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GEOPHYSICAL INVESTIGATION INTO THE REMOTE CAUSES OF ROAD FAILURE ALONG FARIN GADA- ZABOLO ROAD, JOS, NORTH CENTRAL NIGERIA

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ABSTRACT

Detailed geophysical investigation for road failure using Schlumberger and the Werner Array geophysical investigation was carried out. These investigations were done with the aim of revealing the horizontal and the vertical geological discontinuities using their electrical resistivity, intrinsic property of the materials, probable zones of untimely failure along the road. The VES readings of the Schlumberger array method showed that the failed sections of the road had low resistivity values that ranges from 19.3Ωm (ohm-meter) to 80.5Ωm (ohm-meter) while the unfailed sections of the road had resistivity values that ranged from 210.5Ωm (ohm-meter) to 491.2 Ωm (ohm-meter). The failed sections of the road from interpretation had high content of clay in them which is responsible for the failure while the unfailed section is made up of sand mainly. For the Werner array survey, investigation revealed that only the soils around Horizontal Electrical profile 2 (HEP2) were competent because of their high resistivity ranges from 343.06Ωm (ohm-meter) to 2092.30Ωm(ohm-meter) while soils in profiles HEP1 and HEP3 were made up of soils that are incompetent because of their relative low resistivity values ranging from 40.80Ωm(ohm-meter) to 543.80Ωm(ohm-meter). VES readings obtained at locations 9,11,13,14 and 15 had soils that were competent because of their high resistivity values that ranged from19.3Ωm (ohm-meter) to 197.4Ωm (ohm-meter) and were collected from the undamaged sections of the road while locations 1,2,3,4,5,6,7,8,10,12,16,17,18,19,20,21,22,23,24 and 25 had low resistivity values that ranged from 205.3Ωm(ohm-meter) to 1049.8Ωm(ohm-meter) and were collected from the damaged sections of the road. The causes of the road failure in the study area were found mainly to be as a result of clayey top soil/ sub grade soils due to the nature of the geology of the area which is mainly granitic in nature that contain a lot of feldspars which upon weathering gives rise to clay (kaolin). The continuous decomposition into clay (kaolin), poses a great threat to the road due to expansion and contraction of the clay. The coarse grained type of the Biotite Granites are more resistant to weathering and have lesser amount of feldspars in them and upon weathering gives birth to laterites, gravels and sand which have high resistivity values as seen in the undamaged sections of the road while the medium to fined grain type of Biotite Granites have a very high amount of feldspar content in them and upon weathering gives rise to clay which have low resistivity values as seen in the damaged sections of the road. The presence of thin pavements which are unable to withstand pressure exerted on the road was also another cause of the road failure. Hence, the result of this research will form the tools for which the causes of the road failure can be identified and how they can be remedied within the study area using appropriate measures.

Keywords: Geophysical survey, Schlumberger array, Werner array, Pavement and Farin Gada- Zabolo road

INTRODUCTION

The research work was carried out mainly along the FarinGada – Zabolo road, Jos, Plateau State, Nigeria. The study area is located on Latitudes $10^0\ 00^1\ 00^{11}$ to $9^0\ 56^1\ 24^{11}$ and Longitudes $8^0\ 48^1\ 00^{11}$ to $8^0\ 51^1\ 35^{11}$. It is located at the Northern part of the Rukuba Younger Granite Complex ring. The topographical map used is on a scale of 1:50,000. The study area is dominated by the Younger Granite Complex which are Jurassic in age (165+ 25ma), which are believed to have intruded the late Precambrian to the lower Paleozoic basement rock of the Northern Nigeria in N-S which continues Northwards in the Niger Republic. The Younger Granite rocks are topographically distinct because they are easily differentiated because of their smooth topography and lower hills of the basement rocks. (Macleod *et al.*, 1971).

Rock types observed in the study area includes the Biotite granite, dolerite and the granite gneiss. Biotite granites gneiss and minor rock dolerite dominated in the study area. Major Nigerian roads are known to fail shortly after construction before their design age (Olorunfemi *et al.*, 1987). The inadequate provision of drainage facilities to drain out or remove excess water easily on or in the road pavement after heavy showers leads to failure of pavements. Rainfall is the most damaging environmental factor on pavements in tropical Africa. The road network in Nigeria is experiencing a systematic deterioration which is equivalent to an asset loss of about 80 billion per annum (Oguara, 2001).

Rainfall as well as poor construction materials, bad design, usage factor, poor drainage network are some of the factors considered responsible for these failures. Geological factors are likely/rarely considered as precipitators of road failures even though the high way pavement is founded on the geology (Olorunfemi *et al.*, 1987). This is due to non-appreciation of the fact that proper design of highway requires adequate knowledge of the subsurface conditions beneath the highway route, (Malomo *et al*, 1983). The non- recognition of this fact has led to the loss of integrity of many highway routes and other engineering structures across the country. In view of the efforts of the Federal Road Maintenance

Agency (FERMA), to rehabilitate failed segments of the roads across the country, it is imperative that adequate considerations be given to the cause of failures so as to ensure that sufficient safeguards are incorporated in their subsequent rehabilitations. Road failures could be as a discontinuity in road network resulting in cracks, potholes, bulges and depressions (Aighedion, 2007). Failure of road pavements can occur in the form of pelting and rutting, waviness, etc., as was adjudged the most common form of road failure (Gidigasu, 1974, Adeyemi, 2000).

