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Geoengineering Assessment of Subgrade Highway Structural Material along Ijebu Owo – Ipele Pavement, Southwestern Nigeria

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Abstract-- **Geochemical, geotechnical, and geophysical investigations were carried out along Migmatite gneiss underlain Iyere – Ipele pavement (under construction) in order to assess the suitability of the imported subgrade soil. Also static water level (SWL) was obtained from five open wells along the highway. The geotechnical tests include specific gravity, grain size analysis, consistency limits, consolidation, compaction, and California Bearing Ratio (CBR), and shear strength; while geochemical tests were analyzed using X-ray fluorescence and Atomic Absorption Spectrophotometer (AAS). The results show that SiO_2, Al_2O_3 and Fe_2O_3 constitute an average of 46.2%, 23.30% and 26.54% respectively of the soils chemical composition. The silica- sesquioxide ratio of the samples ranges from 0.89 to 0.96 and classified as true laterite. The topsoil along the highway is made of moderately competent/competent soil with resistivity ranging from 298 – 924 ohm-m and thickness of 3.1 - 8.2 m. The SWL varies from 3.3 - 5.5 m with an average of 4.3 m (moderately low). The soils are characterized by high California Bearing Ratio values, moderate shear strength (150 – 200kpa), and unconfined compressive strength (300 – 420kpa) with predominant kaolinite clay mineralogy group. The AASHTO and USCS classification system rate the soils as good and fair/good respectively.**

Keywords- **AASHTO; silica-sesquioxide, geochemical; geoelectric section; highway; shear strength**

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I. Introduction

The frequently distinct engineering behaviour of naturally occurring construction materials within subtropical and tropical regions, as compared with those in temperate zones, has been identified as a key factor in determining the long-term engineering success or failure of road projects in developing countries [1] and is a function of the impact of their interaction with the road environment and the weathering processes. The majority of materials used in highway construction, such as fill materials for embankment construction, aggregates for base and surface courses, are naturally occurring materials. These materials are usually available within certain proximity to the project site and meeting certain physical and chemical characteristics. The quality of a civil engineering project depends on effective preconstruction investigation, material quality, skill and commitment of the work force. These may require understanding of existing ground conditions; properties of materials to be excavated; equipment that will be needed to excavate, grade, transport material to and from site; and dewatering below grade work if necessary; shoring to protect excavations (if need be).

The sub-grade can be defined in terms of location as the upper 600mm of the road foundation. For an elevated highway this will be below the embankment fill and for at-grade sections this would be immediately below the pavement section (Fig. 1). The character of in situ sub-grade material is determined by the geological and weathering conditions of the soil-rock profiles underlying the road. The suitability of the sub-grade material is a function of internal factors such as soil-rock type and its interaction with external factors such as climate and the local moisture regime [2]. Embankments are constructed over prepared and stabilized subgrade. Typical requirement for elevated embankment includes the use of good drainable material spread in thin lifts and compacted to the required density. Where good material sources are easily available, embankment materials falling between the classification of A-1-a and A-4 per AASHTO M145 are preferred. Where a good source is not readily available, stabilization of existing materials should be considered.

This project work deals with the engineering geological assessment of selection and use of naturally occurring materials (in-situ) for pavement construction and earthwork embankments, along Iyere – Ipele roadway (under construction) in Ondo State, Southwestern Nigeria (Fig. 2), which is classified as “Trunk B” road [3], under the ownership and management of Ondo State government. The use of extreme cohesive/expansive and low bearing capacity soil as sub grade soil resulting in prolonged consolidation and

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unnecessary settlement of the roadway is gradually becoming a norm during construction of most Nigeria roads. Even though the coordinator of the project was reluctant in releasing important data as regard soil tests results for further analysis. However the attitude didn't debar the researcher in taking samples, and inspect the site condition in terms material, equipment, and manpower. One of the main reasons why highways in the country fail is that adequate knowledge of the soil situation is not obtained before the commencement of the road work. Knowledge of the soil situation helps both at the design and construction stage of the road. The subgrade should be tested and found to be adequate before usage. The soil for sub base and base course even the material for the wearing course and the pavement must be found to meet the standard before they will be accepted for usage in road construction work.

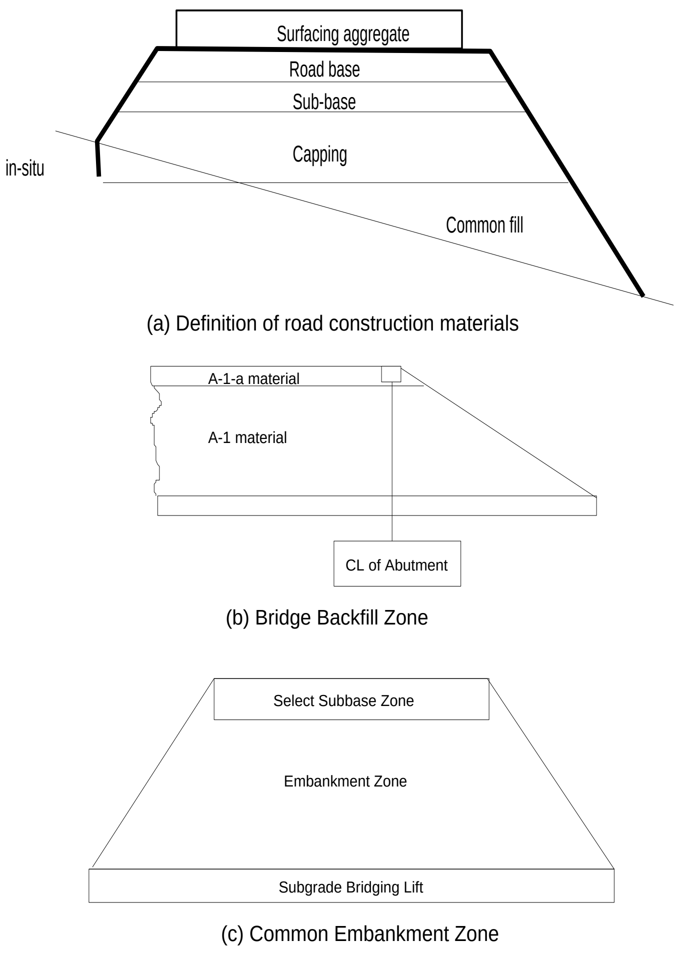

Fig. 1. Schematic diagram of roadway structural elements [4]

