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Terrain Conductivity Evaluation of Road Base Integrity in a Basement Complex Environment

[1]M.I. Oladapo, [2]O.O. Adeoye, [1]K.A. Mogaji and [1]S. Adeoye
[1]Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria
[2]Department of Physics, Adeyemi College of Education, Ondo, Nigeria

Abstract: A shallow electromagnetic evaluation of Federal University of Technology, Akure, Nigeria main road base integrity has been undertaken in this study with the aim of identifying probable zones of untimely failure. Controlled-Source Electromagnetic Method (CSEM) was adopted for the study. The road segment investigated is underlain by four different lithologic units, which are the migmatite gneiss, quartzites, charnockite and granites along the west-east direction of the campus. Quadrature phase (conductivity) and in-phase (magnetic susceptibility) were measured in both vertical and horizontal dipoles. While the vertical dipole mode has a probing depth of 6 m, the horizontal dipole mode probes at a depth of 3 m. The range of quadrature and in-phase values obtained for horizontal dipole mode is from 6 to 50 mS m^{-1} and 0.808 to 20.47 ppt, respectively. For vertical dipole mode, the range of quadrature and in-phase values are -21.00 -71.00 mS m^{-1} and -20.07 to 20.47 ppt. The ratio of vertical conductivity value (C_V) to horizontal conductivity value (C_H) i.e., C_V/C_H was utilized in assessing road-base performance. Road stability was observed where this ratio is greater than 1 ($C_V/C_H>1$) while signs of distress characterized where the ratio is less than or equal to 1 ($C_V/C_H = 1$) in vertical dipole. Likewise, relatively high magnetic susceptibility values in vertical dipole mode characterized zones of early distress. This technique is presumed useful in fast and cheap roadwork performance evaluation.

Key words: Road-base, magnetic susceptibility, lithologic, conductivity and distress

INTRODUCTION

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.

Activities leading to road failure are more of subsurface phenomenon. Such subsurface phenomenon includes the existence of expansive clays, fractured or fault zones, near-surface basement rocks. These factors affect the overlying road network by the different ways they cause instability.

In this study, Controlled-Source Electromagnetic Method (CSEM) in form of terrain conductivity is applied as a fast and relatively cheap engineering geophysics tool to evaluate the integrity of roadway sub-base. The study is aimed at classifying the roadway into stable and failure-susceptible zones. The study is expected to form a new geophysical approach that can be rapidly implemented since data can be acquired as fast as the operator can walk. The method is also non-invasive and environmentally friendly.

Terrain conductivity surveys are routinely used in the United States of America and Canada to map and less routinely, to monitor groundwater contamination (Benson *et al*., 1983; Greenhouse and Slaine, 1983; Greenhouse and Monier-Williams, 1985). Monier-Williams *et al*. (1993) used Geonics EM-31 conductivity meter to map terrain conductivity around waste disposal sites in Sao Paulo, Brazil. Nobes and Mccahon (1999) employed Geonics EM-31 tool to acquire data over an area with the aim of delineating ancient pit that had been covered with earthly materials. CSEM methods are capable of detecting and mapping the distribution of fluids, large voids, faults or lithological contacts (Nobes, 1996; Tezkan, 1999; Everett and Meju, 2003; Benavides and Everett, 2005). The CSEM method can also classify man-made targets such as pipes, underground structures, unexploded ordinances (UXO) (Chesney *et al*., 1984; Qian and Boerner, 1995; Huang and Won, 2003).

As the method is utilized in this study for roadway subsurface evaluation (engineering geophysics), some new considerations are likely to arise.

MATERIALS AND METHODS

Study area description: The road investigated in this study is the flexible pavement roadway existing within the Federal University of Technology, Akure Campus (Fig. 1). The road serves as a link between the university mini campus in the south and the main campus in the north.

