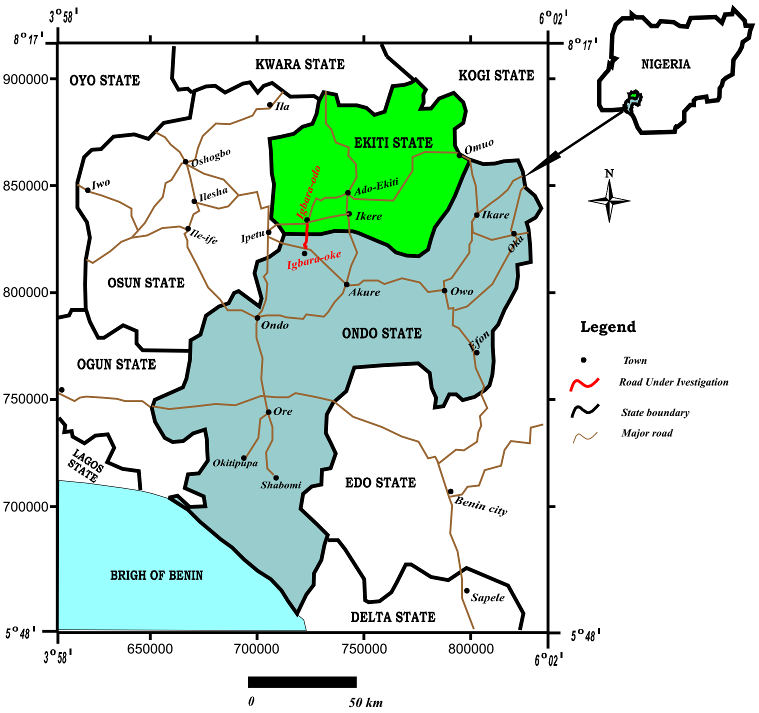


Fig. 1: Road Map of Part of Southwestern Nigeria Showing the Investigated Road (Modified After Spectrum Road Map, 2002)

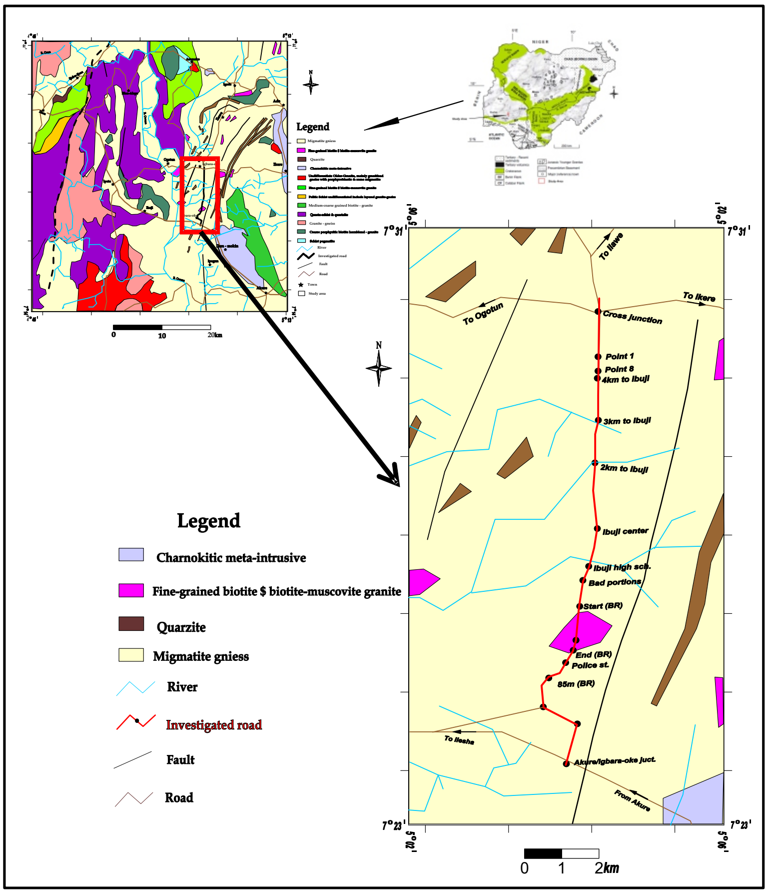


Fig. 2: Geological Map of the Study Area (Modified After Geological Survey of Nigeria, 1976)

A georeferenced road map (Fig. 4), showing the stable and unstable segments, geological boundaries and lineament that cut across the roadway, was generated. This map was used to identify two stable (TR 1 and TR 4) and two unstable (TR 2 and TR 3) segments for surface geophysical investigations. TR 1 and TR 4 were both 200 m long while TR 2 and TR 3 were 380 m and 350 m long respectively. Geophysical investigations involving magnetic and resistivity methods were carried out along the identified traverses. Figure 5 shows typical data acquisition layout. The Proton Precision Magnetometer (GSM-9) GEM model was used to acquire the total field magnetic data along the shoulders of the identified stable and unstable segments of the roadway at 5 m intervals. Two hundred and twenty six(226) stations were occupied.

