Journal of Mining and Geology Vol. 57(2) 2021. pp. 513 - 520 0022-2763

Engineering Properties of Sub-Soils Along Akungba-Ikare Road, Southwestern Nigeria: *Appraising the Effect on Road Construction*

Ale, T.O.
Department of Earth Sciences, Adekunle Ajasin University Akungba Akoko
Corresponding E-mail: **ale.temitayo@aaua.edu.ng**

Abstract
This study is aimed at determining the strength and suitability of subsoils along Akungba-Ikare road, Southwestern Nigeria, as underlying materials for the purpose of engineering constructions. In order to achieve this, ten representative soil samples (D1-D10) were taken from the field and the following laboratory soil tests were conducted on these samples: particle size analysis test, Atterberg limit test, compaction test, specific gravity, consolidation test and California bearing ratio. The particle size analysis for the 10 sampled soils show that the percentages passing number 200 BS sieve are 22.3%, 28.4%, 47.1, 79.7%, 33.8%, 79.1%, 79.8%, 60.1%, 35.4% and 32.5% respectively. Samples D1, D2, D5 and D10 can be deduced as suited for sub-grade, sub-base and base materials as the percentage by weight finer than N0 200BS test sieve is less than or equal to 35%. The values of natural moisture content range, liquid limit, plasticity index, linear shrinkage and specific gravity ranged between 19.6% and 28.5%; 25.3 % and 60.4%; 0.9% and 44.1%; 3.6% and 12.1% and 2.57 and 2.68 which classified these soils as either sand or silty sand. The Maximum Dry Density (MDD) for the sampled soils range between 1754kg/m^3 to 2009kg/m^3 while that of optimum moisture content (OMC) ranges between 12.2% and 17.3%. The unsoaked California bearing ratio values for the subsoil samples range between 26% and 50%. These CBR results show that the soils are only suited for sub-grade course and not sub-base and base course. Based on AASHTO classification, four (40%) of the ten sampled soils has good rating for sub-grade and sub-base. Five (50%) samples have fair rating while the remaining one (10%) samples have poor sub-grade rating. The rate of settlement ranged between 0.58mm/yr and 1.21mm/yr with samples D1, D2, D5 and D10 having values less than 1mm/yr. This implies that the other values will settle under continuous movement of heavy duty trucks.

Keywords: *Subsoil, particle size analysis, atterberg limit test, compaction test, specific gravity, California bearing ratio, consolidation test.*

Introduction

The advantages of road transportation over rail, air and water transportations as well as any other form of human and goods movements in Nigeria have informed its popularity and patronage by most people. Akungba-Ikare road is one of the busiest roads that link the North with the South. The road is as old as the as country itself and has been expanded with time. There is also an improvement on the materials used. Despite the improvement, the road over the years had been repaired on many occasions due to the continuous failing of some sections. When wheel load from articulated and heavy duty vehicles pass through the pavement, they produce shear stresses in the ground below that have potential to cause shear failure in the residual soil. The failed parts are more pronounced during the wet season while in most cases repairs are carried out during dry season. Many factors account for the sorry state of the country's roads, particularly the Akungba-Ikare road. Most importantly is the behavior of the residual soil which is a function of the mineral compositions and reflect the properties of the parent rocks (Akpan, 2005, Amadi, *et al.*, 2012). In recorded history of soil test in the different part of Nigeria; results show that soil materials vary significantly from place to place mostly because of the parent rock type they are formed from. It is therefore imperative to characterize and determine the strength properties of the subsoil that will either support basement or the building before construction. Effect should be deliberate to achieve productivity for the soil material. Some of the causative factors responsible for many of the road failures in Nigeria under geotechnical properties of soils include; low Maximum Dry Density(MDD), poor bearing capacity, high compressibility, and high liquid limit, plasticity index , linear shrinkage, OMC and California bearing ratio (CBR) (Akpan, 2005, Ademilua, 2018). The effects of working on soil with poor geotechnical properties are capable of reducing the longevity of such road at times. Researchers have investigated the geotechnical properties of subsoils to understand the behavior of the soils that had caused significant damage to road construction and solutions to the identified problems with either expansive or unexpansive soils (Akpan, 2005; Amadi, *et al.* 2012; Ademilua, 2018; Oke, 2009; Jegede and Olaleye, 2013; Nwankwoala and Amadi, 2013; Osadebe and Omange, 2005). It is therefore necessary to determine these properties before embarking on any constructions. The engineering approach to this study will focus on the strength characteristics and suitability of the subsoils along Akungba-Ikare road as underlying materials upon which road construction is made.

