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INTEGRATED GEOPHYSICAL INVESTIGATION OF THE FAILED PORTION OF MINNA-ZUNGERU ROAD, MINNA NIGER STATE

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ABSTRACT

Very Low Frequency Electromagnetic (VLF EM) and Vertical Electrical Sounding (VES) geophysical methods were used to investigate the competency of kilometer 37 Minna – Zungeru road, Latitude $9^0$38'37" N to Latitude $9^0$39'06" N, Longitude $6^0$16'09" E to Longitude $6^0$15'20" E and altitude 682 feet to 597 feet. The study is aimed at investigating the causes of road failure other than the constructional factors that were generally believed. Two VLF – EM traverses which are 1.22 km long were established by the sides of the road segment, which cut across the unstable, fairly stable and stable portions. In these traverses, readings were taken at 20 m interval with SCINTEX ENVI VLF. The data were further filtered, analyzed and plotted with Karous Hject filtering. The inphase and quadrature were plotted against the distance which reveals the conductive zones (positive peak of the raw real). 16 VES were acquired with ABEM SAS 1000 tarrameter along the two traverses. These VES were sounded at the positive peak of the raw real VLF plot using Schlumberger array electrode spacing of 100 m. Geological sections were produced from the iterated VES curves produced with Winresist. The geoelectric sections revealed three geological layers which are the top soil, weathered layer and the fresh basement. The resistivity and depth of these layers ranges from 14 to 98, 81 to 990 and 1184 to 12, 940 Ωm 0.5 to 3.2, 1.6 to 39.4 and 3.5 m to ∞ respectively. The geological factors responsible for the road failure susceptibility are based on clayey subgrade beneath the road pavement, water fluctuation in the saturated zone and lateral inhomogeneity.

Keywords: *Vertical Electrical Sounding (VES), Very Low Frequency (VLF)*

1 INTRODUCTION

The usage of road has arrested the attention of all stakeholders in the maintenance of Nigeria highways. The problem is apparently more precarious on cut sections of roadways within the Precambrian basement complex terrain of the country (Oladapo *et al.*, 2008).

It has not only caused a setback to Nigerian economy but it has also led to loss of lives and properties in millions of Naira annually.

Since there is a very strong positive correlation between a country's economic development and the quality of its road network, a country's road network should be constructed in an efficient way in order to maximize economic and social benefits (Ighodaro, 2009).

However, in an attempt to unravel causes of persistent failure of roads across the country, various researchers have identified chiefly the underlying geological conditions among the other factors to be responsible for this mishap (Momoh *et al.,* 2008; Oladapo *et al.,* 2008; Adiat *et al.,* 2009). It therefore becomes imperative to investigate the subsurface geology upon which a road structure is to be founded rather than having recourse to a post-construction investigation and remedies.

1.1 Causes of Road Failure

There are several factors responsible for the failure of roads. These include geological, geotechnical, road usage and constructional practices and maintenance (Ajayi, 1987).

1.1.1 The geological Factors Influencing Road Failure Include; Geological structures (near surface linear features), lateral or lithological heterogeneity in competency of sub-surface, thinning out of faces, presence of cavities and existence of ancient stream channels and shear zones

Other factors are: poor soil compaction; can be difficult to obtain if roads are constructed on poor soil (flooded areas and soil with high clay content). **High water table and poor base;** An area subjects to fluctuation of ground water table, ground water always settle there. The high water table may be responsible for the settlement. If the base for the pavement section is improperly installed, then the pavement section will lack the required strength. Also, if a base fails, water can penetrate the pavement section and get into the sub-grade, causing the sub-grade to fail. **Poor compaction;** If the backfill on the utility trenches is not properly compacted, then the trench can be expected to settle. If the sub-grade of the road is not properly compacted, then settlement can be expected along the road. Extensive compaction test have to be conducted through the life of any road project. **Poor Construction;** The Professional construction Engineer of a road is responsible for the determination of appropriate pavement section. In some cases, failure of the soil cement base is the main reason for the road failure. Ties have simplified this process by developing standard pavement sections to be used in their localities. **Construction in Wet Season;** When the soil conditions are extremely wet, proper compaction is very difficult to obtain therefore, de-watering is extremely important during trench excavation. **Poor Construction Methods;** Poor construction methods manifest when the contractor installing the utilities and preparing the road for paring is not experienced. Shortcuts and failure by some contractors to proper bed lying and backfill utilities are also another poor construction method. Adequate inspection during cement base preparation is of a paramount need.

