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Geophysical investigation of road failure the case of Opoji in Nigeria

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Abstract— Shallow geophysical investigation for road surface failure using 2D Wenner array electrical resistivity image profiling was conducted to produce models of the subsurface revealing horizontal and vertical geological discontinuities. Pseudo sections produced from electrical resistivity profiles show resist ivies of the substratum ranging from 273.94 Ω-m -3566.7Ω-m in profile 1 to 1561.2 Ω-m -4062.4 Ω-m in profile 2 and 714.36Ω-m -3856.4Ω-m in profile 3 and 700.06Ω-m – 3994.65Ω-m in profile 4. An average of 2168.17Ω-m suggested a sedimentary environment while the low resistivity spectrum suggested areas of low permeability or clay intercalation. Geotechnically the high end of the resistivity spectra were attributed to competent zones. This result is in consonance with Weaver's rip ability rating chart.

Index Terms— **Keywords:** resistivity, Wenner array, pseudosection, lateral inhomogeneity, rip ability

1 Introduction

The Government of Nigeria is committed to improve road network within the country and this venture is laudable since to a great extent, it will enhance her economic development. Recent years have seen a major development in the infrastructure of this area, including several new roads linking the towns and villages. The road network is currently estimated at about 194,000 kilometers, with the Federal Government being responsible for about 17 percent, State Governments 16 percent and local Governments 67 percent. This has led to a situation, whereby for a variety of reasons, roads were constructed in areas with a history of surface and subsurface geological degradation. In spite of various rehabilitation efforts, several segments of our highways fail perpetually soon after commissioning. Such rehabilitation has become an annual ritual and a big financial burden on various tiers of Government [1], [2]. This has resulted in the need for reparations and the use of remedial measures to ensure the usability of the transportation network [46].

As more roads are envisaged in the near future, it is necessary to learn from past failures so as to avoid repeated problems in the future, resulting in a waste of the limited economic resources [74]. The incessant incidence of pavement failure of road structure is becoming alarming and has become a common phenomenon in many parts of Nigeria. These failures have been attributed to a number of factors such as inadequate information about the soil and the incompetence of these subsurface geologic materials. Failures are not limited to any particular geologic setting. Failures have been recorded on crystalline, basement, complex rocks and sedimentary formations. In all cases zones of instability is the result of fractures which acts as conduits for ground water seepage and accumulations, as a result fracture zones are weak zones.

Underlying geological materials have different competences to loading. The bearing capacity if soils for example is an index of amount of clay material is an essential parameter to be investigated prior to high way foundation construction. Many works have come to the conclusion that it is paramount therefore to investigate the engineering properties of underlying foundation material through geological, geomorphologic, geotechnical, and geophysical practices, [2], [8].

Field observations and laboratory experiments carried out by [3], [61], [8], [2], showed that road failures are not primarily due to usage or design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behavior of residual soils on which the roads are built. The integrity of geophysical survey to complement geotechnical investigations have grown in the last two decades. Preliminary geophysical studies are capable of delineating materials such as unconsolidated soil formations by contrasts in resistivity and conductivity [89], [80]. They can also detect naturally occurring underground water channels which may expedite weathering and surface deformation. A number of important engineering problems associated with dams, reservoirs, huge and heavy building constructions which can cause road failure have been identified with geophysical methods [5]. This research therefore tries to use Electrical Resistivity Imaging surveying method to study the causes of consistent failure of Uhiele-Opoji road. It involves a longitudinal probe of the failed, fairly stable, and stable portion of the road as well as perpendicular probe using a two dimensional (2D) imaging profile, in order to characterize the near surface geologic materials that constitute the sub-grade, sub-base and the foundation upon which the pavement was founded. It is hoped that solving consistent road failure would ameliorate problems such as

i. Transportation of farm produce from rural communities.
ii. Ease of expense of transport cost to users who now take longer routes to avoid failed portions of the road.

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iii. Check criminals who take advantage of these failed portions to commit robbery on slow traffic.

