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Editorial Comment

The MJG was officially launched and approved by the Management of the Federal University of Technology, Minna in 2015 under the leadership of the pioneer Editor-in-Chief, a German-trained professor, Prof. M. I. Ogunbajo. The Editor-in-Chief worked assiduously with other editorial board members for the Maiden Edition, Volume 1 Number 1 to be a reality. He did this by sourcing for the resources to run the journal, coordinating the activities of the editorial team and soliciting for the assistance of renowned geoscientists and oil and gas industries professionals nationwide to support the journal. At the critical point of producing the edition and when the accepted papers are already in the press Prof. M. I. Ogunbajo died after a very brief illness. May his gentle soul rest in perfect peace. Amen. The contributions of this great scholar and an icon in advancing geological knowledge and capacity building will remain a reference point within the geoscience community in Nigeria and beyond, as the society will dearly miss him. Review process for the second edition, Volume 1 Number 2 was done through electronic format to enable authors respond to comments and observations by the reviewers. This has greatly smoothened the review process and improved the quality of articles compiled for the second edition.

The journal appreciates the efforts put in by reviewers for timely reviews and constructive criticism and suggestions that sometimes lead to outright rejection of papers that does not conform with the journals scope and scientific contributions.

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**Geophysical, Geotechnical and Mineralogical studies of a section along Ilorin–Lokoja
Federal Highway, Southwestern, Nigeria**

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Abstract

The rate of road failure and elevated cost of quality materials used in civil engineering construction has led to the need for investigation of naturally occurring local soils as alternative material in construction industries. This research used geophysical, geotechnical and mineralogical approaches to investigate the condition of soils from failed portions along Ilorin-Lokoja Federal Highway with respect to identifying causes of failure and assessing the natural neighbouring soils as suitable base/sub-base course material. Results of five Vertical Electrical Soundings conducted on critically failed portions of the road show low resistivity values near the surface, suggesting the presence of clay and elevated moisture resulting in oversaturation of the top soil thus leading to failure of that portion of the road. Mineralogical and chemical analyses revealed the absence of high-level swelling clays, dominance of “true laterite” with high concentration of Fe_2O_3 as cementing agent. Low plasticity from geotechnical studies revealed the presence and influence of clay on the integrity of the samples. The samples possess low linear shrinkage values which suggest little potential to shrink or swell when exposed to alternating weather condition. They are poorly graded soils, suggesting uniform grain sizes. The samples generally present parabolic shape during compaction which is an indication of “workability” if used as in-situ construction material. The California Bearing Ratio (CBR) values indicate good ratings and are fairly suitable as base and sub-base material in road construction. Overall, geotechnical evaluations revealed that the sample can only function effectively as subgrade material except in few ($\approx 30\%$) where the soils can serve as sub-base course in pavement construction. Generally, the tested soils possess properties which make them fairly suitable for road construction. However, changes in climatic factor and state of drainage system must be critically considered to ensure a better road network.

Keywords: Geophysical, Geotechnical, Mineralogy, Lokoja, CBR

1. Introduction

The reoccurring records of road failures and collapse of buildings in Nigeria is becoming alarming. Poor construction, lack of drainage, poor design and lack of adequate investigation on the geotechnical competence of potential subgrade and base course material have been attributed as possible cause of failure. Geological factors are rarely considered as cause of road failure even though; the roads are always constructed with geologic material. This is due to non-appreciation of the fact that proper design of road construction requires adequate knowledge of subsurface condition. The geotechnical properties of lateritic soil, which is the most commonly used for road construction in Sub-Saharan Africa are informed by several factors such as time, space,

topography, climate, parent rock (Palanikumar, 2013). Apart from abundance, morphological position, this is probably due to its stable geotechnical and chemical conditions. This soil type has been severally mined for economic purposes and used as material in civil construction works (Ige, 2015). The Ilorin-Lokoja road network covers about 327km with pockets of Bitumen surface. The 325km road was top on the list of most dangerous road in Nigeria in 2016 ahead of Lagos-Sagamu-Ore-Benin, Lagos-Ibadan and Otukpo-Otukpa roads (Distance Calculator, 2018) and has witnessed many robbery attacks, motor accidents, gully developments and limitation in trade exchange between border states/towns. Several research attempts have been made to investigate construction materials, rainfall, inadequate designs as possible causes of failure (Ndefo, 2012) but limited studies have integrated geophysical, geotechnical, chemical and mineralogical tools to resolve causes of failure (Ebhoimen and Luke, 2014). According to Adiat *et al.* (2017), lack of integrated approach to road investigation skews available data and interpretation hence, reoccurring failures. Consequently, the study has used geophysical, geotechnical, chemical and mineralogical approaches to evaluate suitability of the investigated soils in order to provide data base for engineers and other end users.

1.1 Characteristics of Investigated Road Network

The road under investigation is a Federal road that connects two major capital towns in north central Nigeria (Ilorin and Lokoja). Geographically, the area falls in the north central part of Nigeria and lies between latitude $8^{\circ} 04'21''\text{N}$ and $8^{\circ} 34'37''\text{N}$ and longitude $5^{\circ} 36'13''\text{E}$ and $6^{\circ} 58'57''\text{E}$. It is characterized by two distinct seasons (November to March for dry season) and (April to October for wet season). The annual rainfall, temperature and relative humidity are 1200mm, 25°C and 70% respectively. The topography of the areas is undulating due to scattered exposures of rocks such as granite, granite gneiss, schist, amphibolite, banded gneiss and quartzite (Fig. 1) that form the major geology of the area.