1.2 Location and Description of the Study Area

The study area is located at Tudun Wada village of Bosso Local Government area of Niger State, North Central of Nigeria.

The road portion under investigation lies on Latitude 9038'37" N to Latitude 9039'06" N and Longitude 6016'09" E to Longitude 6015'20" E and altitude 682 ft to 597 ft. This portion of the road under investigation is about 1.22 km long. The road portion starts from 37 km to 35.78 km from Minna and 23 km to 24.22 km from Zungeru which falls between Beji and Tudun Wada (figure 1).

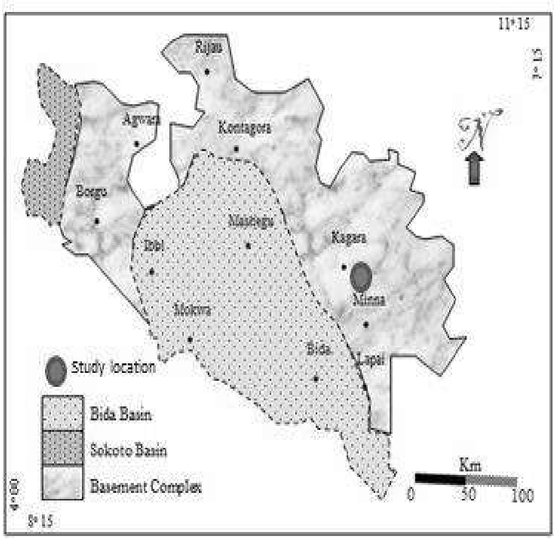

Figure 1: Geological map of Niger State showing the study area.

2 METHODOLOGY

2.1 Instrumentation and Field Procedure.

The equipment used for measurement are ABEM SAS 1000 Digital Resistivity Meter, Garmin etrex10 GPS, Compass clinometer, Measuring tapes, Electrodes, cutlasses, harmer and Scrintrex Envi.

The methodology employed in the study involves very low frequency electromagnetic (VLF–EM) and the electrical resistivity methods. The electrical resistivity method utilizes schlumberger vertical electrical sounding (VES) which entails vertical probing of the sub-surface. The array utilizes electrode spacing for variable depth mapping which will be carried out at both stable and failed segments of the roadway.

These methods were employed to determine sections of the road with anomalous and also with the view of detailing the subsurface geoelectric sequences, mapping subsurface structural features, lithology, water saturation and delineating bed rock relief as a means of establishing the possible causes of the road failure.

The traverses covered both failed and stable segments of the roadway established parallel to the road pavement and extend above 1200 m in length (figure 2).

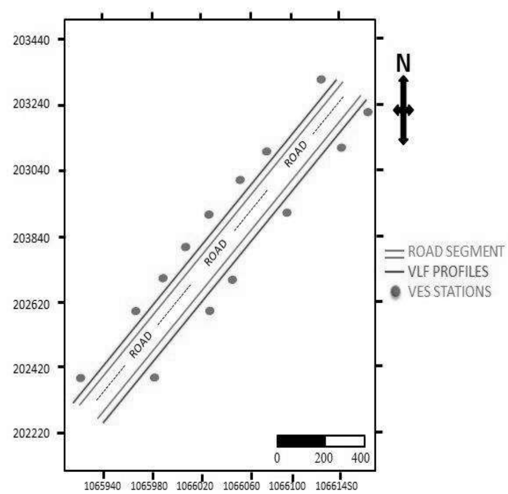

Figure 2: Data Acquisition map of the study area

2.2 Geophysical Methods

2.2.1 Electrical Resistivity Methods

In the electrical resistivity methods electric currents are generated artificially and are induced into the ground. The resulting potential differences are measured at the surface. In artificial field method of electrical prospecting, the voltage measured between the potential electrodes is the sum of the contribution of the entire earth material from various depths. The wider the spaces between the electrodes, the deeper the depth of investigation. The factors influencing the resistivity of the earth (Archie, 1942) are:

i. Porosity

$$\rho r = a\O^{-m}.S^{-n}\rho_w \quad (1)$$

$$F = \frac{\rho_r}{\rho_w} - \frac{a}{\O^m} \quad (2)$$

where:
ρr, is the formation resistivity (Ωm)
Ø, is the porosity
S, is degree of fluid saturation
ρw, is the saturating fluid resistivity (a measure of saturating fluid concentration) (Ωm), and a, m, and n are constants peculiar to the rock type.