2 METHODOLOGY

2. 1 Geology of Study area

The Niger Delta in Southern Nigeria has been prograding outward into the Atlantic Ocean since late Cretaceous times and has Tertiary and Quaternary sediments infill which decrease in age progressively southwards. The deposits comprise from north-east to south-west, the Imo shale, a unit of Palaeocene to Eocene (lower Tertiary) blue grey shale with thin sandstones and limestone; the Eocene to Oligocene Ameki Formation, comprising clays, sandstones and limestone; Oligocene to Miocene clays, sands and grits with occasional lignite (carbonaceous deposits) of the Ogwashi-Asaba Formation and the Miocene to Pilocene Benin Formation composed of coastal-plain sands and pebbly sands with clay lenses and lignite. The sediments were deposited in a variety of environments from marine, through deltaic, estuarine and coastal swamp to lagoon and fluvial. In all, the sediments pile reaches a thickness of around 12,000m [76]. Towards the north the delta is bounded by a basement complex consisting of granites migmatites and gneisses.

2.11 Location

The road investigated, exists within Ekpoma and Irrua towns in Esan West and Central respectively in Edo state Nigeria (Fig 1). The road serves as a link between the University town of Ekpoma and the major high way leading to the Eastern part of Nigeria. The old road linking Irrua and Opoji joins the Ekpoma – Uhiele road at Ugbegun. At the time of study, these roads are undergoing major deterioration as a result of cracks, potholes, rippling and depressions which will in turn lead to road failure. Uhiele – Opoji main road in the central part of Edo state, south-south Nigeria, is situated on a gently undulating terrain with elevation between 296m and 335m above the main sea level on latitude 6^0 41'N, longitude 6^0 10'E (Uhiele), latitude 6^0 42'N, longitude 6^0 11'E (Opoji), and latitude 6^0 43'N, longitude 6^0 17'E (Irrua). The areas lie in a region with typical characteristics of the tropical rain forest such as: multitude of evergreen trees, climbing plants, parasitic plants. Two main seasons exist in the area, the dry season which lasts from November to March and the rainy season which begins in April and ends in October with a short period of reduced rains in August commonly referred to as “August break”. Temperature in the dry season ranges from 20°C to 38°C, and results in high evapotranspiration, while during the rainy season temperature ranges from 16°C to 28°C, with generally lower evapotranspiration. It has a mean annual rainfall about 1400mm and the annual mean temperature is between 25^0C and 30^0C. These climatic conditions are responsible for the development of thick lateritic soils in the area.

2.2 Geophysical method

The resistivity method is used in the study of horizontal and vertical discontinuities of the ground. It can also be used in the detection of three-dimensional bodies of anomalous electrical conductivity. It is routinely used in engineering and hydrogeological investigations of shallow subsurface geology. The method uses artificially-generated low frequency electric currents, introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the expected pattern of potential differences from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities. When subsurface in homogeneities exist, the resistivity will vary with the relative positions of the electrodes. Any computed value is then known as the apparent resistivity (ϱ_a) and will be a function of the form of the inhomogeneity. Apparent resistivity values calculated from measured potential differences will be interpreted in terms of overburden thickness, water table depth, and the depths and thicknesses of subsurface strata. The two most common arrays used for Electrical surveying are the Wenner array and the Schlumberger array [25]. We adopted the Wenner array in this study. Two dimensional images of the subsurface apparent resistivity variation called *pseudo sections* were produced by varying the spacing of the array and repeating the profile along a traverse a number of times. Data plotted in cross-section is a simplistic representation of actual, complex current flow paths.