Study Location

The study area is Akungba – Ikare road in Southwestern Nigeria. This area lies between latitudes 07^0 27'N and 07^0 31'N and longitude 005^0 43'E and 005^0 47'E of the Greenwich Meridian (figure 1). Akungba – Ikare Akoko area is moderately populated and it is surrounded by settlement such as Ogbagi-Akoko, Arigidi Akoko, Ugbe Akoko, Uba-Simerin Akoko, Iwaro Oka, Etioro and Supare Akoko. Akugba-Ikare road falls within the Pre-Cambrian Basement Complex of Southwestern Nigeria which consists of migmatite, gneisses, schist and quartzite into which has been an emplacement of granitic and, to a lesser extent, more basic materials (Rahaman, 1988). The predominant rock types in this area are the Porphyritic granite, Charnokite, Granite gneiss and Quartzite (Figure 2).

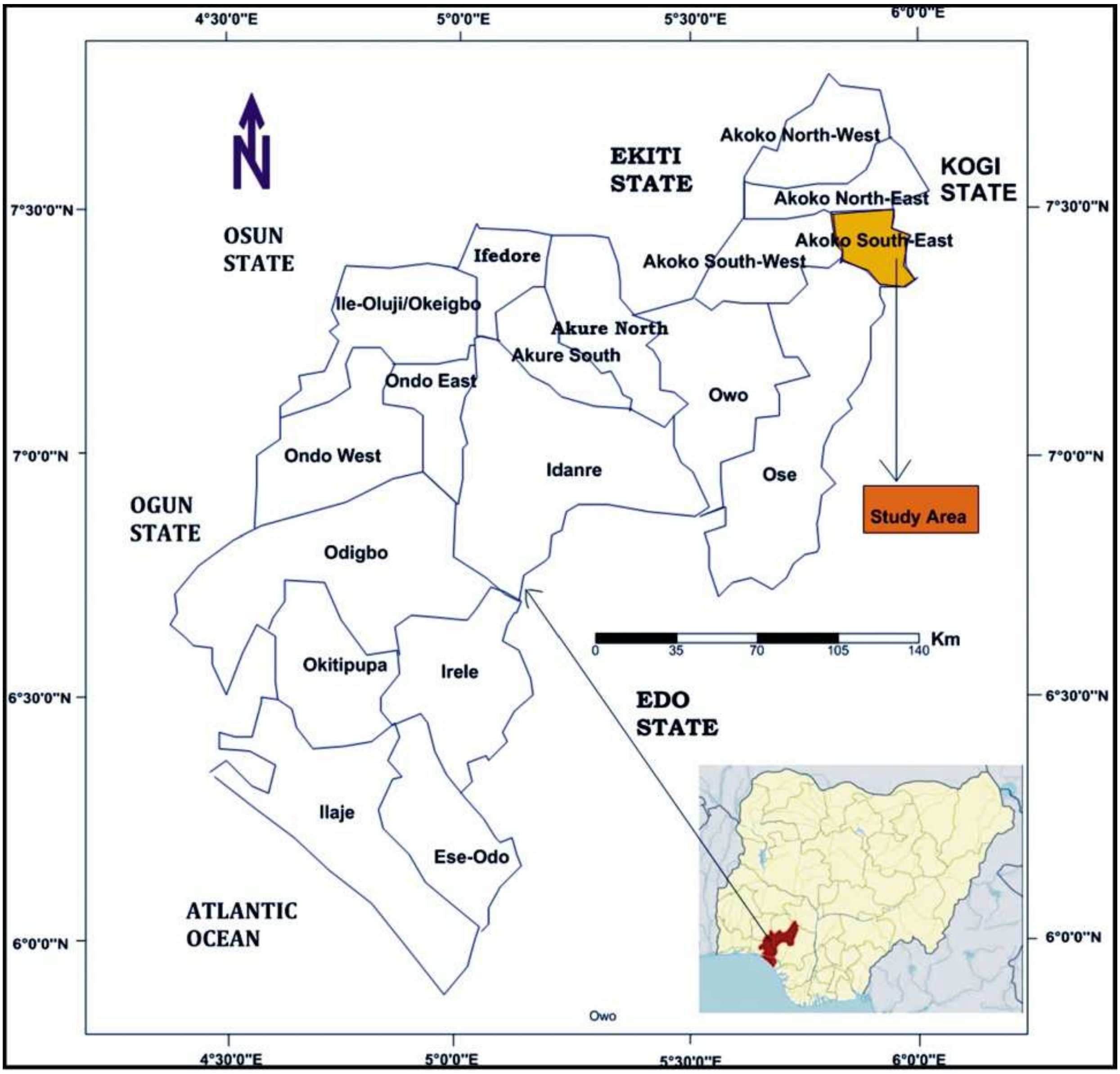

Fig. 1: Map of Ondo State showing Akungba-Ikare road in Akoko South East.