II. DESCRIPTION OF THE STUDY AREA

The Iyere-Ipele highway is located within Owo Local Government Area of Ondo State, Nigeria. It is located between longitudes E5º 35' and E5º 40', and latitudes N7º 07' and N7º 10' (Fig. 2). The road is about 10 km, and extended from Mobil in Owo to Ipele town. The area is characterized by gently undulating relief. The topographic elevation varies generally from less than 340 – 362 m. The area is drained by rivers Ogbese and its tributaries. The drainage pattern is dendritic. The road falls within the Okemesi soil type, derived from Quartz Schist and Gneisses. The soil are very coarse textured, gravelly, pale grayish brown to brown, usually sand soils (Table 1). Also residual soils such as laterites, resulting from the weathering and decomposition of the Precambrian Basement rocks cut across the various rock types in the area. The highway pavement was constructed with/or on the lateritic materials derived from either the in-situ weathering of the underlying lithology very close to the site or brought to complement the existing ones (Fig. 3). Often very shallow over quartz rubble, associated with a topography of steep sided elongated ridges (Fig. 4). Laterites are known to be highly weathered materials rich in iron content and aluminium sesquoxides with varying content of silica and kaolinite depending on the degree of weathering and decomposition.

The study area lies within the crystalline Basement Complex rocks of southwestern Nigeria. The identified lithologic units within the area include; quartzites, quartz schist, migmatite, granite and granite gneiss. However the road is founded on migmatite gneiss and quartz schist (Fig. 5). The migmatite gneiss is strongly foliated, composed of mafic minerals such as biotite, hornblende, and felsic minerals of quartz and feldspar. About 77% of the minerals are quartz, biotite and feldspar with quartz having 40% as the most dominating mineral. In general terms metamorphic classification can be considered as function of mineralogy, texture and fabric. According to Table 2, the rock underlying the highway can classified as geotechnically moderate – strongly anisotropic rocks.

Fig. 2. Location of the Study Area on the Map of Nigeria

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III. METHOD OF STUDY

The study entails geophysical survey, geotechnical investigations, and static water level determination. Before the field surveys, desktop and reconnaissance studies were conducted, followed by geologic study of rocks especially outcrops. Geotechnical investigation involves collection of five (5) disturbed representative samples at every 1 km along the roadway (Fig. 6). Properties tested geochemical and geotechnical tests. The geotechnical tests include the particle size distribution, Atterberg limits, strength, specific gravity, consolidation test, shear test, California Bearing Ratio. Electrical resistivity technique was employed in studying the general geological subsurface lithology and structure [5] along one traverse of length 120m. The geophysical investigation was carried out using the Vertical Electrical Sounding (VES) with Schlumbeger types of electrode configuration. The collected soil samples from each horizon of the profiles were analyzed at the soil Engineering Geological laboratory of Federal University of Technology, Akure, Ondo State. The soil samples were geotechnically tested according to the BS 1377 [6] and ASTM [7] procedures. Moisture content (D2216), Atterberg limits (D4318), Particle size analysis (D422), Oedometer test (D2435), compaction (D1557), California Bearing Ratio test (D1883) and confined compressive test.

The chemical analysis was also carried out on the samples to determine the mineral oxides that were present in each sample. The sample were initially sieved using 2 mm sieve and 2 g of the sieved sample was taken, after which they were put into digesting tube and digested using and HCl, then with $HClO_4$ and H_2O_2. The samples were heated to dryness and make up with distilled water in a 100 ml volumetric flask. The resultant solution was analyzed using X-ray fluorescence and Atomic Absorption Spectrophotometer (AAS). The silicon oxide and Aluminium oxide were analyzed with nitrous oxide while Iron-oxide with oxyacetylene. P_2O5 and TiO_2 were determined by a colorimetric method. The steps were repeated for the remaining samples, and the samples were subsequently allowed to stand for at least one hour in the solutions while they were frequently stirred. The extent to which a residual soil has been laterized may be measured by the ratio of silica (SiO_2) remaining in the soil (except for discrete pebbles of free quartz that may remain) to the amount of Fe_2O_3 and Al_2O_3 that has accumulated. The silica : sesquioxide ratio (S_e) as shown in equation 1, has served as a basis for classification of residual soils (Table 3). Ratios less than 1.33 have sometimes been considered indicative of true laterites, those between 1.33 and 200 of lateritic soils, and those greater than 2.00 of non-lateritic tropically weathered soils.

$$S_e = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \qquad (1)$$

Fig. 3. Some of Site photographs taken along the roadway showing different construction processes and machine/equipment.

TABLE I
Description of Soil Associations in the Study Area (Adapted from [8])

S/N	Soil Association	Parent Rock	Drainage	Property/Characteristics
1	IWO	Coarse grained Granites and Gneisses	Well Drained	Coarse textured, greyish brown, sandy to fairly clayey soils, overlying weathered rock material. Fresh rock at depths of 7 to 9 feet, shallower in steep slopes. Fairly frequent rock outcrop
2	ONDO	Medium grained Granites and Gneisses	Well Drained	Medium to fine textured, orange brown to brownish red, fairly clayey soils overlying orange, brown and red mottled clay. Fresh rock at depths of 10 – 14 feet; occasionally rock outcrop.
3	OKEMESI	Quartz Schist and Gneisses	Well Drained	Very coarse textured, gravelly, pale grayish brown to brown, usually sand soils. Often very shallow over quartz rubble, associated with a topography of steep sided elongated ridges