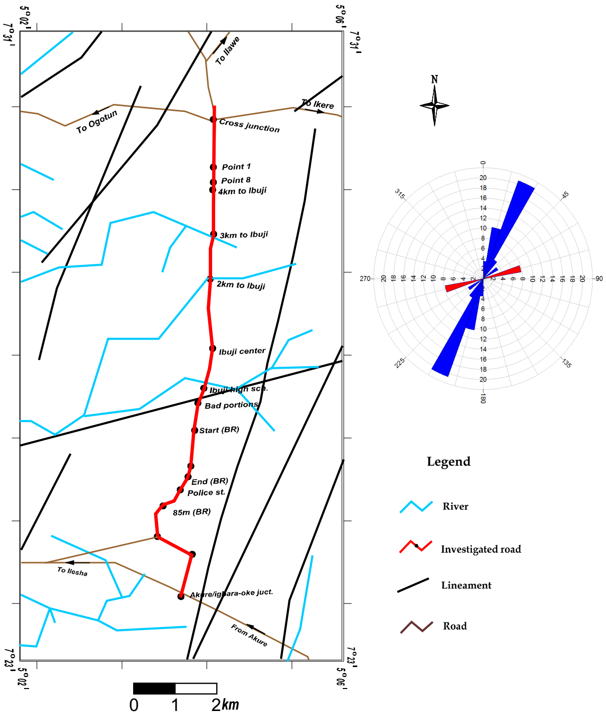


Fig. 3: Lineament Map of the Study Area (Modified After Akintorinwa *et al.*, 2011)

Diurnal variation and offset corrections were applied to the raw data. The resulting residual/or corrected magnetic data were presented as magnetic profiles. Both qualitative and quantitative interpretations were applied through visual inspection of profiles for anomalies diagnostic of geological structures and 2-D modeling using Oasis montaj software respectively. The electrical resistivity method adopted both the 1-D Vertical Electrical Sounding (VES) and 2-D Dipole-Dipole imaging techniques. Resistivity data were acquired using the ABEM SAS 300C Digital Resistivity Meter. The Dipole-Dipole array was employed with 10 m inter-electrode spacing and inter-dipole separation factor (n) that varied from 1 – 5 along the same traverses occupied for magnetic data acquisition. The 2-D resistivity structures obtained from the inverted dipole dipole data using the DIPRO for windows V. 4.0 software were used to constrain the location of nineteen (19) Vertical Electrical Sounding (VES) that adopted the Schlumberger array with electrode spacing (AB/2) ranging from 1 to 100 m. The VES data were presented as sounding curves and quantitatively interpreted using the method of partial curve matching and 1-D computer assisted forward modeling with the WinRESIST software (Vander Velper, 2004). The VES interpretation results were used to generate geoelectric sections along each traverse. The geoelectric sections, magnetic profiles, 2-D magnetic models and the 2-D resistivity structures along each traverse were integrated, correlated and used to establish the causes of the persistent pavement failure along the investigated roadway.

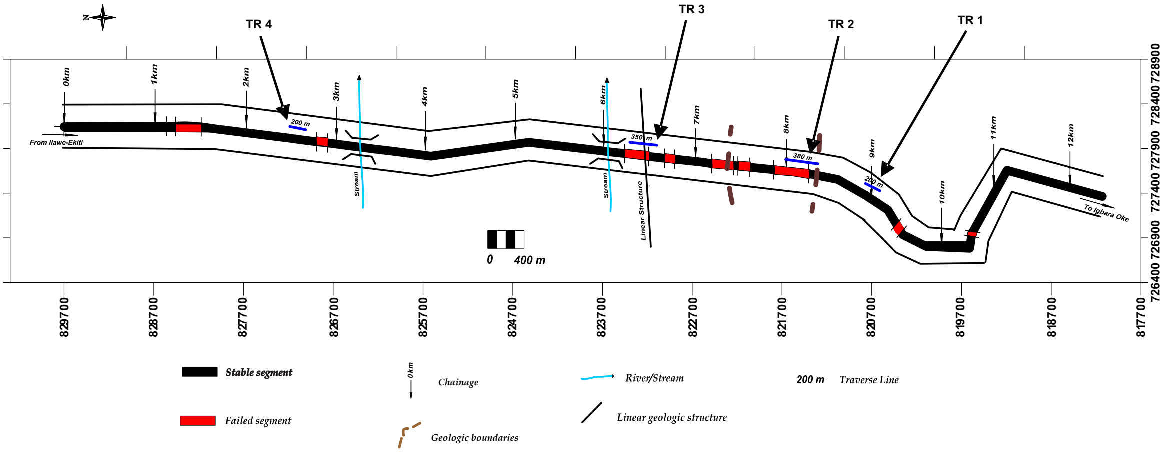
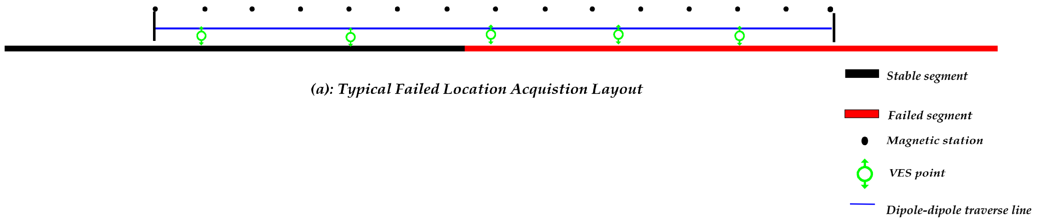
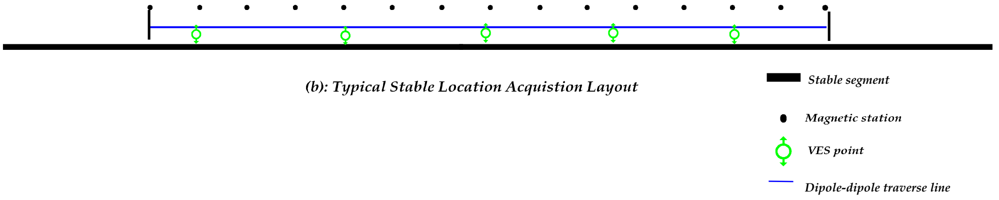


Fig. 4: Road Map of the Study Area Showing Stable and Unstable Segments and Traverses for Data Acquisition



(a): Typical Failed Location Acquistion Layout



(b): Typical Stable Location Acquistion Layout

Fig. 5: Typical Data Acquisition Layout

RESULTS AND DISCUSSION

Resistivity Type Curve

Four (4) VES type curves including the A, HA, KH and KHKH type were identified within the study area with the KH type curve dominating with 58% occurrence (Fig. 6). The entire stable segments (Traverses 1 & 4) and the stable shoulders of the unstable segments were characterized by the A, HA and KH type curves (Figs. 7 & 8) while with the exception of the HA type, the unstable segments were characterized by the KH and KHKH type curves (Fig. 8). These VES type curves (A, KH and KHKH) with increasing layer resistivity within the top two layers are typical of near surface sequence capable of hosting foundation of civil engineering structures (Fatoba, 2012). The HA type curve is however characterized by decreasing layer resistivity and subsoil incompetence at shallow depth.

