Journal of Mining and Geology Vol. 58(2) 2022. pp. 1 - 9 0022-2763

Evaluation of Subsoil Engineering Properties for Road Construction at Oboto, Ondo East, Southwestern Nigeria

Ale, T.O. [1], **Ogunribido, T.H.T.** [1], **Faseki, O.E.** [1], **Ale, T.A.** [2], **Ajidahun, J.** [1], **Olomo, K.O.** [1], **Olubanjo, A.M.** [1], **Olofinyo, O.O.** [3], **Olanigan A.H.** [4], **Ogunleye, R.O.** [4], **Okeile, M.A.** [4] **and Ale, E.O.** [5]

[1]Department of Earth Sciences, Adekunle Ajasin University, Akungba Akoko, Nigeria.

[2]Department of Architecture, Adekunle Ajasin University Akungba Akoko, Nigeria.

[3]Department of Geology, University of Ibadan, Ibadan, Nigeria.

[4]Department of Applied Geology, Federal University of Technology, Akure, Nigeria.

[5]OLAM Group, Nigeria.

Corresponding E-mail: ale.temitayo@aaua.edu.ng

Abstract

Oboto community is located in Ondo East, Southwestern Nigeria in the tropical region. The engineering properties of the twelve soil samples obtained at the depth of between 0.6m and 1m were determined for potential road construction material. The natural moisture content (NMC), liquid limit, plastic limit, plasticity index and linear shrinkage values with their mean and standard deviation values of the twelve soil samples range from 10.2% to 14.4% (12.4% ± 1.42), 39.0% to 48.4% (43.5% ± 3.23), 22.1% to 29.4% (24.9% ± 2.37), 13.9% to 22.7% (18.6% ± 2.64) and 7.9% to 9.3% (8.4% ± 0.46) respectively. The NMC values fall under marginal engineering material; the atterberg limits of the soil samples met the requirement of subgrade material; while the linear shrinkage values show that the soil samples are good as subgrade, subbase and base materials. For grain size analysis, only three soil samples from locations OTP2, OTP10 & OTP11 met the specification of less than 35% of weight finer than NO 200BS test sieve. Ten soil samples fall within the clay medium compressibility except for OTP4 and OTP5 that have silt medium compressibility. The specific gravity shows that the soil samples are within sandy and silty sand. Three soil samples from locations OTP2, OTP11 & OTP12 have good ratings of A-2-6 or A-2-7; soil sample from location OTP3 has fair rating while the remaining soil samples have A-7-6 rating. The California bearing ratio values of 18% to 34% (mean & standard deviation values of 28.4% ± 4.6) show that the soil samples are good as subgrade material. The Maximum dry density and Optimum moisture content values show that the soil samples have fair to poor ratings. Soil samples from locations OTP1, OTP2, OTP3 OTP7, OTP11 & OTP12 have medium degree of compressibility and settlement values of less than 1 mm/year.

Keywords: *Subsoil, Road construction, Settlement, Failure, Oboto*

Introduction

Good roads, drinking water, electricity, security and good maintenance practices must be captured in the sustainable development plan of every nation. Every economy needs good roads to thrive. Roads are directly proportional to the socio-economic development and gross domestic product of the country (Meshida 2006; Olofinyo et al. 2019; Ale 2021; Emmanuel et al. 2021) and should be maximised (Ighodalo 2009). One of the ways to enhance the sustainability of a country is to take past and new detailed engineering geological records of soils to generate engineering geological maps of different regions in Nigeria for characterisation. This will perfectly assist in the construction of new roads and reconstruction of old roads. Most of the federal and state roads have experienced all kinds of failures ranging from technical, to maintenance and to structural (Emmanuel et al. 2021).

Cocoa farming is the major farming activity in the Oboto community. More than 90 percent of the people living there are involved in cocoa buying, selling and farming. Roads linking the farm areas with the major road are not graded and have no drainage. These roads become worse during the rainy season. Erosion water eats up part of the road and causes undulating features on the roads which serve as reservoirs for erosion water. Loaded trucks of cocoa, Lorries, articulated and other heavy vehicles find it difficult to maneuver these roads during wet season and many are seen sucked in the waters. There is therefore the need to carry out soil analysis of these areas for possible construction of the roads.