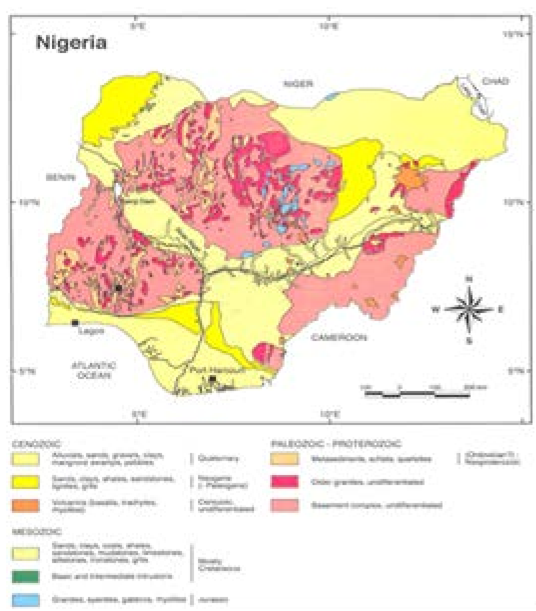

Fig 1. Geological Map of Nigeria

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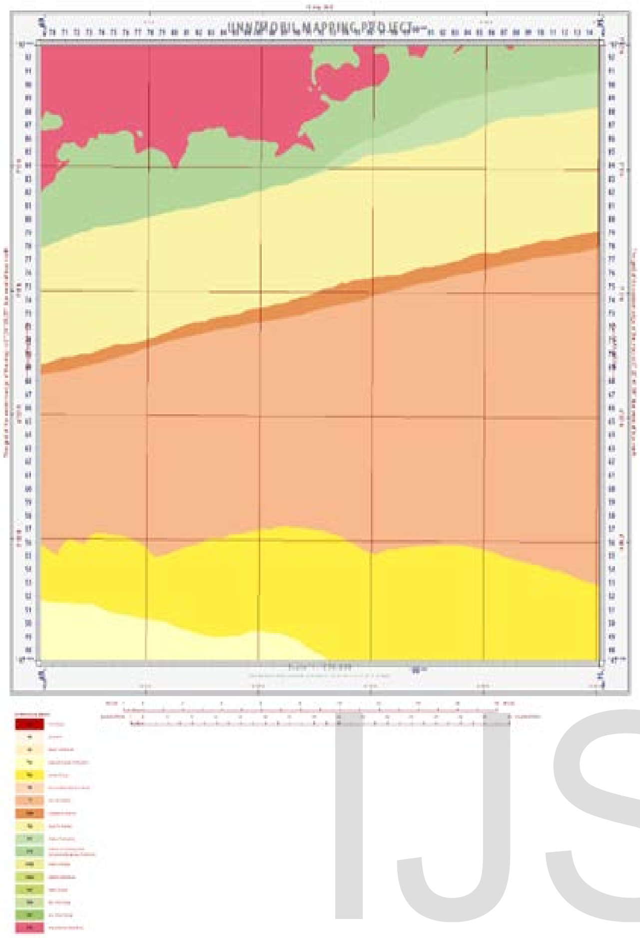

Fig 2. Local Geology of the study area

In Wenner array configuration, potential electrodes are nested within the current electrodes with a common lateral distance between adjacent electrodes called the electrode *a*-spacing. For sounding measurements, the electrodes in a Wenner array are expanded about a center point by equally incrementing the *a*-spacing. The current therefore progressively passes into deeper layers, with the nominal depth of investigation being equal to the a-spacing. This procedure provides apparent resistivity values computed as

$$\rho_a = 2\pi k \, \Delta V/I \qquad (1)$$

that are dependent upon measured voltages (V) in response to vertical conductivity variations of the subsurface. The geometric factor for the Wenner array is G(k) = 2*a.* This simplicity of algebraic form as well as in-field set-up is part of this array's appeal. The Wenner array generally provides for high signal-to-noise ratios, good resolution of horizontal layers, and good depth sensitivity. [25], [94]. The electrical resistivity instrument used was the ABEM SAS (signal averaging system) 1000 Terrameter. During the field work, the ABEM Terrameter SAS 1000 performed automatic recording of both voltage and current, stacked the results, computed the resistance in real time and digitally displays it [11], [34]. The Terrameter was configured in a mode that it displays apparent resistivity and induced polarization data automatically at the same time.