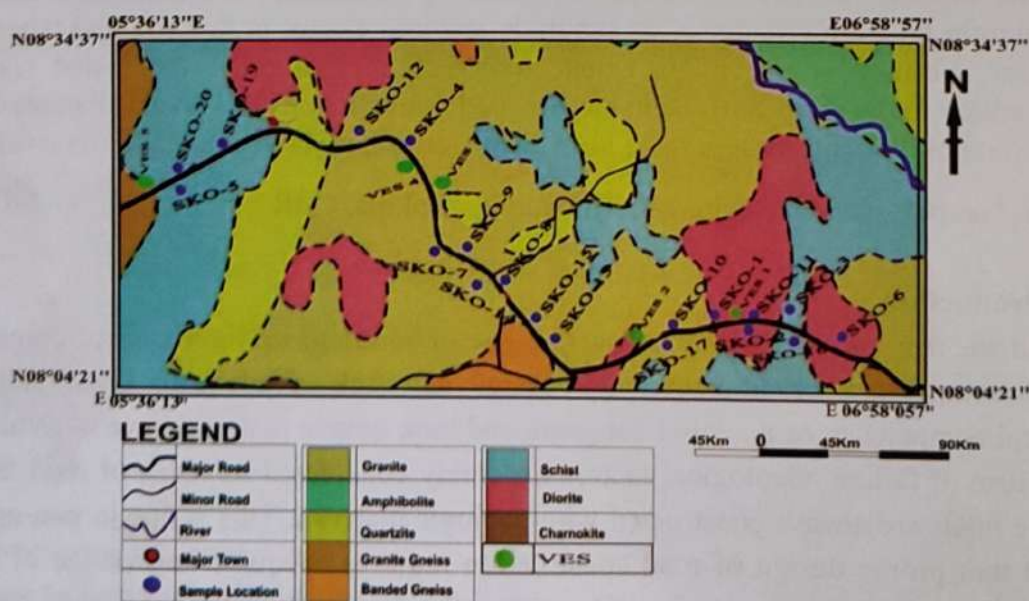


Figure 1: Geologic Map of the study area showing soil sample and VES positions

2. Materials and Methods

2.1 Soils Sampling campaign and locations

Sampling campaign was preceded by identification and selection of study area on a scale of 1:50,000 topographical map of Nigeria (Osi Sheet 224). 20 undisturbed samples were collected within the lateral and vertical extension of the lateritic unit using manually operated soil auger (Kamtchueng, 2015). All samples were collected between depths ranging of 0.6-3.0m to ensure good representation of soils in the zone of laterization. Samples with evidence of plasticity were preferred because of their potential for compatibility (Keller and Dexter, 2012). About 5kg of the soil was packed into polythene bags and were then labelled for easy identification in the laboratory. Two samples were collected, each at both sides of the existing road at every sampling location, with average of 200m interval between two sampling locations (Ministry of Works and Housing, 2013). Initial water contents of the samples were measured on the field before air-dried for 30 days. The positions of soil samples for geotechnical/mineralogical analyses and electrical resistivity sounding are detailed in Tables 1 and 2 respectively. All geotechnical analyses of parameters were carried out as described in BSI 1377 (1990).

Table 1: Sample location coordinates

SAMPLE NUMBER	PARENT ROCKS	SAMPLE LOCATION
SKO-1	Diorite	N08°08'14'' E05°25'45''
SKO-2	Diorite	N07°52'30'' E06°03'34''
SKO-3	Schist	N07°55'36'' E06°24'34''
SKO-4	Granite	N08°15'41'' E05°43'01''
SKO-5	Schist	N08°08'14'' E05°25'45''
SKO-6	Diorite	N07°52'30'' E06°03'34''
SKO-7	Granite	N08°12'38'' E05°52'03''
SKO-8	Granite	N07°50'37'' E06°07'17''
SKO-9	Granite	N07°56'17'' E06°16'55''
SKO-10	Granite	N08°02'42'' E05°56'50''
SKO-11	Diorite	N07°54'18'' E06°13'38''
SKO-12	Granite	N08°01'24'' E05°57'46''
SKO-13	Granite	N08°12'38'' E05°52'03''
SKO-14	Granite	N07°55'36'' E06°24'36''
SKO-15	Granite	N08°01'24'' E05°57'46''
SKO-16	Schist	N07°39'09'' E08°54'46''
SKO-17	Granite	N07°18'46'' E05°16'24''
SKO-18	Quartzite	N08°17'49'' E05°36'34''
SKO-19	Schist	N08°17'49'' E05°36'34''
SKO-20	schist	N08°17'49'' E05°36'34''