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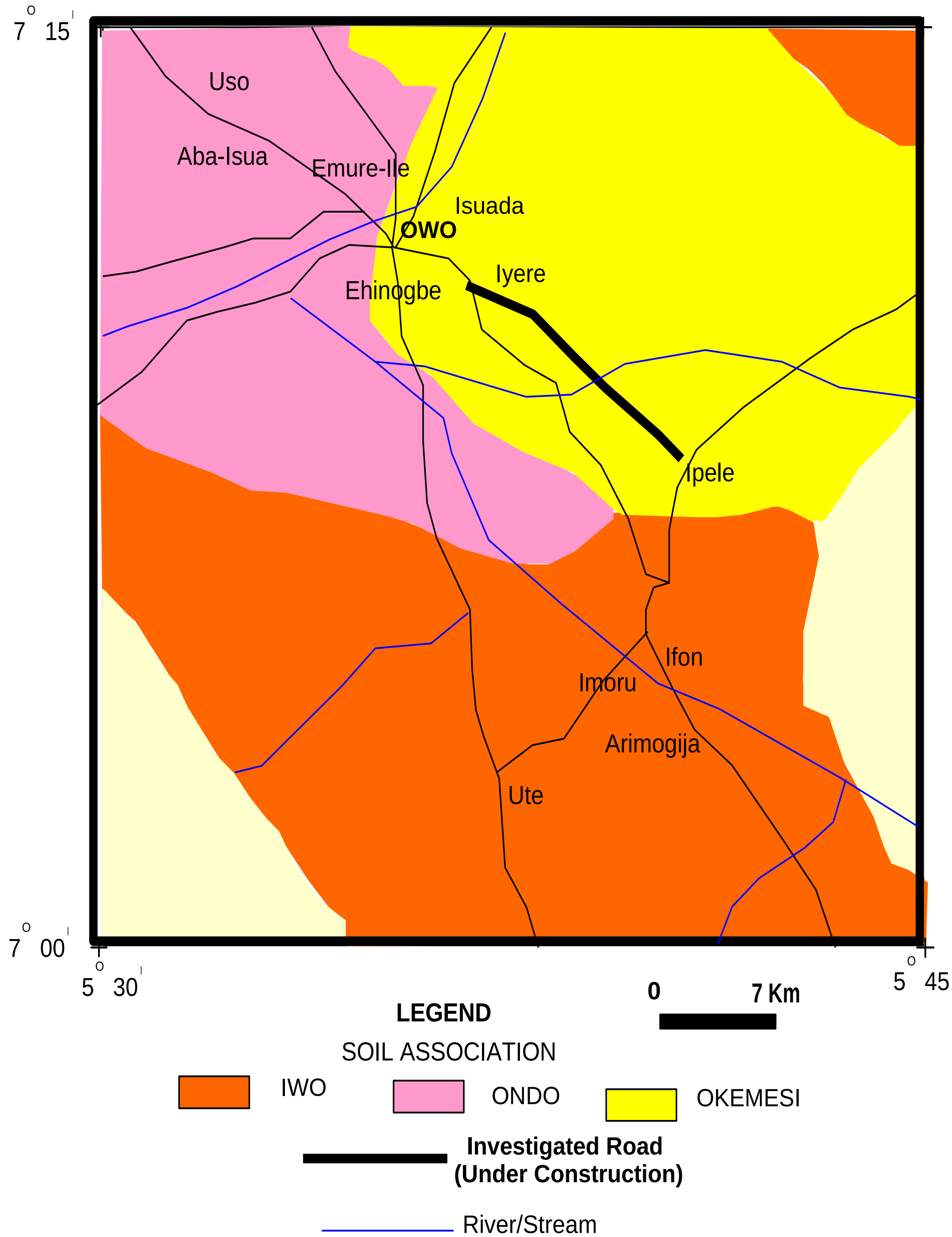

Fig. 4. Soil map around the Study Area (extracted from [8])

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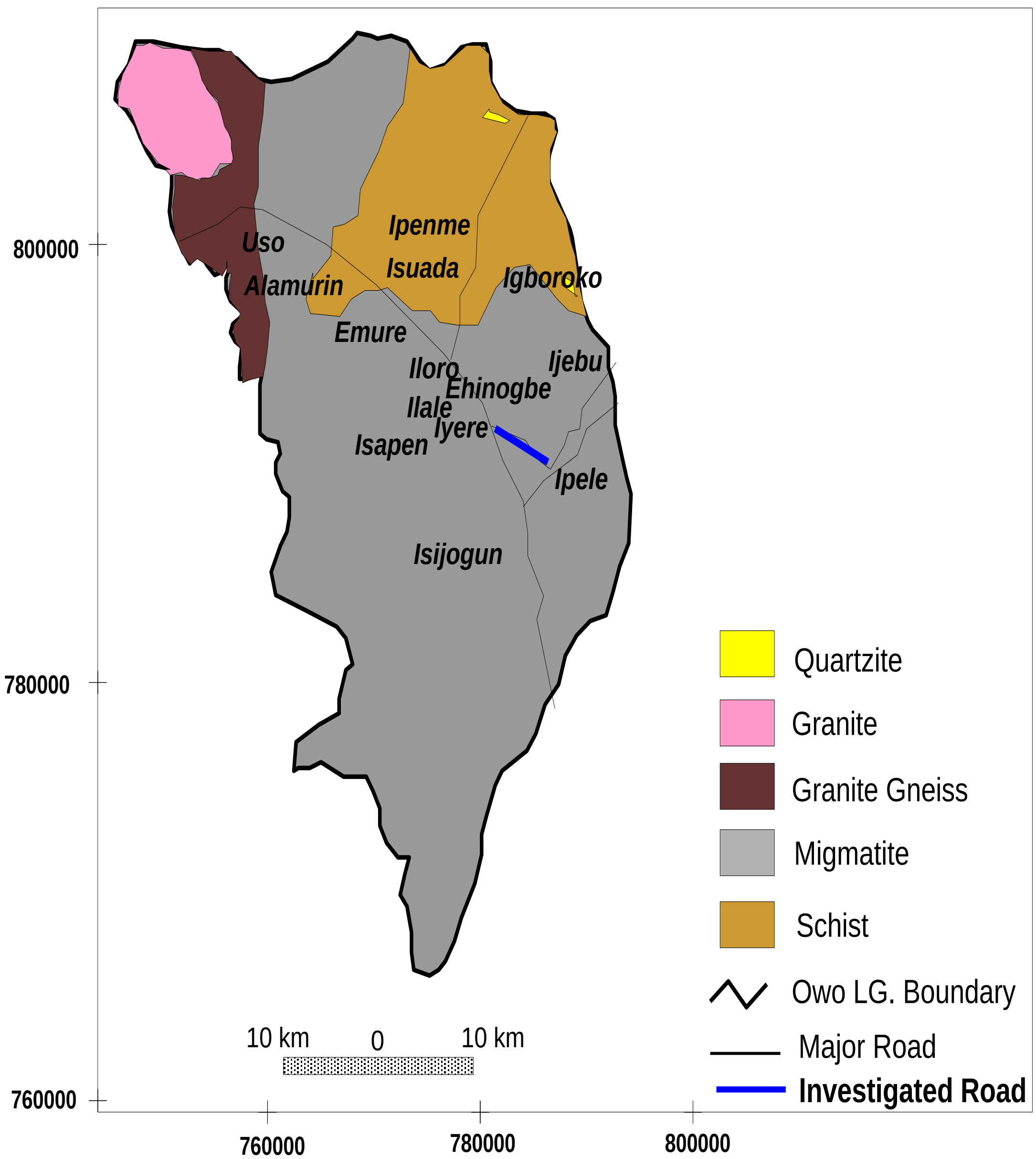