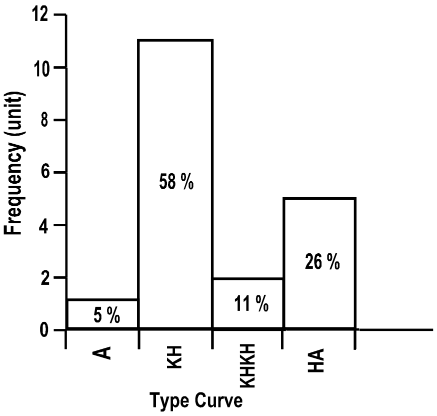


Fig 6: Histogram Showing the Frequency and Percentage of Occurrence of Identified VES Type Curves

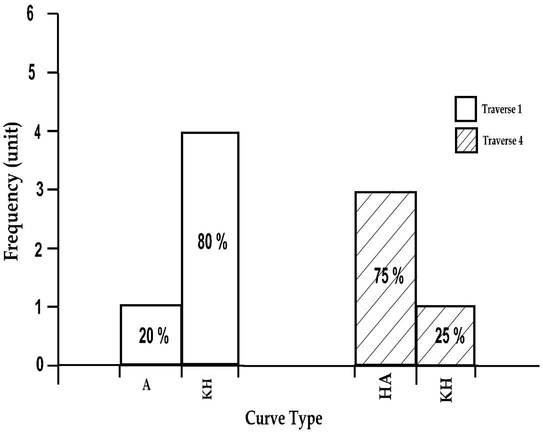


Fig 7: Histogram of Frequency and Percentage Distribution of VES Type Curves Characterizing the Classified Stable Segments

The dominance of the HA type curve with 75 % occurrence along Traverse 4 indicates that this segment though classified stable could be liable to future pavement failure. The KH and KHKH type curves typical of competent near-surface substratum, characterizing some failed locations along Traverses 2 & 3 could indicate failure due to factors other than nature of the subsoil.

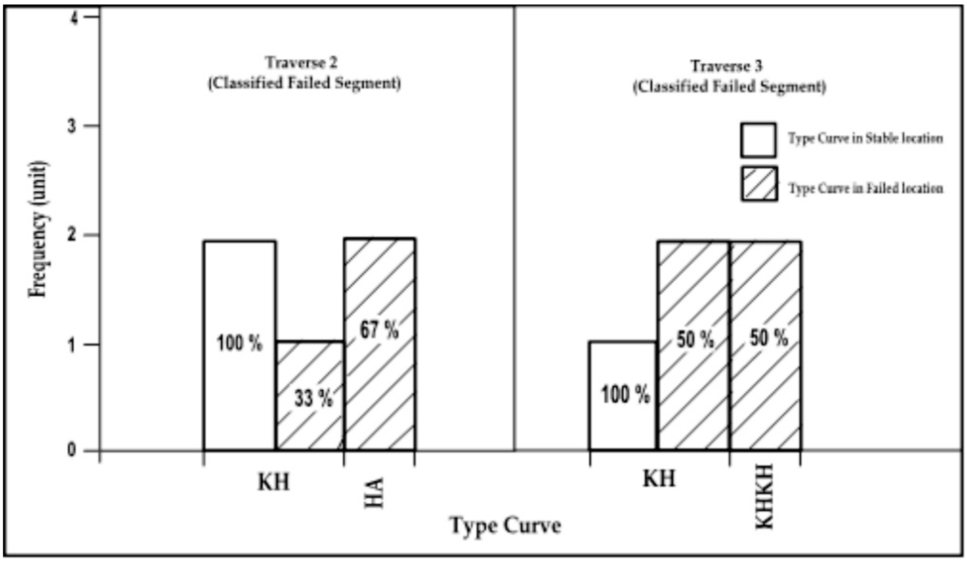


Fig 8: Histogram Showing the Frequency and Percentage Distribution of VES Type Curves Characterizing the Classified Failed Segments

Subsurface Characteristic of the Classified Stable Segments

Figure 9 shows the geoelectric section, magnetic profile/2-D interpretation model and the 2-D resistivity structure along Traverse 1, classified as a stable segment. The traverse is underlain by four (4) geologic layers that is composed sandy clay/clayey sand topsoil, laterite, sandy clay/clayey sand weathered layer and the fresh basement (Fig 9a). The topsoil resistivities and thicknesses are 134 to 311 Ωm and 0.6 to 1.0 m respectively. The laterite has resistivities and thicknesses value of 301 to 535 Ωm and 0.8 to 0.9 m respectively. The underlying weathered layer has resistivity values varying between148 and 442 Ωm and thicknesses of 2.2 to 9.0 m. The depth to basement (overburden thickness) ranges from 3.7 to 10.2 m. The topsoil/laterite constitutes the bedrock on which the road pavement was founded. The sequence displays increasing resistivity with depth and hence increasing competence. The unit ranges in thicknesses from 1.0 to 1.7 m. The magnetic profile displays magnetic lows at the SSW and NNE ends of the profile, typical of anomalous zones (Fig. 9b). The interpreted 2-D subsurface image beneath the traverse shows overburden thicknesses that range between 3.3 to 17.5 m which significantly correlate with the geoelectric model derived overburden thicknesses. The 2-D model also maps a basement topography that correlated well with the geoelectric section with basement depressions at the SSW and NNE ends. The 2-D resistivity structure is displayed in Figure 9c. The topsoil/laterite is merged with the weathered layer, probably because of overlapping resistivity values. The weathered layer is in green colour band while the basement bedrock is in yellow/brownish/purple colour band. The 2-D resistivity structure also shows relatively thick overburden at the flanks of the traverse. None of the 2-D images, including the geoelectric section, identify any failure precipitating geological features such as faults and fractured zone. It also shows that the upper segment (topsoil/laterite) of the substratum has relatively high resistivity values (>250 Ωm) and therefore adjudged competent (Fatoba, 2012).