Materials and Methods

The methodology adopted includes reconnaissance mapping, soil samples collection, laboratory tests and interpretation of tests results. The reconnaissance survey was majorly to identify and map out failed sections of the road under study and where samples will taken. Ten laterite soils samples were taken along Akungba - Ikare road in the southwestern, Nigeria. The following laboratory tests were conducted on the

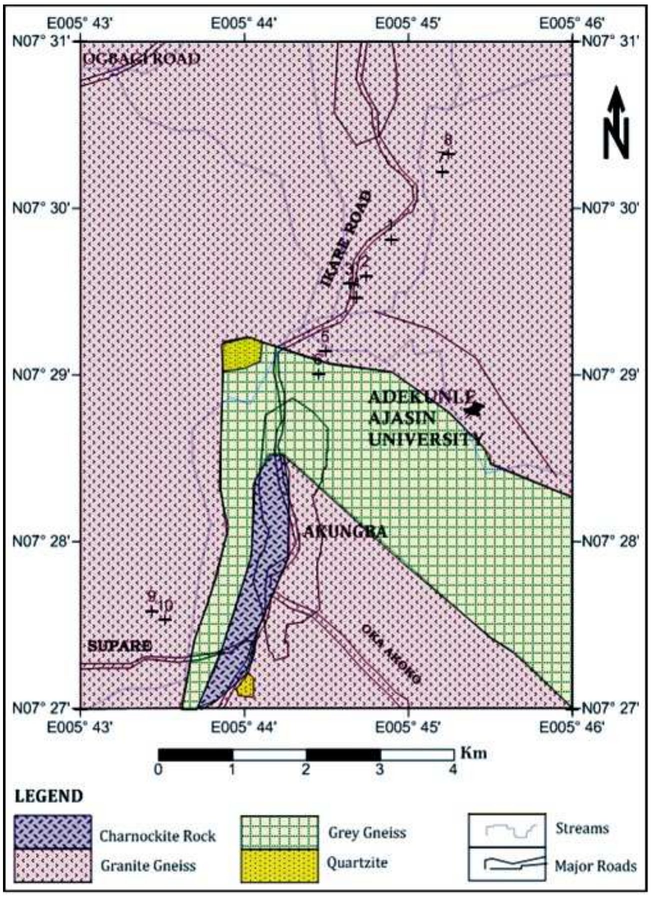

Fig. 2: Geological Map of Akungba – Ikare Akoko. (Modified After AAUA Field Mapping, 2013)

obtained soil samples: Atterberg limits test, specific gravity test, sieve analysis test, moisture content test, were used for classification while compaction test, consolidation test and California bearing ratio test (CBR) were used to determine the strength . All the tests were carried out in accordance with British standard code of practice (BS1377:1990) (British Standard, 1990). The samples are represented with D1 to D10.

Results

The values of Natural Moisture Content range between 19.6% and 28.5% (Table 1). The coarse contents of the soils ranged between 20.2% and 77.7% while the fine contents of the soils range between 22.3% and 79.8% (Table 1). The values of liquid limit, plastic limit and plasticity index range between 25.3 % and 60.4%, 16.3% and 38.1% and 0.9% and 44.1% respectively (table 1). The activity values range between 0.05 and 2.69. The results of linear shrinkage range between 5.0% and 11.4% (Table 1). The specific gravity of the tested soil samples range between 2.57 and 2.68 (Table 1). The Maximum Dry Density (MDD) for the sampled soils range between 1754 kg/m^3 and 2009 kg/m^3 while that of optimum moisture content (OMC) ranges between 12.2% and 17.3% (Table 2). The unsoaked California bearing ratio values for the subsoil range between 26% and 50%. The coefficient of consolidation ranged between 0.1842 and 0.2942. The coefficient of volume compressibility ranged between 0.1882 and 0.4851. The rate of settlement ranged between 0.58mm/yr and 1.21mm/yr with samples (Table 3).