ii. Degree of fluid saturation;
iii. Nature of pore fluid;
iv. Nature and size of grains making up the matrix;
v. Degree of weathering and fracturing; and
vi. Degree of compaction and consolidation

2.2.2 VLF-EM Method

The VLF method has an excellent and simple tool for reconnaissance mapping of conductive mineralized bodies, water bearing fracture and delineation of saline water intrusion to fresh water zone. It is used in this study to delineation possible conductive zones (low resistivity zones).

2.2.2.1 Factors Affecting the VLF-EM Survey

The factors affecting the VLF-EM survey are:

i. The orientation of high tension power lines: Parallel electric power lines are capable of distorting the VLF-EM signals but perpendicularly oriented overhead or underground power lines are suitable.

ii Time: Radio waves utilized by VLF-EM equipment are very effective in the early hours of the day but the signals tend to be distorted as the evening approaches.

iii Equipment: The equipment must be held steady and horizontal while measurement is in progress.

iv Depth of penetration: It can only be used to detect near surface conductors.

v VLF-EM method: The method is totally dependent on an appropriate transmitter operation (Telford *et al.,* 1990).

2.3 Presentation and Interpretation of VLF-EM Data

The raw real and the real imaginary components of the VLF-EM data were filtered and processed with Karous Hjelt software. The processed data were presented as VLF-EM anomaly curves obtained by plotting the inphase (raw real) responses against the station positions.

The prominent VLF-EM anomalies were deeply considered as typical of the top linear features. Example is Basement fractures (Palacky *et al.,* 1981).

From the VLF-EM anomaly curves only the real components of the VLF-EM data were processed for quantitative interpretation despite the fact that both the real and the quadrature components of VLF-EM data were recorded. This is because signals from the inphase components (real components) are usually more diagnostic of linear features than the quadrature component (Amadi and Nurudeen, 1990).

The raw real (inphase) curves were used for the interpretation because they transform every genuine inflexion points of the real anomaly to positive peaks while reverse inflexions become negative peaks (Olorunfemi *et al.,* 2005).

The VLF-EM data was also inverted to produce a 2-D model section of the subsurface. This 2-D section reveals the nature of the conductive portions, the depth and the nature of the conductive zones using Karous and Hjelt, software.

2.4 Presentation and Interpretation of VES Data

The VES data were presented as depth sounding curves obtained by plotting the apparent resistivity (ρa) against the current electrode spacing (AB/2). The WINRESIST software was used to generate computer iterated result from the interpretative results of partial matching technique. The interpretation results were finally used to construct 2-D geoelectric sections which shows the thickness of the layers and the apparent depth of the over burden. The depth and the thickness of the Basement Complex were considered as infinity.

3.0 RESULT AND DISCUSSION

The profiles are quantitatively interpreted to provide locations of conductive zones and zones of anomaly (the inflation points between the inphase and quadrature) which could be of further interest in investigation (figure 3b) (Nabighian, 1982; Adiat et al, 2009; Reynolds, 1997).

Profile 1

There are points of positive high peaks in the VLF plot (figure 3). These positive peaks of the raw real are points of high conductivity which are indicative of the weak zones, fractures or cavities which serve as conduits for the passage of underground water and thus quicken the failure of the road. The plot indicates the conductive areas at 180, 450, 760, 1050, and 1210 m (figure 3a and 3b).

These portions of linear conductive bodies are also observed in the Karous-Hjelt filter plot of 2-D inversion geosection (figure 4) which shows pockets of conductive bodies. They are delineated in this plot by the red and fairly red colour (180, 450, 760, 1050, and 1210 m). The large conductive body at 620 to 780 m is inferred to be either a large portion of clay material or a cavity.