2.2 Geophysical Investigation

The survey was aimed at determining the depth to bedrock, delineating various lithological units that constitute the overburden and to determining the structural disposition of the bedrock in the area under study. For this study, the electrical resistivity method using ABEM SAS 1000 terrameter was employed because it is fast, covers wide range of land area and very reliable. It also has the ability of predicting the thickness of the overburden as well as the thickness of each layer that constitute the overburden. The VES data were acquired using the Schlumberger electrode array with maximum current electrode separation (AB/2m) of 30 m. Field curves were generated by plotting the apparent resistivity values against the electrode spacing (AB/2m). The curves were interpreted using the partial curve matching technique. The manually derived geoelectric parameters were further refined using a forward modelling software, RESIST version 1.0 and the VES data were interpreted based on the approach (Zhoddy, 1989)

Table 2: VES Station Locality and Coordinates

VES STATION	LOCALITY	COORDINATES
VES 1	Obajana	N08°08'14"E05°25'45"
VES2	Alape Village off Iwaa	N07°56'17"E06°07'17"
VES3	Orokere Amuro -Mopa (I)	N07°54'18"E06°13'38"
VES4	Orekere Amuro – Mopa (II)	N07°55'36"E06°24'36"
VES5	Eruku	N08°17'49"E05°36'34"

3. Results and Discussions

3.1 Geophysical Analysis

The characteristics of lithology's are site specific and are discussed station by station.

VES 1

Two geoelectric layers were interpreted from the data obtained (Fig. 2). The first layer is the soil with an average thickness of about 2.1 meters. The second layer is the fresh basement infinite thickness and average resistivity value of 1250.5 ohm-meter. The curve type is "K" which indicates consistent increase in apparent resistivity. The top layer is humus, loose and very pervious with negligible plasticity, thus reduces percolation and retention of water due to the closeness of the bedrock to the surface and its insufficient thickness. Thus, this limits amount of water to be retained in the soil interstices and subsequent development of sheet erosion on the surface. This probably explains the manifestation of exposed parts basement rock at this section of the road.

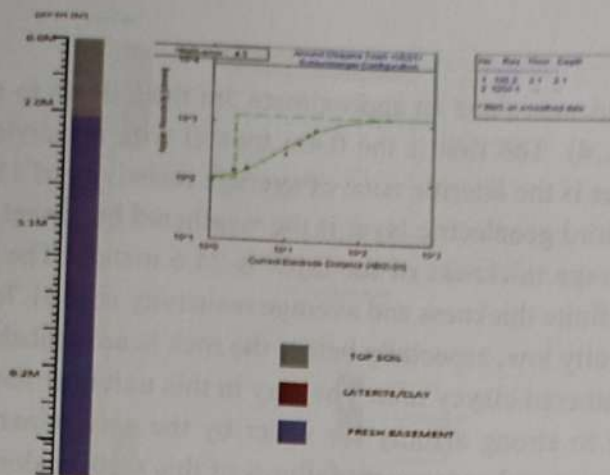


Figure 2: Lithologic Sequence and VES curve at Obajana town

VES 2

Three geoelectric layers yielding “HA” curve (Fig. 3) with less than 4m thick layer of soil over the basement rock. The first geoelectric layer is the thin topsoil with average thickness of 0.6 meters. The second geoelectric layer is the Lateritic layer with average thickness of 3.7 meters. The third and the last geoelectric layer is the fresh basement with infinite thickness and average resistivity of 1193.9-ohm meter. Since clays are known to be porous but have low permeability, the thickness of the lateritic-clay layer plays a role in the accumulation of water in this section of the road. Water accumulation at the surface takes longer time to permeate since there are no drainages. This will cause deterioration of “elements” of the pavement section and consequently leads to failure. The absence of near surface structures also reduces the volume of percolating water into the basement and encourages retention of water in the thin layer clayey unit.

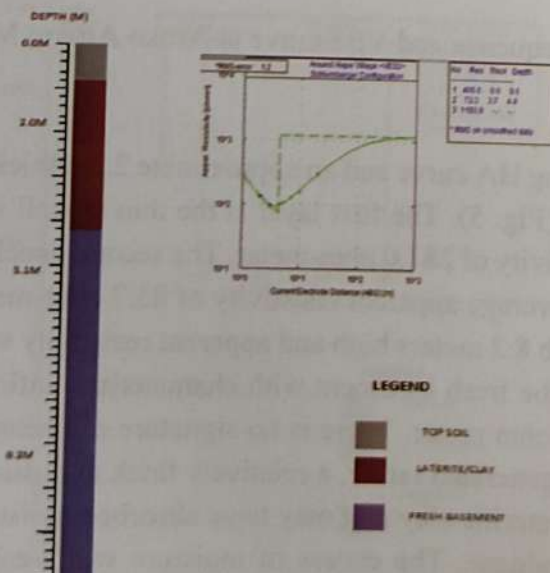


Figure 3: Lithologic Sequence and VES curve at Alape village off Iwa town

VES 3

Four geoelectric layers yielding HA curve and an approximate 5m thick depth to rock head were interpreted from the data set (Fig. 4). The first is the 0.4m topsoil with resistivity of 427 ohm-meter. The second geoelectric layer is the lateritic zone of average resistivity of 111.9 ohm-meter and thickness of 5.0 meters. The third geoelectric layer is the weathered basement with resistivity value of 46.6 ohm-meter and average thickness of the layer is 24.6 meters. The last geoelectric layer is the fresh basement with infinite thickness and average resistivity is 1331.7ohm-meter. The overall resistivity values are generally low, especially before the rock head, probably an indication of the presence of intensively weathered clayey unit. The clay in this unit may absorb percolating water but difficult to release due to strong affinity for water by the clay mineral present. This explains the continuous water lodging and consequent failures of this section along the road.