Discussion

Index properties

The values of Natural Moisture Content range from 19.6% to 28.5% (Table 1). All the values of the sampled soil for NMC are higher than the average range (5–15%) as specified by FMWH (2010) for engineering construction. This is an indication that the soil has high adsorption capability and can cause a great deal of problem if not properly managed. These values range are not suitable as subgrade, subbase and base materials. The result of the tested soil samples show that the values fall into the category of gravel and sand (5% to 50%) as

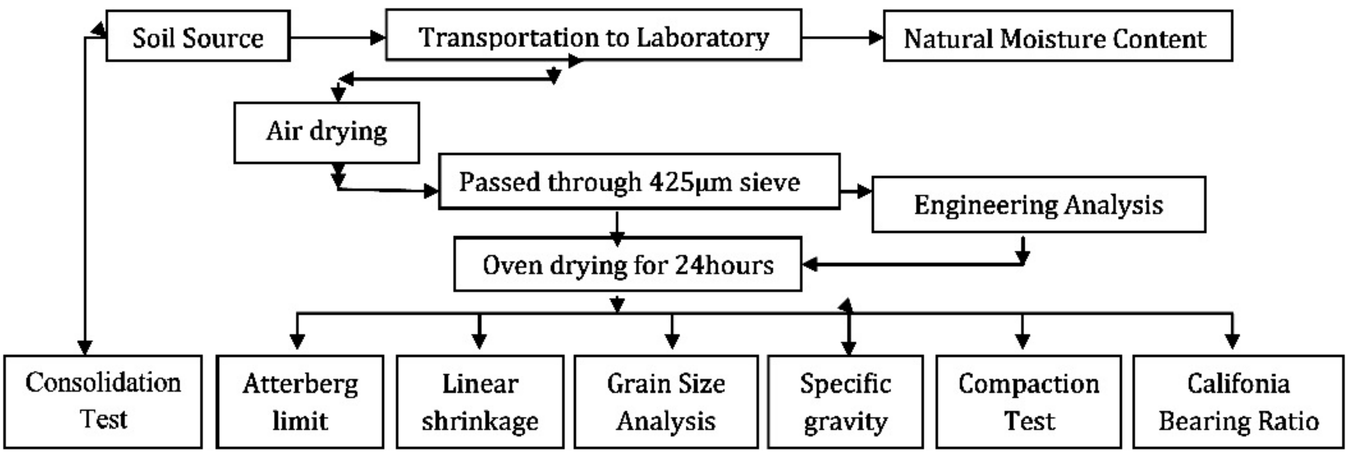

Fig. 3: Schematic diagram of the various tests conducted on laterite soils D1 –D10 sampled along Akungba-Ikare road, Ondo State, Southwestern, Nigeria.

stated by Emesiobi (Emesiobi, 2000) classification of natural moisture content for different soil types. The result of the samples shows that the values fall into the category of gravel and sand. High variation in the moisture content causes large volume changes in the clayey soils (Daramola, *et al.*, 2018).

Sieve analysis test measures the grain-size distribution of a soil when it is passed through a series of sieves. The coarse contents of the soils ranged from 20.2% to 77.7% while the fine contents of the soils range from 22.3% to 79.8% (Table 1). In accordant to the Federal Ministry of Works and Housing general specification requirements for roads and bridges (FMWH, 1997), four (D1, D2, D5 & D10) out of ten sampled soils (40%) are suited for sub-grade, sub-base and base materials as the percentage by weight finer than NO 200BS test sieve is less than 35%. It implies that the other seven subsoil samples are poor highway construction materials due to it percentage of fine and plasticities and will be affected by seasonal variation change. It is therefore necessary to stabilize these soils before use. Again, the sampled soils (D1-D10) are well graded because of the wide range of particle sizes on the grain size distribution curve from fine to coarse (Figure 4).

Consistency limits test establish the moisture contents at which fine grained clay and silt soils transition between solid, semi-solid, plastic, and liquid states; and the ease to which the soil can be deformed when it come in contact with water. The values of liquid limit, plastic limit and plasticity index range between 25.3 % and 60.4%, 16.3% and 38.1% and 0.9% and 44.1% respectively (table 1). Federal Ministry of Works general specification requirements for roads and bridges (FMWH, 1997) recommend liquid limit not greater than 80% and plasticity index not greater than 55% for sub-grade materials. All the sampled soils fall within this specification. Again, liquid limit and plasticity index should not be greater than 35% and 12% respectively for both sub-base and base materials. Seven (Osadebe and Omange, 2005) samples (70%) fall within this specification. The higher the liquid limit and plasticity index of a soil, the poorer the material for foundation and road construction purposes. According to Sowers (Sowers and Sowers, 1970) classification of soil plasticity index; D1 & D8 fall between 0 and 3 and are rated as non plastic with low dry strength. D2-D6, D9 & D10 samples fall within 3 to 15 rating of slightly plastic with slight dry strength while D7 has a value greater than 30 which is rated as highly plastic with high dry strength. Casagrande plasticity chart uses atterberg limit to create a distinction between clay and silt of fine grain soil. Based on Casagrande's plasticity chart classification (Casagrande, 1947); only two samples (D2 & D7) are above the A-line which implies that D2 falls within the medium compressibility (CI) and D7 within the high compressibility (CH). The remaining samples fall within MI classification of Silt below the A-line. The activity of clay is the proportion of plasticity index to clay fraction as percentage. The activity values of the sampled soils are presented in table 1 and on activity charts in figure 5 & 6. The activity values range from 0.05 to 2.69. In clay classification, when the activity is less than 1 it suggest kaolinite, while activity between 1 and 2 suggest illite and greater than 2 implies montmorillonite. In the same vein, activity values less than 0.75 implies that the mineral is inactive, between 0.75 and 1.25 is regarded as normal, and value greater than 1.25 is active (Skempton, 1953). This implies that the clay activities of the sampled soils varied from inactive to active clays; nine samples fall within the inactive and one sample was found to be active based on Skempton (Skempton, 1953) interpretation (Table 1). This also indicates that 9 out of the sampled soils have the predominant clay mineral present to be kaolinite while the remaining one sample is illite. Hence they possess low to high expansion potential as indicated by the activity chart (Figure 7).