Study Area

The study area is Oboto in Ondo East, Southwestern Nigeria. It is bordered by Ondo west in the west, Idanre in the east, Odigbo in the south and south of the Ile Oluji/Oke Igbo local government areas. It lies between longitudes E004^{0} 55' and E004^{0} 57' 30"; and also latitudes N07^{0} 7' 30" to N07^{0} 10' of the Greenwich meridian (Fig. 1). It falls within the humid tropical region with two distinct seasons. The rainy season is from March to October and the harmattan season is from

November to March. The annual rainfall in the area is estimated to be about 2,000 mm (Akinseye, 2010) with a mean monthly temperature of between 25.7°C and 30.2°C as well as high humidity, generally above 50% (Akinseye, 2010). The area is accessible by the federal road stretching from Akure (35 kilometers); its network linked Benin-Ore-Lagos road. The various road networks and foot paths leading to the farmlands make nearly all the areas of coverage accessible with some effort. The drainage pattern in this area is dendritic.

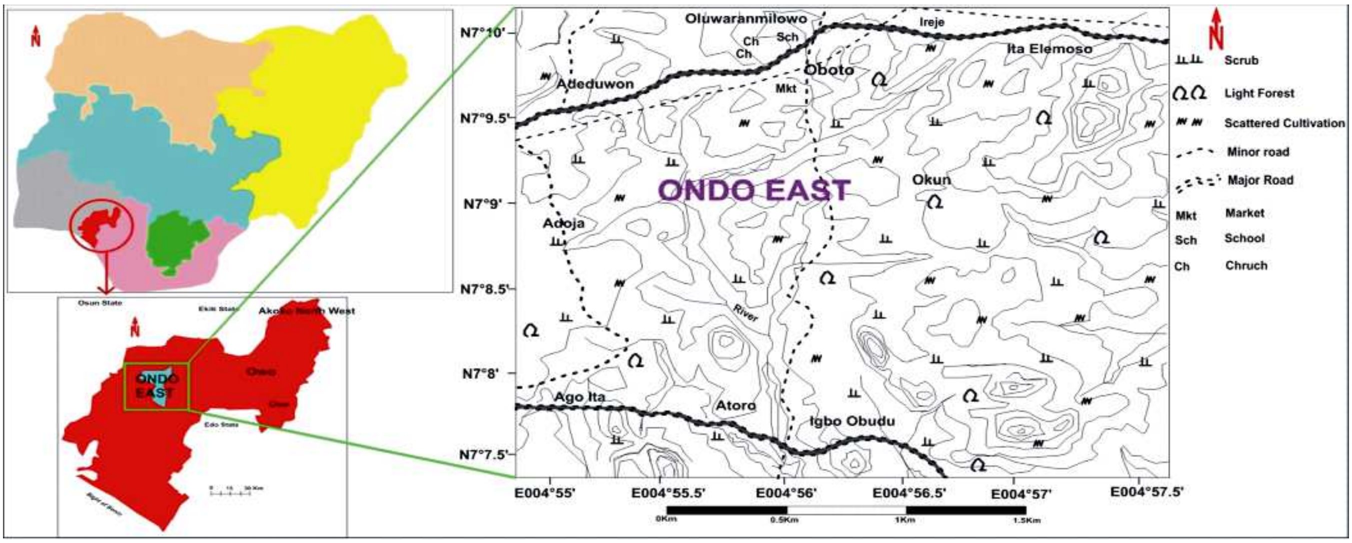

Fig. 1: Location map of the study area (insight is map of Nigeria and Ondo State)

Geology of Oboto, Ondo East, Nigeria

Ondo city and environs fall within the Precambrian Basement Complex of Southwestern Nigeria which are the migmatite, gneisses, schist and quartzite (Rahaman 1988). The dominant rock types in this area are the medium to coarse grained granite and granite gneiss as observed from detailed field geological mapping and the geological map produced (Figure 3). Microscopic observation of the thin sections of both rock types (under Plane polarized light and cross nicol) reveal that granite rock is made up of three major minerals namely biotite, quartz and feldspar while the granite gneiss is majorly composed of Quartz, plagioclase Feldspars, Biotite, Hornblende and Muscovite. The granite rock is medium to coarse-grained. The granite gneiss has moderate to high foliation with not so clearly defined alternating bands of light coloured minerals (quartz- and feldspar-rich) and dark-coloured minerals rich in biotite, hornblende and other ferromagnesian minerals. The rock mainly trends WNW-ESE to ENE-WSW with moderate to steep dips to the south. The granite gneiss shows evidence of pegmatite, vein quartz and quartz lenses. Structures such folds, fractures and sheared zones are visible on the rock which is as a result of tectonic deformation.

