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Geophysical and Geotechnical Investigation of Failed Section of Orsu-Ihiala Road Southeastern Nigeria

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Abstract- The Orsu-Ihiala road failed shortly after repair causing delay in trip time, loss of properties and lives. This research employs geophysical and geotechnical method in investigating the causes of this failure. The study area is part of the Anambra basin consisting of Eocene Ameke Formation, the Oligocene Ogwashi-Asaba Formation and the recent Meander belt. 2-D ERT was carried out along NW-SE section of the road to define the near surface geomaterial while 6 VES was carried out (maximum AB/2 = 55m) to investigate deeper section. Three (3) samples were collected at depth of 1.5m from the failed part of the road for geotechnical investigation. The 2-D pseudo-section shows that the area is underlain by moderate to low resistivity corresponding to partially stable and failed section of the road. VES Investigation of deeper section of the failed zones shows that the area is underlain by four layers; clayey top soil, clay, clayey-sand and sand. The soil is classified as granular material and highly compressible silty-clay as per AASHTO classification. The PI is 16.9%, 7.1% and 14.9%. The LL is 38.5%, 42.5% and 46%. The MDD and OMC is 1.776g/cm^3 and 14.4%, 1.713g/cm^3 and 14.6%, and 1.692g/cm^3 and 14.4%. The CBR (soaked) is slightly above the specified limited. The specific gravity is 2.401gm/cm^3, 2.586gm/cm^3 and 2.413gm/cm^3. The moisture content is 18.2%, 24.2% and 25.4%. The material is generally rated as a fair-poor subgrade material. Poor drainage construction and clayey material found at the subgrade could be the causes of the road failure.

Key word- Atterberg Limit, California Bearing Ratio, Compaction test, road failure, VES, 2-D ERT

1 INTRODUCTION

The foundation upon which engineering projects (constructions) lies is the earth. The type and nature of this subsurface material is essential as regards to how the construction project would fair. Hence it is of paramount importance that the nature and distribution (Heterogeneity/Homogeneity) of subsurface are studied prior to the construction of any engineering project [6].

The study area is located at latitude 5°47'0" – 5°54'0"N and longitude 6°51'0" – 6°59'0" E. The road is an important inter-state road linking Imo and Anambra state, Southeastern Nigeria. The road is known to fail consistently shortly after repair resulting to delayed trip time, discomfort rides, injuries, loss of lives and properties.

A good road payment is a stretch of smooth laid down asphalt for a comfortable ride. A bad road or road failure is therefore any visible cracks or holes that may obstruct such smooth ride [1]. Road failures could be any disjointedness in a road network resulting in cracks, potholes and depressions.

Most Nigerian paved roads are known to fail soon after building and way before their life span (design age). It is however becoming a routine ritual for roads to be continuously repaired shortly after construction. Reason for this is could be; inadequate knowledge of the surface prior to the construction, poor nature of the construction material or poor knowledge of the near surface material (geological difficult material) [1].

Geological derived materials/structures that can contribute to road failures includes: Geology of the area (near surface geology sequence and geological structures such as fractures, joints and faults), Placement of groundwater (shallow water table), Presence of Soluble rocks (limestone, chalk, gypsum etc.), Presence of clay (shrinking/swelling ability), Soil nature and geochemistry (pH, sulphate and chloride), Peat and unconsolidated recent deposit, existence of ancient stream channels and shear zones, geomorphological factors, topography and surface/subsurface drainage system [2].

Investigation conducted by the department of material geotechincs and quality control Federal Ministry of Works Nigeria, revealed that most premature failures experienced in Nigerians roads are attributed to week subgrades [8]. The behavior of subgrade soil in a completed road structure is of paramount importance especially when the stability and performance of the structure is most critical. This would in most cases be during the rainy season when the degree of water saturation into the subgrade is increased. Underground water places a significant role in the stability of the subgrade. It is therefore important that subgrade materials should have some level of strength under saturated condition. The parameter to measure this strength is California Bearing Ratio. It is imperative to obtain an accurate geotechnical data on subgrade as a precondition to facilitate accurate design of durable road pavements. This research therefore integrates geophysical and geotechnical techniques in investigating the causes of the failure of Orsu-Ihiala road, Southeastern Nigeria.

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(A) (B)

Plate 1: Severe Potholes and Ponding Water on Potholes at (A) Amanachi and (B) Isseke (Orsu-Ihiala road)