The results of linear shrinkage range between 5.0% and 11.4% (Table 1). Brink *et al.,* (Brink, *et al.,* 1982) stated that linear shrinkage value below 8% is an indicative that a soil is good as either a base, sub-base and sub-grade materials. Only 50% (samples D1, D5, D6, D8 &D10) of the sampled soils are within this specification. Gidigasu, (Gidigasu, 1974) also stated that soils with below 10% is good; six (6) samples meet this specification.

The specific gravity of soil material is the proportion of its density to that of water. The specific gravity of the tested sampled soils range between 2.57 and 2.68 (Table 1). These range of values obtained are within the reportedly Maignien (Maignien, 1966) results on the tropical African lateritic soils which range between 2.5 and 3.6. The specific gravity values are relatively low which indicate coarse soils. Also, correlation of the results with Bowles (Bowles, 1992) classification shows that these laterite soils are either sand or silty sand (Table 1).

According to AASHTO (1993) soil classification, samples gotten from locations D1, D2, D5 and D10 are classified as either A-1-b or A-2-4 materials (granular material) with rating of excellent to good materials for

Table 1: Summary of all the geotechnical index tests on the soil samples

S/N	NMC	LL (%)	PL (%)	PI (%)	LS (%)	SG	% FINE	% Coarse	CLAY	AASHTO (GI)	Activity	Rmk	PR	CLAY TYPE
D1	26.3	26.8	25	1.8	5.7	2.6	22.3	77.7	16.4	A-1-b(0)	0.11	I	3.71	Kaolinite
D2	19.6	30.2	20.9	9.3	3.6	2.58	28.4	71.6	7.1	A-2-4(0)	1.31	A	1.44	Illite
D3	25.8	33.6	25	8.6	10.7	2.62	47.1	52.9	19.9	A-4(0)	0.43	I	1.34	Kaolinite
D4	26.9	41.2	31.1	10.1	12.1	2.58	79.7	20.3	24.5	A-5(9)	0.41	I	1.32	Kaolinite
D5	28.5	33.7	28	5.7	6.4	2.57	33.8	66.2	19.8	A-2-4(0)	0.59	I	1.31	Kaolinite
D6	23.1	49.8	38.1	11.7	11.4	2.59	79.1	20.9	31.3	A-7-6(0)	0.18	I	1.20	Kaolinite
D7	26.0	60.4	16.3	44.1	10.7	2.58	79.8	20.2	7.1	A-7-6(0)	0.25	I	1.07	Kaolinite
D8	27.0	26.6	25.7	0.9	7.1	2.62	60.1	39.9	18.3	A-4(0)	0.05	I	1.04	Kaolinite
D9	27.0	32.7	24.3	8.4	9.3	2.68	35.4	64.6	21.0	A-4(0)	0.4	I	1.35	Kaolinite
D10	23.5	25.3	20.7	4.6	5.0	2.62	32.5	67.5	18.3	A-2-4(0)	0.25	I	1.22	Kaolinite

NMC natural moisture content, **SG** specific gravity, **LL** liquid limit, **PL** plasticity limit, **PI** plasticity index, **LS** linear shrinkage, **GI** group index, **AASHTO** American Association of State Highway Transportation Office, **PR** plasticity ratio

