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Electrical resistivity imaging and magnetic surveys for evaluating highway failures along Ogbagi – Ikare, Southwestern Nigeria

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ABSTRACT: *A geophysical survey, involving electrical resistivity imaging and magnetic method was carried out for evaluating the cause(s) of the three failed segments along Ikare – Ogbagi highway, southwestern Nigeria. A total of fifty - six magnetic data points, three dipole-dipole resistivity and nine Schlumberger vertical electrical sounding datasets were acquired along three traverses across the failed and stable portions of the road. Results showed two major magnetic responses; high and low zones identified as shallow basement/competent or high magnetized weathering resistant strata and weak zones/low weathering resistant strata respectively. High magnetic amplitudes were observed between 0 – 15 m / 25 - 30 m and low between 15 – 25 m / 30 - 100 m for traverse I; high between 40 -- 50 m with a peak at 45 m position and low between stations 0 - 40 m / 55 - 65 m for traverse II, while on traverse III high responses were between 40 – 60 m and low between 0 – 40 m / 65 – 80 m . Low resistivity columns were observed between 15 - 25 m / 50 -90 m and high responses between 0 – 15 m / 25 – 50 m along traverse; low responses between 0 - 35 m / 45 – 60 m and high between 40 - 45 m, while for traverse III, low resistivity spectrum was observed between stations 0 - 25 m / 40 – 45 m with high responses between stations 25 - 35 m / 60 – 80 m. Three – four geoelectric/geologic sequences were delineated to include; the sandy clay/clayey sand topsoil of 66 - 178 ohm-m and 0.5 - 3.6 m thick; clayey weathered layer with lower resistivity range of 18 - 81 ohm-m, underlain by partially weathered/fractured/fresh basement of 461 - 2594 ohm-m. The stable portions are underlain by sandy materials with relatively high topsoil resistivity (>170 ohm-m) and thickness values (>3.5 m), while the distressed/failed portions are characterized by a thin clayey cover of the first two layers (< 3.5 m) and subsurface fractures F_1 – F'_1 and F_2 –F'_2. It can, therefore, be concluded that the causes of highway failures are; near surface fractures/lithological contacts as potential groundwater seeps, pockets of clayey-filled basement depressions/clayey substrate with a good soak and swelling tendency of the highway pavements.*
KEYWORDS: *Geoelectrical, geological, highway, resistivity, stable, substrate*

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I. Introduction

Discontinuities as cracks, potholes, bulges and depressions are common surface features of most Nigerian highways where pavement failures are evident. Pavement failures have been attributed to factors such as poor state of funding of many road projects, insufficient information about the soil properties and poor suitability of subsurface geologic materials.

Gross low costing of road projects arising from poor budgeting, in most cases, has led to poor deliverables, in terms of project design/quality assurance, drainage facilities, the use of sub-standard/poor materials. This is an important factor for an increase incessant failure of roads in Nigeria and other third Worlds. Good enough are roads whose designs accommodate high volumes and stresses of modern automobiles and heavy traffics in a sustainable manner. These roads are usually a product of innovation built on knowledge of geotechnical properties of soils and practices. Knowledge-driven research on civil engineering and geotechnical of this kind has potential to support good road construction practices, thereby ameliorate indices of road failures.

Advocacy on the use of water proof based asphalt, rock aggregates as concrete, stabilizations of soils with either rock flour or cement and better drainage system has drastically improved the conditions of road. Nevertheless, the above ideated solutions may have addressed highway failures attributed to expansive soils, excessive use of the road network and geotechnical factors in the tropics [1], [2], [3], [4] and [5]. However, the probable existence of active near surface geological features such as faults, cavities, lateral or lithological heterogeneity, thinning out of facies/lateral facie changes may be inimical to integrity of pavement foundations as earlier observed in other areas with similar geological settings [6], [7], [8] and [9]. Features as these that are important for consideration are usually hidden from discrete geotechnical data sampling techniques.

Failures as discontinuities are synonymous with road hoisted in the basement and sedimentary terrains. This is evident in earlier studies [10], [11], [12], [13], [6], [8], [4] and [9]. Ikare - Ogbagi highway is founded on crystalline basement complex rocks of southwestern, Nigeria [14]. It is a major road that links Ikare, the commercial hub of Akoko, to other neighbouring towns, such as Ogbagi, Odo - Irun/Oke - Irun, Ese, Iye – Akoko (Figure 1). The road also serves as interstate linking Ekiti - State to Ondo - State via Ado – Ekiti (state capital) enroutes Irun – Akoko.

Continuous failure of Ikare - Ogbagi highway as cracks, wavy surfaces and potholes, inhibits smooth vehicular movements. Worse hit are locations at The Nigerian Police Station, Ogbagi, and Awelewa Guest House axis. Safety of lives, farm products and colossal economic loss to highway rehabilitation, in a perennially struggling economy of the communities in this area, have led to this study.

In order to obtain a complete picture of road pavement conditions, discrete data points must be taken over denser spacing than direct samplings [15]. This practice and its attendant much cost makes geotechnical methods inhibitive. Geophysical techniques with good coverage and denser data sampling capability and much less costs, however, are potentially useful in characterizing road foundation with accuracy over an expanse area. Hence, magnetic and electrical resistivity methods have been employed for this study.

The methods could investigate and determine parameters and subsurface characteristics such as poor soil instability, depth to bedrock, weathered basement trough/bedrock topography, rock type, layer boundaries, depth to groundwater table and presence of weak zones/expansive thin or thick clays on pavement, inhomogeneities, cavities, ancient relics and generally underground geological structures of different physical properties [16], [17], [18], [19] and [15].

In this present study, the electrical resistivity involving 2D resistivity imaging and vertical electrical sounding techniques are deployed while the magnetic method is ground - based survey for providing non-discrete datasets for subsurface study to outline geological structures/formations provoking highway foundation. The relevance of these two surveyed methods, the 2D resistivity imaging in particular, in mapping subsurface structures, discontinuities and weak zones/weathered bedrock trough find wide applications in environmental, engineering and geotechnical investigations [17], [20], [21], [22], [23], [24], [25], and [9]. Failed segments of road highway are usually weak zones that are generally characterized by relatively low resistivity and low magnetic responses as opposed to the stable zones with typical high resistive and high magnetic signatures. This study is poised to evaluate the possible causes and/or forms of road failures in this area since the future states of roads and other civil works are dependent on detailed and adequate on the variations in soils properties/water contents, bedrock configuration and structures. These subsurface information are significant for this study and foundation design practices.