Corresponding Author: K.A. Mogaji, Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria

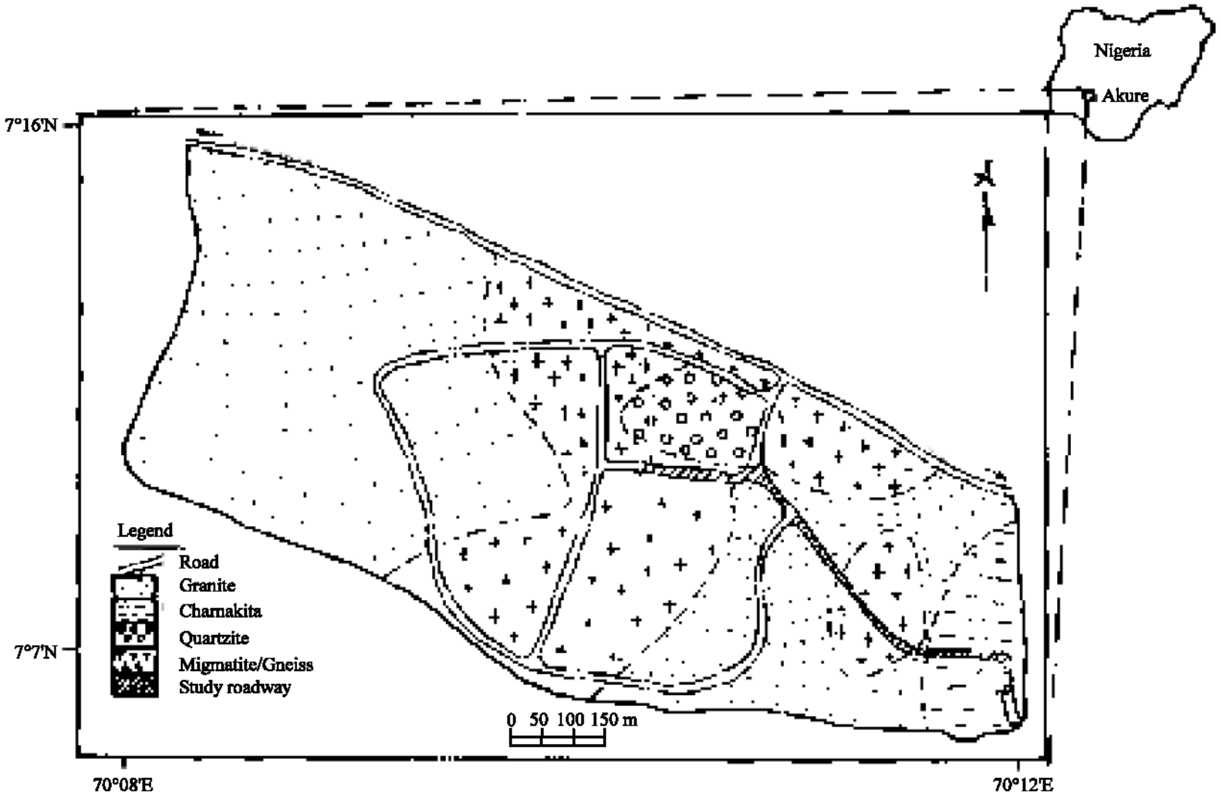

Fig. 1: Map of Federal University of Technology, Akure showing the geology and the study roadway

Major access to the university main campus from Akure metropolitan area is through the mini campus in the south, hence the road remains the most utilized of all roads on campus. At the time of study, the road has not undergone any major failure. However, some micro cracks have started to come into sight on some portions of the roadway.

The university campus is situated on the northwestern flank of Akure town on the southern flank of Ibadan-Akure-Benin Federal highway. The university which occupies an area of about 5 km^2 is situated within latitude 7° 16'N and 7° 18'N and longitude 5° 07'E and 5° 09'E.

Geomorphology and geology: The Federal University of Technology, Akure is situated on a gently undulating terrain with elevation between 350 m above mean sea level on the southeastern flank and 390 m at the north central area of the campus. The area lies in the tropical rain forest with mean annual rainfall of about 1300 mm. Annual mean temperature is between 18 and 33°C. The campus is well drained with the dendritic drainage pattern via three major streams that flow in the southern direction.