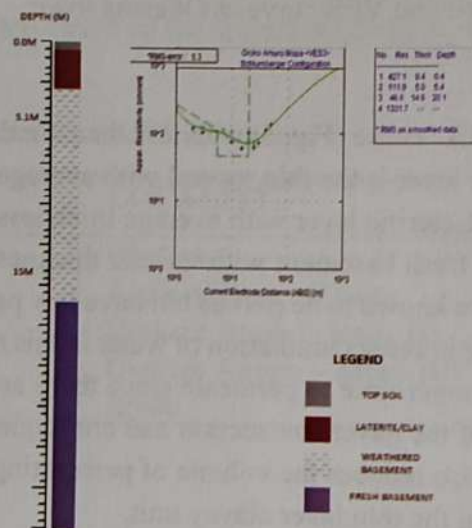


Figure 4: Lithologic Sequence and VES curve at Aroko Amuro Mopa

VES 4

Four geoelectric layers yielding HA curve and an approximate 2.3m thick depth to rock head were interpreted from the data set (Fig. 5). The first layer is the thin topsoil with average thickness of 0.7 meters and apparent resistivity of 281.0 ohm-meter. The second geoelectric layer is the lateritic unit of 2.3 meters thick and average apparent resistivity of 83.7 ohm-meter. The third layer is the weathered basement rock with 8.2 meters high and apparent resistivity value of 215.1 ohm-meter. The last geoelectric layer is the fresh basement with characteristic infinite thickness but average apparent resistivity of 320.1-ohm meter. There is no signature of lineaments structure within the AB/2 spread from the curve generated rather, a relatively thick unit, suspected to be lateritic clay was interpreted. Again, this lateritic clay unit may have absorbed moisture into its interstices and remain in the absence of drainage. The excess of moisture will weaken the strength (bearing capacity) of the soil, thus contributing to the geotechnical failure at this portion of the road.

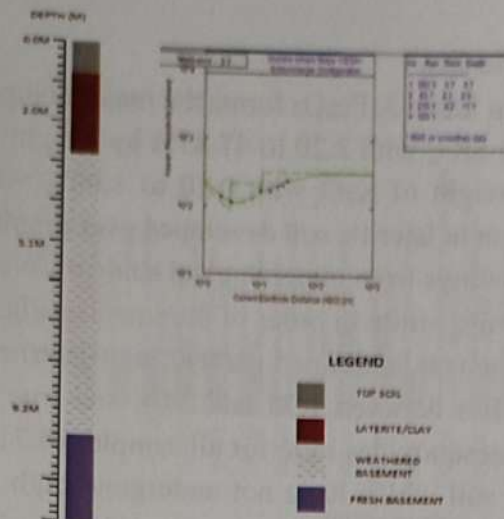


Figure 5: Lithologic Sequence and VES curve at Orekere Amuro Mopa

VES 5

This point is particularly notable as a “hide out” for robbers because of the degree of damage. Four geoelectric layers yielding HA curve and an approximate 4.1m depth to rock head were interpreted from the data set (Fig. 6). The first geoelectric layer is the thin topsoil with average thickness of about 1.0 meters. This is followed by 3.6m lateritic clay while the third layer has average thickness of 4.9m. The average apparent resistivity of each layer is 79.4, 15.2- and 22.0-ohm meter respectively. The last geoelectric layer is the fresh basement whose thickness is infinite but an average apparent resistivity value of 328.0-ohm meter. It can be explained that VES 4 and 5 have similar failure history.