2 GEOLOGY

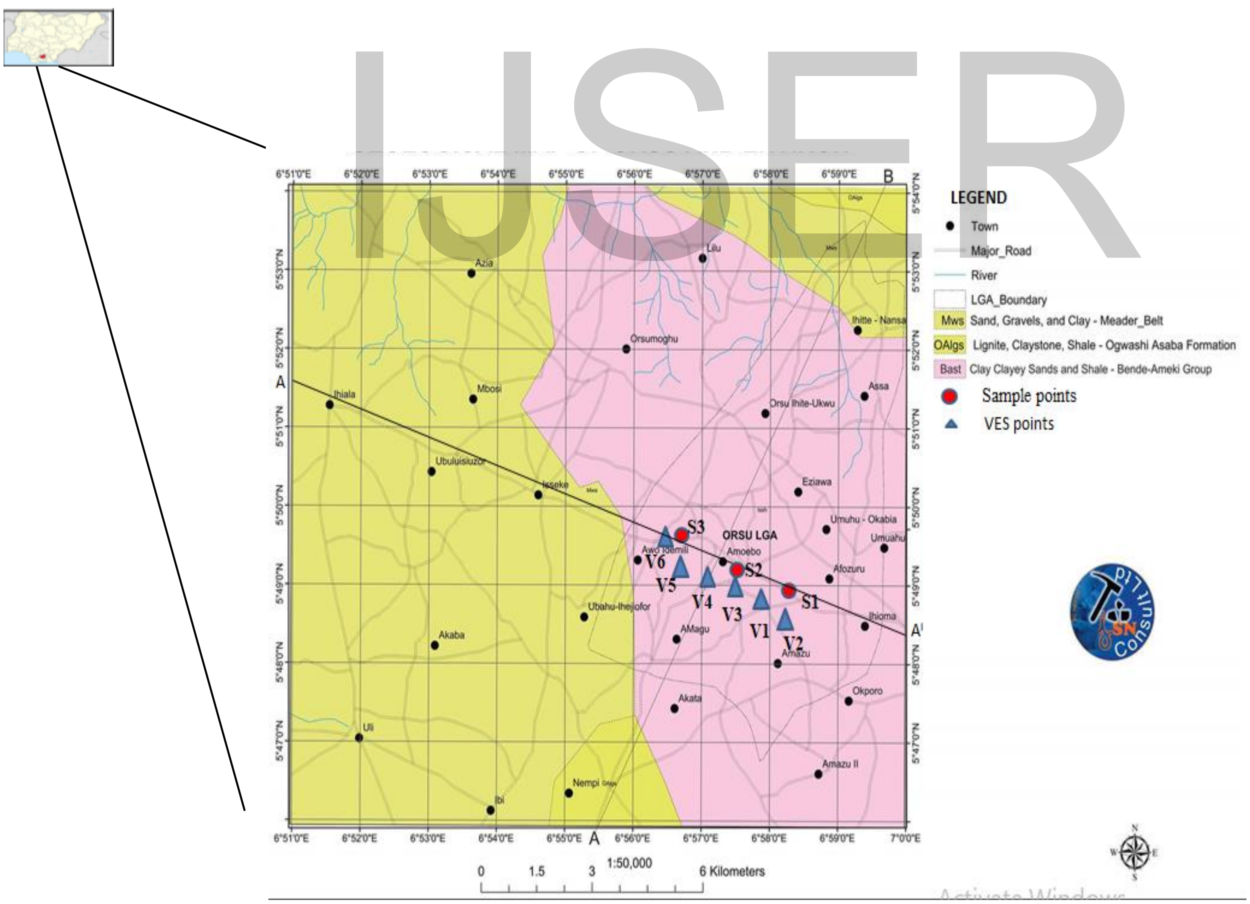

Fig.1: Geology and sampling map (Modified after Nigeria Geological Agency)

The study area is composed Anambra basin. This is characterized by two major Formations with the recent Meander belt (prototype of Benin Formation). The Eocene Ameke Formation is the oldest and it underlies the

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Oligocene Ogwashi Asaba Formation and this in turn is overlaid by the recent Meander belt. The Meander belt is a product of the weathering and erosion of the Benin Formation, composed of sands, silts and pockets of clay. The stratigraphy and geology is shown in table 1 and Fig.1 respectively.

Table 1: Stratigraphy of the study area (modified after Egboka, 1985).

Age	**Formation**	**Lithology**
Recent	Meander belts (Benin)	Sand, gravel and clay
Oligocene	Ogwashi-Asaba	Consolidated sands with lignite seams
Eocene	Ameke	Clayey sandstones and sandy claystone

3 METHODOLOGY

The methods utilized in this study involved geological, geophysical and geotechnical approaches. Geological survey involves the careful description of the geology and the encountered lithology. Geophysical survey involving the use of electrical resistivity was employed; both VES (Vertical Electrical Traversing) and 2-D ERT (Electrical Resistivity Tomography) were carried out using Schlumberger and Wenner configuration respectively. The instrument used was Abem terrameter Signal Averaging System (SAS) 4000. As the name implies, the instrument is capable of taken up to ten or more consecutive readings and displaying their average. The continuously updated running average is displayed automatically in digital form on the display unit in a cycle of 1-4 which can be selected by the operator. Accessories includes; four electrode, four wire rims, battery, marked ropes, measuring tape, hammer and a ranging pole.

2-D ERT was carried out at to investigate near surface earth material. A transverse was taken along the NW-SE direction of the road to cover the failed, partially stable and stable sections of the road. Wenner method was adopted for this near surface investigation, with a=3, 6, 9 and 12m. As soon as the near surface was material was characterized on the basis of the electrical resistivity, a total of 6 VES were carried out on the failed section of the road (with maximum of AB/2 = 55m) to determine the depth extent of the incompetent material and to further reveal the nature of deeper earth materials. The result of the 2-D ERT was interpreted to produce 2-D psedosection using interplex 2-D and suffer 13 softwares while the VES was interpreted using Inteplex 1D and Zodhy softwares.

Samples from the failed section of the road were collected at depth of 1.5m and were subjected to geotechnical test. A total of three (3) were collected and instrument used includes; hand auger and its extension, air tight sample bag, masking tape and marker.

The samples were analyzed at Arab contractors A.O.O NIG .LTD. located at Alakwo, Owerri Imo state Nigeria. The laboratory parameters analyzed include: Sieve analysis, Atterberg limit (plastic limit, liquid limit, plastic index and linear shrinkage), compaction tests (maximum dry density/optimum moisture content), soaked CBR test, natural moisture content test (by speedy moisture tester) and specific gravity test. These tests were analyzed in accordance with the general specification Road and Bridges, Volume II, revised 1997, Government of the federal republic of Nigeria and classified using American Association of State Highways and Transportation Officials (AASHTO) and Unified Soil Classification System.