Rocks of the Precambrian basement complex of southwestern Nigeria (Rahaman, 1976) underlie the study area. The lithological units include granites, gneisses, quartzites and charnockite. Pavement outcrops of granites, gneiss and quartzites occur in several locations, mostly in the northwestern and central parts of the study area. The area is cut in various places by quartzo feldsparthic veins and bands which give them their foliation characteristics.

A single long NW-SE traverse of 2,180 m length was established parallel to the roadway on its northern edge. Buried and overhead utilities are situated on the southern edge of the roadway. In electromagnetic prospecting, such buried and overhead facilities create artificial electromagnetic disturbances thus constituting a source of noise in the acquired data. Measurement interval of 10 m was adopted for the field data gathering. The Geonics EM-31 conductivity meter was utilized for the study. The equipment boom orientation was kept parallel to the roadway throughout the data acquisition phase.

Field measurement of two properties of the subsurface was undertaken. These properties are the in-phase (magnetic susceptibility) and quadrature or out-of-phase (conductivity). When triggered, a transmitter coil located at the anterior end of the tool induces circular eddy current loops in the earth. The magnitude of any of these current loops is directly proportional to the terrain conductivity in the loop vicinity.

The quadrature or out of phase or imaginary component gives the ground conductivity and attains its maxima and minima amplitude a quarter of a period (45°) later than the primary field. The in-phase component also known as the real component attains its own maxima and minima in step with the primary field and is used primarily in the EM-31 for calibration purposes. It is however, significantly more sensitive to large metallic objects and hence very useful for mapping buried metal objects.

The EM-31 tool has the advantage of rapid implementation because it does not make contact with the ground before readings could be undertaken. One person can handle the survey by putting strap of the tool around the neck. Because the coil separation is 3.7 m, the maximum probing depth is 6 m at coaxial vertical dipole mode and 3 m at horizontal dipole mode. Thus, two data sets were acquired for each in-phase and quadrature at each station. The tool is incapable of investigating deep seated structures. Consequently, the tool could be described as an excellent match for road performance evaluation, which is a near-surface phenomenon.

RESULTS

The results of this study are presented as profiles (Fig. 2-4). In interpreting the electromagnetic data profile, the in-phase and the quadrature are needed for the assessment of the roadway performance. Naturally, the upper lithologic units are expected to contain less moisture than the underlying units as a result of compaction and gravitational pull of the water filling the pore spaces. The upper layers are well compacted such that porosity reduces and fluids contained in the pore spaces are forced out. Consequently, the conductivity of the deeper moist layer is expected to be higher than that of the topsoil. Anything or situation in the contrary constitute an anomaly (electromagnetic).

The range of values obtained in the field are as summarized below:

In-phase Horizontal	In-phase Vertical	Quadrature Vertical	Quadrature Horizontal
-0.08-20.47	-20.07-20.47	-21.00-71.00	6.00-50.00

The horizontal quadrature values (acquired through horizontal dipole mode) shows the conductivity of the first 3 m from the surface while the vertical quadrature values show the conductivity of the deeper moist layer up to 6 m, the maximum probing depth of the EM-31 tool used for data acquisition. Comparison of the two sets of quadrature values showed that the conductivity of the vertical dipole mode, C_V is greater than the conductivity of the horizontal dipole mode, C_H. In essence, the ratio C_V/C_H is greater than 1 ($C_V/C_H>1$). Another part of the profile