Fig. 5. Geological map of the Study Area (modified after [9])

TABLE 2
Basic Classification of metamorphic Rocks

Geotechnical Grouping	Typical Rock Type
A. Isotropic	Massive Quartzite Marble Hornfels
B. Moderately Anisotropic	Gneiss Bedded Quartzite Amphibolite
C. Strongly Anisotropic	Shale/Slate Phyllite Schist

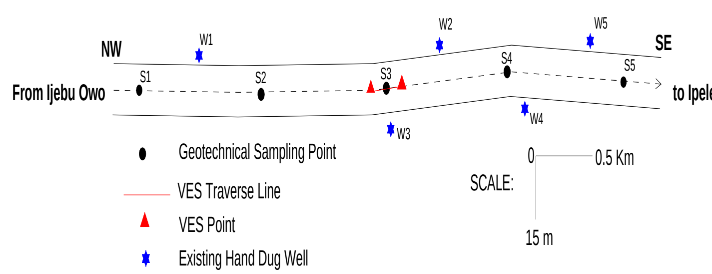

Fig. 6. Simplistic Sketch of Data Acquisition Map for the Study

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IV. RESULT AND DISCUSSION

A. Geochemical Analysis

The basic quality and performance selection requirements for fill material can be considered as placed stability; resistance to erosion, degradability and workability which depends on the mineralogical make-up of the soil [10]. The result of chemical analysis showing the different oxide forms of the major elements contained in the soil samples, and silica-sesquioxide ratio is presented in Table 3. The samples are well dominated (in ascending order) by SiO_2 - Fe_2O_3 - Al_2O_3 with a little over 95 % of the materials being characterized by these three elements oxide. The remaining less than 5% of the composition is dominated by Na_2O and K_2O. The SiO_2 varies between 45.30 – 47.10%. Fe_2O_3 and Al_2O_3 of the samples range from 25.00 – 28.32% and 21.4 – 25.40% respectively. The % Na_2O and K_2O concentrations also vary between 1.11 – 1.19 and 1.23 – 1.68 respectively. All the samples show high concentrations of SiO_2, Fe_2O_3, and Al_2O_3 with little or no variation.

TABLE 3
Classification of Soil based on Silica:Sesquioxide

Soil Type	Sesquioxide
Laterite Soil	1.33 or less
Lateritic Soil	1.33 – 2.00
Non-Laterite	2.00 and over

TABLE 4
Result of the Chemical analysis of the lateritic soil samples

Oxides (%)	S1	S2	S3	S4	S5
MgO	0.23	0.22	0.22	0.21	0.22
Al_2O_3	25.40	24.39	22.74	21.4	22.56
SiO_2	45.30	46.20	45.60	46.80	47.10
P_2O_5	0.00	0.00	0.11	0.01	0.11
Na_2O	1.19	1.16	1.12	1.11	1.15
k_2O	1.25	1.68	1.41	1.23	1.43
CaO	0.17	0.26	0.24	0.21	0.22
TiO_2	0.70	0.90	0.63	0.53	0.81
V_2O_5	0.11	0.09	0.13	0.11	0.13
Cr_2O_3	0.03	0.05	0.05	0.04	0.05
MnO	0.03	0.05	0.05	0.03	0.02
Fe_2O_3	25.50	25.00	27.70	28.32	26.20
S_e	0.89	0.93	0.90	0.94	0.96
Class	True Laterite	True Laterite	True Laterite	True Laterite	True Laterite

The enrichment of Fe_2O_3 in each of the samples can be attributed to chemical weathering of mafic mineral composition of the parent rock and ferruginization of Fe-bearing minerals [11]. Also enrichment of Al_2O_3 can be attributed to the weathering alteration of feldspar to clay mineral causing leaching of Al_2O_3 by infiltrating acid rain/recharge water into the ground. This implies that the subgrade (imported) soil must been from the same parent rock and suggestive of rock rich in aluminosilicates minerals. Silica-Sesquioxide ratio of the ranges from 0.89 to 0.96 and classified as True Laterite according to [12] laterite classification.