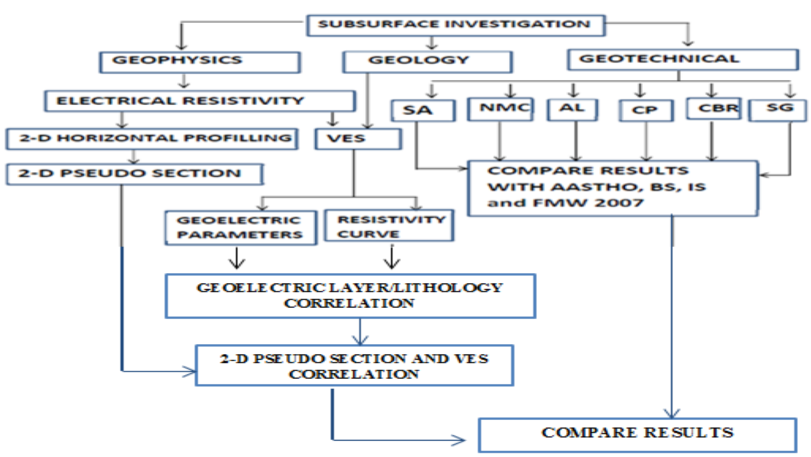

Fig. 2: Flow chat of adopted methodology

NMC: Natural moisture content, SA: Sieve analysis, AL: Aterberg limit, CP: Compaction test, SG: Specific gravity, CBR: California bearing ratio, VES: Vertical electrical sounding

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4 RESULTS AND DISCUSION

4.1 Geophysical results

4.1.1 2-D ERT

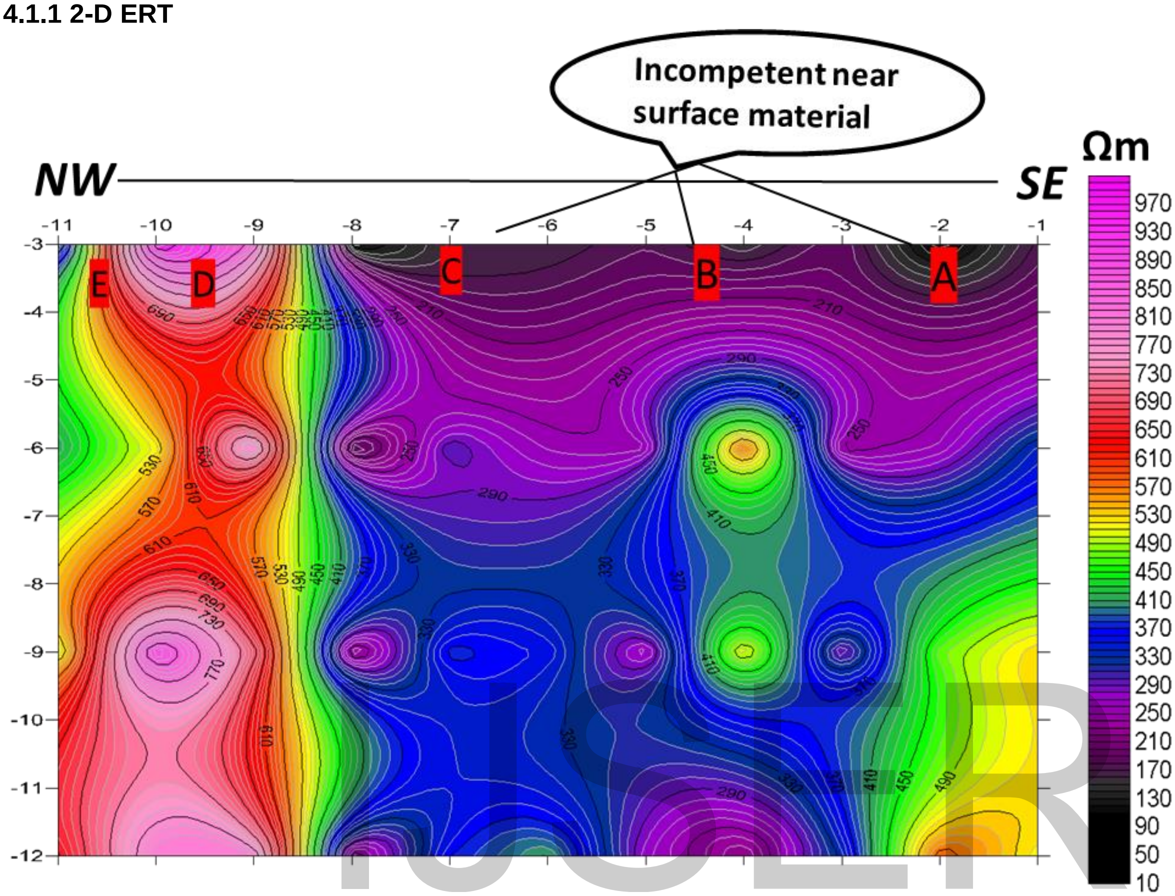

Fig. 3: 2-D ERT along Orsu-Ihiala road

The resistivity of earth material has a relationship with the strength of the material. Earth materials having low resistivity may generally indicate poor strength. At the near surface (0-4m) the resistivity at the Southeastern part of the road is relatively low while resistivity of the Northwestern end is relatively high and this corresponds to the failed and partially stable portion of the road respectively. The area highlighted zones (A, B and C) represent the low resistivity (less than 130Ωm) materials interpreted to be clay deposit and are found on the Southeast area. It can be observed that this clay deposit diminishes towards the Northwestern part of the road as a result of possible transition from the clay rich Ameke Formation to the sand rich recent Meander belt (See Fig 1 and 3). It should be important to note that this recent Meander belt is a product of the weathered and eroded Benin Formation coming from the upland to the downland. The most failed portion of the road was observed to be at Amaebo LGA and this represents the shallowest elevation (151m). Water through run-off is most likely to end in this section and this could mean intense volume change in the clay, with a resultant effect of rapid swelling and shrinkage when water enters or leaves the clay (water variation during in the clay during wet and dry season). The department of Geotechnics Federal Ministry of Works Nigeria has always stressed the nature of the subgrade materials to be the root causes of major premature road failure in Nigeria [8]. And this could be the case for the Orsul-Ihiala road. The zone represented by D and E represent the fairly stable and stable part of the road with resistivity values of 430Ωm and 900Ωm respectively. These zones were interpreted as sand with varying clay content (clayey sand).

