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Geophysical investigation of Oke-Agbe-Oyin Road failure using VLF and double dipole

***K. O. Ozegin**, **S. O. Azi** and **D. O. Isiwele**
Department of Physics, Ambrose Alli University, Ekpoma, Nigeria.
***e-mail: ozeginkess@yahoo.com; 08034953007**

Abstract

The result of this paper is to establish a consistent approach to geophysical handling of road failure using electrical Resistivity method-Double Dipole and Electromagnetic method- VLF (Very Low Frequency). The work was done along Oke-Agbe Road in Ondo State. Computer iterated data from the study area enabled the delineation of the investigated portion of the road into highly weathered and non weathered zones with Resistivity values ranging from* 37 – 595 *Ωm. The form of road failure identified in this study is due to subsidence arising from differential settlements associated with clayey, fairly thick, geotechnical weak and low resistivity near surface horizon. The results obtained clearly demonstrates the relevance this kind of study in highway feasibility studies and roadway evaluation.

1.0 Introduction

Geophysical method of prospecting and delineation of anomalous zones in the subsurface extends its wide application to buried materials (both of economic values and non alike), inhomogeneity of subsurface, bedrock properties / behaviour and even lateral changes with time in the subsurface.

Electrical Resistivity and electromagnetic methods have gradually and systematically made their way to the top in the successful search and exploitation of the subsurface. The use of these methods plays a prominent role in the study of earth crust. These methods are commonly used in getting detailed information about geologic setting (mapping) and foundation study. Some of these include subsurface lithology, subsurface mapping, lithological boundary differentiation and geothermal exploration.

The incessant failures and near-zero efficiency rehabilitation work on the roads has become a thing of common concern. While the failures have become a common phenomenon as they are permanently on the increase, the problem seems to be more precarious on cut sections of roadways within the Precambrian basement complex areas of the country. Generally, in Resistivity surveying technique, current is passed into the ground by means of two current electrodes and the potential drop across a second pair of potential electrodes is measured. Hence the double dipole array involves the passing of current into the subsurface through the current electrodes and the potential difference is measured through the potential electrodes where both pairs of electrodes are maintained at a common distance “a”. The separation of both pairs of electrodes is usually kept at (n+1)a. Where n is a multiple of a.

Electromagnetic survey is one of the widely accepted methods of geophysical exploration [1]. It utilizes the principle of the subsurface response to the propagation of alternating current and magnetic force. Off all the types of Electromagnetic procedures, the VLF has a unique acceptance by the exploration industries because of its accuracy, low power consumption, processing and presentation of data and eventually its ease of use. Thus, VLF measures the field strength and phase displacement around conductive geologic structures such as faults and fractures.

Several factors are responsible for road failures. These include geological, road geomorphological/geotechnical, road usage, poor or bad construction practices and maintenance. Field observations and laboratory experiments carried out by [2] showed that road failures are not primarily due to usage or design/construction. The influence of Geology and geomorphology in the design and construction phases may not have been adequately considered. Or the problems could also be as a result of inadequate knowledge of the characteristics and behaviour of residual soils with which our roads are built. The geological factors in road failures are in-situ and encompass the nature of soils (laterites) and the near surface geologic sequence, existence of geological structures such as cavities, ancient stream channels and shear zones. The collapse of concealed subsurface geological structures and other zones of weaknesses are controlled by regional fractures and joint systems along which silica leaching has led to rock deficiency. They are also known to contribute to failures of highways and rail tracks. The geomorphological factors are related to topography and surface/subsurface drainage systems. The subsurface geologic sequence and concealed geological structures can be mapped by geophysical method(s) [3,4] hence geophysics is quite relevant in highway site investigations.

In recognition of the devastating effects of road failure in recent years, this paper is designed with the following objectives in mind: to identify zones of weakness, determine the subsurface condition of the bedrock and mapping of the bedrock subsurface structural features such as faults, fractures, joints, and lithological boundaries with the subsequent geological stress implications. The double dipole and VLF were used for the geophysical survey on the failed section of the Oke-Agbe – Oyin road in Akoko North LGA of Ondo State.