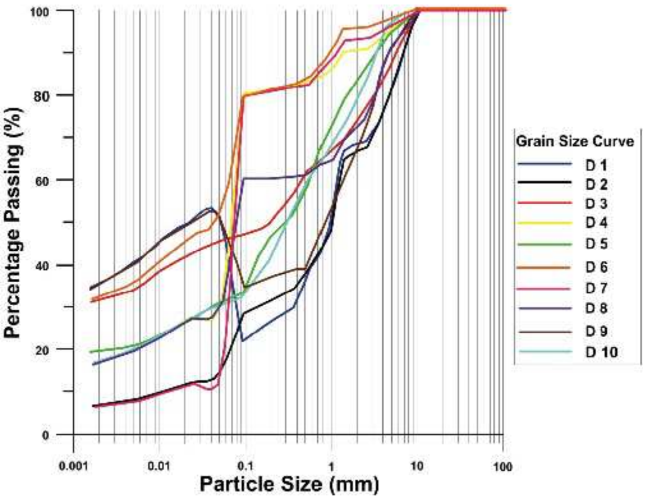

Fig. 4: Grain size distribution curves for the 10 soils

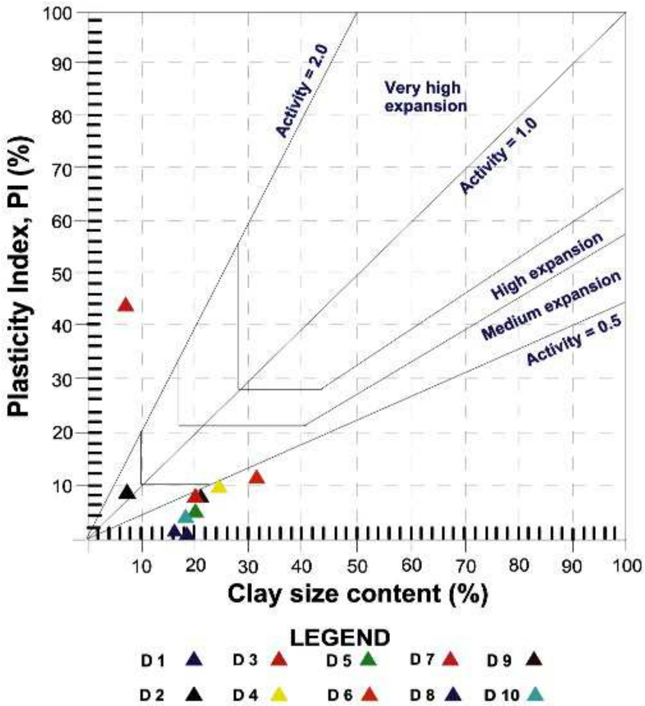

Fig. 5: Plots of the sampled soils on activity chart for the study area

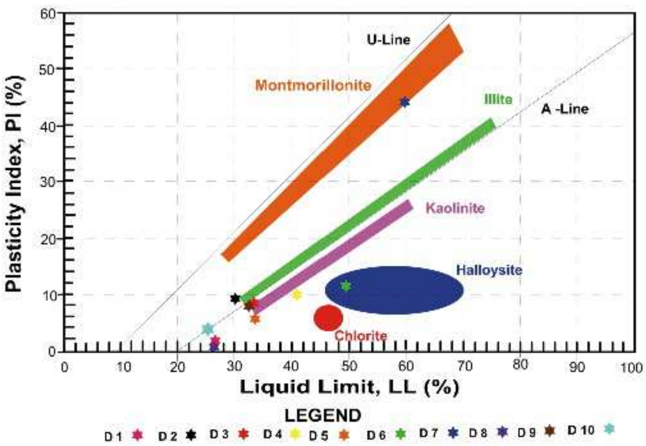

Fig. 6: Plots of the activity character of all the sampled soils

highway construction works having satisfied all the conditions for constructing sub- grade and sub-base materials. Samples of D3, D4, D8 & D9 (A-4 & A-5) are rated as fair sub-grade material while samples of D6 &D7 (A-7-6) are rated as poor sub-grade materials (Table 1).

Soil Strength Properties

Low maximum dry density value has been considered as the major contributory factor to the incessant road failure in Nigeria. Soils with high maximum dry density values at relatively low optimum moisture content are valuable and good for road construction (Jegede, 1997).

Therefore, compaction of soils for highway construction should be done in a way to achieve the highest degree of compression in order to prevent consolidation when wheel load from vehicle pass through the pavement to transmit load into the subsoil