Three profiles/traverses, with two parallel/longitudinal and the last being perpendicular/transverse to the road segment were established and had a length of 250m each. Traverse I and Traverse II were established along parts of the road that showed major cracks and rippling of the pavement and a fairly stable part respectively while Traverse III was established midway of Traverse I. The profiles were located between the geographical grid of latitudes 6^0 41' 57.7'' N and 6^0 41' 50.05″ N, and longitudes 6^0 10' 47.06'' E and 6^0 10' 44.06'' E for Profile line I, Latitudes 6^0 41' 55.09'' N and 6^0 42' 00.02'' N and longitudes 6^0 10' 48.02'' E and 6^0 10' 41.07'' E for Profile line II and Latitudes 6^0 42′ 00.01″ and 6^0 42′ 03.05″ and longitudes 6^0 10′ 41.03″ and 6^0 10′ 34.04″ for Profile line III**.**

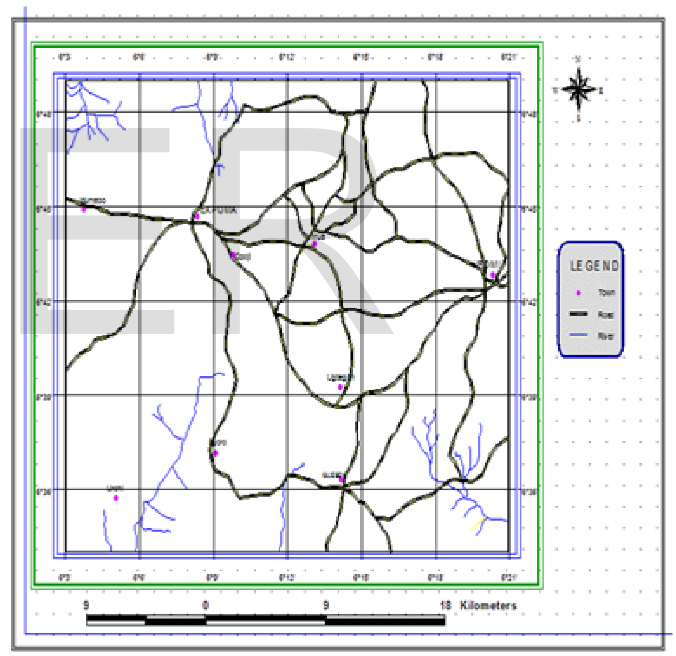

Fig 3. Access roads and drainage

4. Results

The data collected were automatically fed into the instrument to generate a two dimensional (2-D) resistivity model for the subsurface which can be referred to as Electrical Image. These values obtained were used for the qualitative interpretation of the profiles. Two dimensional (2D) electrical imaging surveys are widely used to map areas of moderately complex geology where conventional resistivity surveys and profiling may be inadequate. The results from such surveys are usually plotted in the form of a pseudosection which gives an approximate picture of

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the subsurface geology. Dense sampling of subsurface resistivity variation at shallow depth (electrode spacing of 10m) aims to investigate the lateral variation in electrical properties. Expanding the Wenner array spacing (20m; 30m; 40m) characterized its sensitivity for vertical variation in the subsurface resistivity below the center of the array. A common way to present apparent resistivity data is to plot the recorded values beneath the array midpoints at depths equal to a specified fraction (usually 1/3 or 1/2) of the array lengths. Contouring of the resistivity values reflects variations in apparent resistivity along the surveying line. Since the depths are not true depths, such a plot is called pseudosection [47]. Even though true depth information cannot be directly inferred from pseudosections, they are valuable tools for qualitative analyses and quality control [31], [32], [79]. The apparent resistivity distribution of the subsurface structure was then inverted using the commercial RES2DINV® software to estimate the true resistivity structure. This produces a subsurface map of the "apparent" resistivity distribution (psuedosection). The algorithm uses a 2D smoothness constrained, least-squares inversion with a Jacobian matrix calculation for the first iteration and then employs a quasi-Newtonian technique to reduce numerical calculations [53], [54]. The inversion is stopped once the difference of the root mean square (RMS) error between the current and previous iterations is less than 0.1%. The inverted data produce the 2D resistivity distribution map, which is then used for extracting information about the contact between sediment and bedrock.