Along Traverse 4, the second classified stable segment, Figure 10 shows the geoelectric section, magnetic profile/ 2-D interpretation model and the 2-D resistivity structure along Traverse 4, also classified as stable segment. Four (4) geologic layers (Fig.10a) that comprised of sandy clay/clayey sand topsoil with resistivities and thicknesses of 153 to 351 Ωm and 1.4 to 2.0 m respectively; clay/sandy clay weathered layer with resistivities and thicknesses of 80 to 127 Ωm and 3.1 to 6.1 m respectively; partly weathered/fractured basement with resistivity values varying between 183 and 366 Ωm and thicknesses ranging from 6.7 to 9.3 m and the fresh basement with infinite resistivity underlying the traverse. The depth to basement rock head varies from 5.0 to 7.7 m. In the upper 5 m, on or within which the road pavement is founded, the geoelectric section shows that the fairly thick (1.1 – 1.9 m) and high resistivity and hence relatively competent topsoil is underlain by a significantly thick and relatively low resistivity clayey weathered substratum. The magnetic profile (Fig. 10b) identifies one major anomalous zone typical of faulted rock observed at distances 120 to 200 m while the remaining part of the profile was magnetically quiet. The interpreted 2-D subsurface model beneath the traverse shows uneven bedrock topography and relatively thick

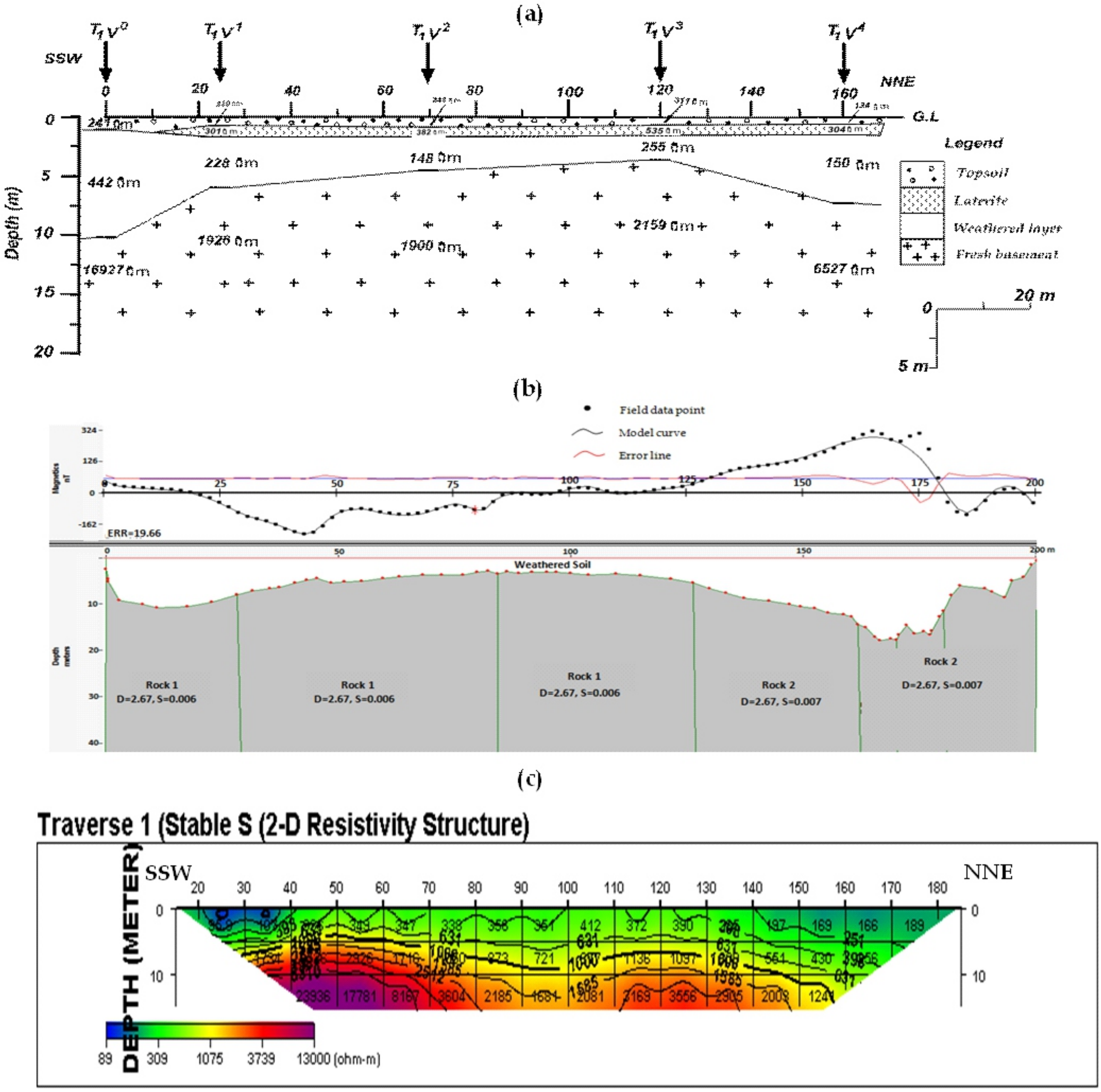


Fig. 9: (a) Geoelectric Section (b) Magnetic Profile and 2-D Model and (c) 2-D Resistivity Structure along Traverse 1 (Stable Segment)