Materials and Method

Twelve disturbed subsoil samples were collected from twelve trial pits along the minor road in Oboto, Ondo East Southwestern Nigeria. Soil samples were obtained between 0.6m and 1m depth and were kept in labeled polythene nylon bags (OTP1-OTP12). The soil samples for natural moisture content were collected into different sealed nylon to prevent moisture loss; and were determined immediately in the laboratory. Soil samples were air dried for 14 days before conducting other analysis. The other laboratory tests are Atterberg limit test, linear shrinkage test, grain size analysis, specific gravity, compaction test, consolidation test and California bearing ratio test; and were carried out in accordance with British standard code of practice (BS1377: (1990). Atterberg limits tests, linear shrinkage test, specific gravity and grain size analysis were done in accordance with American Society for Testing and Materials (ASTM) D4318, ASTM D494, ASTM D854 (using pycometer method) and ASTM D422-63 standards respectively. The set of sieves used consist of the following sizes: 4.75mm, 2.36mm, 1.18mm, 850µm, 425µm, 300µm, 150µm, 75µm and pan. The strength tests of a standard Proctor test, California bearing ratio test (penetration resistance) and consolidation test were carried out in accordance with

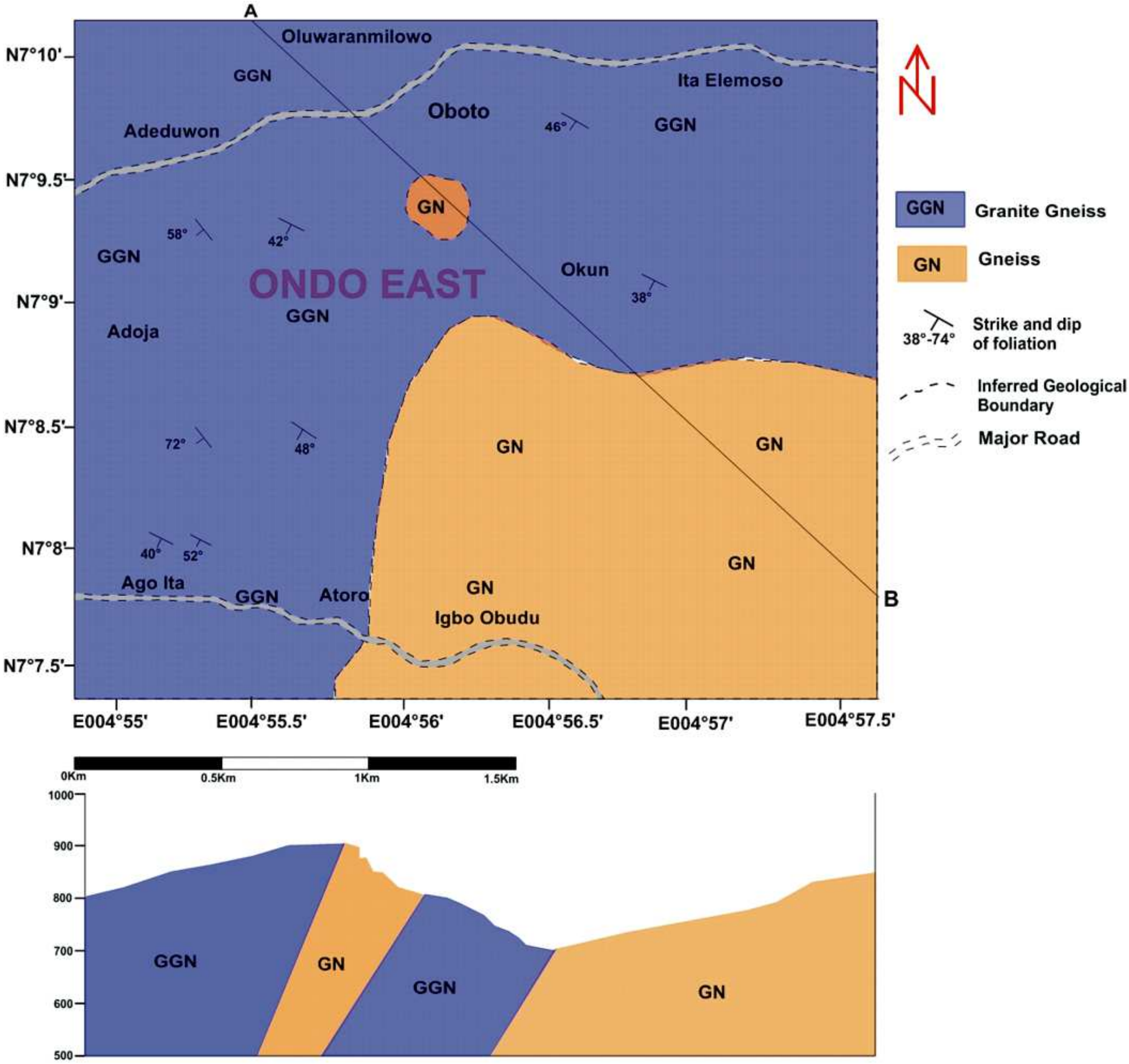

Fig. 2: Geological map of Oboto, Ondo East, Southwestern Nigeria

ASTM D 698, ASTM D1883-05 and specifications respectively. All the analyses were carried out at the Federal University of Technology, Akure. The obtained values were interpreted in accordance with the Nigeria specification.

Result

The values of the natural moisture content range from 10.2% to 14.4% (mean and standard values of 12.4% ± 1.42) (tables 1). The coarse contents and fine contents of the soil samples with their mean and standard deviation values range from 57.8% to 77.7% (63.9% ± 6.45), and 22.3% to 42.2% (36.1% ± 6.45) respectively as presented in table 1. The liquid limit, plastic limit and plasticity index values with their mean and standard deviation values for the twelve soil samples range from 39.0% to 