B. Vertical Electrical Sounding

The geoelectric section along the traverse established is shown in Figure 7. Lithologically, it is made of topsoil, weathered layer, confined fracture basement, and basement rock. The topsoil is characterized by resistivity ranging from 298 – 924 ohm-m and thickness varying from 3.1 – 8.2 m and composed of clay sand and laterite. The weathered layer underlain the topsoil, and has resistivity ranging between 943 ohm-m and 1264 ohm-m, indicating a lateritic rich weathered layer. The thickness of the weathered layer ranges from 1.3 to 2.4 m. The fractured basement delineated is confined within the fresh basement and show low fracture density with thickness less than 5 m, and resistivity range of 298 – 443 ohm-m. The fresh basement is characterized with resistivity values ranging from 765 – 943ohm-m. Therefore using Table 5 classification, the topsoil along this traverse can be regarded as moderately competent/competent soil material to host and support the under-constructed pavement.

C. Geotechnical Analysis

Table 6 presents the summary of the geotechnical results obtained from five samples. Grain size analysis can be used to characterize the subsoil material for engineering foundation, which can serve as a guide to the engineering performance of the soil type and also provides a means by which soils can be identified quickly.

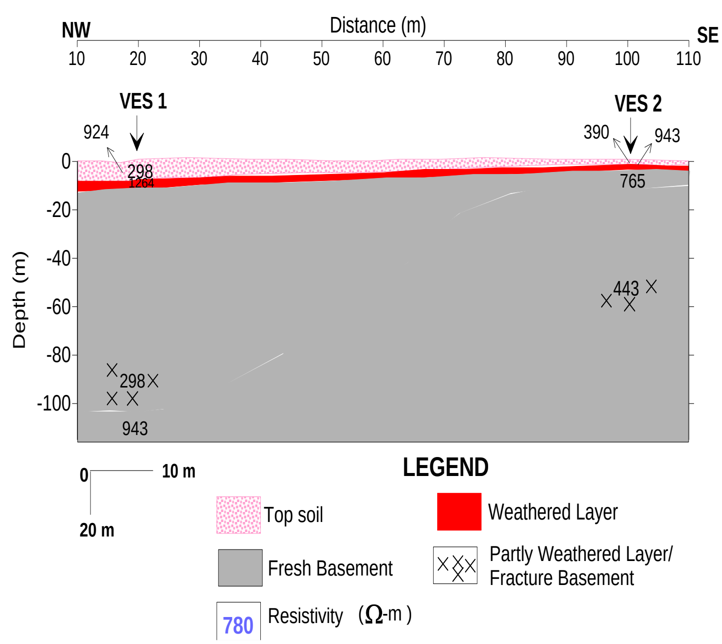

Fig. 7. Geoelectric Section along a segment of the Highway

TABLE 5
Rating of subsoil competence using Resistivity values (adapted from [13])

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App. resistivity range (ohm-m)	Lithology	Competence rating
< 100	Clay	Incompetent
100 – 350	Sandy clay	Moderately competent
350 – 750	Clayey sand	Competent
> 750	Sand/Laterite/Crystalline Rock	Highly competent

The particle size distribution curves obtained from the study area are presented in Table 5, and typical curve is shown in Figure 8. The gravel and sand contents vary from 2.0 – 2.7% and 70.5 – 75.4% respectively. The % silt and clay of the soil samples range from 12 to 18.9% and 7.3 to 13.2%. The composition of the samples is dominated by sand and silt (SM). The Casangrade plasticity chart (Fig. 9) shows that the fines in the samples is dominated by silt of intermediate plasticity except sample S1 which is characterized by clay of intermediate plasticity or compressibility. Most of the soil samples are plotted within the Kaolinite clay mineralogy group. Kaolinite is formed by the alteration of feldspars, feldspathoids and other aluminium silicates due to hydrothermal action. Weathering under acidic conditions is also responsible for kaolinization [14]. The plasticity of clay soil is influenced by the amount of its clay fraction and the type of clay minerals present, since the amount of attracted water held in a soil is influenced by clay minerals [15].

Kaolinite is the chief clay mineral in most residual and transported clays, is important in shales, and is found in variable amounts in fireclays, laterites and are associated with acid igneous rocks such as granites, granodiorites and tonalites, and with gneisses and granulites. Sample S1 is plotted close to illite, which develops as an alteration product of feldspars, micas or ferromagnesian silicates upon weathering or may form from other clay minerals during diagenesis. Like kaolinite, illite also may be of hydrothermal origin. The development of illite, both under weathering and by hydrothermal processes, is favoured by an alkaline environment.

TABLE 6
Summary of Geotechnical Properties of the Analyzed Soil Samples

Tests/Sample	**S1**	**S2**	**S3**	**S4**	**S5**
% Gravel	2.4	2.7	2.0	2.4	2.3
% Sand	72.4	70.5	73.2	75.4	71.5
% Silt	12.0	15.9	16.1	14.3	18.9
% Clay	13.2	10.8	8.7	7.9	7.3
Specific Gravity	2.68	2.66	2.65	2.66	2.65
Liquid Limit (%)	44.4	43.4	45.2	42.6	47.8
Plastic Limit (%)	21.3	30.7	30.1	28.4	31.6
Plasticity Index (%)	23.1	12.7	15.1	14.2	16.2
OMC (%)	12.3	12.5	12.6	13.1	11.8
MDD (Kg/m³)	1726	1743	1748	1725	1771
CBR (%) (unsoaked)	69	64	73	69	74
C_v (m^2/yr)	0.31978	0.33056	0.31431	0.33812	0.30988
UCS (Kpa)	385.10	420.50	392.40	405.70	382.20
Shear strength (Kpa)	177.55	199.60	181.10	189.20	175.60
USCS Group	SC	SM	SM	SM	SM
AASHTO Classification	A-2-7	A-2-6	A-2-7	A-2-6	A-2-7
USCS Rating	Fair to good	Fair to good	Fair to good	Fair to good	Fair to good
AASHTO Rating	Good	Good	Good	Good	Good