Vertical Electrical Sounding (VES) were taken at the points of positive peaks of conductive zones to delineate the nature of the conductive materials imbedded in it. Seven VES points were established on this traverse at 0, 180, 450, 600, 750, 1050 and 1120 m which are the points of the positive peaks in the raw real VLF plot (figure 3a).

The data generated were used to produce geoelectric sections that delineate 3 zones of variations in resistivity and thickness values which are top layer, weathered layer and fresh basement of various thicknesses.

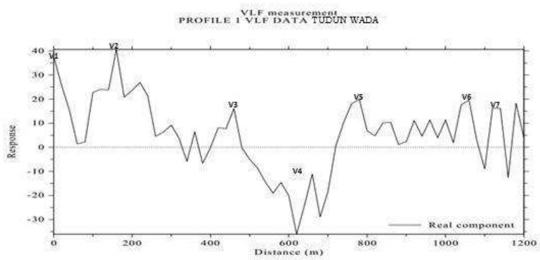

Figure 3a: VLF raw real plot

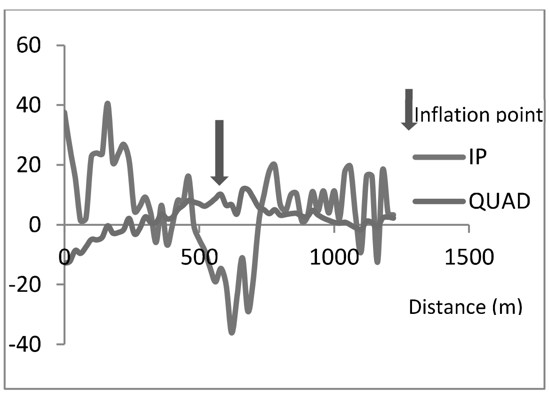

Figure 3b: VLF raw real and filter real excel plot

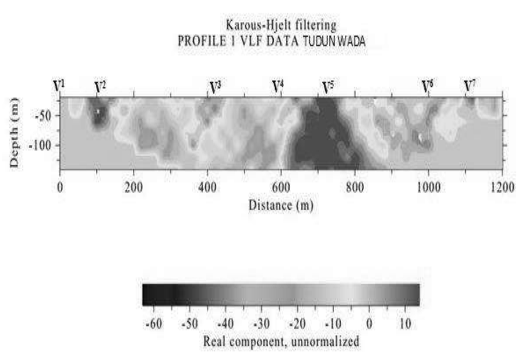

Figure 4: 2-D Karous Hjelt plot

* V1V[1] – V7V[7] are points of correlation.

The top soil has a range of 18 to 62.6 Ωm except VES stations 3 which has resistivity of 98.4 Ωm and a thickness of 1.3 m. These ranges of resistivity depict clay and sandy clay with an average thickness of 1.3 m. The variation in the estimated overburden thickness and resistivity ranges from 0.7 to 43.9 m and 7.59 to 991 Ωm respectively. There is an indication that weathered basement was encountered in all the VES locations at a very shallow depth (figure 5). The fresh basement was encountered in all the VES points except VES station 6 and 7 where fresh basement is not delineated. The resistivity of this basement range from 1114.5 Ωm to 6,977.1 Ωm. The clay content of the overburden and the weathered layer constitute the major cause of the road failure as investigated.

Table 1 : Summary of VES data traverse 1

VES	LAYERS	CURVE TYPES	APPARENT RESISITIVE (Ωm)	THICKNESS (m)	DEPTH (m)	INFERED LITHOLOGY
1	1	A	60.2	2.3	2.3	Top soil (clay)
	2		187.3	6.6	8.9	Weathered layer
	3		2292			Fresh Basement
2	1	A	40.6	1.1	1.1	Top soil (clay)
	2		81.6	3.6	4.7	Sandy clay
	3		7090.2			Fresh Basement
3	1	A	98.4	1.3	1.3	Top soil (Sandy clay)
	2		286.4	8.7	10.0	Weathered layer
	3		15503			Fresh Basement
4	1	H	121.7	1.2	1.2	Top soil (Sandy clay)
	2		59.8	3.0	4.1	Clay
	3		1684			Fresh Basement
5	1	A	17.5	2.6	2.6	Top soil (clay)
	2		111.2	4.0	6.5	Sandy clay
	3		1189.8			Fresh Basement
6	1	K	41.6	0.9	0.9	Top soil (clay)
	2		162	4.3	5.1	Weathered layer
	3		433.7			Weathered layer
7	1	A	18.9	1.9	1.9	Top soil (clay)
	2		137.4	9.7	11.7	Weathered layer
	3		990.2			Weathered layer