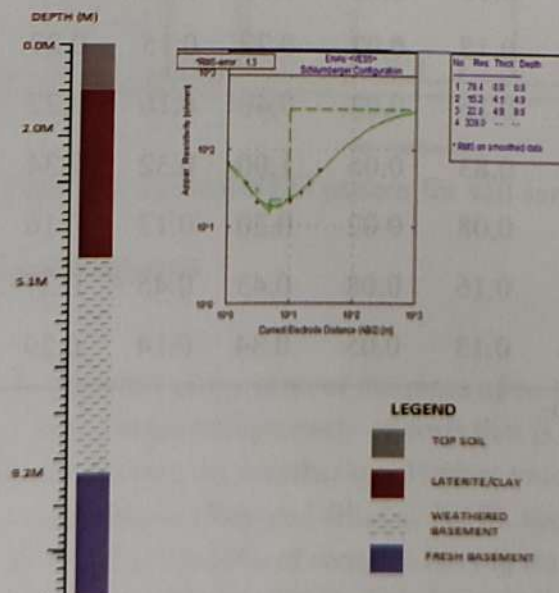


Figure 6: Lithologic Sequence and VES curve at Eruku

3.2 Chemical and Mineralogical Studies

The chemical composition is presented in Table 3. Fe_2O_3 forms the major component ranging from 32.00 to 79.20% by weight followed by SiO_2 with 2.20 to 47.83% by weight. 6.92 to 18.11% by weight Al_2O_3 with 0.08 to 0.34% by weight of K_2O with 0.20 to 1.00% weight of CaO . This distribution describes the general situation in lateritic soil developed over granitic rocks of Nigeria. (Oke *et al.*, 2013). It also supports the findings from mineralogical study of selected samples which indicated the presence of quartz > kaolinite > illite in order of dominance (Fig. 7 and 8). From the sesquioxides ratio, three classes of laterite can be defined namely; non-laterite (where $\text{S-S} > 2.0$); lateritic soil (where sesquioxides ratio lies between 1.33 and 2.0); and true laterite soil (where sesquioxides ratio ≤ 1.33). The average sesquioxides ratio for all samples (0.71) is lower than 1.33 suggesting that they are "true laterite" soil which have not undergone high level of laterization (Kamtchueng, 2015). Thus, they have good potential to serve as sub-base or base course material during construction. Though, the values of soluble CaO , MgO and K_2O are generally low, suggesting complete weathering, the value of "R" obtained revealed that there is possibility of further weathering.

Table 3: Chemical Analysis of Soil Samples

Element/ Sample	SiO_2	Fe_2O_3	Al_2O_3	MnO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^+	Ratio (R)	Total (%)
SKO 1	2.10	79.20	6.92	0.55	0.02	0.40	0.15	0.08	3.65	6.85	0.07	100.00
SKO 3	7.07	64.00	11.16	0.28	0.05	0.50	0.14	0.16	4.30	12.34	0.24	100.00
SKO 5	14.42	65.60	11.01	0.13	0.05	0.44	0.14	0.19	3.47	4.55	0.46	100.00
SKO 7	7.18	68.90	8.72	0.15	0.70	0.45	0.15	0.24	3.91	9.60	0.23	100.00
SKO 9	16.73	68.00	9.01	0.15	0.02	0.27	0.15	0.27	0.72	4.69	0.54	100.01
SKO 11	36.25	47.50	10.68	0.15	0.03	0.40	0.16	0.27	0.55	4.01	1.50	100.00
SKO 13	47.83	32.00	12.17	0.83	0.06	1.00	0.32	0.34	2.68	2.75	2.50	100.00
SKO 15	23.19	39.00	18.11	0.08	0.02	0.20	0.13	0.16	4.97	14.12	0.90	100.00
SKO 17	15.74	67.50	11.42	0.16	0.08	0.43	0.45	0.37	0.80	3.08	0.20	100.03
SKO 19	15.42	67.60	10.04	0.13	0.05	0.34	0.14	0.29	3.47	2.55	0.43	100.00

$$\text{Ratio (R)} = \text{SiO}_2 / \text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$$



Figure 7: Mineral Composition and Dominance Chart

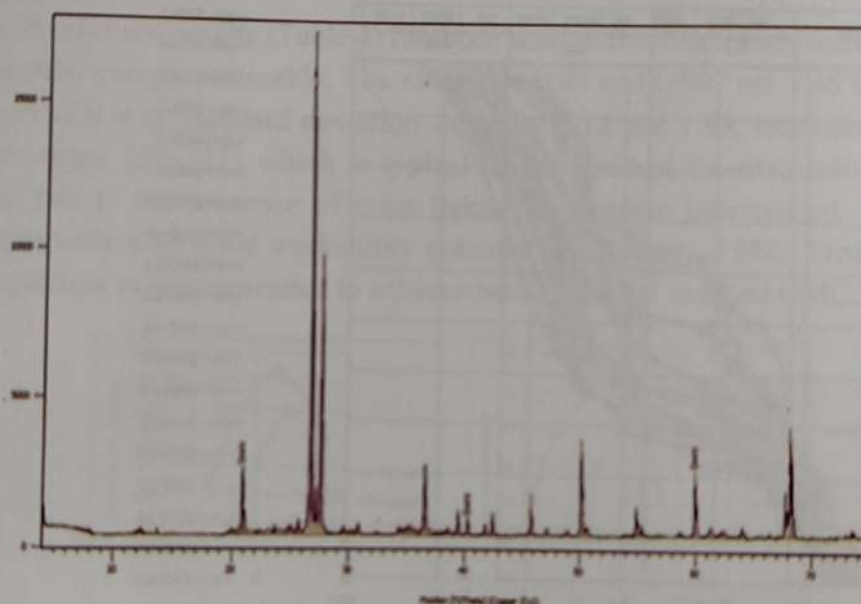


Figure 8: Typical XRD pattern for soil sample (SKO-1)

3.3 Geotechnical investigation

Specific Gravity

Specific gravity can be estimated as the ratio of the mass of soil to the mass of an equal volume of water. It is a basic and index important property of soils that is closely linked with mineralogy of chemical composition and history of weathering. Higher value of specific gravity gives more strength for roads and foundations (Roy and Bhalla, 2017). From Table 3, the values of specific gravity range from 2.50 to 2.72 with 60% of samples having less than 2.60. All soils analysed are classified as silty sand (Roy and Bhalla, 2017). This is an indication of the fair suitability of the samples as road construction material.