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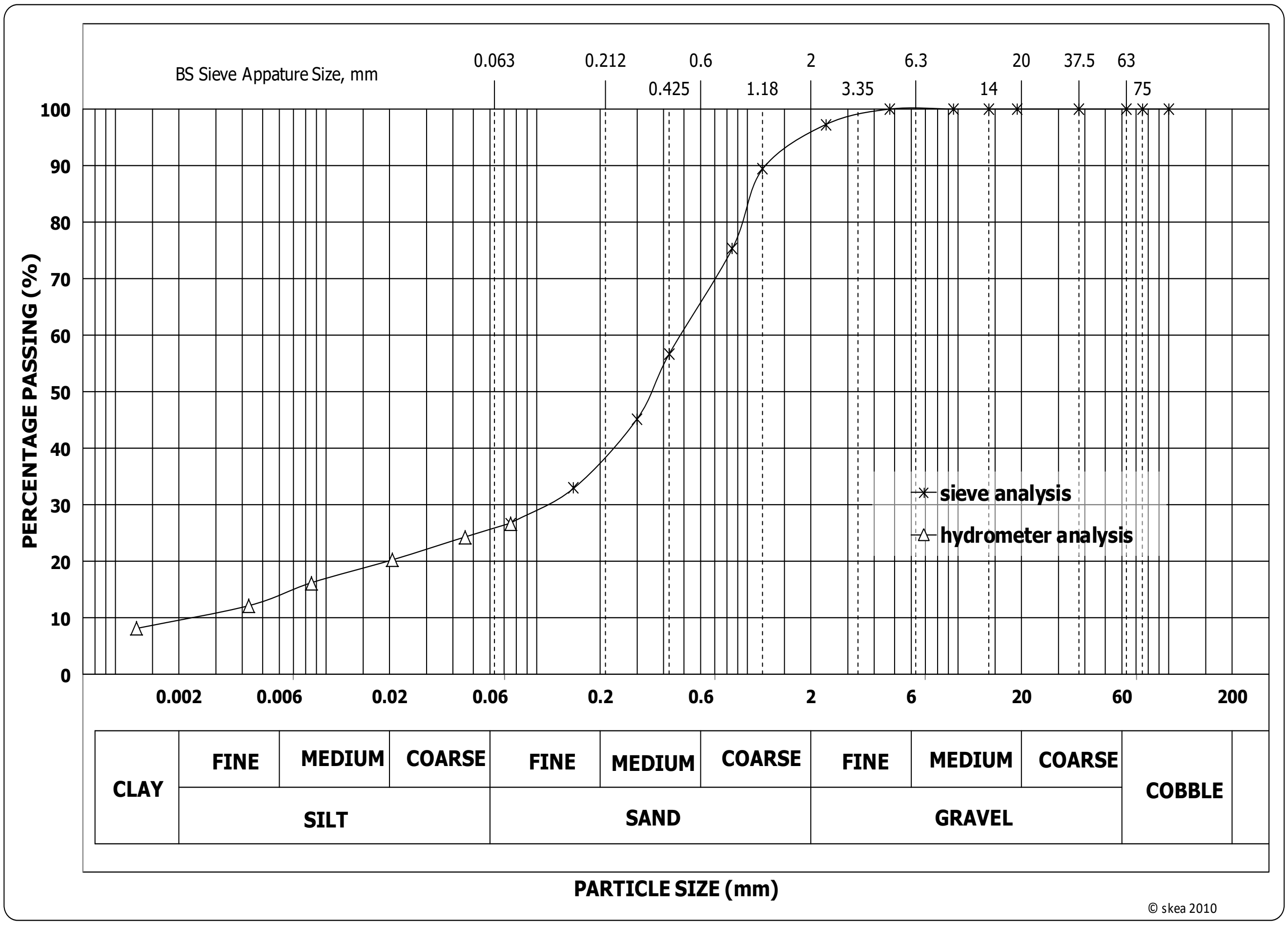

Fig. 8. Grain Size Analysis Curve for Sample S2

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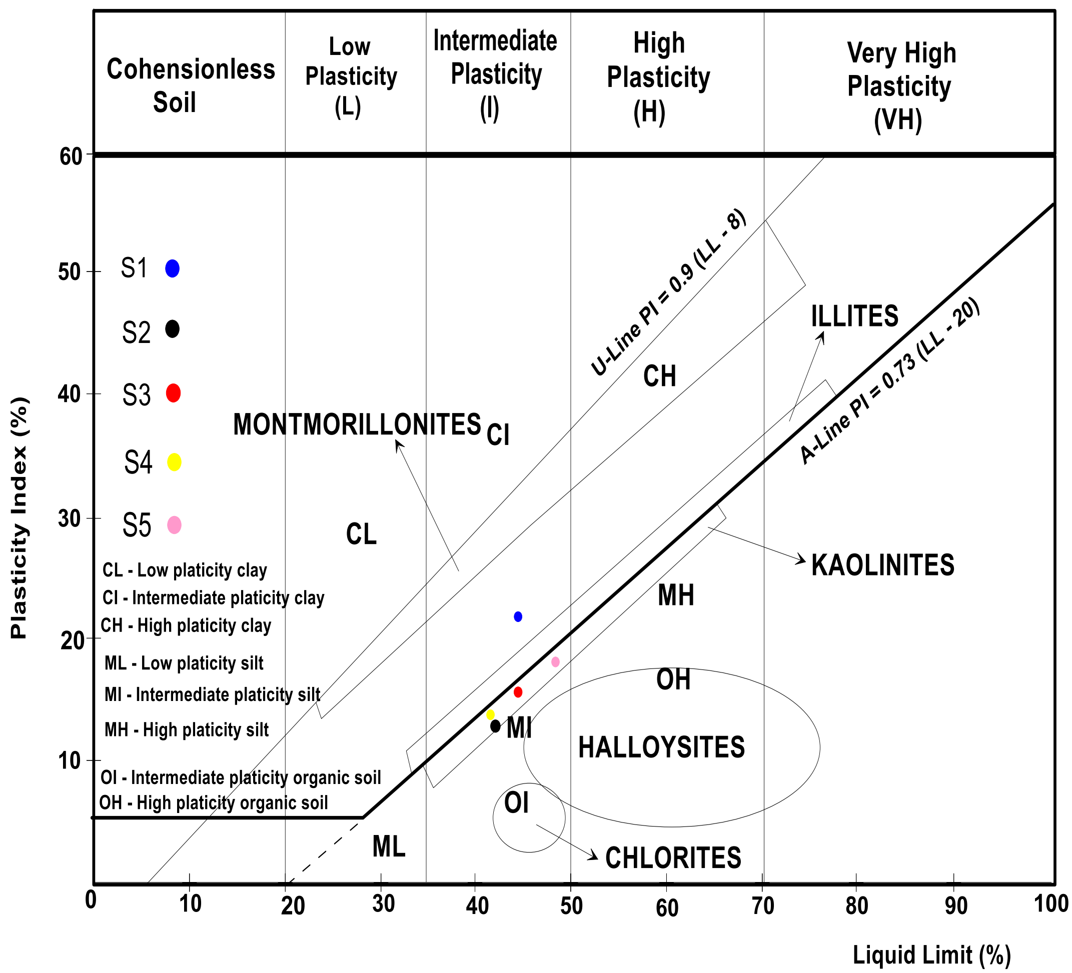