Surfer ® 10 which is a grid-based graphics program was also used to produce psudo sections of apparent resistivity. Thus there is a correlation of two pseudo sections of same profile. 3D maps surface maps were used also produced by the Surfer program to display the apparent resistivity, to obtain a better resistivity image of the subsurface in the study area. The figures below shows the pseudo section plots of profiles as well as 3D maps of of the subsurface as interpreted from the resistivity distribution.

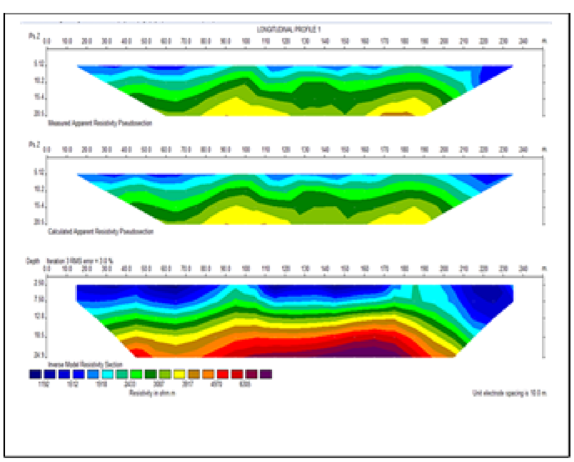

Fig 4. Pseudo sections of apparent resistivity data. Profile I

Pseudo section plots of Apparent Resistivity Data fig 4 shows stratified layers for the first profile along Uhiele – Opoji road at kilometer 140. The regions with very low resistivity values represented by blue color. The pseudo sections from top to bottom are

(a) Measured and interpreted apparent resistivity values of the profile
(b) Calculated apparent resistivity values of layers of profile
(c) Computer interpreted iterated inverse model resistivity section of the profile

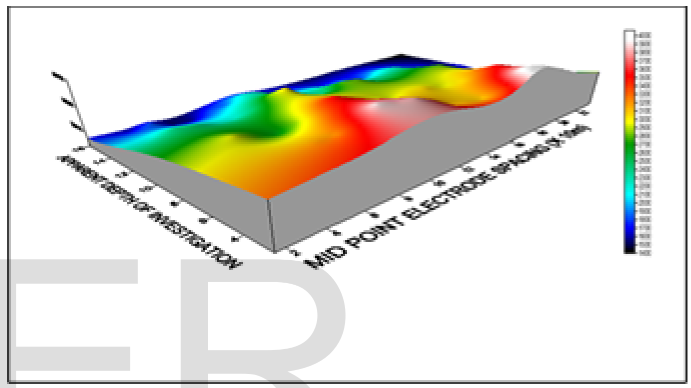

Fig 5. 3D reistivity map of profile I

The 3D resistvity map fig 5. Of the vicinity of profile I shows a surface resistivity distribution with an interpreted ridge about mid-way which is thought to bisect weak zones probably due to jointing

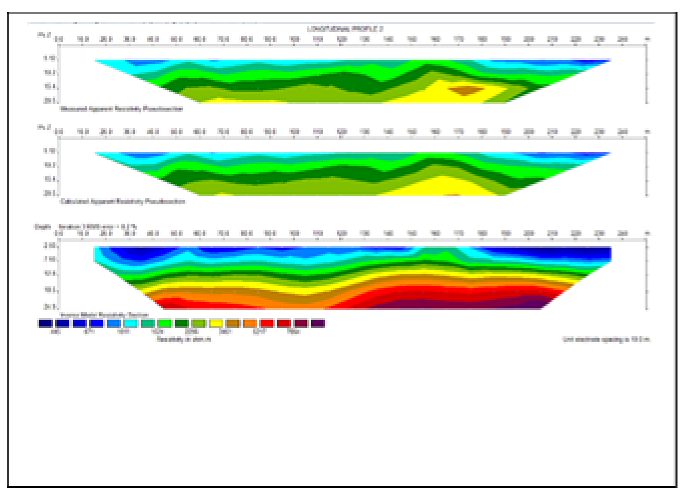

Fig 6. Pseudo sections of apparent resistivity data profile II

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Pseudosection plots of Apparent Resistivity Data fig 6.