The majority of road failures in the tropics can be attributed to geotechnical factors as reported workers such as (Gidigasu, 1972; Meshida, 1985; Adeyemi 1990; Momoh et al 2008). The problem of premature failure of our roads has been of great concern to most of geotechnical engineers and geophysicists. It is important to note that in many cases, the materials on which these roads were constructed might not be in harmony with the road sub grade specifications that in some cases might not be good enough there by making Nigerian roads to fail before their life span elapses, (Jegede, 2000,2004). Improper drainage network has led to the occurrence of potholes thus resulting to road failures. (De Graft Johnson 1972) proposed a criterion for rating a probable field performance of lateritic soil and position in pavement based upon aggregate as well as specific gravity and water absorption tests. Significant difference need not exist between geotechnical properties of the below stable zones and unstable sections of flexible highway pavements in the tropics. Depreciation in the shear strength and compressibility of the soil occur upon inundations to reduce their bearing capacity leading to foundation failures.

This research attempts to investigate the geological and geophysical factors in terms of the nature of the subsoil, the near surface structures and the bedrock structural disposition as possible causes of the failed road sections along Farin Gada – Zabolo raod in Plateau state using the Schlumberger and Wenner array methods.

Location of Study Area and General Geology

The study area is part of the Naraguta sheet 168NE. It is bounded by latitudes 10^0 00^1 00^{11} to 09^0 56^1 24^{11} and longitudes 08^0 48^1 00^{11} to 08^0 51^1 35^{11}. The settlements there are easily accessible to the major road from Farin Gada to Zabolo we have other minor roads that are all surrounded by the younger granite ring complex. Figure 1 is a map showing the location of the study area.