48.4% (43.5% ± 3.23), 22.1% to 29.4% (24.9% ± 2.37) and 13.9% to 22.7% (18.6% ± 2.64) respectively (Tables 1). The linear shrinkage values of soil samples with their mean & standard deviation values range from 7.9% to 9.3% (8.4% ± 0.46) (tables 1). The specific gravity values with mean and standard deviation values of the soil samples range from 2.61 to

2.65 (2.63 ± 0.01) (tables 1). The result of the California bearing ratio test ranges from 18% to 34% (mean & standard deviation values of 28.4% ± 4.6) (tables 2). The maximum dry density of soil samples range from 1590Kg/m^3 to 1804Kg/m^3 (mean & standard deviation values of 1687.5Kg/m^3 ± 72.4) while the optimum moisture content ranges from 10.4% to 14.4% (mean & standard deviation values of 12.8% ± 1.35) (table 2). The Coefficient of consolidation values, coefficient of volume compressibility values and settlement values with their mean and standard deviation values range from 0.1847 to 0.2594 (0.2216± 0.0224) , 0.2194 to 0.3921 (0.3068± 0.0518) and 0.7652 to 1.2428 (0.979± 0.1434) respectively(table 2).

Discussion

Index Properties

The geotechnical properties of subsoil are the x-ray that reveals the class/category of the soil material and its role in engineering construction. The values of the natural moisture content range from 10.2% to 14.4% (mean and standard values of 12.4% ± 1.42) (tables 1). Comparing the obtained results with the Underwood (1967) classification of natural moisture content values; all of the soil samples fall under marginal engineering material. The Federal Ministry of works and Housing (FMWH, 2010) specification stated that any soil material with natural moisture content value greater than 15% should be avoided in engineering construction activities. All the samples are within the recommendation. Excessive moisture content in soil can cause a great deal of problems if poorly managed (Daramola et al. 2015). There will be a decrease in the shear strength of the soil because of the fairly high values of soil moisture content recorded for soil samples obtained during the dry season. The soil samples are suitable for both subbase and subgrade materials.