4.1.2 VES

6 VES were carried out at the failed portion of the road (Zone A, B and C), in other to further define the earth materials in deeper section. The results of the VES were interpreted using Zohdy and Interplex1D software and it was guided by the simple analysis of field data. The characteristics of the VES curve were determined through the shape of the curve. By implication both the features of each layer and their maximum depth of penetration was determined by observing the VES curves (See Fig 4-9).

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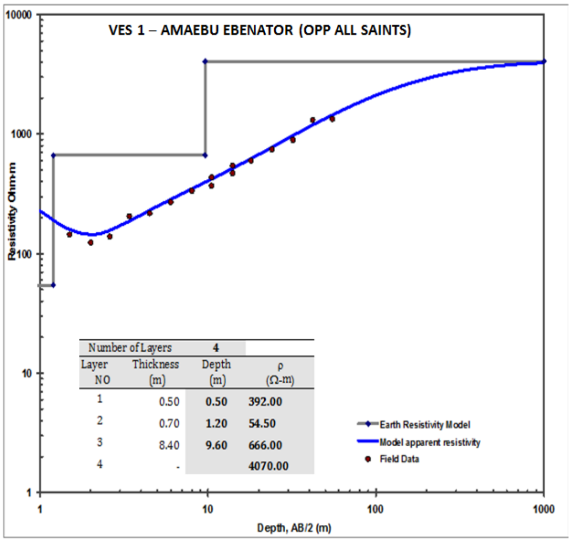