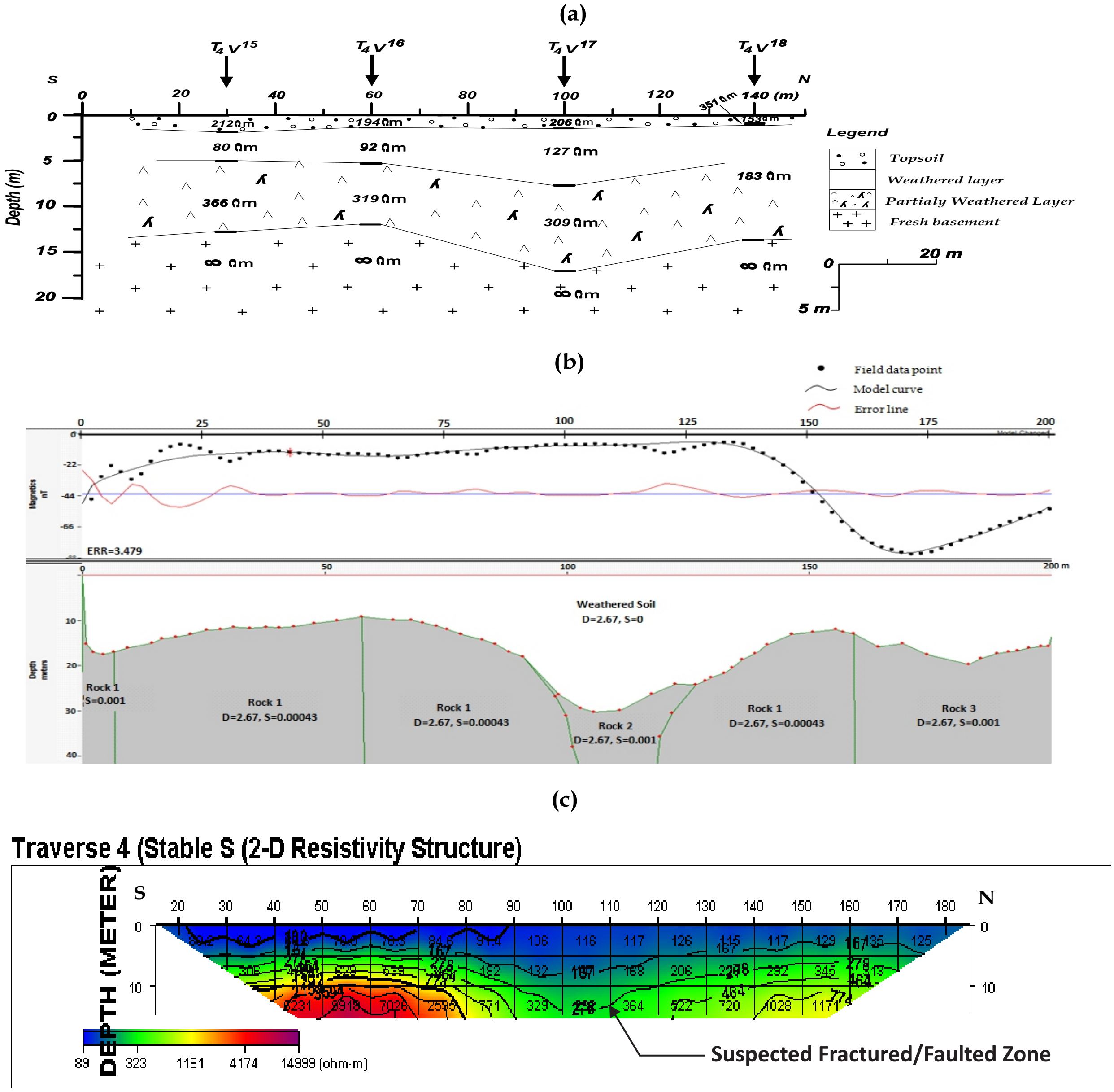


Fig. 10: (a) Geoelectric Section (b) Magnetic Profile and 2-D Model and (c) 2-D Resistivity Structure along Traverse 4 (Stable Segment)

overburden that ranges between 9.1 to 27 m. This significantly correlated with the topography and depth to the fresh basement derived from the geoeletric section. The 2-D resistivity structure displayed in Fig. 10c delineates three (3) geologic layers. The topsoil completely merged with the weathered layer to form the first layer in blue colour band. The partly weathered/fractured basement is in green colour band while the basement bedrock is in yellow/brownish colour band. The 2-D structure shows that this traverse is completely underlain by incompetent low resistivity subgrade while suspected fractured zones at distances 90 -140 m and at the northern flank of the traverse coincide with zones of high magnetic susceptibility typical of mineralization and suspected fractured/faulted zones on the 2-D magnetic model. This segment is characterized by fairly competent topsoil that is underlain by significantly thick but low resistivity incompetent weathered layer and a fairly wide suspected vertical discontinuity though currently stable, could be susceptible to failure in the nearest future. The current stability could thus be attributed to recent rehabilitation/reconstruction works.