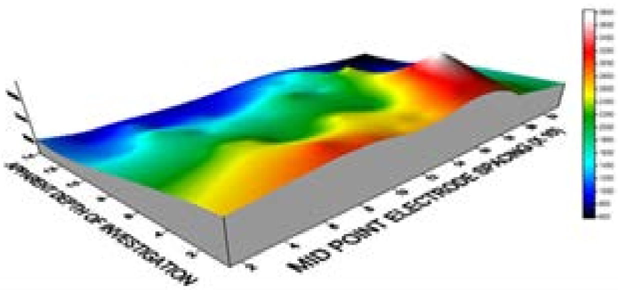

Fig 7 3D resistivity map of profile II

shows stratified layers for the second longitudinal profile of the road section (along Uhiele – Opoji road) Again the pseudosection plots from top to bottom are

Measured apparent resistivity values of the profile followed by calculated apparent resistivity values of the profile and then computer iterated inverse model resistivity section of the profile

A 3D map of the vicinity of the above profile fig 7 shows prominent resistivty ridges at the ends of the profile and low resistivity top soil.

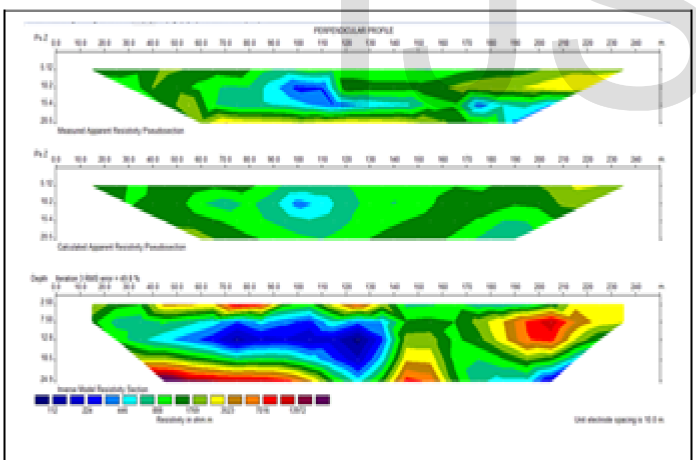

Fig 8. Pseudosection of apparent resistivity data profile III

The pseudosection plots of Apparent Resistivity Data ffig 8 gives indications of stratification of layers on the basis of resistivity contrast along the transverse profile of the road section (along Uhiele – Opoji road). The blue regions with very low resistivity values seem to be lensoids the pseudosection plots are from top to bottom (a) Measured apparent resistivity values of the profile (b) Calculated apparent resistivity values of the profile (c) Computer iterated inverse model resistivity section of the profile

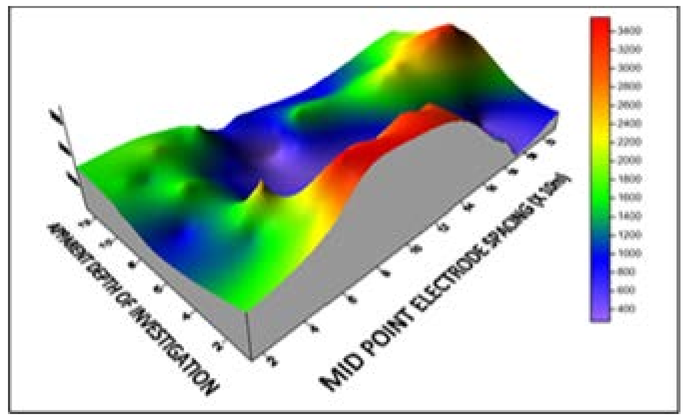

Fig 9. 3D resistivity Map of profile III

On the other hand a 3D map of same vicinity of the profile III fig 9 shows low middle conduit of low resistivity values rather than lens of low resistivty. It is probably a track of permeable zone and thus a weak zone due to water percolations.