Fig. 4: Geoelectric curve for VES 1

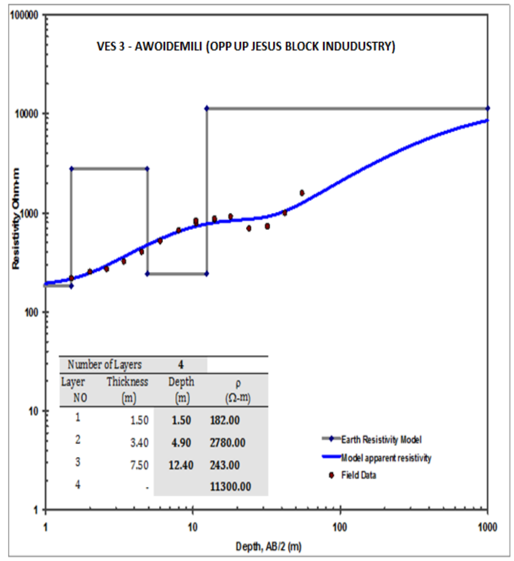

Fig. 7: Geoelectric curve for VES 3

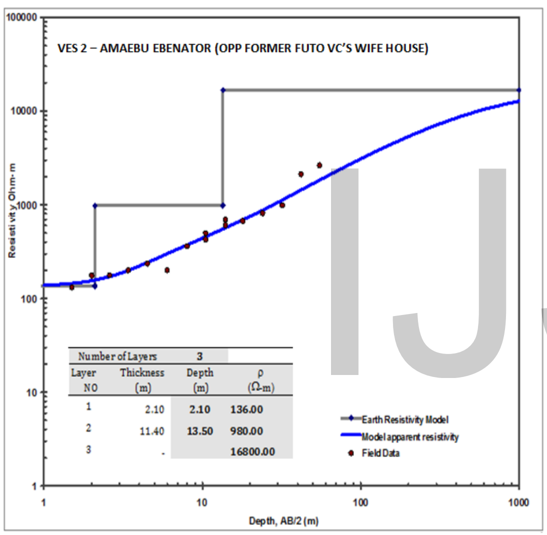

Fig. 5: Geoelectric curve for VES 2

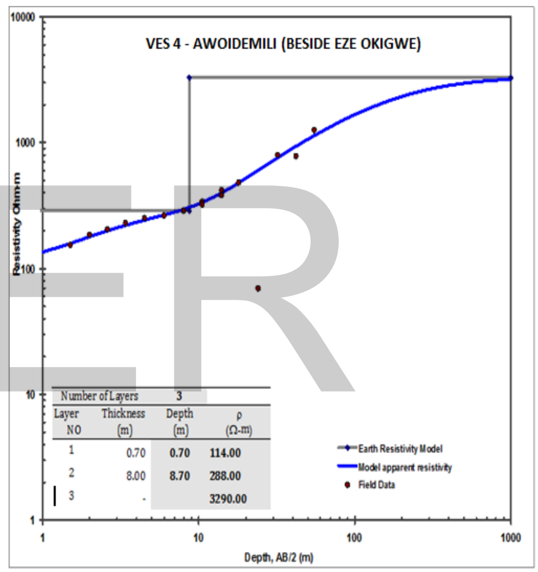

Fig. 8: Geoelectric curve for VES 4

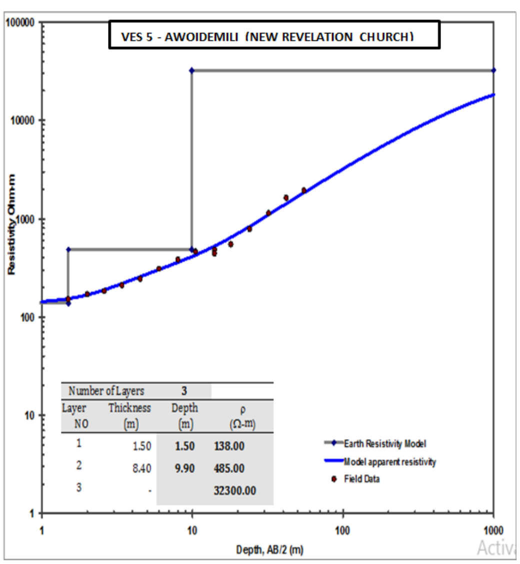

Fig. 6: Geoelectric curve for VES 5

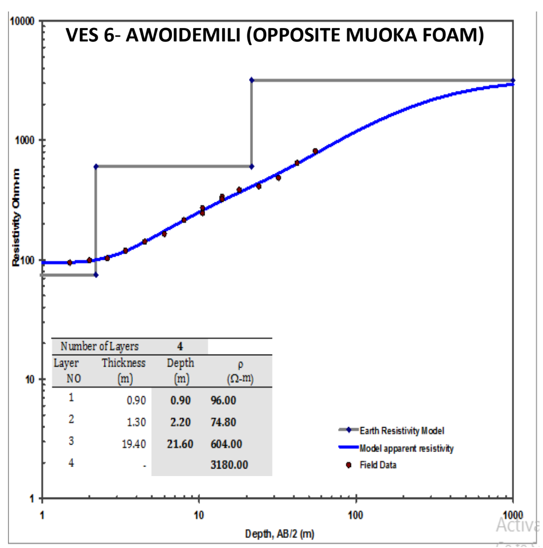

Fig. 9: Geoelectric curve for VES 6

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Geo-electric section correlation

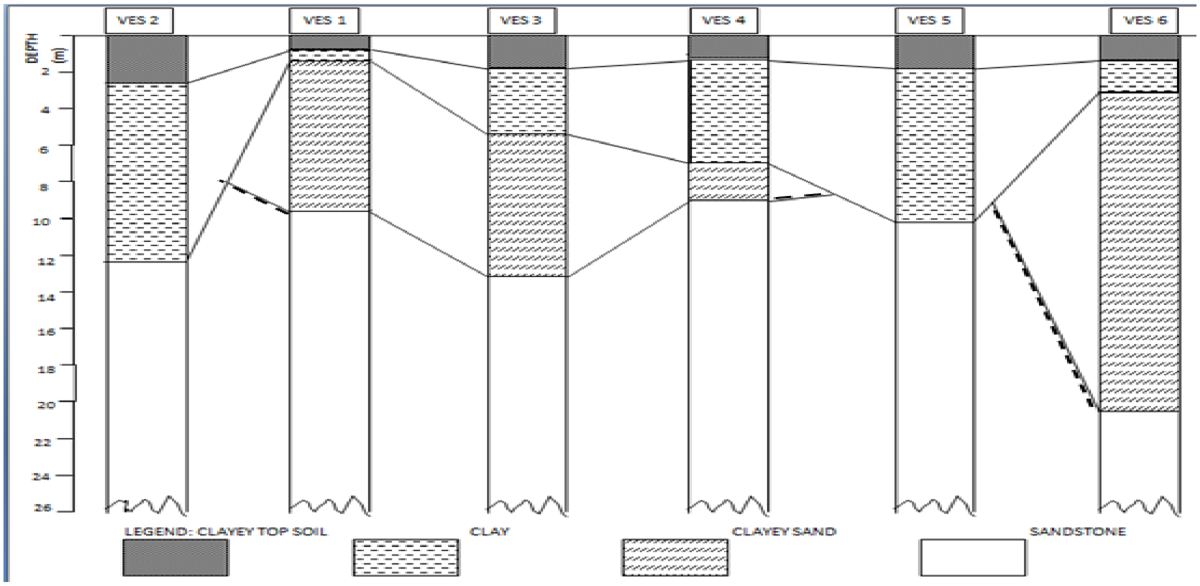

Fig.10: Geoelectric section of the Orsu-Ihiala road

Six (6) VES carried out at zone A – C (zones of incompetent near surface earth materials) was stacked side by side along the SE – NW direction (see Fig.1 and 10). Maximum penetration depth is approximately 37m, this will allowed the visualization of the soil distribution to this depth. This correlated geoelectric section was used to revalidate the classification of the near surface geomaterials as incompetent and also to further investigate properties of deeper geomaterials in the subsurface.

The geo-electric section was deduced from the VES curve (see Fig.4 - 9) and the geo-electric section as shown in the Figure 10 delineates four subsurface layers which were defined as clayey top soil, clay, clayey sand and sandstone. The soils resistivity values range from 54.50Ωm to 32300Ωm, corresponds to clay and sand respectively. First Layer was identified as lateritic clayey top soil with resistivity of 96Ωm - 392Ωm and thickness of 0.5m – 2.1m. The second layer was identified as clay/clayey sand with resistivity of 54Ωm - 980 Ωm and thickness of 7.5m– 19.4m while third/fourth layer was identified as sand with resistivity of 3290Ωm - 32300Ωm

The geoelectric correlation show a fair-good correlations of the soil type distribution, dotted lines were used to mark doubtable contacts. At an average of 1.7m below the surface an incompetent soil was observed across the VES points indicating that the near surface (Subgrade) is of poor quality. This material was further described as clayey topsoil and it correlated very well with the geotechnical result of the analyzed samples. It could also be observed that at an average of 12m below, the quality of the soil improved (sand with resistivity above 2700Ωm). This is possible indication that even with deeper competent geomaterial, a poor subgrade material could still lead to significant road failure.

4.2 Geotechnical Results

The results of the geotechnical tests carried out on the three soil samples collected along the failed portion of the road are shown below (See Fig.11- 23).