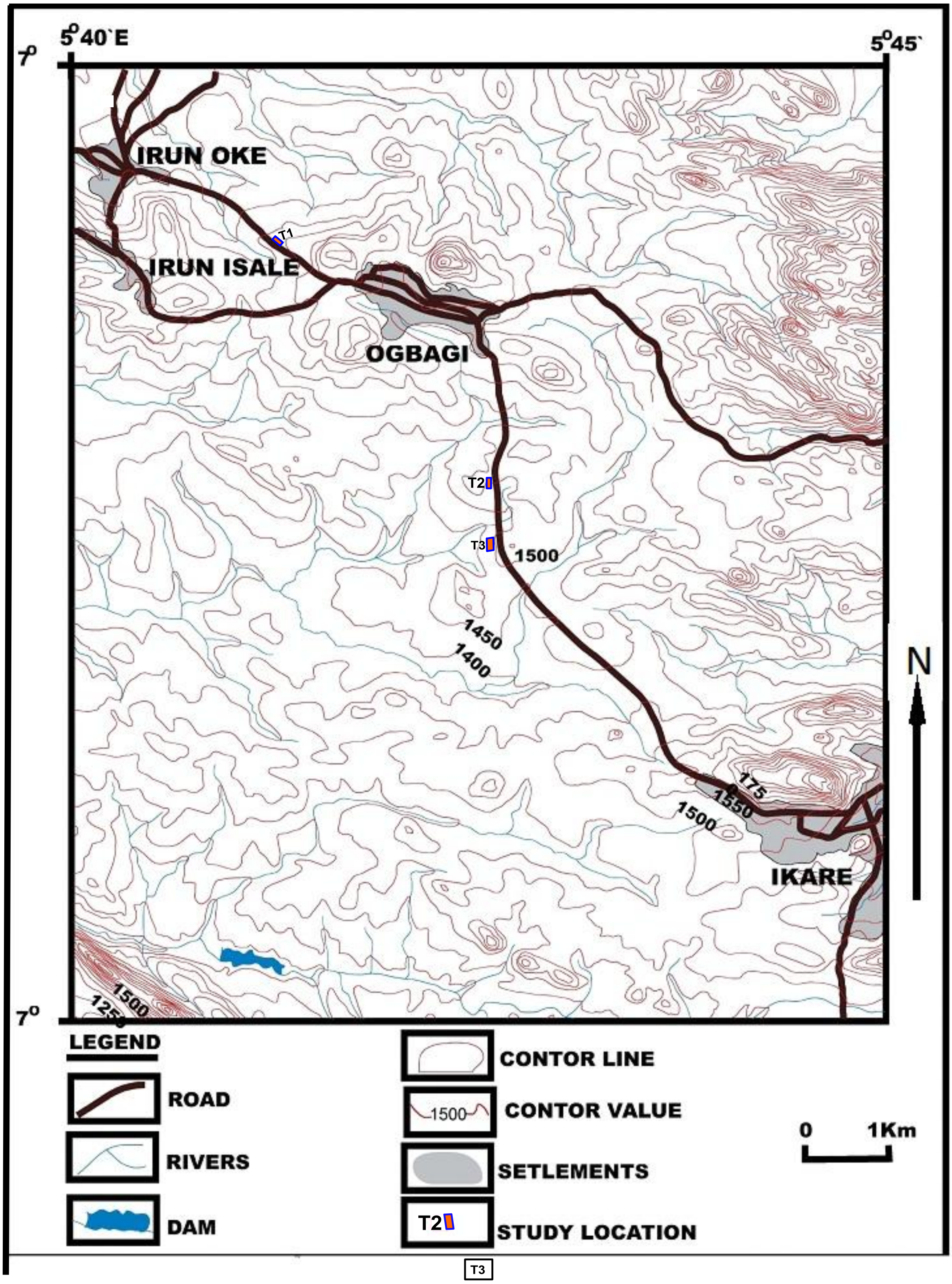


Figure 1. Location map of Ogbagi – Ikare highway and topographic system

II. Description Of The Study Area

The study area is Ikare - Ogbagi highway. It lies in the northern part of Ondo - State in southwestern Nigeria covering geographical coordinates between Latitudes 07^{o} 33'N and 07^{o} 37'N North of the equator and Longitudes 005^{o} 40'E and 005^{o} 45'E East of the Greenwich meridian**.** The elevation varies from 415 to 480 m above sea level within the confine of the study area (Figure 1). It is easily accessible through a network of tarred road that runs from Ikare - Akoko via Ogbagi – Akoko to Ado – Ekiti. Ogbagi – Akoko, the centre of the study sites, is linked to other towns in Akoko such as Ikare, Irun Oke/Isale, Iye and Arigidi which makes it an important town in Akokoland (Figure 1).

The vegetation is tropical rain forest type, with rainfall almost through the whole year between March – October, and short dry season between November – February [26]. This rainfall distribution encourages thick vegetation, farming and timber business activities to flourish. The annual mean maximum and minimum temperature are 33^0 C and 18^0 C respectively [26]. The drainage pattern in this area is dendritic pattern. However, trellis patterns may develop where granite and gneiss rock units are faulted as a result of deformation.

The study locations and their surroundings are underlain by Southwestern Precambrian Crystalline Basement Complex [14] and [27]. Basement rocks are concealed in most places, particularly at these locations. The locations are covered by thick residual deposits /weathered materials from parent rocks distinguished as migmatitic gneiss complex. Lithological unit, at the study sites, is generally granite gneiss with residual soils covering at different depths extent.