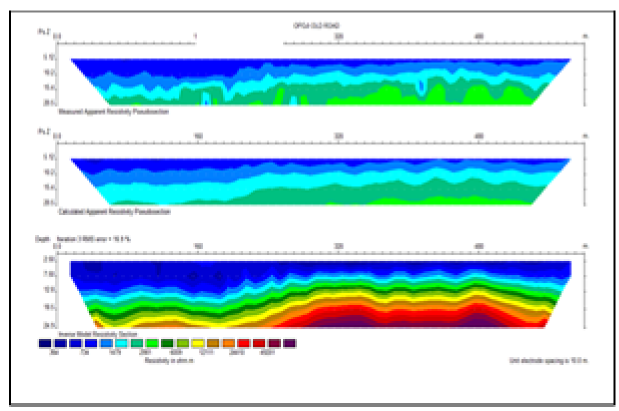

Fig 10 Psedo section of apparent resistivity data profile IV

Pseudosection plots of Apparent Resistivity Data showing the stratified layers for the Opoji old road- profile iv are from top to bottom a. measured apparent resistivity values of the profile with lateral inhomogenieties b. Calculated apparent resistivity values of the profile smoothened out the inhomegenieties c. computer iterated inverse model resistivity section of the profile.

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5. Discussion

reful examination of the resistivity pseudosection curves shows a set the appropriate resistivity range that corresponds to the lithological variations beneath these profiles.

For example along the first profile (Table 1), the apparent resistivity at 5m depth ranges between 798.76 ohm-m to 2335.3 ohm-m. Increasing depth to 10m, the range was between 273.94 ohm-m to 3293.2 ohm-m. As the depth increased to 15m, the resistivity range was 310.04 ohm-m to 2523 ohm-m. When the depth increased to 20m, the resistivity range was 412.79 ohm-m to 3566.7 ohm-m.

Along the second profile (Table 1), the different electrode spacing (10m, 20m, 30m, and 40m) showed different resistivity ranges. The apparent resistivity values at shallow depth of 5m range between 1561.2 ohm-m to 2214.4 ohm-m. With increasing depth to 10m, this range changes between 1614.7 ohm-m to 3034.2 ohm-m. Again when the depth increased to 15m, the resistivity range was 2657.7 ohm-m to 3534.4 ohm-m. As the depth increased to 20m, the resistivity range becomes 3151.4 ohm-m to 4062.4 ohm-m. There is an indication that variations in resistivity values are controlled by incorporated thickness of formation down to the basement.

On the third profile (Table 1), which was perpendicular to the road direction, the apparent resistivity at 5m depth ranges between 714.36 ohm-m to 1687.7 ohm-m. Increasing depth to 10m, the range was between 1211.2 ohm-m to 2511.7 ohm-m. With depth increased to 15m, the resistivity range was 2018.7 ohm-m to 3856.4 ohm-m. When the depth was increased to 20m, the resistivity range was 2281.7 ohm-m to 3193.9 ohm-m.
Profile IV (Table 1), was established along Opoji old road which is about 500m away from the first road. This traverse is intended to check the continuity of the subsurface geology in this terrain. The apparent resistivity at 5m depth ranges between 700.06 ohm-m to 999.72 ohm-m. Increasing depth to 10m, the range was between 789.78 ohm-m to 1995.54 ohm-m. With depth increased to 15m, the resistivity range was 1288.55 ohm-m to 3984.59 ohm-m. When the depth was increased to 20m, the resistivity range was 1231.54 ohm-m to 3994.65 ohm-m.
Table two indicates that the different ranges of resistivity are probaable the result of different rock types [53], [54]. Other factors such as permeability, and porosity, water saturations also affect the observed ranges of resistivy as seen in fig 10 where a conduit of low resistivity is the result of water percolation.