4.2.1 Sieve analysis

Results of sieve analysis indicated 26% passing of sieve seize 0.75mm for sample S03 which when compared with the AASTHO M145, BS and FMW, 1997 revealed fair-good subgrade materials for road and bridges. The implication of the result is that only 26% of the total grain size of S03 could be classified as clay. Analysis of sample S02 and S01 showed that S02 and S01 can be classified as slity-clay, composed majorly of compressible clay material with above 40% passing of sieve size 0.75mm. It could be observed that fineness (at 1.5m depth) generally increases along the Southeastern direction of the road and this may be attributed to the local geology as it is observed to be the transition of the clay rich Ameke Formation to the Recent sand rich Mender belt (weathered and eroded Benin sand).

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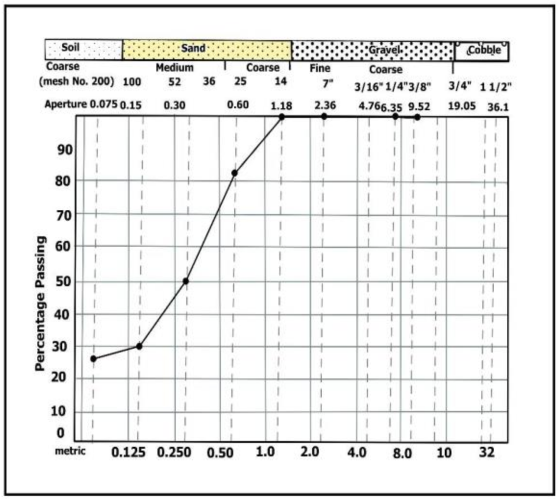