Subsurface Characteristic of the Classified Failed Segments

Figure 11 shows the geoelectric section, magnetic profile and the 2-D resistivity structure beneath Traverse 2 classified as an unstable segment. The traverse runs from a stable shoulder to a failed segment (Fig 5). 2-D modeling of the magnetic profile was not carried out because of the noisy nature of the profile. The traverse is underlain by five (5) geologic layers (Fig. 11a) namely clay/lateritic clay topsoil; laterite; clay/sandy clay weathered layer; partly weathered/fractured basement and the fresh basement. The topsoil has resistivities and thicknesses of 92 to 398 Ωm and 0.8 to 1.5 m respectively. The laterite resistivities and thicknesses range from 395 to 1942 Ωm and 0.3 to 2.4 m respectively. The underlying weathered layer has resistivities of 66 to 387 Ωm and thicknesses of 2.3 to 10.6 m while the partly weathered/fractured basement is localized beneath VES 9 with resistivity and thickness value of 613 Ωm and 5.6 m respectively. The fresh basement constitutes the last layer with resistivities of 3612 Ωm to infinity. The depth to the rock head varies from 7.8 to 12.1 m. The topsoil/laterite/weathered layer that constitutes the bedrock on which the road pavement was founded is completely associated with significantly thick (>1.5 m) lateritic subgrade and relatively high resistivity weathered layer beneath the stable shoulder while the failed segment is partly underlain by lens of laterite and relatively low resistivity weathered layer (< 151 Ωm) typical of incompetent substratum.The magnetic profile (Fig. 11b) displayed series of negative peaks anomalies. The magnetic field anomaly amplitude varies between -340 and 154 nT. The anomalous zones whose center were denoted and labeled as F1 to F5 are typical of thin to thick dykes (suspected rock instruction, fractured, shear or faulted zones). Observation from the profile shows that the location between distances 0 to 35 m within the stable shoulder is magnetically quiet and devoid of structural features while other locations along the traverse may be fissured. The 2-D resistivity structure is displayed in Fig. 11c. The latertic clay/laterite topsoil (blue/green colour band), weathered layer/fractured basement (green colour band) and the fresh basement (yellow/brownish/purple colour band) are the geologic layers identified on the image. The topsoil partly merged with the weathered layer probably due to overlapping resistivity values at some locations.

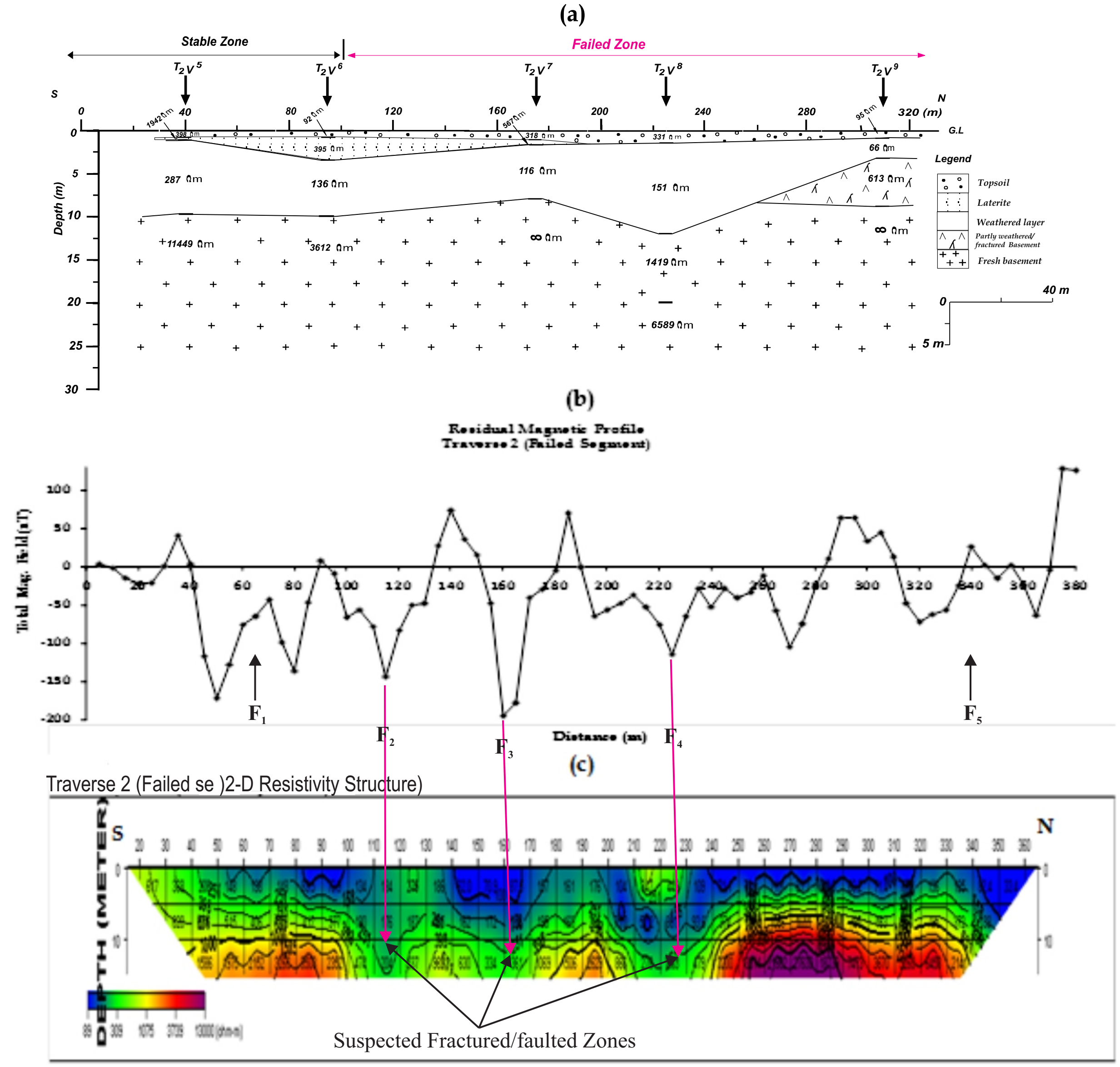


Fig. 11: (a) Geoelectric Section (b) Magnetic Profile and (c) 2-D Resistivity Structure along Traverse 2 (Failed Segment)

The bedrock topography is uneven and significantly correlates with the geoelectric section. The 2-D resistivity structure displays relatively low resistivity vertical discontinuities within the high resistivity basement bedrock typical of suspected fractured/faulted basement (Fig. 11c). These suspected structures correlated with peak negative magnetic anomalies (F2–F4).