Fig. 9. Plots of the soil samples on Casagrande's plasticity chart

Therefore using Table 7, the soils are rated as "fair to good" as pavement subgrade material. This is also corroborated by the AASHTO classification in Figure 10 which shows that the samples have good properties suitable as subgrade material.

The values of specific gravity of the samples range between 2.65 – 2.68. According to [16], the standard range of value of specific gravity of soils lies between 2.60 and 2.80; these values are considered normal. Specific gravity is known to correlate with mechanical strength of soil and may be used as a basis for selecting suitable highway pavement construction materials particularly when used with other pavement construction materials. The liquid limit (LL) values range between 42.6 to 47.8%, plastic limits (PL) range between 21.3 to 31.6% and plasticity index (PI) is between 12.7 to 23.1%. The Federal Ministry of Works and Housing [17] recommends LL of 50% (max.), PI of 20% as (max.), plastic limit of 30 % (max.) and % Fines of 35 maximum for highway subgrade soil. Hence the soils satisfy this requirements as subgrade material.

Compaction is concerned with relationships between moisture content, applied effort and density. Compaction is undertaken on the road to enhance the mass density and hence the strength, rigidity and durability of placed materials [18]. In the laboratory compaction testing is undertaken to predict moisture density responses of a material to applied effort and to provide a reference with which to control on-site compaction during construction. The maximum dry density (MDD) for the soil samples varied between 1725 and 1771 kg/m3 at standard proctor compaction energy while the optimum moisture content (OMC) range between 12.3 and 13.1%. An important part of the grading of the site often includes the compaction of fill. Compaction is defined as the densification of a fill by mechanical means. This physical process of getting the soil into a dense state can increase the shear strength, decrease the compressibility, and decrease the permeability of the soil. All the soil samples have moderately high MDD at low OMC.

The California Bearing Ratio (CBR) is an empirical test employed in road engineering as an index of compacted material strength and rigidity, corresponding to a defined level of compaction. All compacted samples show unsoaked CBR values ranging between 64 and 74%. The Federal Ministry of Works and Housing [17] recommends a California Bearing Ratio of greater than 10% for subgrade materials.

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TABLE 7
Characteristics of Compacted Subgrade for Roads and Airfields [19]

Major Division	Subdivision	USCS Symbol	Name	Value as Subgrade
Coarse-grained soils	Gravel & Gravelly soils	GW	Well graded gravels or gravel-sand mixtures, little or no fines	Excellent
		GP	Poorly graded gravels or gravelly sands, little or no fines	Good to excellent
		GM	Silty gravels, gravel-sand-silt mixtures	Good to excellent
		GC	Clayey gravels, gravel-sand-clay mixtures	Good
	Sand and Sandy soils	SW	Well-graded sands or gravelly sands, little or no fines	Good
		SP	Poorly graded sands or gravelly sands, little or no fines	Fair to good
		SM	Silty sands, sand-silt mixtures	Fair to good
		SC	Clayey sands, sand-clay mixtures	Poor to fair
Fine-grained soils	Silts and clays with liquid limit less than 50	ML	Inorganic silts, rock flour, silts of low plasticity	Poor to fair
		CL	Inorganic clays of low plasticity, gravelly clays, sandy clays etc.	Poor to fair
		OL	Organic silts and organic clays of low plasticity	Poor
	Silts and clays with liquid limit greater than 50	MH	Inorganic silts, micaceous silts, silts of high plasticity	Poor
		CH	Inorganic clays of high plasticity, fat clays, silty clays etc.	Poor to fair
		OH	Organic clays, organic silts, with high plasticity	Poor to very poor
Peat		PT	Peat and other highly organic soils	Not suitable

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	Granular Materials (35 % or less passing No. 200)							Silt-Clay Materials (More 35 % or less passing No. 200)			
General Classification	A-1			A-2							A-7
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5 A-7-6
Sieve analysis, percentage passing:											
No. 10 (2.00 mm)	50max	....	....	....	....	....	....	....	....	....	....
No. 40 (0.425 mm)	30max	50max	51max	....	....	....	....	....	....	....	....
No. 200 (0.075 mm)	15max	25max	10max	35max	35max	35max	35max	35max	36min	36min	36min
Characteristics of fraction passing No. 40 (0.425 mm)											
Liquid Limit	....	....	....	40max	40min	40max	41min	40max	41min	40max	41min
Plasticity Index	6max		N.P	10max	10max	11min	11min	10max	10max	11min	11min
Usual types of significant Materials	Stone fragments Gravel and Sand		Fine Sand	Silty - Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as subgrade	Excellent to Good							Fair to Poor			