III. Materials And Methods

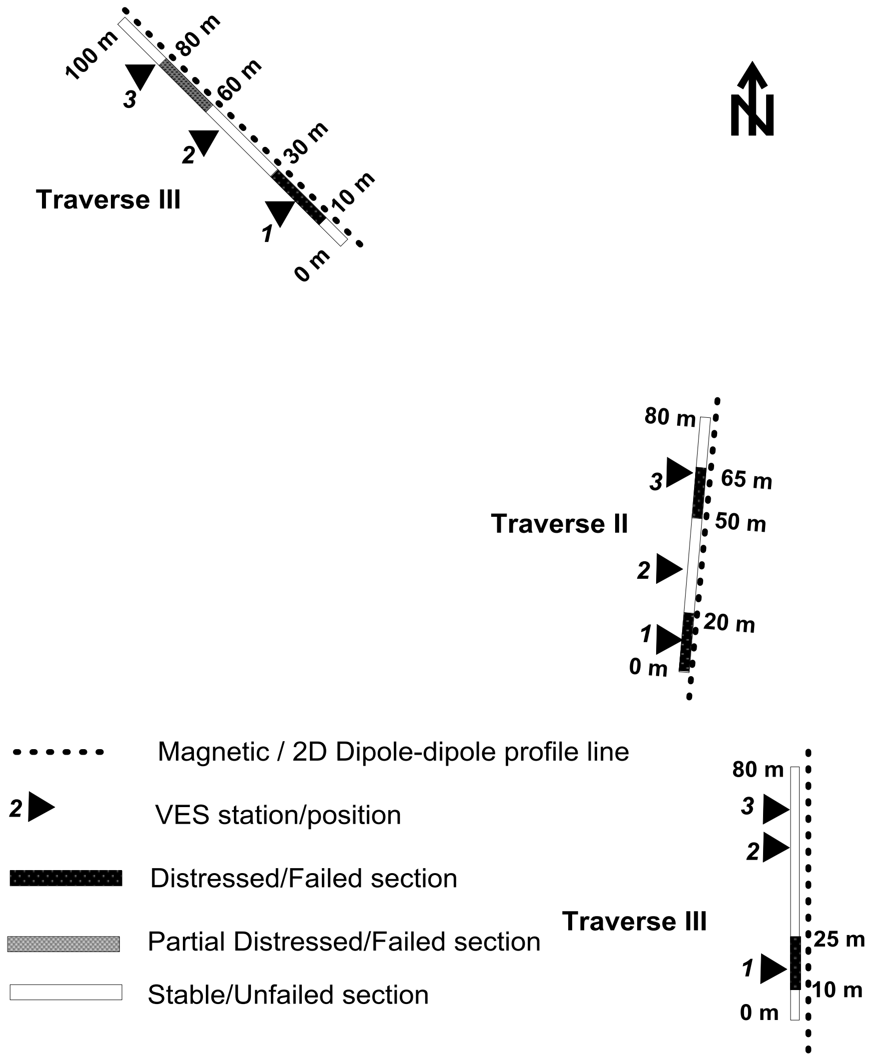
3.1 Data Acquisition Techniques

Magnetic and resistivity data were collected along predefined traverse lines away from magnetic source(s) along the shoulders of the highways segments (Figure 2 a). Traverse I, enclosed between geographical coordinates N0796051/E0839263 and N0796053/E0839163/Elevation 415 m, was established along parts of the road which showed major failed portions as cracks and ripples with minor stable parts while Traverses II and III were along the part of the road that showed major failed portions sandwiched by two fairly stable portions. The two traverses were enclosed between geographical coordinates N0799086/E0836655 and N0799087/E083575 /Elevation 475 m) and N0799011/E0835489 and N0799015/E0835409/Elevation 470 m) respectively. The total distance covered for traverses I, II and III are 100, 80, and 80 m respectively (Figure 2 a). Magnetic base station was established where magnetic intensities were first repeatedly read and taken 8 times, averaged and recorded at their respective spatial positions. Timings of the discrete magnetic readings of 3 seconds per reading were also taken and recorded. The base station readings were taken to observe for any diurnal variation on the data. Subsequently, magnetic intensity readings were repeatedly taken twice at 3 seconds time interval at 5 m station intervals along the traverses. These series of discrete measurements with timings and geo-referencing of positions from Global Positioning System [28] were done concurrently and recorded. Average of these readings was recorded and used for processing and interpretation purpose. A total of 284 data points of magnetic intensity readings, excluding the base station readings, were collected. The measurements were made with hand – held Proton Precision Magnetometer equipment, with the equipment in 'total field' mode.

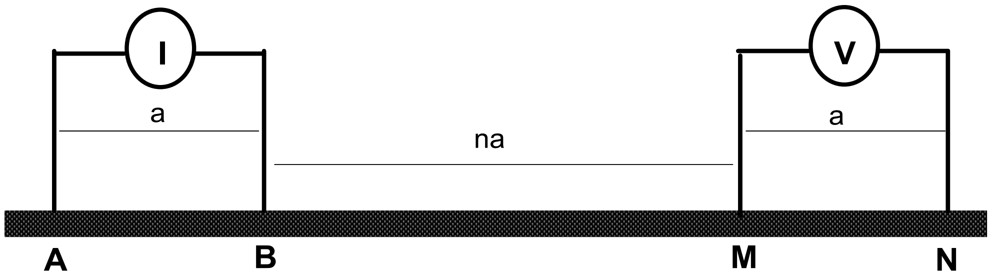
Resistivity datasets were collected on the three different traverses/profiles (Figure 2 a) using ABEM SAS 1000 resistivity meter in 'rho' mode. For the 2D Dipole-dipole resistivity imaging (Figure 2 b), a spacing of 5 m between respective electrodes and the N-factor n = 1 - 4, covering a total length spread of between 15 m for n = 1 and 30 m for n = 4 were adopted. Schlumberger vertical electrical sounding data were also collected at three different points over the distressed/failed portions and stable segments of the road sections on each of the traverses. The traverse I has stations 10 -30, 60 - 80 m as partial to total distressed/failed segments, traverses II and III at positions 0 - 20, 50 - 65 m and 10 - 25 m respectively as failed segments of the road section (Figure 3). A total of nine (9) VES data were acquired concurrently with the measurements of geographical coordinates. Maximum of AB/2 distance covered was 65 m to allow for better depth of investigation. Measurements of apparent resistivities were displayed automatically and recorded for both the resistivity datasets at the time of their respective field data collections.

3.2 Data Processing/Interpretation

Magnetic data were corrected for diurnal variation and subsequently plotted against the station positions to obtain magnetic profiles over the three traverses along the highway shoulders (Figure 2 a). Magnetic survey was tailored towards the mapping of vertical discontinuities, fault/fracture zones and shallow basement. Fault/fracture zones usually have infilling of sediments thereby containing earth materials that are expected to give magnetic response(s) relative to the host, and are important targets in this study. 2D electrical resistivity



(a) state of the highway, geophysical traverses and sounding stations



Geometric Factor = $\pi n(n+1)(n+2)a$

(b) Dipole-Dipole electrode array [22]

Figure 2. Geophysical data acquisition plan in the study area

datasets were processed using DIPROWin software. The field data were fed into the DIPROWin software programme for data inversion using an iterative smoothness constrained least square inversion [29] and [22] to give subsurface geological model in terms of 2D resistivity structures along the three traverse/sites. The inversion removes geometric effects from pseudosection to give a reflection of the true depth and layer resistivities down depths. Vertical electrical sounding data were plotted as field apparent resistivity values (in ohm-m) against AB/2 spread (in metres) on bi-logarithms scale for data accommodation and manual curve matching tasks. The raw geoelectric parameters obtained from manual task served as initial models refined or improved upon by computer iteration. Winresist software package was used for the iteration. The results of the iteration were refined resistivity curves and the display of subsurface geoelectric parameters (Figure 3).