2.0 Theoretical analysis

The Double Dipole theory is well known [5]. The method is based on Ohms law, which is expressed as;

$$J = \sigma E \qquad (2.1)$$

But the apparent resistivity of Double Dipole array is given as: $\rho a = \pi n(n+1)(n+1)\frac{Va}{I}$ (2.2)

for values of n «1. However, when the dipoles are widely separated, n »1, we have

$$\rho a = 2\pi n^3 \frac{L\Delta V}{I} \qquad (2.3)$$

This is the approximation usually applied to resistivity surveys and also applicable here.

The VLF, on the other hand, is designed for long distance transmission. From the Biot-Savart law, we have that the involved linear distance is always less than the wavelength provided that we have a low frequency source. [2]. Here, the electric dipole is likened to the magnetic dipole once we interchange the E and H components of the wave. This is the vertical component which represents the real part of the VLF probe. The five vectors needed to determine the electric and magnetic fields within a given zone are B, H, E, D and J. while the first four describe the electromagnetic field, J describes the motion of a free charge; where

B = the magnetic induction in Weber's per square meter,
H = the magnetic field intensity in Amperes turns per meter,
E = the electric filed intensity in volts,
D = the electric displacement in Coulombs per square meter ,
J = the electric current density in Amperes per square meter.

From Maxwell's equation, these five vectors are related in parts by [6],

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (2.4)$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad (2.5)$$

In conducting zones, the field obeys the equation; $\nabla^2 \frac{E}{H} = 0$ (2.6)

While in zones having an appreciable conductivity satisfies the equation; $\nabla^2 \frac{E}{H} = i\sigma\mu\omega$ (2.7)

where μ = magnetic permeability, and σ = conductivity

` Now, in zones where failure occurs, E and H must satisfy certain boundary conditions at the interfaces. ie. the field vectors and their derivatives must be continuous within the various zones, but where discontinuity occurs in δ or μ, discontinuities in E and H will also exist.

Equation (2.6) is obeyed by static electric or magnetic fields and equation (2.7) may be written as

$$\nabla^2 \begin{matrix} E \\ H \end{matrix} = \sigma\mu \frac{\partial}{\partial t} \begin{matrix} E \\ H \end{matrix} \qquad (2.8)$$

which is the vector diffusion equation. It must be noted that in cases where there exits a current density J due to sources independent of the electromagnetic field, we have;

$$\nabla \times H = \sigma E + \varepsilon \frac{\partial E}{\partial t} \qquad (2.9)$$

3.0 Methodology

The experimental work was carried out at Oke-Agbe - Oyin Road which is located in Akoko North-West Local Government Area of Ondo State in the Southwestern basement complex of Nigeria. It lies within longitude 5^0 45^1 and 5^0 50^1 and latitude 7^0 35^1 and 7^0 40^1. The altitude of Oke-Agbe is about 200ft above the sea level. Oke-Agbe lies within the tropical climate. The annual rainfall is about 1500mm. Rock exposure are very common within the study area as many outcrops are seen beside the road.

The double dipole array and the VLF profiling were used to investigate the failed portion of the said road. It must be noted however that, while the VLF involves transversing profiles of given intervals with the receiver and antenna held at right angles to each other for readings to be taken, the double dipole involves the continuous increase of the distance between both pairs of electrodes. The ABEM WADI and RESISTIVITY METER (STRATAMETER) were used for the VLF and Double Dipole investigation respectively.

4.0 Results and discussions

4.1 VLF Section

The ABEM WADI high amplitude are observed at distances 120,140,160,180 and 210m and low amplitudes are observed at distances 130,.150m, 170m and 190m. (Figure 1). The high amplitudes is the conductive zone, and it indicate areas of basement depression, while the low amplitudes is the non-conductive zones which indicates the near surface basement.

Minor depression is observed between station 140 -150m, while the major depression is between 180 and 210m. This is the point of total failure

4.2 Dipole-Dipole section

The various stages of decomposition of the subsurface rocks are displayed in the variable resistivity distribution (37-595Ωm) of the Pseudo-section (Figure 2). Intensely weathered rocks are manifested as very low resistivity values, which characterize the northern flank of the stable road section and increases with depth, with nearly uniform and parallel contours. High resistivity values are manifestations of near surface partially weathered or fresh rock. The bedrock surface is uneven in the failed portion or segment of the road. The uneven bedrock interface may have aided settlement of the subgrade within the zones with relatively thick weathered layer and a consequently failure of the roadway.