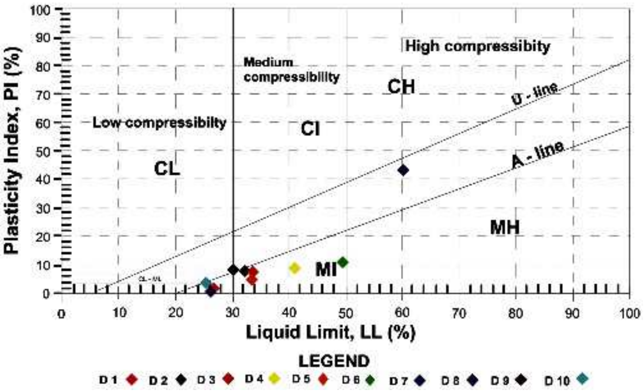

Fig. 7: Plots of the sampled soils on Casagrande Plasticity chart (ASTMD 2487)

below. The Maximum Dry Density (MDD) for the sampled soils range from 1754 kg/m^3 to 2009 kg/m^3 while that of optimum moisture content (OMC) ranges from 12.2% to 17.3% (Table 2). According to Wood (1937) classification, Samples D1, D2, D3, D9 & D10 fall between excellent and good. D4, D5, D6 & D8 have fair ratings while the D7 poor rating (table 2). The best way to remediate the soils with fair and low MDD is to compact the soil to have higher unit weight by removing the void ratio so as to have better engineering properties.

The California Bearing Ratio is used to measure the mechanical strength of subgrades and base course materials as well as to determining the thickness of the pavement requirement (Simon, *et al.*, 1973, Adeyemi, 2002). The unsoaked California bearing ratio values for the subsoil range from 26% to 50%. Federal Ministry of Work and Housing (1997) recommended soaked CBR for sub-grade, sub-base and base soils not less than 5%,

Table 2: Results of the Compaction and California Bearing Ratio (CBR) tests

S/N	MDD (Kg/m^3)	OMC (%)	Unsoaked C.B.R. (%)	Soaked C.B.R.(%)
D1	1967	14.2	40	27
D2	1968	13.4	43	23
D3	2009	12.2	50	24
D4	1787	16.5	34	19
D5	1832	15.4	33	16
D6	1841	15.4	32	11
D7	1754	17.3	26	12
D8	1835	17.2	34	18
D9	1972	13.8	32	16
D10	1994	12.5	33	19

30% and 80% respectively. The result for soil samples shows that all the soils are only suited for sub-grade course and not sub-base and base course (Table 2). The soil can be upgraded to base and sub-base course by increasing the percentage of coarse aggregates in the soil and thus concomitantly increasing the CBR value (strength) of the soil.
The coefficient of consolidation ranged between 0.1842 and 0.2942. The coefficient of volume compressibility ranged between 0.1882 and 0.4851. Going by the analysis of Bell (Bell, 2007), laterites from samples 1, 2, 5, and 10 fall within the medium degree of compressibility and are of silty type while others of Samples D3, D4, D6, D7, D8 and D9 fall within the high degree of compressibility and are of clay soil type (Table 3).

The rate of settlement ranged from 0.58mm/yr to 1.21mm/yr with samples D1, D2, D5 and D10 having values less than 1mm/yr while others have their values above the prescribed requirement of failure. This implies that the latter values will settle under continuous movement of heavy duty trucks. The water table level of Akungba - Ikare area is generally low as compared to other areas; because of the presence and population of the Adekunle Ajasin University community on the available water resources. This means that the vertical effective stress is transferred from the pore water to the soil particle grains. This could have been a major reason for the settlement in the failed portions.

Conclusion and Recommendations

This study has provided insight into the properties of subsoils obtained along Akungba-Ikare road, Southwestern, Nigeria.

- ✓ The Consistency characteristics (i.e. liquid limit, plastic limit and plasticity index) and the linear shrinkage show that majority of the sampled soils are good as sub-grade, sub-base and base materials.
- ✓ Majority of the particle size distribution of the soils indicate that they are unsuitable for base materials by standard acceptance specifications.
- ✓ Results show that majority of the soils have fair to excellent maximum dry density values at relatively low optimum moisture content rating and good for road construction.

Table 3: Summary of the Consolidation Results

S/N	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
CV	0.2121	0.2622	0.2522	0.2214	0.1842	0.2362	0.2641	0.2482	0.1884	0.2942
MV	0.4241	0.4851	0.3992	0.4041	0.3912	0.4442	0.3246	0.3832	0.3284	0.1882
S	0.94	0.72	1.11	1.21	0.92	1.14	1.04	1.02	1.02	0.58

Cv coefficient of consolidation, ***Mv*** coefficient of volume compressibility, ***S*** settlement

- ✓ The CBR results show that the soils are only suitable for sub-grade course and not sub-base and base course.
- ✓ Based on AASHTO classification, four (40%) of the ten sampled soils has good rating for sub-grade and sub-base. Five (50%) samples have fair rating while the remaining one (10%) samples have poor sub-grade rating.

In sum, road failure in this part of the Southwestern Nigeria is a combination of fairly bad soil materials, drop of water level and not so good construction design. These subsoils can still be improved through stabilization and/or further compact the soils to have higher unit weight.