IV. Results And Discussion

Generally, magnetic interpretation of plots is qualitative in this study. Magnetic highs may indicate shallow basement or depth to bedrock and stable zones, while magnetic lows suggest possible fractures or fault zones. It is in this premise that high and low magnetic zones were delineated by inspection of the magnetic signatures and change in gradients of the plots. The three profile plots were on top of each of the 2D structure models/ geoelectric sections for correlation purposes. These are shown in Figure 4. However, the sounding curves vary generally from simple 3 - layered A and H curves (occurrence 11.1% each) to 4 –layered HA types, with 77.8% occurrence. A maximum of four subsurface geological layers identified include; the topsoil, the weathered layer, the partially weathered/fractured basement and the presumably fresh bedrock

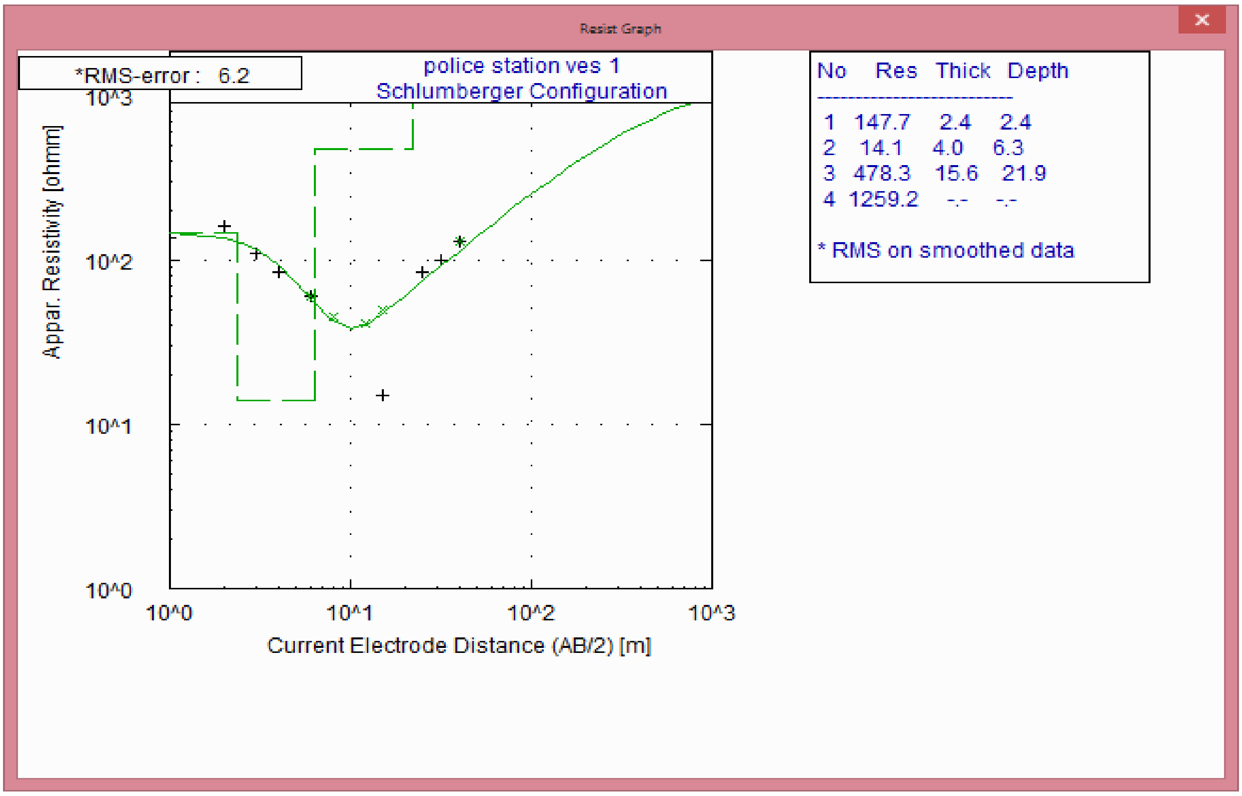


Figure 3. A typical depth sounding curve displaying 1D geoelectric section along a traverse.

Figure 4 shows the magnetic profile plot, 2D resistivity structure and 2D geoelectric section for traverse 1. High magnetic amplitudes were observed at 40 - 55 m and 65 - 100 m (Figure 4 a). High magnetic signatures correspond to high magnetized weathering resistant strata and relatively high resistive zones. These zones suggest shallow basement or competent earth strata and stable portions for civil engineering construction purposes. Low magnetic signatures are observed within distances 0 – 35 m and between 55 - 65 m spread. These magnetic lows correlate with blocks of weak subsoil or relatively low weathering resistant earth materials identified caused by subsurface discontinuities or vertical/near vertical geological structures / thin aquitard overlying the basement on the 2D structure model and as basement depression/pockets of clayey near surface weathered column on the corresponding 2D geoelectric section (Figure 4 b).

2D geoelectric section shows the presence of intermediate resistivity topsoil with resistivity (160 - 174 ohm-m) and (1.0 - 1.4 m) thick, very low resistivity weathered layer presumably clayey material and/or high moisture content (40 - 41 ohm-m and 1.8 - 2.5 m thick), followed by variable thicknesses of partially weathered/fractured and fresh basement/bedrock with resistivity between 478 – 7895 ohm-m (Figure 4 c). The detection of these weak zones/asement depressions/geological features and relatively thick column of clay substrate underlying the topsoil is the important results from this traverse. The failed portions of the road highway segment coincide with these weak zones as evident from the magnetic high amplitude zones and 2D structure and section.