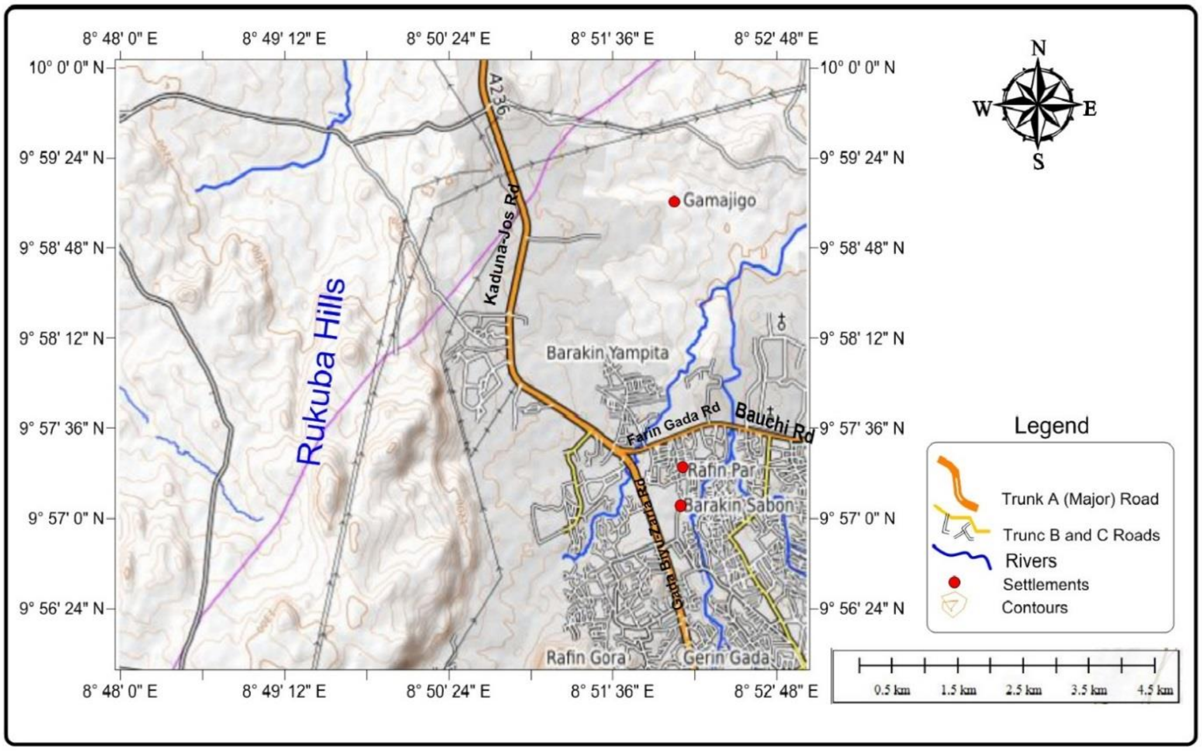


Figure 1: Map showing the location of the study area

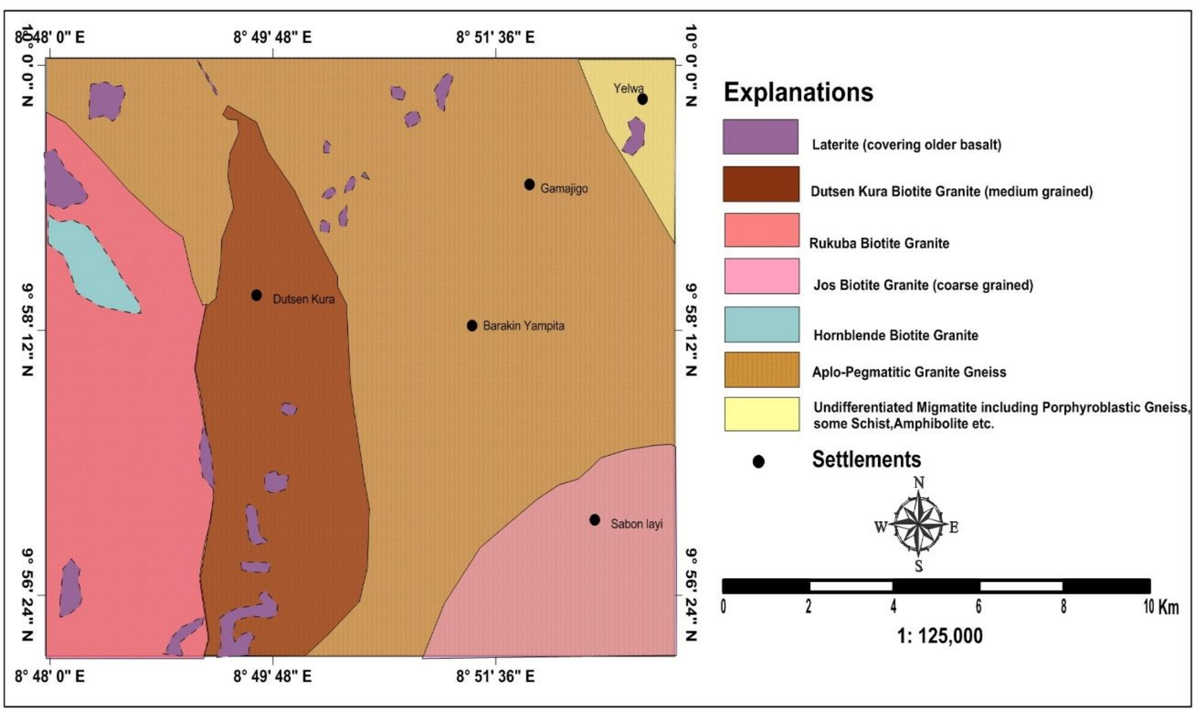


Figure 2: Map of the study area

The geology of the study area (fig 2) is predominated by granitic rocks such as coarse grained biotite granite as corrected on the map occurring as ring complexes but can be distinguished from another by their locality and grain size. Generally, granites are plutonic rocks composed of alkali feldspars, quartz, mica and small portion of mafic minerals. The Biotite granites are the most predominant in the study area. The proportions of mafic minerals are used to name and classify the minerals.

The rocks are classified as follows:

i. Jos Biotite Granite (coarse grain)
ii. Jos Biotite Granite (fine to medium grain)
iii. Jos Biotite Granite (medium to coarse grain)

MATERIALS AND METHODS

Electrical resistivity imaging data of the subsurface was acquired using the ABEM SAS terrameter along traverses using the Schlumberger array and the Wenner array. The equipment is capable of measuring the apparent resistivity as well as the self-potentials at the same time using the current and the potential electrodes. Electrode spacing of 1 – 165m was used for every VES point. A total of 25 VES points was investigated which cut across both the damaged and the undamaged sections of the road in the area of study. Here, electrical current is applied between a pair of current electrodes and an apparent potential difference is passed across the pair potential electrodes and the resultant electrical resistance is measured. In the schlumberger array method, all the four electrodes are arranged colinearly while the distance between the inner electrodes is kept constant, the distance between the outer electrodes are varied for each measurement with half electrode spacing [AB/2] ranging between 1 and 165m. WINRESIST version 1.0 software was used for the interpretation of results. Geo-electrical parameters derived from the model includes: top soil, laterite, fractured granite and fresh granite. For the Werner array method, the ABEM SAS Terrameter was equally used and three profiles were taken both at the damaged and the undamaged sections of the road. Readings were taken at the east – west direction with both the potential and current electrodes been moved at the same time. Electrode distance of 15m was used for the measurements. The SPSS software was used for the interpretation of results.

RESULTS AND DISCUSSION

Twenty – five (25) Vertical Electrical Soundings (VES) were acquired within the study area for the Schlumberger array method and the obtained resistivities, layer thicknesses and curve types for the 25 VES stations are presented in Table 1. The sounding curve types obtained from the study area are A, H, KH, QH and Q (Table 1). The sounding curve type's ranges from 2 to 5 layers with the H curve type dominating the five (5) representative curve types within the study area as shown in Figure 3. The geoelectric layers deduced from the resistivity data are topsoil, clay soil, fractured unit and fresh basement, For the Werner array configuration, three (3) Horizontal Electrical Profiles were carried out within the study area and the obtained resistivities, layer thicknesses and their geoelectric properties for the 3 HEP stations are shown in Table 2. All the measurements were taken both at the damaged and the undamaged sections