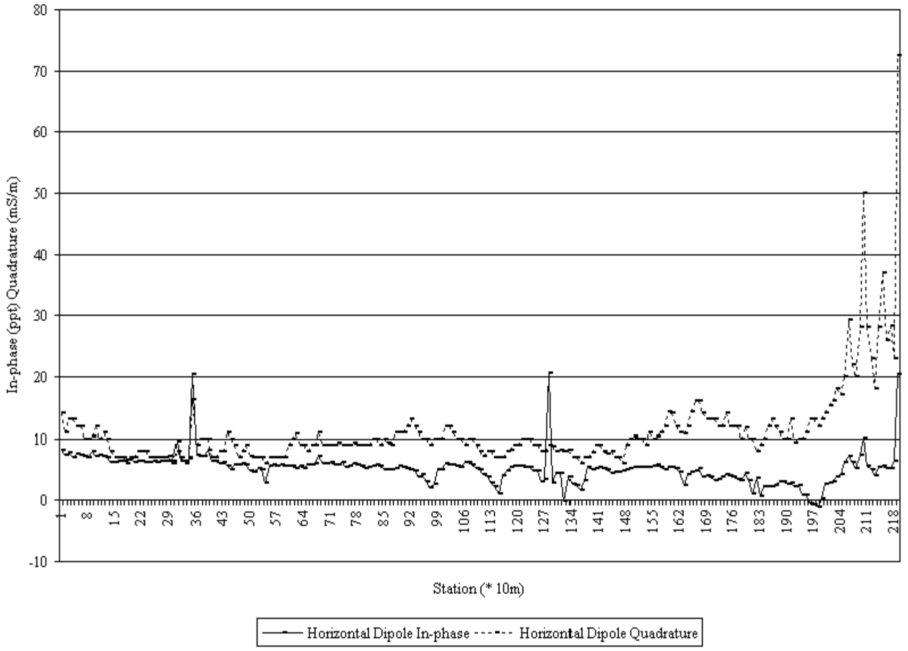

Fig. 2: Horizontal dipole terrain conductivity and magnetic susceptibility profile of Federal University of Technology, Akure roadway

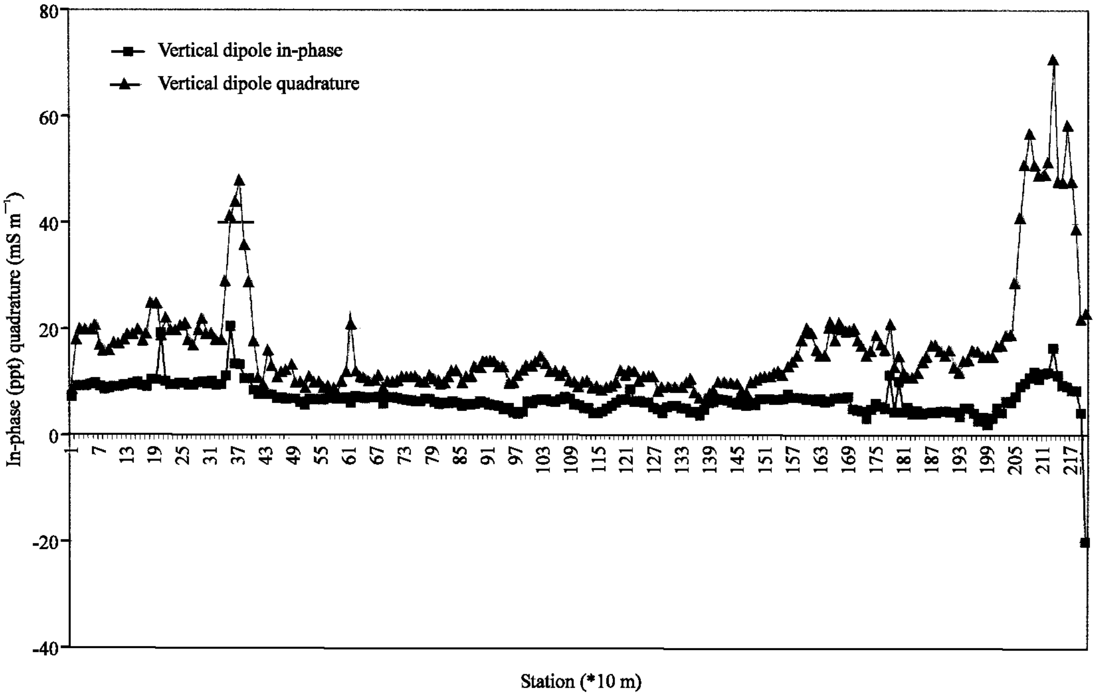

Fig. 3: Vertical dipole terrain conductivity and magnetic susceptibility profile of Federal University of Technology, Akure roadway