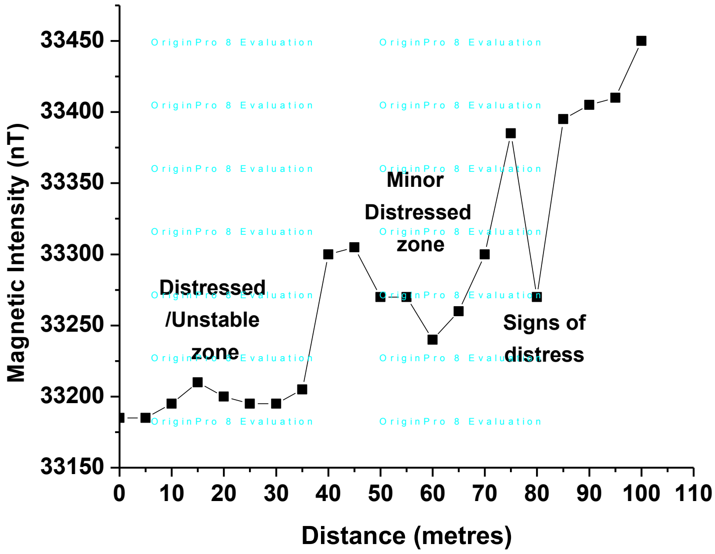
Figure 5 shows the magnetic profile plot, 2D resistivity structure and 2D geoelectric section for traverse II around Awelewa Guest House. High magnetic amplitude is generally observed on this traverse indicating high magnetized weathering resistant subsurface earth material within distances 0 - 80 m, with a sharp maximum peak observed at 45 m station position (Figure 5 a). Magnetic responses (>100 nT) characterized the plots in all the station positions. The continuously high spread in magnetic signature is an indication of near surface/homogeneous basement strata which is significant in this site. Distressed but stable portions as cracks and ripples are evident from the site observation. Evidence of subsurface discontinuity or weak zone on the 2D structure model and basement depression/pocket of clayey near surface weathered column on the corresponding 2D geoelectric section abounds (Figure 5 b). This finding is significant as the distressed portion is found in the axis. The 2D resistivity structure model shows the presence of low to intermediate resistivity cutting into the bedrock at two different zones marked F_1 – F_1 and F_2 – F_2 along the traverse. The zones are suggestive of clay substratum or linear geological structures that impact negatively on road engineering structures. Three main geologic layering - sandy topsoil (125 - 145 ohm-m and 0.8 - 5.3 m thick), the weathered layer (2.1 – 4.0 m thick and 20 - 239 ohm-m in resistivity) and partially weathered/fractured/fresh basement/bedrock with 212 – 2049 ohm-m in resistivity make up the subsurface units from the geoelectric section in the area (Figure 5 c).

Figure 6 shows the magnetic profile plot, 2D resistivity structure and 2D geoelectric section for traverse III around The Nigerian Police Station Ogbagi along Ikare - Ogbagi road section. The surveyed length is 80 m. Significantly high magnetic signatures were observed generally from this site, particularly at stations between 45 - 50 m (Figure 6 a). High magnetic signatures correspond to high magnetized weathering resistant strata, high resistive and most competent zones most suitable for geotechnical and civil engineering foundation works. These zones correlate with the stable portions of the road as shallow basement strata A sharp drop in magnetic intensity value at station 45 m constitutes a change in slope. The change in gradient is suggestive of a weak zone or vertical/near vertical discontinuity/interface representing a conduit or migrating path marked (F_1 - F_1) sandwiching between two highly resistive blocks on the corresponding 2D resistivity structure (Figure 6 b). On the other hand, low magnetic signatures were observed at the extreme of the traverse between stations 70 – 80 m and may have suggested pockets of weak zones of near surface clayey/sandy clay materials/weathered column on the corresponding 2D geoelectric section (Figure 6 c). The failed portions of the road highway segment coincide with these zones as evident from surface observation. The magnetic high amplitude zones coincide with stable portions.

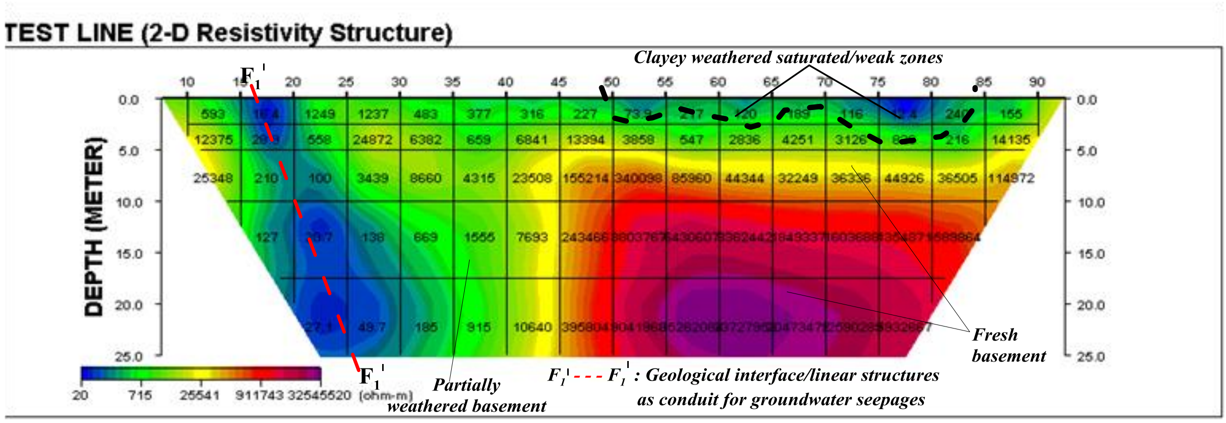
2D resistivity imaging and geoelectric section show the presence of intermediate resistivity sandy topsoil (133 - 164 ohm-m) and thickness (2.2 - 2.4 m), low resistivity second layer presumably clayey and sandy weathered materials and/or high moisture content (3.9 - 8.1 m thickness and 14 - 178 ohm-m in resistivity) and variable thicknesses of partially weathered/fractured/fresh bedrock (340 -4561 ohm-m), to make the subsurface.