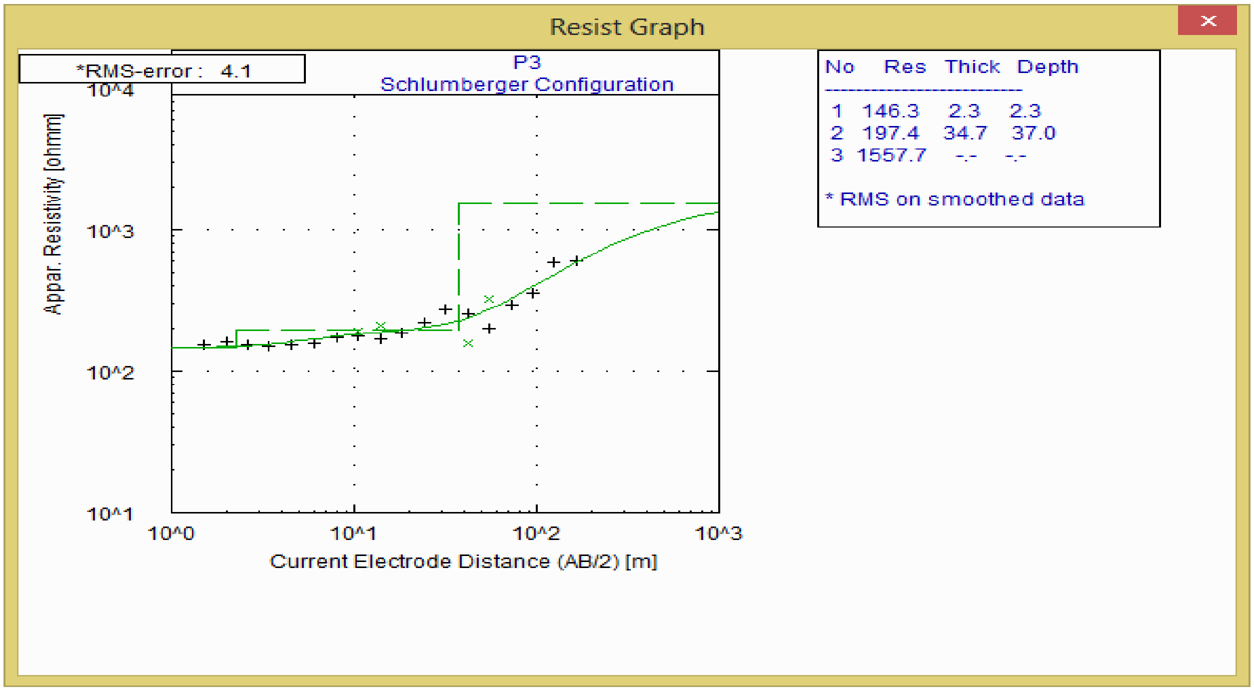


Figure 3a: Typical type of a curve for 3 layered earth

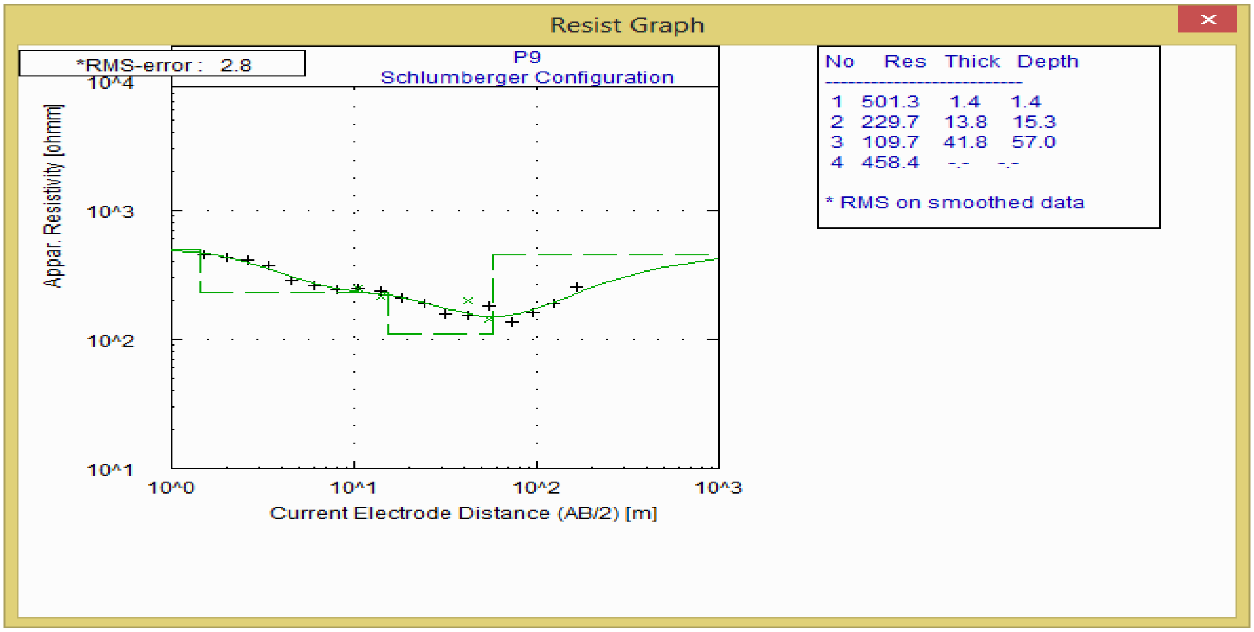


Figure 3b: Typical type QH curves for 4 layered earth

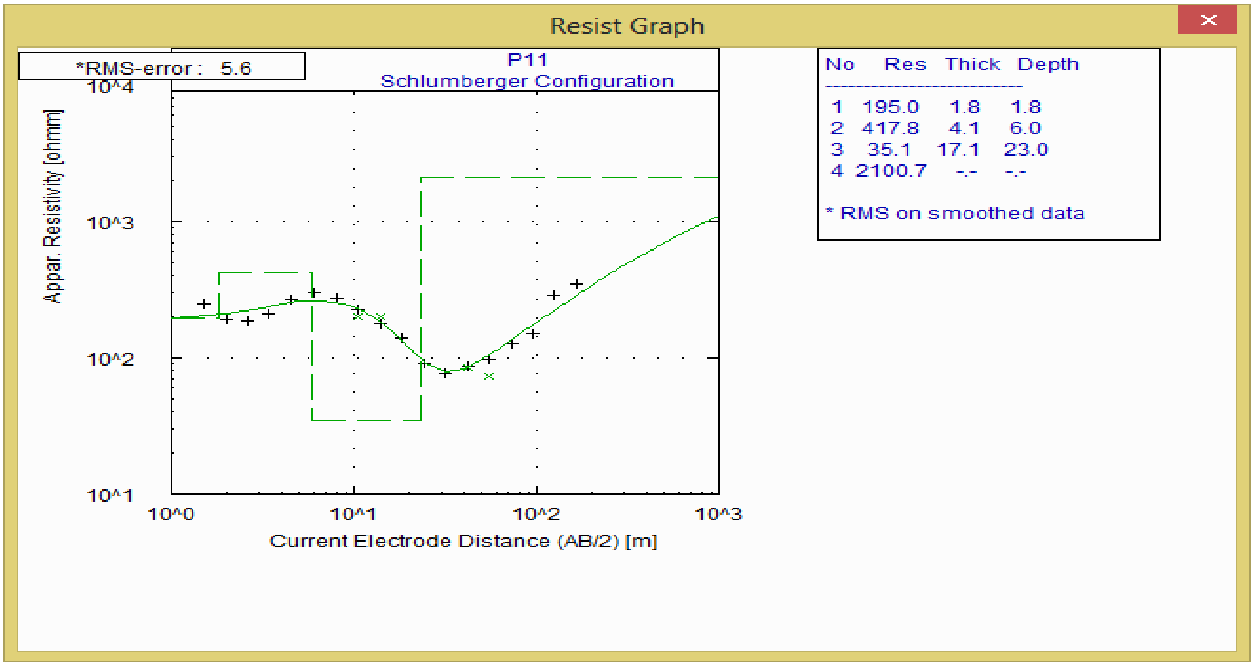


Figure 3c: Typical type KH curves for 4 layered earth

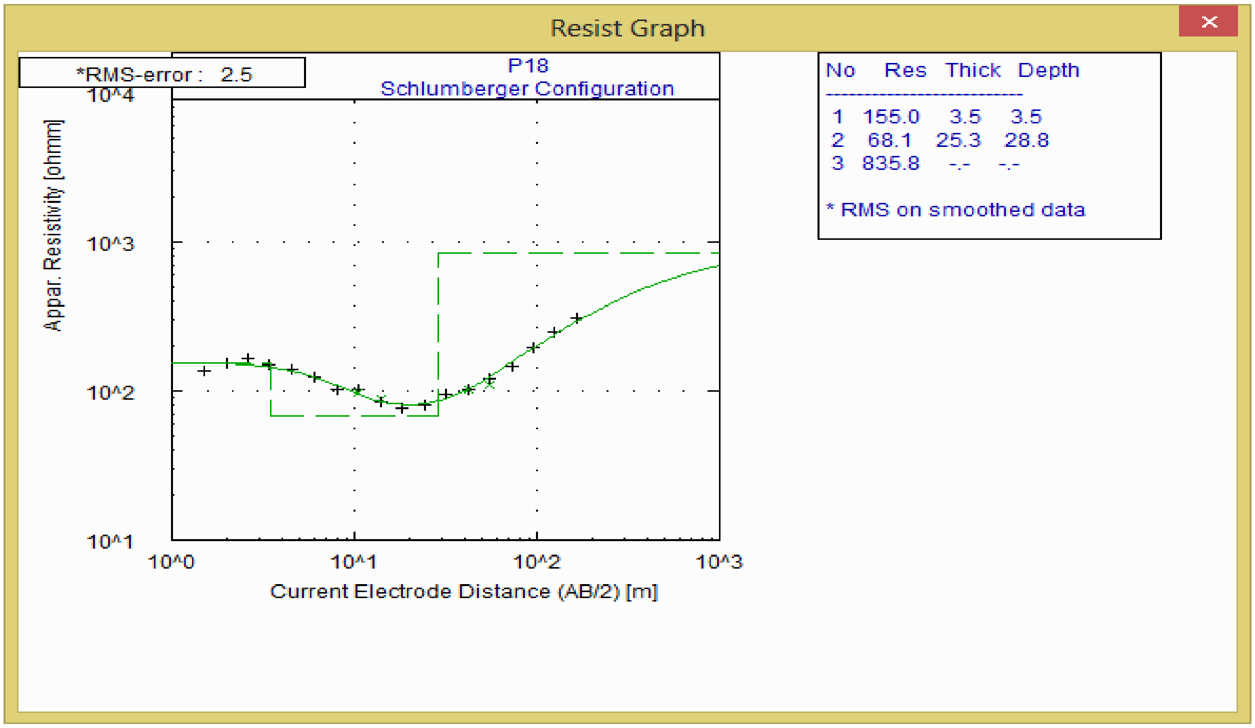


Figure 3d: Typical type H curves for 3 layered earth

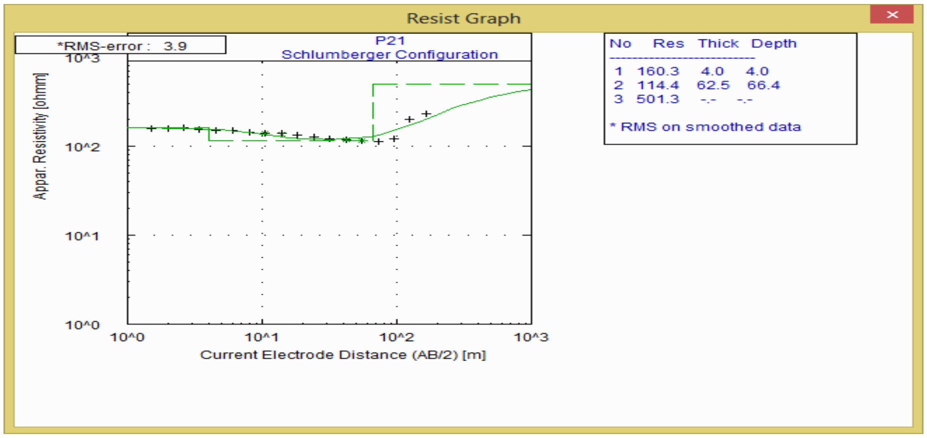


Figure 3e: Typical type Q curves for 3 layered earth

Table 1: Summary of Geo-electric parameter and VES curves

VES No	Resistivity (Ωm)				Thickness (m) Depth (m)			Depth (m)			Curve Type
	Ᵽ1	Ᵽ2	Ᵽ3	Ᵽ4	h1	h2	h3	d1	d2	d3	
1.	119.0	19.3	3488.1		9.9	12.0		7.9	19.8		H
2.	153.5	60.7	3949.4		2.3	24.9		2.3	27.3		H
3.	146.3	197.4	1557.7		2.3	34.7		2.3	37.0		A
4.	167.6	59.5	877.0		11.9	35.4		11.9	47.3		H
5.	219.9	80.5	4053.0		11.0	16.5		11.0	17.6		H
6.	73.8	210.5	1837.9		0.7	24.8		0.7	25.4		A
7.	90.1	237.7	664.9		1.4	48.3		1.4	49.7		A
8.	111.3	205.3	57.6	2578.3	1.3	5.8	12.8	1.3	7.1	19.9	KH
9.	501.3	229.7	109.7	458.40	1.4	13.8	41.8	1.4	15.3	57.0	QH
10.	506.5	272.2	124.1	672.4	1.3	5.2	14.6	1.3	6.5	21.1	QH
11.	195.0	417.8	35.1	2100.7	1.8	4.1	17.1	1.8	6.0	23.0	KH
12.	594.2	317.9	63.2	1256.3	2.5	7.3	32.4	2.5	9.7	42.1	QH
13.	321.8	1049.8	94.1	875.5	0.8	5.9	22.0	0.8	6.7	28.7	KH
14.	436.9	232.8	46.1	2650.1	0.7	14.1	16.9	0.7	14.9	31.8	QH