3.4 Grain Size Distribution

The result from grain size analysis is presented in Table 4 while the graphical representation is in Fig. 9. The presence of fines greater than 80% in a soil mass will reduce the value of the maximum density (MD) and strength, thus increasing the susceptibility to weakening due to action of water (Prakash and Jain, 2002). Fig. 9 shows set of poorly graded curves (a slant *S*) suggesting uniform soils with high percentage of particular class of grain over others. Thus, during compaction of these soils, inadequate distribution of particle size will prevent volume reduction (Kamtchueng, 2015). From the table 3, 65% of the samples have sand particles greater than 40% while 45% of the samples have fines greater than 35% recommended for sub-base course (Table 4). Also, all none of the samples analysed met the not more than 20% fines recommended for base course. However, 75% of the samples fall in the “Good” while 25% fall in the “fair” on the Engineering Use Chart

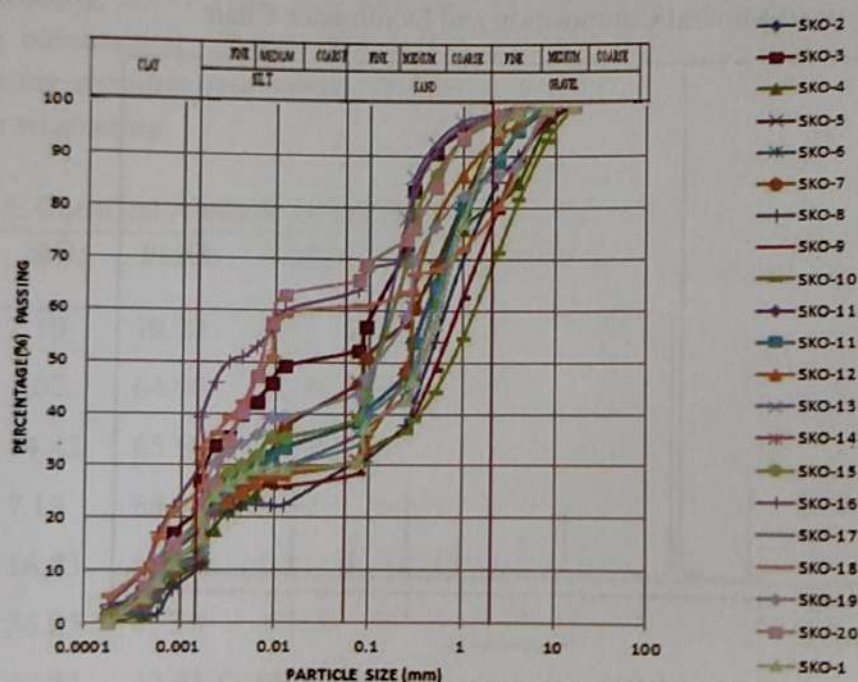


Figure 9: Grain size distribution Pattern of the analysed samples

3.5 Atterberg Consistency Limits

Results on the Table 4 shows LL range from 19.0 to 47.0% with standard deviation of 8.27; PL range from 9.0 to 22.8% with standard deviation of 4.53; and PI range from 9.5 to 24.8% with standard deviation of 4.62. According to Hasboun classification of plasticity, 65% fall in the category of “intermediate” plasticity (7-17%), while 35% fall in the “Low” plasticity (1-7%) (Hasboun, 1994). Nine of the samples are within not more than 15% PI for base course material. Also, all samples have $\leq 60\%$ LL for sub-base while only SKO-2, SKO-4, SKO-8, SKO-11 and SKO-16 & 17 exceeded not more than 35% of LL. 90% of the samples plots below the A-line of the Casagrande’s chart suggesting presence of non-swelling kaolinite clay (Farrokhpour, 2016).

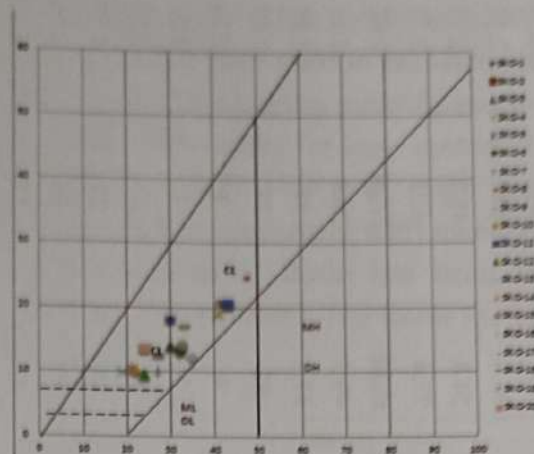


Figure 10: Positions of soil samples on the Casagrande's soil classification chart.

3.6 Compaction

The Modified Proctor test results (Table 4) has been used in this discussion since it represents the highest compaction energy obtainable. The range of MDD and OMC are 1.46 to 1.87% and 9.50 to 16.0% respectively with standard deviation values of 0.12 and 1.93, respectively. All samples have parabolic shape (Fig. 11) which is typical of the residual (in-situ) soils developed over basement rock due to the presence of mica flakes (incomplete laterization). The samples are generally compactible with good workability potential (O'Flaherty, 1988). From Fig. 11, higher energy of compaction is recommended to achieve better MDD at reduced OMC.