V. Conclusion

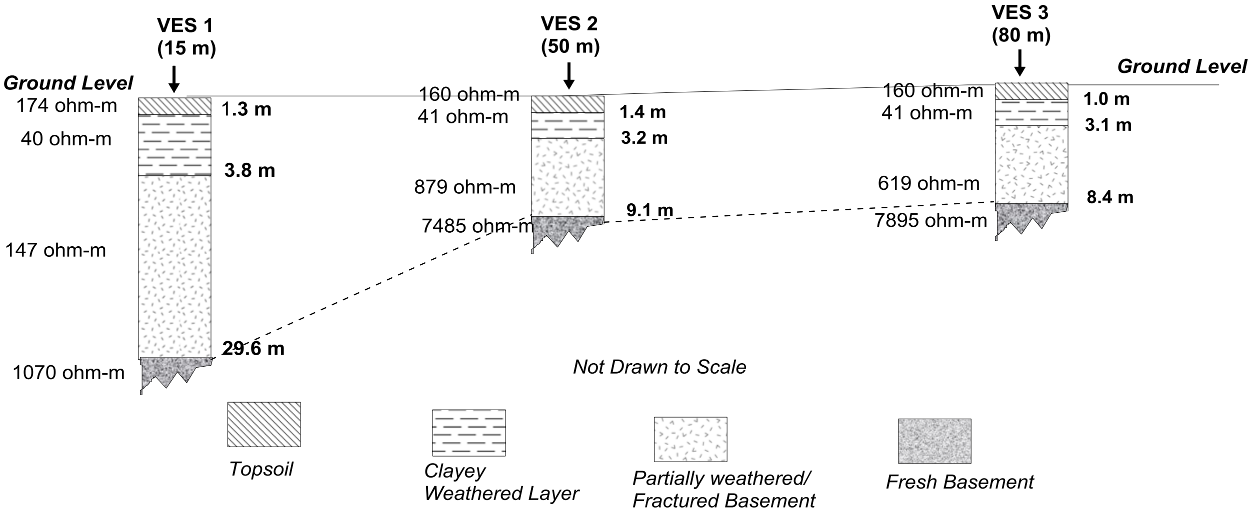
Correlation of the magnetic plots, 2D structures/resistivity imaging inverse models as well as the geoelectric sections in detecting the concealed weak zones and/ or expansive clayey soils, with low magnetic anomaly and low resistivity signature less than 100 ohm-m, has increased the confidence index for the causes of highway failures in this study. The weak zones identified in this case include, localized pockets of concealed cavity filled with expansive clayey materials at near the surface, lithological contacts/discontinuities, deep weathering and basement depressions, which are outside the purview of discrete data from other considerations. The first upper two layers with relatively low resistivity values characterize failed/distressed /uncompetent strata with poor bearing capacity. Thus, the weathered basement, which has shown relatively high resistivity responses, shows



(a) magnetic plot

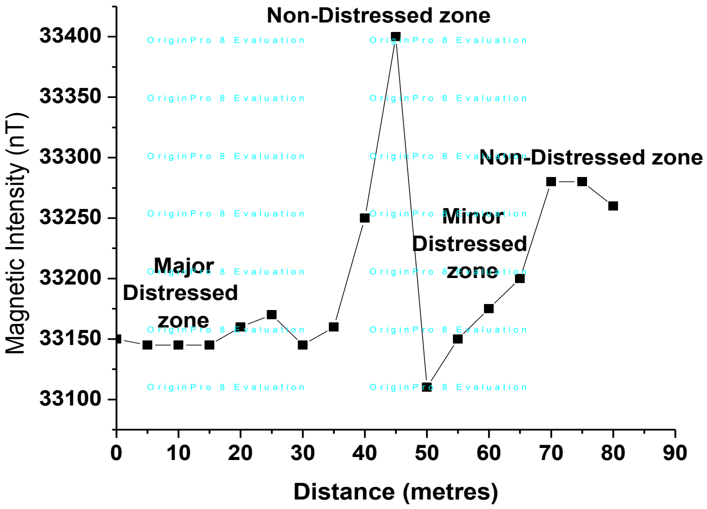


(b) 2D structure model

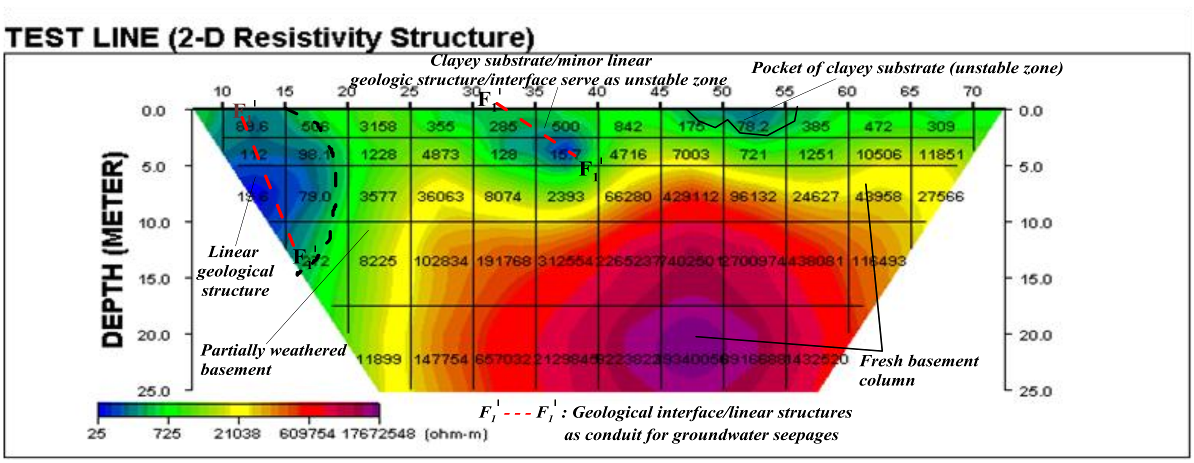


(c) geoelectric section

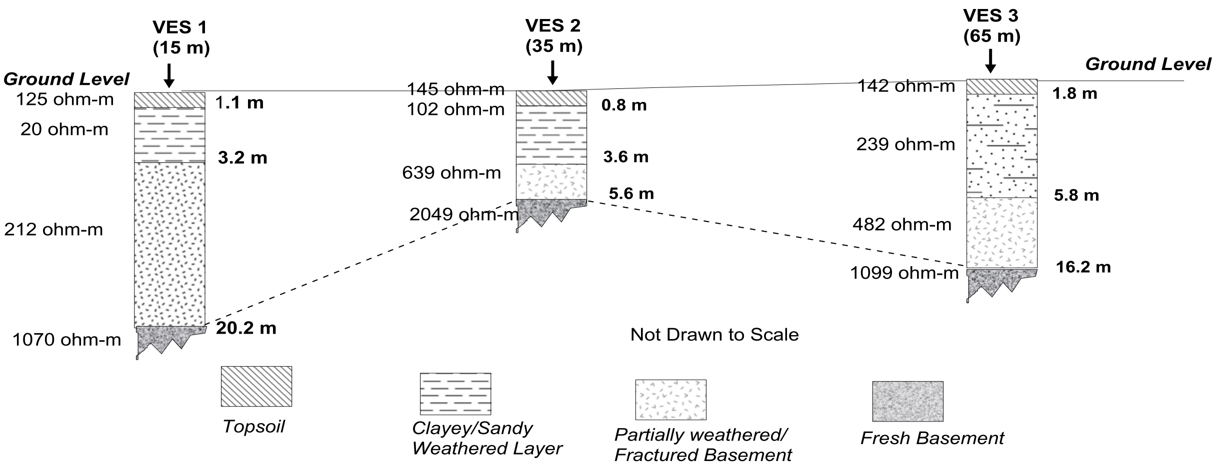
Figure 4. Composite geophysical results along traverse I