15.	313.0	491.9	85.3	765.0	1.4	9.4	28.7	1.4	10.8	39.5	KH
16.	220.4	418.1	102.1	880.3	5.2	6.9	22.3	5.2	12.1	34.4	KH
17.	206.1	386.0	99.4	927.0	1.7	3.5	25.5	1.7	5.2	31.1	KH
18.	155.0	68.1	835.8		3.5	25.3		3.5	28.8		H
19.	117.3	15.9	1108.2		8.4	12.6		8.4	21.0		H
20.	176.6	70.3	449.9		8.4	12.6		8.4	21.0		H
21.	160.3	114.4	501.3		4.0	62.5		4.0	66.4		Q
22.	400.9	45.0	571.0		0.9	15.7		0.9	16.6		H
23.	182.2	75.7	994.1		4.6	22.1		4.6	26.7		H
24.	251.7	64.3	1331.6		9.5	26.6		9.5	36.1		H
25.	273.6	107.1	373.2		2.1	58.7		2.1	50.8		H

In other to interpret the result of the tests carried out above, a chart showing the rating of the subsoil competence using resistivity values was put forward by Boyawa and Olayiwola, (2015) as shown below:

Comparing the table with the values obtained from the VES readings, resistivity values in layer 2 were used for the interpretation because that is the layer that is undisturbed. Low resistivity values are indicative of soils which are mainly cohesive in nature like clay, shale, etc. High resistivity values are indicative of soils that are cohesion less in nature like sand, gravel, laterite, etc, as seen in Table 2 by Boyawa and Olayiwola, (2015).