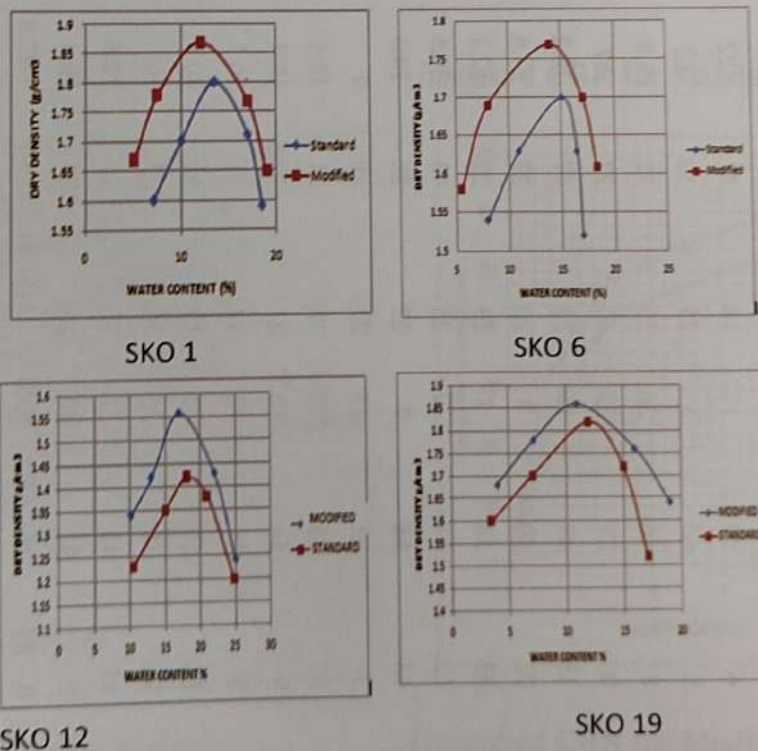


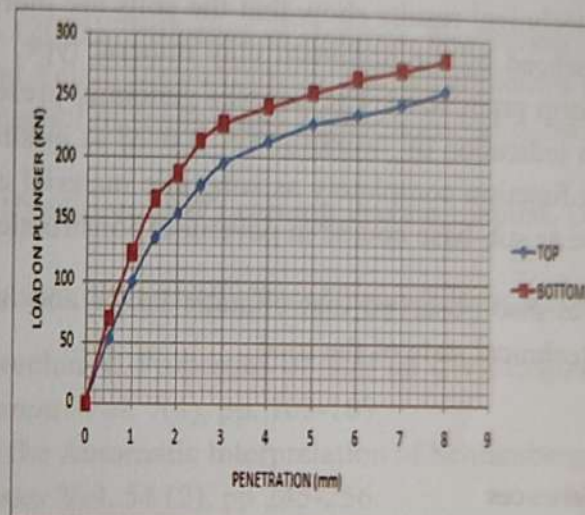
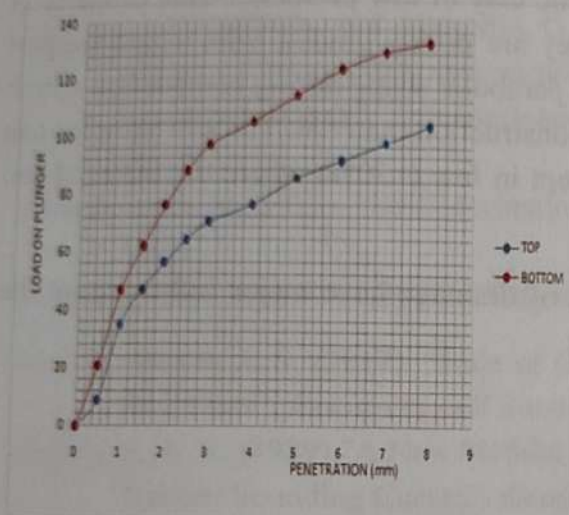
Figure 11: Typical Compaction curves of selected samples indicating parabolic behaviour of the samples

Sample No	Grain size Distribution					Atterberg limits			Compaction at Modified			CBR at Modified		Specific Gravity
	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cm ³)	Unsoaked (%)	Soaked (%)			
SKO-1	5	65	5	25	30	12	18	12	1.87	69	38.2			2.63
SKO-2	0	28	32	40	43	22.5	20.5	16	1.68	49.3	20.4			2.56
SKO-3	2	44	22	33	30	16	14	15	1.6	35.5	17.9			2.55
SKO-4	6	64	12	18	41	22	19	14	1.6	60.9	30.6			2.66
SKO-5	5	65	5	25	30	12	18	12	1.87	69	38			2.63
SKO-6	8	46	26	20	32	18.8	13.2	14	1.77	59	36			2.53
SKO-7	0	27	33	40	27	17	10	15.7	1.48	33.4	11.5			2.52
SKO-8	15	48	16	21	47	22.2	24.8	9.5	1.7	54.8	41.2			2.70
SKO-9	22	50	8	20	27	14.6	12.4	11	1.84	71.4	42.7			2.72
SKO-10	32	38	7	23	22	12.1	9.9	12	1.77	55.88	27.28			2.62
SKO-11	12	51	12	25	43	20.5	20.5	16	1.68	49.3	20.4			2.56
SKO-12	13	58	7	22	24	14.5	9.5	13	1.68	47.7	21			2.55
SKO-13	2	62	15	21	19	9	10	15	1.68	62	31			2.63
SKO-14	37	35	10	18	21	10.5	10.5	11	1.86	4	3			2.70
SKO-15	9	54	16	21	32.5	18.4	14.1	14	1.67	3	1			2.57
SKO-16	3	35	18	44	41	20.3	20.7	14	1.67	57	17			2.57
SKO-17	12	56	13	19	41	20.1	20.9	14	1.7	48	21			2.59
SKO-18	13	26	25	36	33	16	17	14	1.74	59	36			2.56
SKO-19	15	43	11	31	35	22.8	12.2	16	1.57	43	17			2.55
SKO-20	2	32	40	26	24	10.3	13.7	16	1.46	26	13			2.50
RANGE	0-37	26-65	5.40	18-44	19-7	9-22.8	9.5-24.8	9.5-16	1.46-1.8	3-71.4	1-42.7			2.50-2.72
TOTAL	213	927	333	528	642.5	331.6	308.9	274.2	33.89	957.18	484.18			51.9
AVERAGE	10.65	46.35	16.7	26.4	32.13	16.58	15.445	13.71	1.6945	47.859	24.209			2.595
STD DEV	10.0957	13.0838	10	8.074652	8.272	4.52776	4.621059	1.9257	0.1170009	19.28428155	12.26890545			0.06328715