(a) magnetic plot

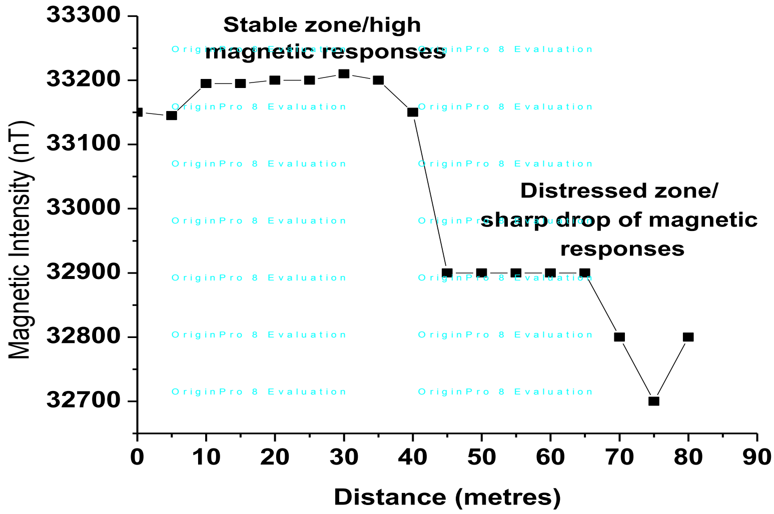


(b) 2D structure model

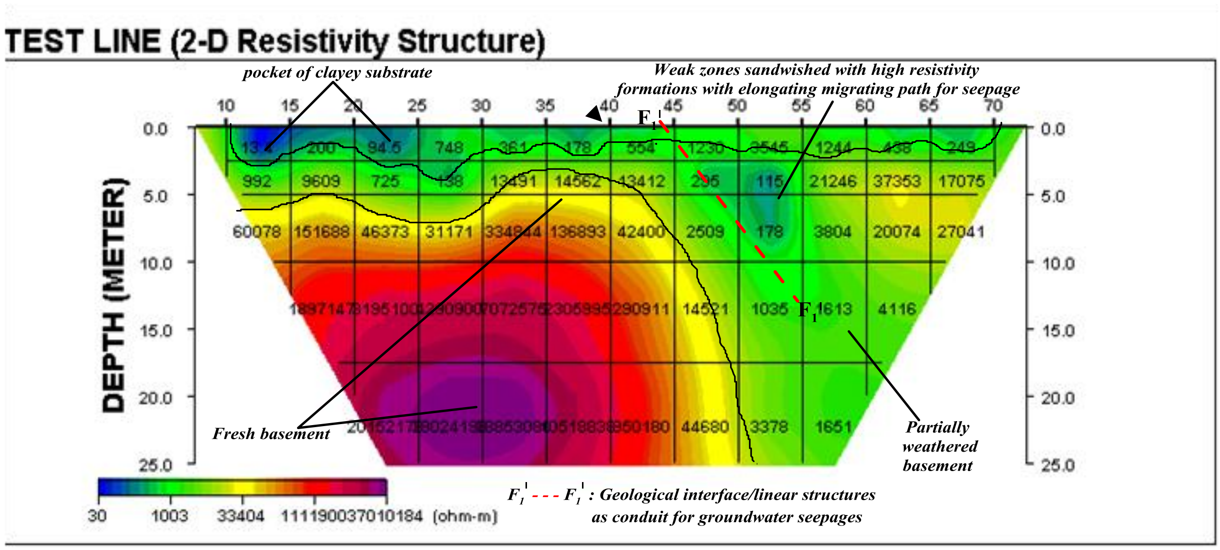


(c) geoelectric section

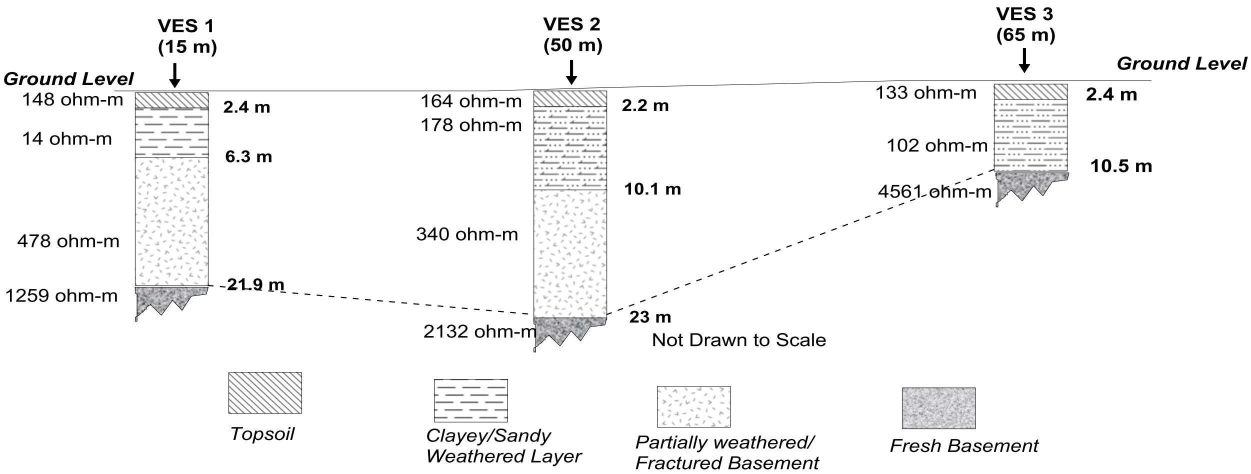
Figure 5. Composite geophysical results along traverse II



(a) magnetic plot



(b) 2D structure model



(c) geoelectric section

Figure 6. Composite geophysical results along traverse III

good bearing capacity The layers with higher resistivity response is the basal or fresh basement rocks with excellent bearing capacity but occurred at a greater depth except in few places. Static groundwater level in the area is found at greater depth of 10.5 m deep, therefore, has no significant effect on the low rise shallow foundation required along the highway. Other causes which may have provoked failure of the road highway segments in the study are drainage problem/ ponding and poor maintenance practices as the traverse II and III segments of road highway are generally founded on fairly stable pavement except for the traverse I that exhibits intense degree of failures arising from blocks of relatively low weathering resistant earth materials or vertical/near vertical low resistivity zones identified as subsurface discontinuities or weak zones in this study.