Fig. 11: Sieve Analysis of sample S03

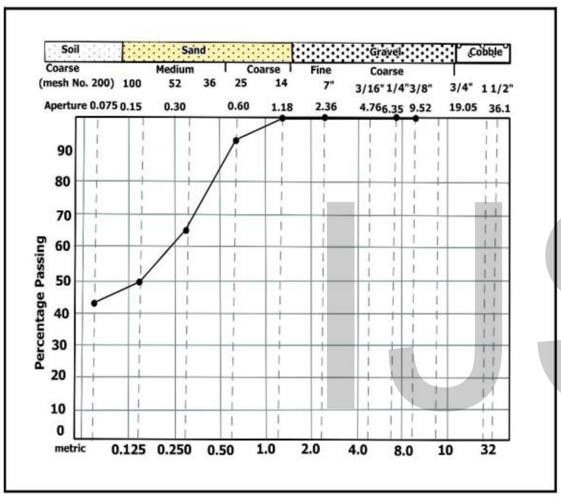

Fig. 12: sieve Analysis of sample S02

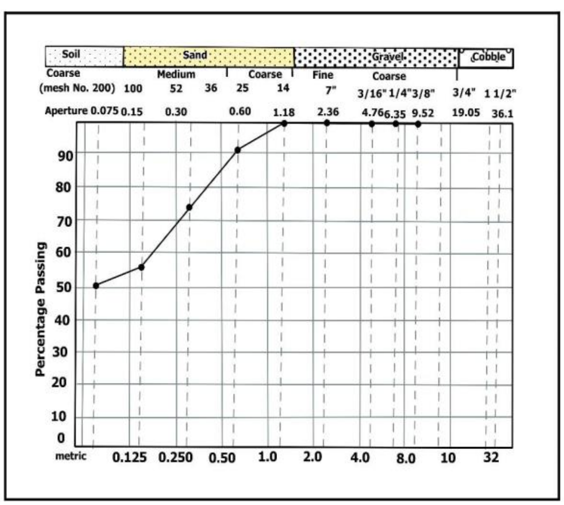

Fig.13: sieve Analysis of sample S01

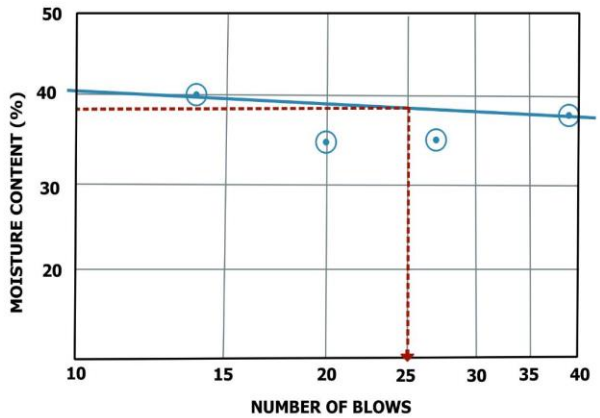

Fig. 14: Atterberg Limit for Sample S03

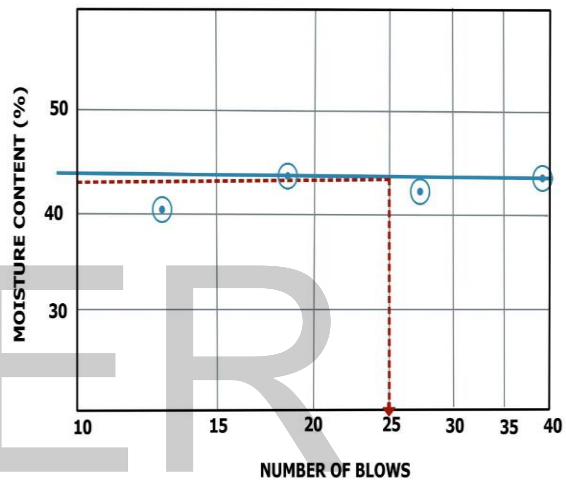

Fig.15: Atterberg Limit for Sample S02

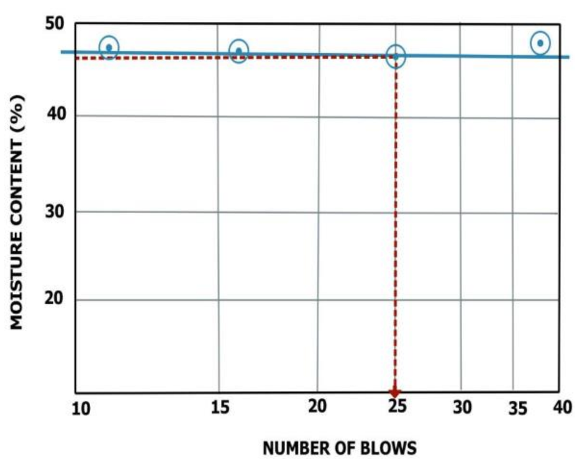

Fig.16: Atterberg Limit for Sample S01

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4.2.2 Atterberg Limit

The Atterberg Limit is used to define the plasticity of the soil (the critical water content that will allow the soil to behave in a semi-solid, plastic, liquid or viscous manner) see Fig.17. The result revealed that the Plasticity index (a computation of corresponding Liquid Limits (LL) and Plastic Limit (PL)) are relatively low (16.9%, 7.1% and 14.9% for S03, S02 and S01 respectively). The LL for S03, S02 and S01 are 38.5%, 42.5% and 46% respectively and are referred to as intermediate plasticity [3] while their swell potential are classified as medium [9].

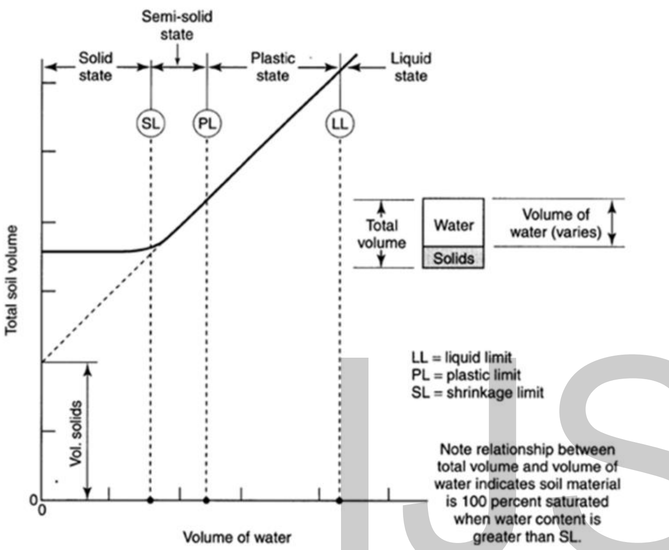

Fig.17: Variation of total soil volume and consistency with change in water content for a fine-grained soil (McCarthy and David 2006).

Table 2: The relationship between LL, SL, plasticity and potential of swell (Holts & Gibbs 1956)

LL	SL	Plasticity	Swell potential	Description
< 35	> 15	Low	Low	Lean or silty
35 - 50	10 - 15	Intermediate	Medium	Intermediate
50 -70	7 -12	High	High	Fat
70 -90	< 11	Very high	Very high	Very fat
>90		Extra high		Extra fat

The PL of 21.6%, 35.4% and 31.1%, and LL of 38.5%, 42.5% and 46% for S03, S02 and S01 respectively is indicative of possible presence of calcium rich Kaolinite mineral (see table 3) as the plasticity of soil is influenced by the amount of its clay fraction and the type of clay minerals present [3] The plasticity and liquid limit decreases in the following order.

Montmorillonite> Chlorite >Illite> Kaolinite

Table 3: Relationship between the LL, PL and the clay mineral (Adopted after Carter and Bentley, 1991)

Clay minerals	Ca^+		Na^+	
	LL	PL	LL	PL
Montmorillonite	123 – 177	65 – 79	280 – 700	86 – 97
Illite	69 – 100	36 – 42	61 – 75	34 – 41
Kaolinite	34 – 73	26 -36	29 – 52	26 – 28

The result of the linear shrinkage can be classified as medium/very high potential of swell [9]. Result shows that sample S01 and S03 has medium potential of swell while sample S02 has very high potential of swell and this might be the reason for the consistent failure of this road at Amaebo LGA (this have the shallowest elevation, allowing more ponding runoff water) even shortly after repair.

4.2.3 Compaction

The maximum dry density (MDD) and optimum water content (OMC) is 1.776g/cm^3 and 14.4% for S03, 1.713g/cm^3 and 14.6% for S02 and 1.692g/cm^3 and 14.4% for S01. The decreasing MDD and increasing OMC along SE profile of the road conforms with 2-D ERT distribution of the near surface material as incompetent clayey material (this is because clay has high tendency of retaining water and hence would have low dry density with high moisture content). This is an indication that the soil is generally loose and will make a poor subgrade material.

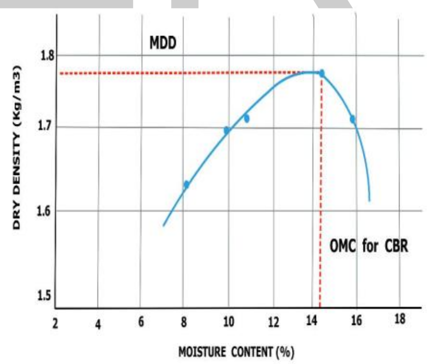

Fig. 18: Compaction test for Sample S01

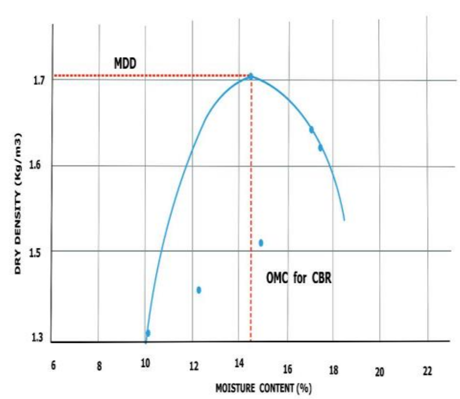

Fig.19: Compaction test t for Sample S02

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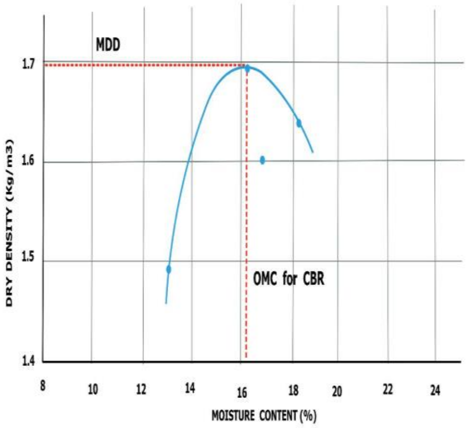