Table 4: Summary of Geotechnical Properties of Studied Soil Samples

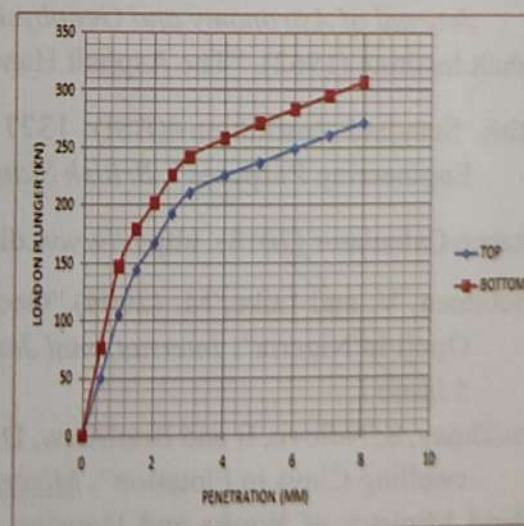
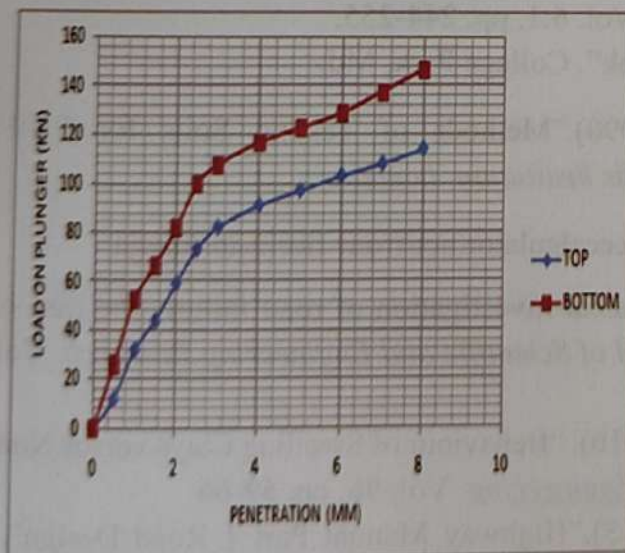
3.7 California Bearing Ratio (CBR)

Table 4 contains the unsoaked and soaked CBR values at modified energies of compaction. The soaked data at modified energy has been used in the interpretation of the study since they simulate the worse state of the soil and the highest possible energy of compaction respectively. 40% of the samples have $\geq 30\%$ CBR values for base course. The remaining 60% meet the requirement as subgrade (Asphalt, 1962). However, large portion of the soils may need mechanical, physical and/or chemical improvement with strong cementing agent prior to their use as base materials. California Bearing Ratio has been found to have great inverse relationships with amount of fines, PI and OMC. The lower the values of these parameters, the higher their CBR values (Table 4).



Soaked CBR for Standard Proctor

Unsoaked CBR for Standard Proctor



Soaked CBR for Modified Proctor

Unsoaked CBR for Modified Proctor

Figure 12: Typical California Bearing Ratio for Soaked and Unsoaked SKO-2 sample

4. Conclusion

The investigation reports background geophysical, geotechnical and mineralogy information on lateritic soils obtained along Ilorin-Lokoja federal highway. The following deductions were made:

Geophysical study revealed 3-4-layer units of topsoil, lateritic zone, weathered basement and fresh basement rock. The thickness and geoelectric values vary in space. The basement rocks are not fractured within the scope of current electrode spread. Mineralogical and chemical analysis revealed the absence of high-level swelling clays, dominance of "true laterite" with high concentration of Fe_2O_3 and Al_2O_3 that serve as cementing agent.

Geotechnical results show that the soils are inorganic clay of low plasticity. This property is influenced by the dominant clay mineral type. They are poorly graded soils which suggest uniform grain sizes. The samples generally present parabolic shape during compaction which is an indication of "workability" if used as in-situ construction material. The soil samples can only function completely as subgrade material except in few ($\approx 30\%$) where the material can serve as sub-base course in pavement construction.

It was also observed that climatic factor and lack of drainage have major influence on the geotechnical state of the road.

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