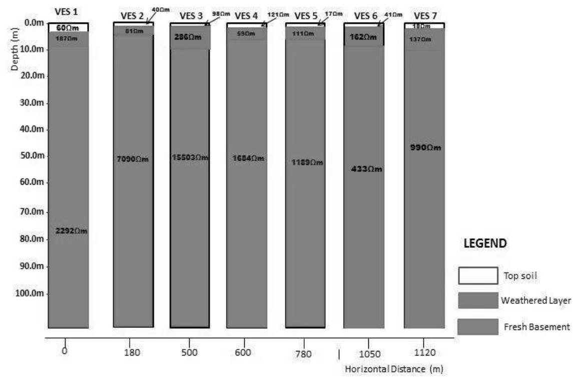

Figure 5: Geoelectric section of profile 1

Tranverse 2

The plotting of the VLF raw real data and the distance generate a VLF signature which depict high and low conductive areas. The positive peak of the raw real shows the conductive zones which are zones of weakness, fracture or cavity. These areas are indicated on the VLF plot at distance 80, 240, 400, 450, 700, 830 and 1150 m (figure 6). There is a very high conductive body observed at 700 (figure 6). This is inferred as either fracture or a fault or an intrusion of a conductive body. This portion of the road experienced a major failure.

The Karous-Hjelt filtering was used to invert the VLF data to 2-D geosection model that shows the conductive bodies in various sizes and depth. The conductive zones are red colour while the low conductive areas are shown as green to deep blue colour (figure 7.). The high conductive zone identified at distance 700 m in the raw real VLF plot is inferred either as a fracture or an intrusion of a different body.

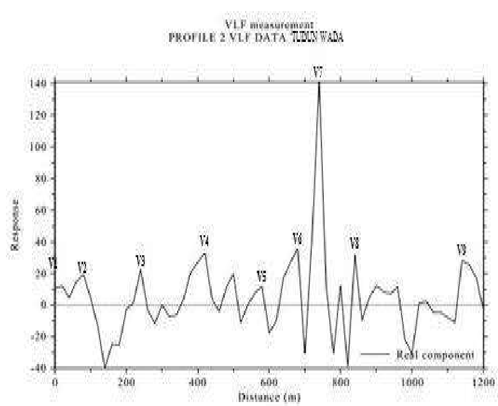

Figure 6: VLF raw real plot

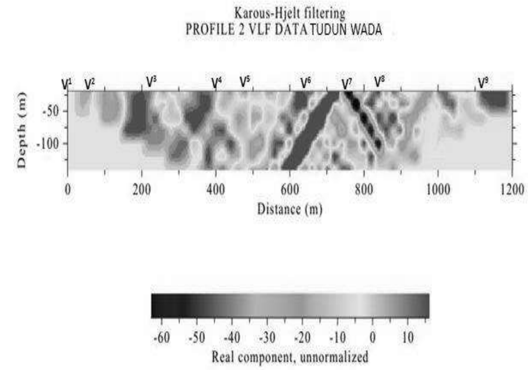

Figure 7: Karous-Hjelt plot 2

- $V1V^1 – V9V^9$ are points of correlation.

Nine VES points were established at the inflection points of positive peaks of the raw real VLF plot at distance 0, 100, 250, 400, 650, 700, 800 and 1150 m in the W-E direction of the traverse, and the data were used to produce a geoelectric section (figure 8). The geoelectric section shows the variation of resistivity and thickness values of the subsurface layers and this provides the information of the geoelectric sequences with the penetrated depth. The constructed geoelectric section revealed the presence of four geoelectric layers. These layers are: the top soil, the weathered layer, partly weathered (fractured basement) and the fresh basement.