Table 1. range of apparent resistivity values and lithologic variations

Profile 1	Layer	Least Value	Maximum Value	Inferred Lithology
Resistivity	1	798.76	2335.3	Shales/Clays
(Ohm-m)	2	273.94	3293.2	Shales/Clays
	3	310.04	2523	Shales/Clays
	4	412.79	3566.7	Shales/Clays
Profile 2	Layer	Least Value	Maximum Value	Inferred Lithology
Resistivity (Ohm–m)	1	1561.2	2214.4	Shales
	2	1614.7	3034.2	Shales
	3	2657.7	3534.4	Shales
	4	3151.4	4062.4	Sandstones
Profile 3	Layer	Least Value	Maximum Value	Inferred Lithology
Resistivity	1	714.36	1687.7	Shales/Clay
(Ohm-m)	2	1211.2	2511.7	Shales
	3	2018.7	3856.4	Shales
	4	2281.7	3193.9	Shales
Profile 4	Layer	Least Value	Maximum Value	Inferred Lithology
Resistivity	1	700.06	999.72	Clays
(Ohm-m)	2	789.78	1995.54	Clays
	3	1288.55	3984.59	Shales
	4	1231.54	3994.65	Shales

We have also attempted to correlate the observed ranges of resistivity with engineering properties of soil in other to make inferences on the relative strength or rippability of the materials at road construction sites. Seismic velocity is conventionally one of such engineering properties which is related to resistivity by the equation: $\mathbf{Log_{10}\, \rho = m\, Log_{10}\, \mathit{Vp} + c}$. Here ρ is resistivity while V_P is p wave siesmic

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velocity [85], [53]. Table 3 shows such a correlation indications a rating of rippability rock scale of 1-5 with 5 as the rippable end. Thus most incompetent materials studied have resistivity as low as 400ohm-m.

Table 2 range of resistivity of different types of Earth materials

Granite	$5x10^3 – 10^6$
Basalt	$10^3 - 10^6$
Slate	$6x10^2 – 4x10^7$
Marble	$10^2 – 2.5x10^8$
Quartzite	$10^2 – 2x10^8$
Igneous and Metamorphic Rocks	
Limestone	$50 – 4x10^2$
Sandstone	$8 – 4x10^3$
Shale	$20 - 210^3$
Sedimentary Rocks	
Clay	1 – 100
Aluminum	10 – 800
Groundwater (fresh)	10 – 100
Sea water	0.2
Soils and water	

6. Conclusion

Geophysical methods (geoelectrical, ground penetrating radar, seismic refraction, etc) have become increasingly practiced in engineering site characterization, as being non-invasive, non-destructive, rapid and cost-effective method. Among these methods, geoelectrical survey is a very attractive tool for delineating subsurface properties without soil disturbance. Electrical Resistivity though a fundamental property of earth material varies with rock or sediment type, porosity and the quality and quantity of water.
Several attempts have been made by many researchers to explore the phenomenon of electrical resistivity in soils and its relationship with other soil properties; such as water content, thermal resistivity, salinity, CEC, hydraulic conductivity, ground water distributions etc.

Rock Class	**I**	**II**	**III**	**IV**	**V**
Description	**Very Good Rock**	**Good Rock**	**Fair rock**	**Poor Rock**	**VeryPoor Rock**
Seismic Velocity (m/s)	>2150	2150 – 1850	1850 – 1500	1500 – 1200	1200 – 450
Rating	26	24	20	12	5
Rock Hardness	Extremely Hard Rock	Very Hard Rock	Hard Rock	Soft Rock	**VerySoft Rock**
Rating	10	5	2	1	**0**
Rock Weathering	Unweathered	Slightly Weathered	Weathered	Highly Weathered	**Completely Weathered**
Rating	9	7	5	3	**1**
Joint Spacing (mm)	>3000	3000 – 1000	1000 – 300	300 – 50	<50
Rating	30	25	20	10	5
Resistivity	>3000	3000 – 1500	1500 – 700	700 – 300	<300
Rating	>4.0	3.5	3.0	2.5	<2.0

Table 3. Rippability Chart ratings

Few studies have been carried out to correlate electrical resistivity and geotechnical parameters of soil such as moisture content, plasticity index, grain size etc [37]. In the case of Opji high way study, careful processing of generated Wenner array data revealed subsurface image capable of distingushing top soil, permeable zones in the soil,

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structurally weak zones of the earth, and a correlation of siemic velocity with resistivity also show that rippability of weak zones is imparative for solid road pavement.

We recommend that detailed resistivity surveys should be routinely run along road construction for the perpose of identifying rippable zones innimical to the engineering construction.

7. Acknowledgment

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