Fig. 10. AASHTO Soil Classification and Rating [20]

The result shows that the California Bearing Ratio values of the soils are much higher than 10%. Hence suitable as foundation material for road construction. The coefficient of consolidation (C_v) for the soil samples ranges from 0.3099 - 0.3381 m^2/yr. Using Table 8 according to [21] the values of coefficient of consolidation (Cv) m^2/yr obtained for samples correspond to soils with low rate of consolidation. Typical curve of consolidation is shown in Figure 11. The shear strength of a soil is a basic geotechnical engineering parameter and is required for the analysis of foundations, earthwork, and slope stability problems. This is because of the nature of soil, which is composed of individual soil particles that slide (i.e., shear past each other) when the soil is loaded.

The summary of the results of the unconfined compression test and shear strength are presented in Table 6. The unconfined compressive strength and shear strength of the tested soils range from 382.20 – 420.50 Kpa and 177.55 – 199.60 Kpa respectively. Considering the range of values of unconfined compressive strength in Table 9, consequently the soil samples fall within the range of 0.3 – 12.5 MPa which is considered as hard – moderately hard soil. Also the range of values obtained for shear strength fall within the very stiff soil classification (Table 10). The shear strength of a soil is a basic geotechnical engineering parameter and is required for the analysis of foundations, earthwork, and slope stability problems [22], [23]. This is because of the nature of soil, which is composed of individual soil particles that slide (i.e., shear past each other) when the soil is loaded. Since soil fails as a result of shear, the soil samples have moderate internal resistance per unit area to resist failure and sliding along any plane inside it.

Static water level (SWL) measured from open wells along the highway varies from 3.3 m to 5.5 m with an average of 4.3 m. The hydraulic head measured with respect to sea level ranges between 337.7 m to 340.5 m (Table 11).

TABLE 8
Typical Values of the Coefficient of Consolidation (C_v) [21]

Coefficient of Consolidation, C_v (m^2/year)	Rate of Consolidation
<0.01	Very low
0.1-1.0	Low
1-10	Medium
10-100	High
>100	Very high

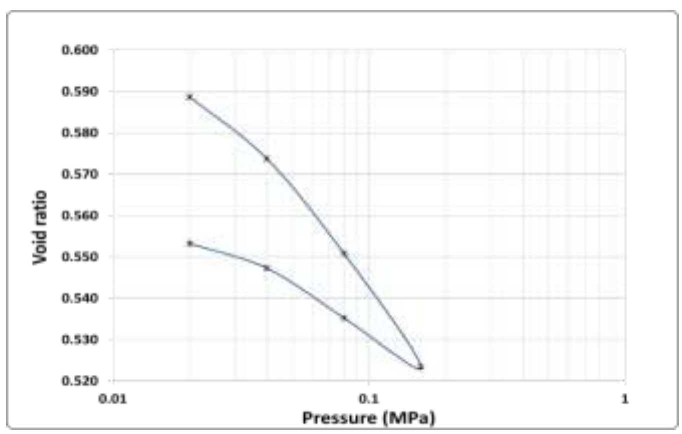

Fig. 11. Consolidation Plot for Sample C

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TABLE 9
Grades of Unconfined Compressive Strength [24]

Description	Approximate unconfined compressive strength
Very soft to soft	36 – 300 Kpa
Hard to moderately hard	0.3 – 12.5 MPa
Moderately strong to strong	12.5 – 100 MPa
Strong to very strong	Greater than 100 MPa

TABLE 10
Consistency of Soils using Shear Strength [24]

Description	Approximate undrained shear strength (Kpa)
Hard	Over 300
Very stiff	150 – 300
Stiff	75 – 150
Firm	40 – 75
Soft	20 – 40
Very soft	Less than 20

Consequently, the SWL in the area is moderately low, therefore it may not seriously affect the subgrade. However excessive cut into the subsoil would lead to high water level situation which could compromise the integrity of the pavement structures.

TABLE 11
Hydro-geological Field Measurements obtained Along the Highway

S/No.	Easting	Northing	Elevation (m)	S.W.L (m)	H.H (m)
WL-1	780089	810057	341	3.3	337.7
WL-2	780061	810713	343	4.9	338.1
WL-3	780458	810398	342	4.2	337.8
WL-4	780473	810584	344	3.8	340.2
WL-5	780632	810342	346	5.5	340.5

V. CONCLUSION

The study was to assess the engineering characteristics of the subgrade used for flexible pavement construction along Iyere – Ipele, Southwestern Nigeria. Even though the road was still under construction as at the time of conducting this research. The chief-engineer on site (in charge of the highway) was very offensive to the researcher (with the thought that the researcher was trying to spy design parameters of the highway) especially during the reconnaissance survey and sample collection. Therefore this limited the samples collected to five and one traverse established for VES survey. All the samples show high concentrations of SiO_2, Fe_2O_3, and Al_2O_3 with little or no variation. Silica-Sesquioxide ratio of the ranges from 0.89 to 0.96 and classified as True Laterite. The soils are predominantly silty sand with intermediate plasticity and characterized with moderate shear strength (150 – 200kpa), and unconfined compressive strength (300 – 420kpa). The soils clay mineralogy is basically kaolinite except sample S1 which shows near illite-group. The geoelectric section shows topsoil that is characterized by resistivity ranging from 298 – 924 ohm-m and thickness varying from 3.1 – 8.2 m and composed of clay sand and laterite. The result of the geoelectric correlate well with the soils' laboratory geotechnical properties. The soils satisfy the recommended values of consistency limits, and California Bearing Ratio. The AASHTO classification rates the soils as good subgrade, while USCS rating is fair – good. Therefore judging from the results obtained the soils are suitable as subgrade/foundation pavement material.

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