The top soil has resistivity value ranging between 3.3 and 50.9 Ωm, except in VES 6 which has the resistivity of 150.85 Ωm. These resistivity values correspond to clay, clayey sand and sandy clay. The top soil is majorly characterized by relatively low resistivity values (less than 80.5 Ωm) suggesting weak zones that are capable of affecting the road stability. The weathered and partly weathered layer is characterized by resistivity ranging from 144.1 to 267.4 Ωm and its thickness varies from 1.4 to 78 m. This low resistivity corresponds to clayey sand and sandy clay as most predominant. This relatively low resistivity is inimical to the stability of the road structure. It should be stated that this low resistivity values may be attributed to water saturation in these weathered zones. The basement has resistivity ranging from 1717.1 to 9616.6 Ωm with thickness variation from 5 m to infinity. The depth to bedrock of the overburden is generally shallow. This also constitutes to the failure of the road.

Table 2 : Summary of ves data traverse 2

VES	LAYERS	CURVE TYPES	APPARENT RESISITIVE (Ωm)	THICKNESS (m)	DEPTH (m)	INFERED LITHOLOGY
	1		11.3	0.5	0.5	Top soil (clay)
1	2	A	67.8	12.0	12.4	Sandy clay
	3		7026.1			Fresh Basement
	1		36.7	2.8	2.8	Top soil (clay)
2	2	H	2.5	5.7	8.5	clay
	3		192.5			Weathered layer (sand)
	1		49.2	3.2	3.2	Top soil (clay)
3	2	H	13.8	31.4	34.7	clay
	3		246.5			Weathered layer
	1		14.2	1.9	1.9	Top soil (clay)
4	2	H	8.9	1.6	3.5	clay
	3		1983			Fresh Basement
	1		144.1	1.4	1.4	Top soil (sand)
5	2	H	93	7.8	9.2	Sandy clay
	3		13,180			Fresh Basement
	1		62.7	1.1	1.1	Top soil (sandy clay)
6	2	H	36.7	4.3	5.4	clay
	3		1079.2			Fresh Basement
	1		14.2	1.9	1.9	Top soil (clay)
7	2	H	8.9	1.6	3.5	clay
	3		1983			Fresh Basement
	1		62.7	1.1	1.1	Top soil (sandy clay)
8	2	H	36.7	4.3	5.5	clay
	3		1079.2			Fresh Basement
	1		45.4	1.2	1.2	Top soil (clay)
9	2	H	12.3	3.0	4.2	clay
	3		4929.2			Fresh Basement

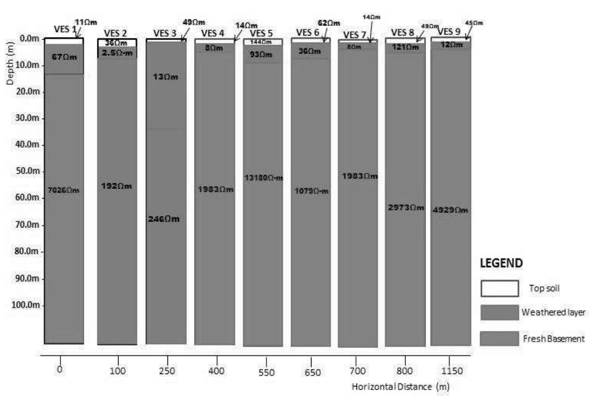

Figure 8: Geoelectric section of profile 2

3 CONCLUSION

The VLF Geophysical method was used to delineate the presence of near surface linear features such as sinkholes, cavity, faults, contact zones and conductive zones. It is however, important to state that limitation of the software used in processing the VLF data in the exaggeration of the probing depth particularly when the traverse is long (the longer the traverse the more the depth is exaggerated). Consequently the depth obtain from the VLF EM interpretation was not used.

Table 1 and 2 show the summary of the interpreted VES results of the study locations which were used to generate the geoelectric sections (figure 5 and 8). These suggest three scenarios; the first is that the area is underlain by three geological layers which are the top soil, weathered layer and basement. The second is the weathered layer which occurs as the second layer at a shallow depth to the surface. The presence of the weathered layer can also undermine the stability of the road if not properly handled. The third scenario is that the study area is characterized by the occurrence of fresh basement at a very shallow depth (figure 8).

3.2 Recommendation

1 Clay formation is not a good engineering material for road sub base.

2 Lack of provision of drainages of the high way could obstruct the stability of the road.

3 There should be proper excavation of conductive materials in any road pavement.

4 Sinkholes that are detected should be filled with high resistivity materials.

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