In relation to the Geology of the study area, it is mainly made up of the Biotite Granite rocks. The coarse grained type are more resistant to weathering and have lesser amount of feldspars in them and upon weathering gives birth to laterites, gravels and sand which have high resistivity values while the medium to fined grain type of Biotite Granites have a very high amount of feldspar content in them and upon weathering gives rise to clay which have low resistivity values. The following interpretation was arrived at.

From the interpretation, VES 9, 11, 13, 14 and 15 are competent which were acquired from the undamaged sections of the road because of their low feldspar which upon weathering gave rise to sand and laterite while 1,2,3,4,5,6,7,8,10,12,16,17,18,19,20,21,22,23,24 and 25 were acquired from the damaged section of the road because of their high feldspar content which gave rise to clay upon weathering.

Also, from the werner array survey carried out, three profiles were taken in other to delineate the horizontal layers of the subsoil under investigation. Below are the readings obtained.

Geoelectric profile: $\rho = 2\pi aR$

Where ρ =Resistivity, a = area (electrode distance), R = Resistance

Table 2: Soil competence rating with their resistivity

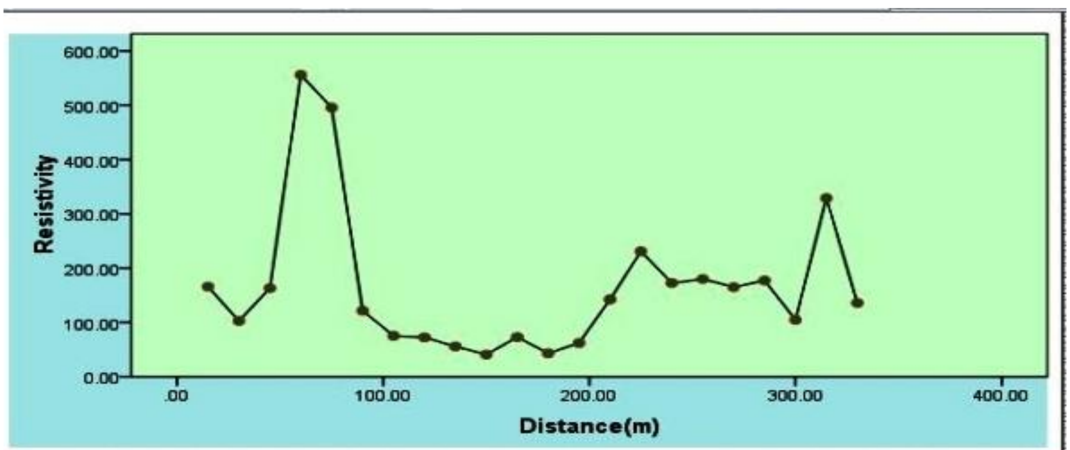
App Resistivity Range ohm-m	Lithology	Competence Rating
< 100	Clay	Incompetence
100 – 350	Sandy clay	Slightly competent
350-750	Clay sand	Competent
>750	Sand/laterite/crystalline rock	Highly competent