Fig.20: Compaction test for Sample S03

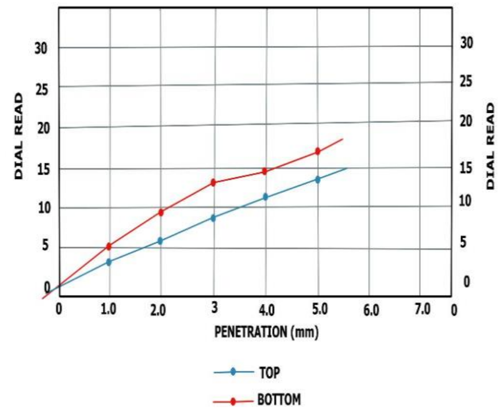

Fig. 21: CBR for Sample S03

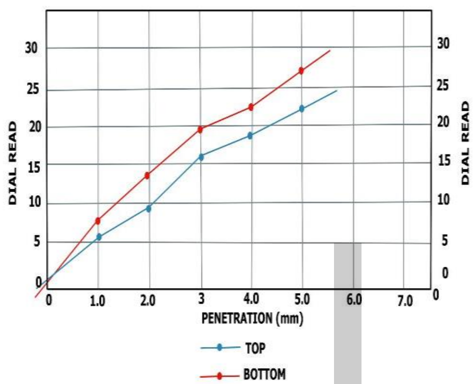

Fig.22: CBR for Sample S02

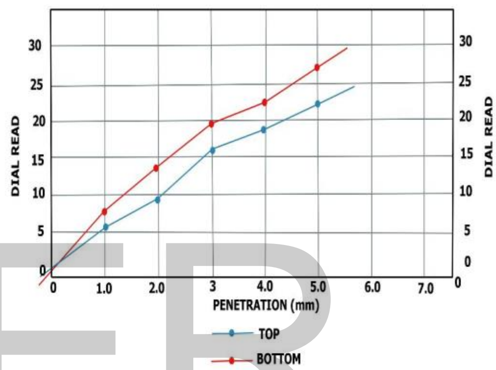

Fig.23: CBR for Sample S01

4.2.4 California Bearing Ratio (CBR)

The California Bearing Ratio (soaked) for sample S03, S02 and S01 are slightly under, slightly above and much more above the Nigerian FMW specification of Roads and bridges respectively. It can be noted that the soaked CBR increases NW along the Orsu-Ihiala road. The low CBR for sample S03 (even though the soil is classified as granular material), is evidence that the soil is highly porous and with moisture influx will be highly damaging to the road pavements erected on it**.**

4.2.5 Natural moisture content

The moisture content of the samples is 18.2%, 24.2% and 25.4% for S03, S02 and S01 respectively. This result conforms to the sieve analysis that classified S03 as granular material**.** When compared with the OMC this result showed a linear relationship. As expected Natural moisture content increases with increasing optimum water content. The NMC and OMC are in conformance and this translates to a stronger confidence of the interpreted results.

4.2.6 Specific gravity

The specific gravity of studied samples is 2.401gm/cm^3, 2.586gm/cm^3 and 2.413gm/cm^3 for S03, S02 and S01 respectively. Which indicates moderate organic content and moderate porosity (especially sample S03).

4.3 Correlating Geophysical and Geotechnical Results

At near surface (below 2m), the 2-D ERT, VES and geotechnical investigation all pointed out that the earth material is of incompetent nature. There is a strong tie between geophysics and geotechnics which is evident as a low resistivity value of the earth material corresponds to the poor geotechnical properties of the samples. The 2-D ERT, VES and geotechnical results also show that at approximately 1.7m the clay richness increases toward the Southeast along the profile which can be explained as possible transition from sandstone of the recent Meander belt to the clay rich Eocene sandstone of the Bende-Ameke Formation.

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5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Having carried out the investigation of the failure of Orsu-Ihiala road, it could be necessary to conclude that:

1. The road payment is founded on a clayey subgrade
2. The clayey content diminishes along NW part of the road as a result transition from the clay rich Ameke Formation to the sand rich recent Meander belt.
3. This clayey subgrade material showed geotechnical results that are beyond the standard for subgrade materials
4. The incompetent clayey constituent of the material (the subgrade soil) on which the road pavement was built on, was the possible cause of the failure of the road. This is because clayey subgrade soils have the propensity of engrossing water which makes it swell and under enforced wheel load stress will subsequently result to road failure, as witnessed at the study area.
5. Poor drainage system was also observed to be a contributing factor responsible for the possible failure of the road.
6. The failure of the road is more geological related than technical (no evidence of used sub-standard engineering material)

5.2 Recommendations

Having carefully carried out this research, the following are therefore recommended:

1. The soils could be improved by stabilization, there are different available stabilization methods
2. Alternatively, a cut to spoil method could be adopted, provided they are within economic haulage distance from the construction site
3. The poor drainage pattern can be overcome by construction of well-structured drainage systems
4. For better understanding of the mineralogy, samples should be investigated using X-ray diffraction techniques.

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