References

[1]. Gidigasu, M. D., Geological, Resistivity and Geotechnical properties of the superficial deposit found in Carrighton hill area, unpublished M.Sc, Thesis, and National University of Ireland, Erie, 1977

[2]. Madebors, A. O., Pavement design, guidelines and practice for different geological area in Nigeria, 1983, 290-297.

[3]. Adeyemi, G. O., Highway geotechnical properties of laterite residual soil in Ajebo-Ishara geological transition zone of southwestern Nigeria. Unpublished PhD Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria. 1992, 320-335.

[4]. Oladapo, M. I., Olorunfemi, M. O. and Ojo, J. S., Geophysical investigation of road failure in the basement complex area of southwestern Nigeria. Research Journal of Applied Sciences, 2008, 3(2): 103-112, ISSN 1815-932X

[5]. Ogunribido, T. H. T., Mohammed, M. Z., and Adesuyi, A. R., Effect of Engineering Properties on Pavement Failure in Ogbagi Area, Southwestern Nigeria. Journal of Environment and Earth Science, 2015, 5(4); 39-44,

[6]. Olorunfemi, M. O., Idonigie, A. I., Coker A. T. and Babadiya, G. E., Application of the electrical resistivity methods in foundation failure investigation. Global Journal of Geological Sciences, 2004 a , 2(1), 139-151.

[7]. Mohammed, M. Z. and Omoniyi, B. A.,Electrical Resistivity and VLF-Electromagnetic Surveys for the Assessment of Structural Failure in Oroke High School, Akungba Akoko, Ondo State, Southwestern Nigeria. Science Research Annals. 2008, 4(1), 9 -20

[8]. Momoh, L. O., Akintorinwa, O. J. and Olorunfemi, M. O., Geophysical investigation of highway failure - a case study from the basement complex terrain of southwestern Nigeria. J. Appl. Sci. Res., 2008, 4(6): 637-648.

[9]. Mohammed, M. Z., Geophysical Evaluation of Highway Foundation Failure in Part of Akungba-Akoko, Southwestern Nigeria, Journal of Emerging Trends in Engineering and Applied Sciences, 2018, 9(5), 246 - 252

[10]. Adegoke, Anthony, W. C. and Agada, O. A., Geotechnical characteristics of some residual soils and their implications on road design in Nigeria". Technical Lecture.Lagos, Nigeria. 1980, 1 – 16.

[11]. Meshida, E. A., Laterites on the highways – understanding soil behaviour. West African Technical Review. 1981, 112 – 118.

[12]. Ajayi, L. A., Thought on road failures in Nigeria. The Nigerian Engineer, 1987, 22 (1): 10 – 17.

[13]. Ayolabi, E. A., Folorunso, A. F., Jegede, O. E.. An Application of 2D Electrical Resistivity Tomography in GeotechnicalInvestigation of Foundation Defects: A Case Study. Journal of Geology and Mining Research, 2013, 3(12), pp. 142-151.

[14]. Rahaman, M. A. and Ocan, O., The Nature of the Granulite Facies Metamorphism in Ikare Area, Southwestern Nigeria. In Precambrian Geology of Nigeria, GSN, 1978, 152-162.

[15]. Tigistu, H. and Alemayehu, A., Electrical resistivity tomography and magnetic surveys: Application for building site characterization at Gubre, Wolkite University site, western Ethiopia, Ethiopia Journal of Science, 2014, (37)1, pp. 12 – 27.

[16]. Dobrin, M. B, and King, R. F., Introduction to Geophysical prospecting. McGraw-Hill book, New York, 1976, 1 - 630.

[17]. Telford, W. M., Geldart, L. P. and Sheriff, R. E., Applied Geophysics. Second edition, 1990, 522-539.

[18]. Reynolds, J. M., An Introduction to Applied and Environmental Geophysics. John Wiley and Sons, Ltd, UK, 1997, 1 - 800.

[19]. Kearey, P., Michael Brooks and Lan Hill, An Introduction to Geophysical Exploration.Third edition. Blackwell Science Ltd, UK, 2002, 183-197.

[20]. Griffiths, D. H. and Barker, R. D., Two-dimensional resistivity imaging and modeling in areas of complex geology. J. Appl. Geophys., 1993, 29: 211–226.

[21]. Olayinka, A. I. and Yaramanci U., Choice of the best model in 2-D geoelectrical imaging: case study from a waste dump site. Eur. J. Environ. Eng. Geophys. 1999, 3: 221-244.

[22]. Loke, M. H., Electrical Imaging Surveys for Environmental and Engineering Studies. (A Practical Guide to 2-D and 3-D Surveys), 2000. Copyright (1997, 1999).

[23]. Greenhouse, J. and P. Pehme, Applications of geophysics in geotechnical and environmental engineering, EEGS, 2001, Denver, Colo.

[24]. Bentley, L. R., and Mehran, G., Two and three-dimensional electrical resistivity imaging at a heterogeneous remediation site. Geophysics, 2004, 69 (3): 674–680.

[25]. Osinowo, O. O., Akanji, A. O., Akinmosin, A., Integrated geophysical and geotechnical investigation of the failed portion of a road in Basement Complex terrain, Southwest Nigeria.Materials and Geoenvironment, 2011, 58 (2), 143–162.

[26]. Balogun, O. Y., Senior secondary Atlas. Second Edition, Longman Nig. Plc, Lagos. 2000, 12-19.

[27]. Rahaman, M. A., Review of the Basement Geology of South-western Nigeria. In: Kogbe, C. A. (Ed.), Geology of Nigeria (2nd eds.). Rockview Nigeria Limited, Jos. 1989. 39–56.

[28]. Garmin, L., GPSMAP 76CSx Mapping GPS Owner's Manual. 2009. Part Nos 190-00558-00 Rev.E (May), 1 - 57

[29]. Loke, M. H. and Barker, R. D., Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophys. Prospect., 1996 b, 44: 131–152

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Muraina Zaid Mohammed. "Electrical resistivity imaging and magnetic surveys for evaluating highway failures along Ogbagi – Ikare, Southwestern Nigeria." *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 9(1), (2021): pp 21-31.