Table 3: Interpretation of the result by comparing their apparent resistivity with Table 2

VES Location	Apparent Resistivity	Lithology	Competence Rating	Remarks
1	19.3	Clay	Incompetent	Clayish
2	60.7	Clay	Incompetent	Clayish
3	197.4	Sandy clay	Slightly competent	More of clay
4	59.5	Clay	Incompetent	Clayish
5	80.5	Clay	Incompetent	Clayish
6	210.5	Sandy clay	Slightly competent	More of clay
7	237.7	Sandy Clay	Slightly competent	More of clay
8	205.3	Sandy Clay	Slightly competent	More of clay
9	329.7	Clay sand	Competent	More of sand
10	272	Sandy Clay	Slightly competent	More of clay
11	417.8	Clay sand	Competent	More of clay
12	217.9	Sandy clay	Slightly Competent	More of Clay
13	1049.8	Sandy/Crystalline rock	Highly competent	Sand/laterite crystalline rock
14	332.8	Clay sand	Competent	More of sand
15	491.9	Clay sand	Competent	More of sand
16	418.1	Clay sand	Slightly Competent	More of clay
17	386.0	Clay sand	Slightly Competent	More of clay
18	68.1	Clay	Incompetent	Clayish
19	15.9	Clay	Incompetent	Clayish
20	70.3	Clay	Incompetent	Clayish
21	114.4	Sandy clay	Slightly competent	More of clay
22	45.0	Clay	Incompetent	Clayish
23	75.7	Clay	Incompetent	Clayish
24	64.3	Clay	Incompetent	Clayish
25	101.1	Sandy clay	Slightly competent	More of clay

Table 3a: Summary of the Geoelectric parameters for horizontal profile 1

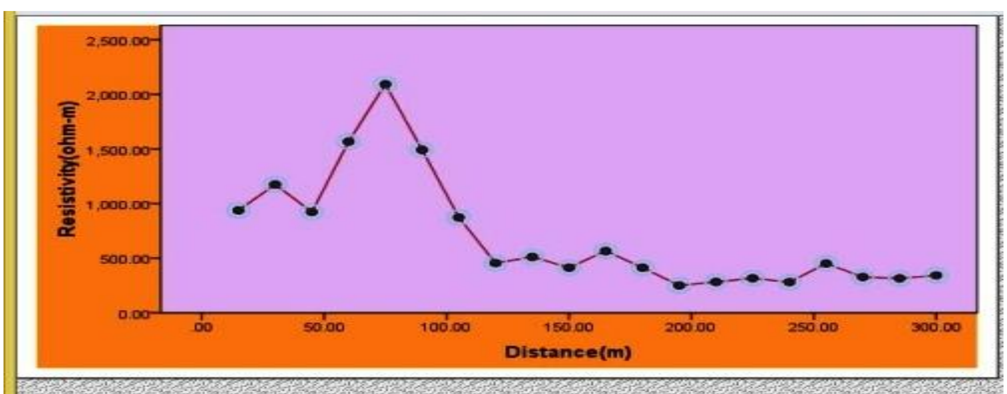
HP	Area	Resistance(ohm)	Resistivity(ohm-m)	Remark
1	15	1.76	165.94	Slightly Competent
2	15	1.09	102.73	Slightly Competent
3	15	1.73	163.04	Slightly Competent
4	15	5.90	556.06	Competent
5	15	5.26	495.74	Competent
6	15	1.29	121.57	Slightly Competent
7	15	0.799	75.30	Incompetent
8	15	0.769	72.47	Incompetent
9	15	0.591	55.70	Incompetent
10	15	0.433	40.80	Incompetent
11	15	0.775	73.04	Incompetent
12	15	0.457	43.07	Incompetent
13	15	0.659	62.10	Incompetent
14	15	1.51	142.31	Slightly Competent
15	15	2.45	230.90	Slightly Competent
16	15	1.83	172.47	Slightly Competent
17	15	1.91	180.01	Slightly Competent
18	15	1.75	164.93	Slightly Competent
19	15	1.88	177.18	Slightly Competent
20	15	1.11	104.61	Slightly Competent
21	15	3.49	328.92	Slightly Competent
22	15	1.44	135.71	Slightly Competent