Figure 12 displays the geoelectric section, magnetic profile/2-D interpretation model and the 2-D resistivity structure along Traverse 3, the second classified unstable segment. The traverse is underlain by five (5) geologic layers that is composed of clay/lateritic clay topsoil, laterite, clay/sandy clay weathered layer, partly weathered/fractured basement and the fresh basement. The topsoil resistivities and thicknesses are 182 to 736 Ωm and 0.7 to 1.0 m respectively. The laterite has resistivities and thicknesses value of 264 to 1240 Ωm and 0.5 to 1.1 m respectively. The underlying weathered layer has resistivities value of 71 to 251 Ωm and thicknesses of 2.3 to 12.0 m. The basement bedrock topography is even with depth to rock head varying from 3.5 to 13.7 m. The topsoil/laterite constitutes the bedrock on which the road pavement was founded. The 1.2 to 1.9 m thick pavement bedrock, completely underlain the traverse with relatively thin (0.5 to 1.1 m) laterite. However, the underlying weathered layer has relatively low resistivity values beneath the failed segment when compared with the stable shoulder. The magnetic profile (Fig. 11b) shows two (2) anomalous zones typical of thick dyke (suspected rock intrusion, fault and fracture zones) with characteristic negative and positive peaks as identified by Bayode and Akpoarebe (2011) along a structurally controlled spring in Ibuji, about one km from the traverse. The interpreted 2-D magnetic subsurface image beneath the traverse shows that the anomalous zone between distances 0 to 80 m within the stable shoulder is due to basement intrusion while between distances 250 to 310m, the 2-D image shows that this location is characterized by thick overburden and low magnetic susceptibility (0.002 cgs) relative to the surrounding rocks. This zone correlates well with the fractured basement zone identified on the geoelectric section. The 2-D resistivity structure (Fig. 12c) delineates three (3) geologic layers. These layers are the sandy clay/latertic clay topsoil (blue/green colour band), weathered layer (green colour band) and the fresh basement (yellow/brownish colour band). The topsoil merged with the weathered layer at most locations. The 2-D resistivity structure shows that the subsoil on which the road pavement is founded is completely underlain by high resistivity competent layer with the exception of distances 20 to 50 m, 110 to 130 m and 250 to 310 m. Two (2) major vertical discontinuities (suspected fractured/faulted zones) were also identified within the failed segment at distances 70 to 120 m and 250 to 310 m, with characteristically very low resistivity values whose surface expression (see Fig. 12c) may have precipitated the pavement failure.

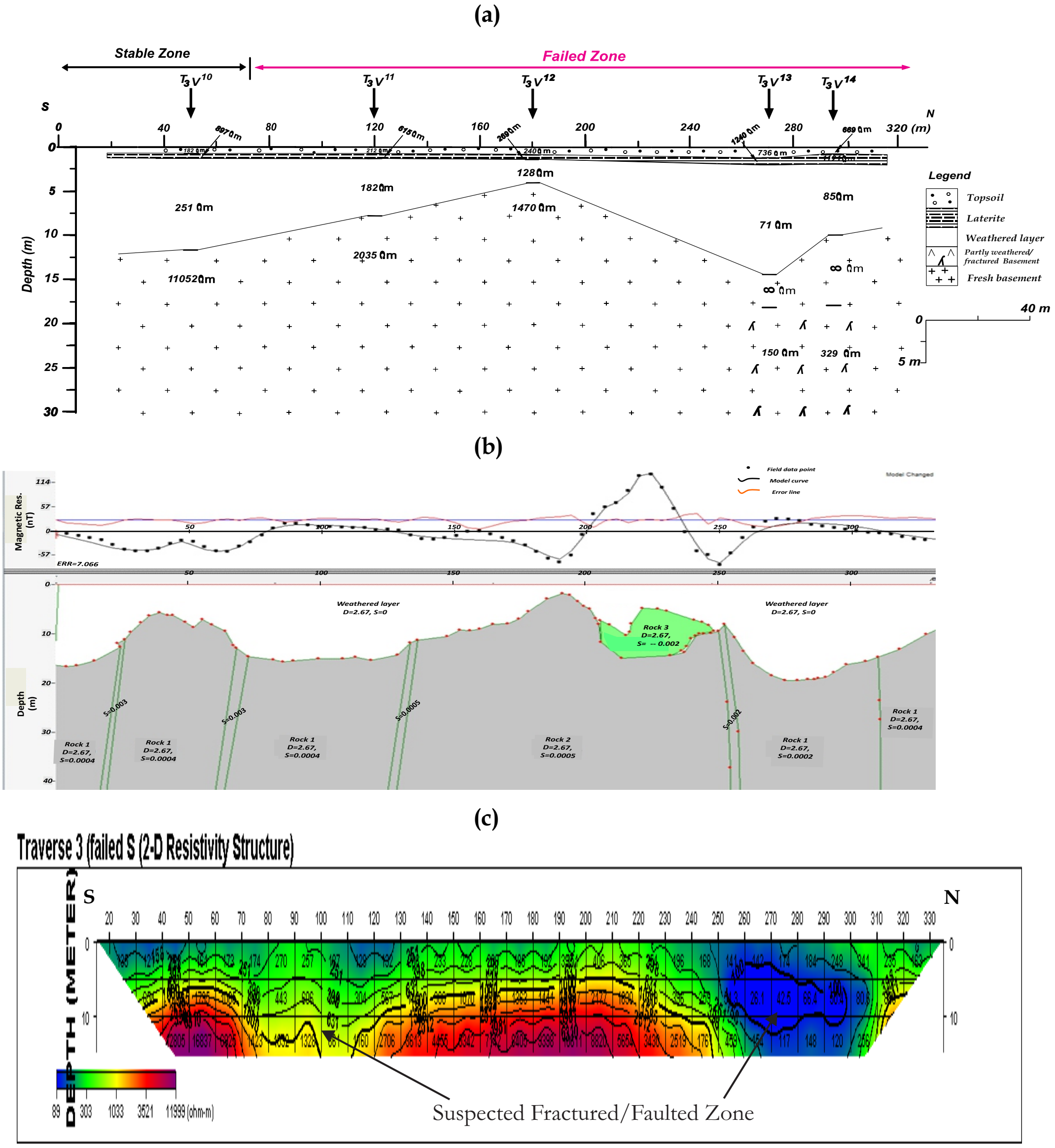


Fig. 12: (a) Geoelectric Section (b) Magnetic Profile and 2-D Model and (c) 2-D Resistivity Structure along Traverse 3 (Failed Segment)