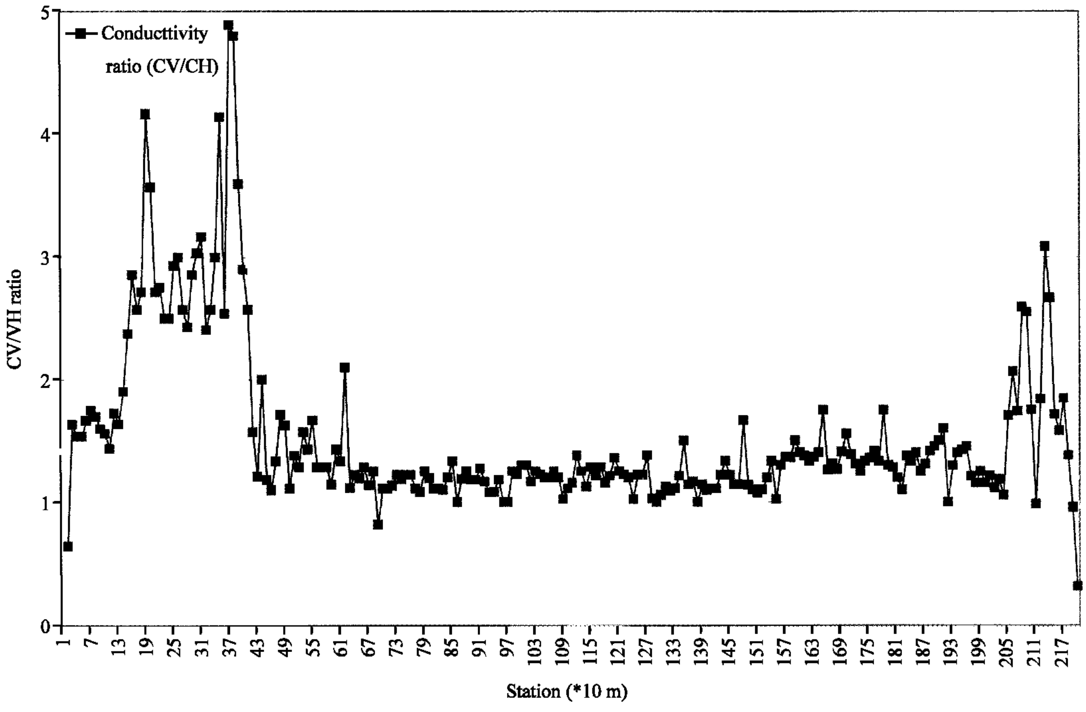

Fig. 4: Profile of conductivity ratio (C_V/C_H) along Federal University of Technology, Akure roadway

shows where the ratio C_v/C_H is less than or equal to 1 ($C_v/C_H \leq 1$). The electromagnetic profile had therefore assisted in dividing the whole section into two, based on the ratio of vertical horizontal conductivity values.

The first category where $C_V/C_H > 1$ spans stations 1-66 on the profile while stations 67-153 (Fig. 4) represent the area where the ratio C_V to C_H is either less or equal to 1 i.e., $C_V/C_H \leq 1$. Stations 32-39 and stations 202-217 (Fig. 4) also showed an interesting signature depicted by a large difference between the horizontal one is much greater than 1 ($C_V/C_H >> 1$). Furthermore, there are areas on the in-phase profile where the signature rises, (e.g., stations 1-39) and areas of low values (stations 181-193). The inference that could be made based on the in-phase profile corroborates that of the quadrature in some areas which revealing new things in others.