Horizontal Profile 1

Table 3b: Summary of the Geoelectric parameters for horizontal profile 2

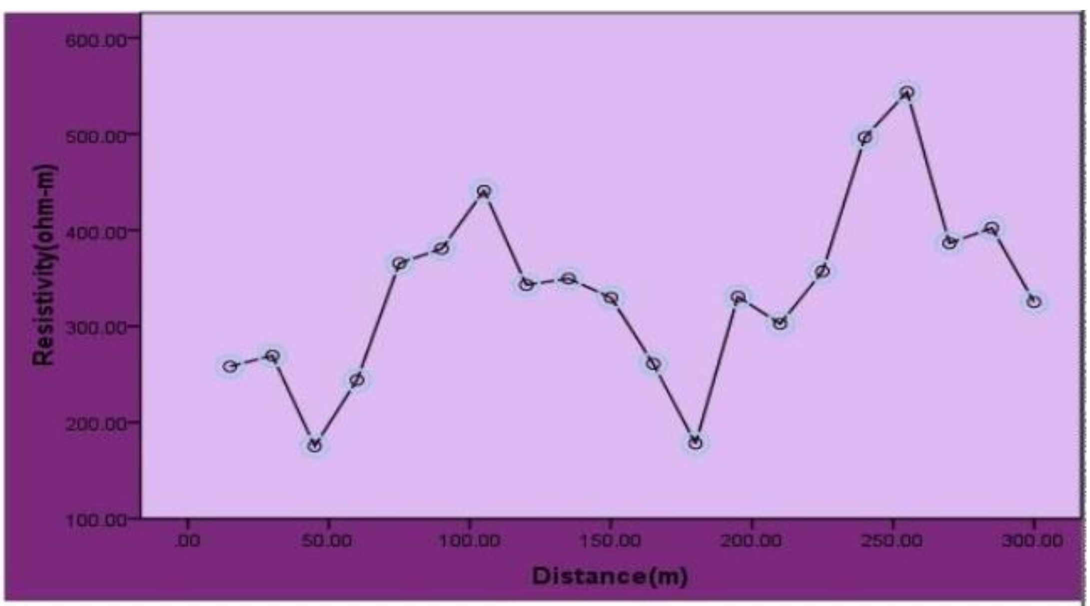
HP	Area	Resistance(ohm)	Resistivity (ohm-m)	Remark
1	15	9.95	937.76	Highly Competent
2	15	12.46	1174.32	Highly Competent
3	15	9.80	923.62	Highly Competent
4	15	16.63	1567.34	Highly Competent
5	15	22.20	2092.30	Highly Competent
6	15	15.83	1491.94	Highly Competent
7	15	9.72	873.67	Highly Competent
8	15	4.83	455.20	Competent
9	15	5.43	511.76	Competent
10	15	4.39	413.74	Competent
11	15	6.00	565.48	Competent
12	15	4.54	413.74	Competent
13	15	2.65	249.74	Slightly Competent
14	15	3.00	282.74	Slightly Competent
15	15	3.36	316.67	Slightly Competent
16	15	2.98	280.85	Slightly Competent
17	15	4.79	451.44	Competent
18	15	3.47	327.03	Slightly Competent
19	15	3.35	315.73	Slightly Competent
20	15	3.64	343.06	Slightly Competent
21	15	1.44	135.71	Slightly Competent
22	15	1.44	135.71	Slightly Competent



Hrozontal profile 2

Table 3c: Summary of the Geoelectric parameters for horizontal profile 3

HEP	Area	Resistance(ohm)	Resistivity(ohm-m)	Remark
1	15	2.74	258.23	Slightly Competent
2	15	2.86	269.54	Slightly Competent
3	15	1.86	175.30	Slightly Competent
4	15	2.59	244.10	Slightly Competent
5	15	3.88	365.68	Competent
6	15	4.04	380.76	Competent
7	15	4.68	441.07	Competent
8	15	3.64	343.06	Slightly Competent
9	15	3.71	349.65	Slightly Competent
10	15	3.50	329.86	Slightly Competent
11	15	2.77	261.06	Slightly Competent
12	15	1.89	178.12	Slightly Competent
13	15	3.51	330.80	Slightly Competent
14	15	3.21	302.53	Slightly Competent
15	15	3.79	357.19	Competent
16	15	5.27	496.68	Competent
17	15	5.77	543.80	Competent
18	15	4.10	386.41	Competent
19	15	4.27	402.43	Competent
20	15	3.45	325.15	Slightly Competent



Horizontal profile 3

In other to interpret the result of the tests carried out above, a chart showing the rating of the subsoil competence using resistivity values was put forward by Boyawa and Olayiwola, (2015)(Table. 1). The chart was used for the competence rating of the soils in all the profiles. From the results obtained from the interpretation of the Werner array, only the soils around horizontal electrical profile, HEP2, were competent because of their high resistivity values that ranged from 343.06 Ωm to 2092.30Ωm and were gotten from the undamaged sections of the road which was mainly made up of sand particles. At HEP1 and HEP3, soils around these profiles are incompetent because of their low resistivity values that ranged from 40.80Ωm to 197.4Ωm and were gotten from the damaged sections of the road and were mainly made up of clay (kaolin). At HEP2, VES 9,11,13,14 and 15 were taken at the undamaged sections of the road while at HEP1 and HEP3, VES 1,2,3,4,5,6,7,8,10,12,16,17,18,19,20,21,22,23,24 and 25 were taken from the damaged sections of the road which equally conforms with the result gotten from the schlumberger array investigation.

CONCLUSION

The study revealed the VES data curves which are: H, QH, A, KH and Q with the H type been the dominant one. The two 4 geo-electric layers deduced from the resistivity data are top soil, laterite, weathered granite and fresh granite. The high clayey nature (kaolin), of the damaged sections of the road keep occurring due to high amount of feldspars in them and upon weathering gives birth to clay (kaolin), as seen in the damaged sections of the road. The results of this research will be very useful for the repairs and the rehabilitation of the damaged sections of the road within the study area if appropriate measures are carried out.

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