CONCLUSION

In this study, integrated geophysical investigation of the stable/unstable segments of the Igbara-Oke/Igbara-Odo road has been carried out as a mean of establishing the cause(s) of the incessant pavement failure along the road. The results of the geophysical investigations showed that the stable segments (entire stable segments and the stable shoulder of the classified failed segments) which serve as control in this study are generally characterized by the following:

(i) lateritic subgrade that is significantly thicker than the threshold of 1.5 m identified by Fatoba (2012) for pavement stability;
(ii) characterized by A and KH VES type curves commencing with increasing layer resistivity and hence competence with depth within the upper two layers;
(iii) characterized by relatively high resistivity weathered layer (> 151 Ωm); and
(iv) generally devoid of geological structures such as faults, fractures and joints.

While the unstable (failed) segments are characterized by:
(i) relatively thin or non-existing lateritic subgrade;
(ii) VES type curves starting with decreasing resistivity (H or Q type) typical of incompetent substratum;
(iii) low resistivity weathered layer (< 151 ohm-m); and
(iv) subsurface geological structures suspected to be faults, fractures, joints, lithologic boundaries and vertical discontinuities.

It can therefore be concluded that the causes of the persistent pavement failure in this study area can be attributed to the following:

(a) Failure caused by clayey subsoils with relatively low resistivity (< 151 ohm-m) capable of absorbing water which make them swell and collapse under imposed wheel load stress as observed along Traverse 4, though currently stable due to recent rehabilitation works.
(b) Failure precipitated by differential settlement on road cut into saprolite (decomposed rock rich in clay) with high moisture content as observed along Traverse 2 and also identified by Oladapo *et al.* (2008).
(c) Failure initiated and sustained by the presence of geological structures such as geologic boundaries, faults and fractures as observed along Traverses 2, 3 and 4.

REFERECES

Adegoke-Anthony, W. C. and Agbada, O. A. (1980). Geotechnical Characteristics of Some Residual Soils and their Implications on Road Design in Nigeria. *Technical Lecture*. Lagos. pp.1-16

Adeleke, B. O. and Leong, G. C. (1978).Certificate of Physical and Human Geography. West African Ed. Oxford University Press Ibadan, Nigeria.

Ajayi, L.A. (1987). Thought on Road Failure in Nigeria.*Nig. Eng.,* 22(1): 10-17.

Akintorinwa, O. J.; Ojo, J.S. and Olorunfemi, M. O. (2011). Appraisal of the Cause of Pavement Failure along the Ilesa-Akure Highway, Southwestern, Nigeria using Remotely Sensed and Geotechnical data. *Ife Journal of Science*, 13(1):185-197.

Bayode, S. and Akpoarebe, O. (2011).An integrated geophysical investigation of a spring in Ibuji, Igbara-Oke, Southwestern Nigeria. *Ife Journal of Science*, 13(1):63-74

Fatoba, J. O. (2012). Geoelectric, Geotechnical and Remote Sensing Investigation of Flexible Highway Pavement Failure along Shagamu – Benin Expressway, Southwestern Nigeria. *Unpublished Ph.D Thesis, Obafemi Awolowo University, Ile-Ife.*377 pp.

Federal Survey (1978).Atlas of the Federal Republic of Nigeria, 1st Edition. *Federal Surveys Lagos, Nigeria.* pp.136

Geological Survey of Nigeria (1976).Geological Map of Ilesa, Akure, Ondo and Ado-Ekiti.

Iloeje, N.P. (1981). A New Geography of Nigeria (New Revised Edition). *Longman Nig. Ltd., Lagos, Nigeria.* pp.201

Mesida, E.A.(1981). Laterites on the Highway-Understanding Soil Behavior. *West African Technical Review*, pp: 112-118

Mulei, S. M.; Mwatelah, J. K. Z. and Asano, E. (2002). Investigation of Causes of Failures of Flexible Pavement; A Case Study of Nairobi-Thika Highway. *Journal* *of Civil Engineering,* vol 7:13-26

Nigeria Meteorological Agency (NIMET) (2007). *Daily weather forecast on the Nigerian Television Authority.* Nigerian Metrological Agency. Oshodi, Lagos.

Oladapo, M. I.; Olorunfemi, M. O. and Ojo, J. S. (2008). Geophysical Investigation of Road Failure in a Basement Area of Southwestern, Nigeria. *Research Journal of Applied Sciences*, 3(2): 103-112

Spectrum Road Map of Nigeria (2002). 13th Editions Revised, *Spectrum Book Limited.*

Rahaman, M. A. (1976).Review of the Basement Geology of Southwest Nigeria, Geology of Nigeria. In: C. A. Kogbe (ed.), Geology of Nigeria. *Elizabethan Publishing,* p. 41-58.

Rahaman, M. A.(1988). Recent Advances in the Study of the Basement Complex of Nigeria. *Precambrian Geology of Nigeria*, G. S. N, p. 11-41.

Vander Velpen, B. P. A. (1988). WinRESIST Version 1.0 Software. *M.Sc. Research Project.* ITC. Delft, Netherlands.