Particle size analysis is used to rate soils according to their suitability to support road pavements and building constructions. The coarse contents and fine contents of the soil samples with their mean and standard deviation values range from 57.8% to 77.7% (63.9% ± 6.45), and 22.3% to 42.2% (36.1% ± 6.45) respectively as presented in table 1. According to the Federal Ministry of Works and Housing general specification requirements for roads and bridges (FMWH, 1997); the subgrade, subbase and base materials for construction must have less than 35% of weight finer than NO 200BS test sieve. Three soil samples (from locations OTP2, OTP10 & OTP11) met this specification while the remaining soil samples from the nine locations (OTP1, OTP3, OTP4, OTP5, OTP6, OTP7, OTP8, OTP9 & OTP12) did not meet this requirement and will be affected by seasonal variation change. All the soil samples are well graded because of the wide range of particle sizes on the grain size distribution curve from fine to coarse (Figure 3). In addition, none of the soil samples can be regarded as clean sand because they all have more than 5 percent of silt or clay passing through the #200 sieve.

The liquid limit, plastic limit and plasticity index values with their mean and standard deviation values for the twelve soil samples range from 39.0% to 48.4% (43.5% ± 3.23), 22.1% to 29.4% (24.9% ± 2.37) and 13.9% to 22.7% (18.6% ± 2.64) respectively (Tables 1). Soils with high liquid limit and high plasticity index values should be avoided at all cost in engineering constructions. The Nigerian specification of good/excellent soil as directed by FMWH (2010) recommends liquid limit not greater than 80% and plasticity index not greater than 55% for sub-grade materials while soil for sub-base and base materials should not be greater than 35% and 12% respectively. All the soil samples met the requirement for sub-grade soil. On the other hand, no sample met the requirement for subbase and base materials. The plasticity Index values of the soil samples fall between slightly plastic (3% -15%) and medium plastic (16% -30%) with slight and medium dry strength of Sowers (1979) classification.

The linear shrinkage values of soil samples with their mean & standard deviation values range from 7.9% to 9.3% (8.4% ± 0.46) (tables 1). Soil samples from five locations (OTP2, OTP3, OTP5, OTP11 and OTP12) fall within the recommended standard of Ola (1983) and Brink et. al, (1992) of 8% while all the samples met Gidigasu (1974) recommendation of 10% for a good soil material. Based on this linear shrinkage test, all the soil samples are good for subgrade, subbase and base materials but can further be improved upon. The obtained atterberg limits and linear shrinkage values are in the range of values gotten by Ogunribido et al (2015), Ale (2021, 2022), Ale et al (2022) Adekanye et al (2021), Olofinyo et al (2022) in the southwest basement complex of Nigeria.

Based on Casagrande's plasticity chart classification (1947); ten of the twelve soil samples are above the A-line except for soil samples in OTP4 & OTP5 that have more of silt in their fine contents. Ten soil samples from locations OTP1, OTP2, OTP3, OTP6, OTP7, OTP8, OTP9, OTP10, OTP11 and OTP12 fall within the clay medium compressibility (CI) while the remaining two soil samples from locations OTP4 and OTP5 fall within the silt medium compressibility (MI) (figure 4). The activity values of the twelve soil samples are presented in table 1 and on the activity chart in figure 5. The activity values range between 0.70 and 1.00. Skempton (1953) clay classification puts activity value less than 1 as kaolinite; activity value between 1 and 2 as illite while value greater than 2 as montmorillonite. Similarly, activity values less than 0.75 implies inactive mineral; between 0.75 and 1.25 is regarded as normal mineral, and value greater than 1.25 is active mineral. This implies that only one soil sample from location OTP3 has an inactive clay mineral while the remaining eleven soil samples have normal clay mineral (Skempton, 1953) (table 1). All the twelve soil samples have kaolinite to be the predominant clay minerals present and possess low to very low expansion potentials as indicated by the activity chart (figure 6).