5.0 Conclusion

The results of the computer interated Double Dipole data interpretation and the VLF profiling enabled the delineation of the investigated road into two lateral zones. The weathered and non weathered zones. Hence, fractured zones are usually indicated by significant cross over points, which of course were absent in the iterpretations from the study area. However, there were numerous crossover and rapid amplitude variations which represents the weathered zone. Intensely weathered rocks are manifested as very low resistivity values, which characterize the northern flank of the stable road section and increases with depth, with nearly uniform and parallel contours. In addition, the investigated failure was generally characterized by non-uniform apparent resistivity values for the weathered zones and uniform apparent resistivity values which increased with depth at the stable zones. Finally, the form of road failure identified from the study was due to subsidence resulting from differential settlement associated with thick clay horizons as observed on the road section.

Figure 1: Very Low Frequency (VLF) Profile of Oke-Agbe–Oyin Road. (*a* = 10*m*).

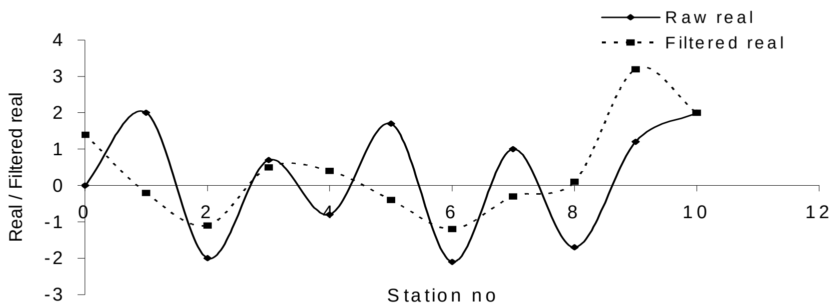
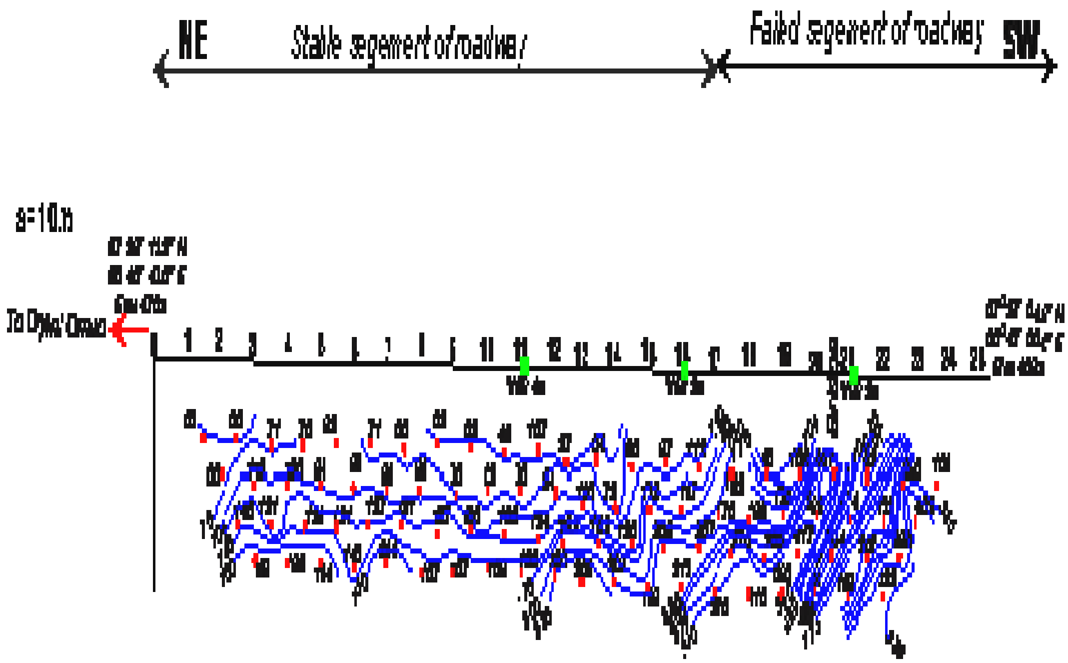


Figure 2: Pseudo section from Double – Dipole



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