Recommendation

Adequate hydraulic structure should be provided in this area as well as other roads with similar problem in Nigeria.

References

AASHTO (1993). Standard specification for transportation materials and methods of sampling and testing, 14th edn. American Association of State Highway and Transportation Officials, Washington, DC

Ademilua, O. (2018). Geotechnical characterization of subgrade soils in Southwestern Part of Nigeria. In: Proceedings of first and second international conferences of the Nigerian Association of Engineering Geology and the Environment, Lagos, Nigeria, vol 1, pp 42–48

Adeyemi, G.O. (2002). Geotechnical Properties Of Lateritic Soil developed over quartz schist in Ishara Area Southwestern Nigeria. Journal of Mining and Geology 38(1):65-69.

Akpan, O. (2005). Relationship between road pavement failures, engineering indices and underlying geology in a tropical environment. Glob J Geol Sci 3(2):99–108

Amadi, A.N., Eze, C.J., Igwe, C.O., Okunlola I.A. and Okoye, N.O. (2012). Architect's and Geologist's view on the causes of building failures in Nigeria. Mod Appl Sci 6(6):31–38

Bell, F.G. (2007). Engineering geology, 2nd edn. Butterworth-Heinemann Publishers, Oxford, p 581

Bowles, J.E. (1992). Engineering Properties of soils and their measurements, 4th International Edition. McGraw Hill Incorporated, pp 53-58.

Brink, A.B.A., Patridge, J.E. and Williams, A.A.B. (1982). Soil Survey for Engineering, Claredon, Oxford, p378

British Standard (BS) 1377 (1990). Methods of testing soils for civil engineering purposes. British Standards Institution, London

Casagrande A (1947) Classification and identification of soils. American Society of Engineers, Reston, pp 783–811

Daramola, S.O., Malomo, S. and Asiwaju-Bello, Y.A. (2018). Premature failure of a major highway in Southwestern Nigeria. The case of Ipele–Isua highway. Int J Geo-Eng 9:1–12

Emesiobi, FC (2000) Testing and quality control of materials in civil and highway Engineering. ISBN 078-2009-36-16 pp5-7

Federal Ministry of Works and Housing (FMWH) (1997). General specification for roads and bridges, vol II. Federal Highway Department Lagos, Abuja, p 317

Federal Ministry of Works and Housing (FMWH) (2010). General specification of roads and bridges 2:137–275

Gidigasu, M.D. (1974). The degree of weathering in the identification of laterite materials for engineering purposes. Eng. Geol., 8(13):216-266.

Jegede, G. (1997). Highway pavement failure induced by soil properties along the F209 highway at Omuoke, southwestern Nigeria. Niger J, Sci

Jegede, O.G. and Olaleye, B.M. (2013). Evaluation of engineering geologic and geotechnical properties of subgrade soils along realigned Igbara-Ikogosi Highway, South-west Nigeria. Int J Eng Sci 2(5):18–21

Maignien, R. (1966). Review of research on laterites. UNESCO Natural Resources, Research IV.

Nwankwoala, H.O. and Amadi, A.N. (2013). Geotechnical investigation of sub-soil and rock characteristics in parts of Shiroro–Muya–Chanchaga Area of Niger State, Nigeria. Int J Earth Sci Eng 6(1):8–17

Oke, S.A., Amadi, A.N., Abalaka, A.E., Nwosu, J.E. and Ajibade, S.A. (2009). Index and compaction properties of laterite deposits for road construction in Minna Area, Nigeria. Niger J Constr Tech Man 10(1–2):28–35

Osadebe, C.C. and Omange, G.N. (2005). Soil properties and pavement performance in the Nigerian rainforest; a case study of Shagamu–Benin road, Southwestern Nigeria. Ife J Sci 7(1):119–122

Rahaman, M.A. (1988). Recent advances in the study of the basement complex of Nigeria. In: Precambrian geology of Nigeria. Geological Survey of Nigeria Publication, Kaduna, pp 11–43

Simon, A.B., Giesecke, J. and Bidlo, G. (1973). Use of Lateritic Soils for Road Construction In North Dahomey, Engineering Geology, Amsterdam, vol.19:1-13.

Skempton, A.W. (1953). The colloidal "activity" of clays. In: Proceedings of 3rd international conference of soil mechanics, Zurich, pp 57–61

Sowers, G.B. and Sowers, G.F. (1970). Introductory soil mechanics and foundations. Macmillian, NY, p556

Woods, K.B. (1937). Compaction of Embankments. Proceedings of Highways. Resources, Washington, vol.18(2):142-181.