DISCUSSION

In areas where C_V/C_H is greater than 1, the road in such segment is relatively stable; bearing in mind that moisture content is expected to increase with depth. This is what we have between stations 1 and 66 (Fig. 4). The layers underlying the road under study here are well compacted and materials with low conductivity such as clayey sands could be found in this area. Seasonal fluctuations in the water table in response to variations in amount of available water recharge coupled with monthly precipitation can be expected to affect soil conductivity. This thus makes the depth to water table shallower during the wet season than during the dry season when evapotranspiration is high. The three basic layers overlying the crystalline basement complex rocks in tropical and sub-tropical region comprises the topsoil, the conductive regolith and the highly resistive bedrock. Within this region is the rather interesting signatures of stations 32-39 where the ratio C_V/C_H is much greater than 1 (the largest throughout the entire profile). This could be the source of the stream flowing into the University dam. This further attests to the fact that the lithologic composition of this area cannot be clay (which is porous but not permeable). For the mere fact that the rock underlying the road here allows the flow of water to the University dam (high permeability) indicates that the underlying rock cannot be clayey but a lithologic contact. The geology of the study area reveals that this first lithologic contact is between quartzite and charnockite. The charnockite, underlain by lateritic material makes this area relatively stable. One other reason that could be attributed to the high conductivity values, particularly between stations 32-39 (Fig. 4) is the fluid streaming potential generated by the flowing spring to the University dam, causing the large difference in vertical conductivity value relative to the horizontal conductivity (Fig. 2 and 3). Granite, which are acidic rocks, are depicted on the quadrature profile as high conductivity and also as high values for magnetic susceptibility (in-phase).

From stations 67-153 (Fig. 4), the ratio C_V/C_H either equal to or less than 1. The first 3 m therefore become either more conductive than or as conductive as the (underlying) subsequent three meters of rocks. This zone being a charnockite and granite zones could be assumed to have a presence of clayey materials near the surface. However, the in-phase profile shows a rise, indicating the presence of near-surface basement. This near-surface rock is granite. This is because outcrops of granite were observed close to roadway in this segment. It consists of saprolite materials that have a high water retention capacity. Within this region, the basement is close to the surface as shown on the profiles in Fig. 2 and 3 by the high magnetic susceptibility and low quadrature value. The near-surface saprolitic material and the underlying basement could have negative impact on the road performance. The former, retaining a lot of water within its interstitial spaces is detrimental to the road overlying within the subsurface. All these might be responsible for the visible cracks and depressions observed on the asphalt overlay. Admittedly, the roots of the trees lining both sides of the road could also cause some of the cracks.

These roots are incapable of causing the numerous depressions and potholes lining this section of the road. The last station 153 (Fig. 4) within this segment is a lithologic contact between charnockite and granite.

Stations 202-217 (Fig. 4) also showed an interesting signature on the electromagnetic profile. The signature is similar to that obtained between stations 32-39 (Fig. 4), which has earlier been described as the likely source of the water flowing into the University dam.

Signatures for stations 32-39 and stations 202-217 (Fig. 4) have a wide separation of the vertical and horizontal profiles. This profile (station 202-217) was acquired over a confirmed underground water reservoir used in servicing the offices in the southern part of the campus, close to the Industrial Design Studio.

CONCLUSIONS

This study is the first of its kind in the application of electromagnetic methods in the assessment of roadway integrity. Most of the deductions made were from observations recorded in this work. Generally, those areas where the ratio of vertical conductivity to horizontal (C_V/C_H) is greater than 1 are mostly the charnockite zones and are the stable portions of the road where road failure is unlikely, for now.

The other sections considered vulnerable to failure have $C_V/C_H \leq 1$. This region, which shows a drop in conductivity value indicates the presence of freshly, weathered saprolitic materials that have high water retention capacity and overlie the granitic materials in the region. The rise in in-phase profile within this region indicates the nearness of the basement to the surface as recorded in the vertical dipole. In this region, the zone of distress has manifested as cracks and depressions.

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