The specific gravity values with mean and standard deviation values of the soil samples range from 2.61 to 2.65 (2.63 ± 0.01) (tables 1). According to Sowers (1979) classification, the range of specific gravity values indicate that the soil samples contain considerable amounts of clay and silt and further suggest slight to moderate shrinkage and swelling activities. Coduto (1999) noted that nearly all soils have specific gravity values between 2.60 and 2.80 and gave the range of Kaolinite rich clay, Montmorillonite rich clay and Illite rich clay to be between 2.60 and 2.66, 2.75 and 2.78, and 2.60 and 2.86 respectively. Again, these twelve soil samples fall within the kaolinite rich clay group. The tested soils have moderately high values that fall within sandy and silty sand in Bowles (1992) classification. These soil samples are classified as inorganic soils in Ramamurthy & Sitharam (2005) classification. The obtained value of the soil samples for specific gravity fall within 2.5 and 3.6 that was reported by Maignien (1966) for tropical African lateritic soils.

According to American Association of State Highway and Transportation Officials (AASHTO, 1993) soil classification; soil samples from three locations (OTP2, OTP11 & OTP12) have good ratings of A-2-6 or A-2-7. Soil sample from location OTP3 has fair rating of A-6 while the remaining soil samples from locations OTP1, OTP4, OTP5, OTP6, OTP7, OTP8, OTP9 and OTP10 are classified as A-7-6 materials (granular material with poor rating). The A-7-6 poor rating soil samples are not good enough for subgrade and subbase materials (table 1). The closer the group index value is to 0 the better the soil and vice versa. This group index value is most appropriate for A-7-6 soil. This implies that OTP 5 and OTP12 of group index values of 1 are better soil when compared to soil samples from locations OTP1 and OTP10 with group index values of 5 of the same A-7-6 rating. A good soil for highway subgrade may not be sufficiently good for other construction activities.

Table 1: Summary of the geotechnical properties of trial pits sampled soil

Trial Pit	NMC (%)	LL (%)	PL (%)	PI (%)	LS (%)	SG	Fine (%)	Coarse (%)	Clay (%)	AASHTO	Activity	USCS	Clay Type	GI
OTP1	**10.2**	48.4	26.2	22.2	8.6	2.62	**42.2**	**57.8**	**24.5**	A-7-6	0.91	CI	K	5
OTP2	**10.6**	39.0	22.1	16.9	7.9	2.64	**24.1**	**75.9**	**18.4**	A-2-6	0.92	CI	K	0
OTP3	**11.2**	40.0	22.8	17.2	7.9	2.63	**36.9**	**63.1**	**24.5**	A-6	0.70	CI	K	2
OTP4	**13.4**	46.2	29.4	16.8	8.6	2.64	**39.8**	**60.2**	**18.3**	A-7-6	0.92	MI	K	3
OTP5	**10.6**	42.6	28.7	13.9	7.9	2.65	**36.7**	**63.3**	**16.1**	A-7-6	0.86	MI	K	1
OTP6	**14.4**	45.4	23.4	22.0	8.6	2.63	**38.1**	**61.9**	**26.2**	A-7-6	0.84	CI	K	3
OTP7	**12.8**	42.0	24.1	17.9	8.6	2.63	**38.3**	**61.7**	**22.1**	A-7-6	0.81	CI	K	3
OTP8	**12.0**	44.3	25.7	18.6	8.6	2.62	**39.6**	**60.4**	**25.7**	A-7-6	1.00	CI	K	3
OTP9	**13.2**	44.6	24.5	20.1	8.6	2.61	**41.4**	**58.6**	**25.2**	A-7-6	0.80	CI	K	4
OTP10	**13.8**	48.2	25.5	22.7	9.3	2.62	**40.3**	**59.7**	**28.0**	**A-7-6**	0.91	CI	K	5
OTP 11	**13.4**	39.6	22.2	17.4	7.9	2.63	**22.3**	**77.7**	**18.1**	**A-2-6**	0.96	CI	K	0
OTP12	**13.0**	41.3	23.6	17.7	7.9	2.61	**34.0**	**66.0**	**19.9**	**A-2-7**	0.89	CI	K	1
Mn±SD	**12.4±1.42**	43.5± 3.23	24.9± 2.37	18.6±2.64	8.4±0.46	2.6±0.01	**36.1±6.45**	**63.9±6.45**	**22.3±3.94**					

LL = Liquid limit, **PL** = Plastic limit, **PI** = Plasticity Index, **LS** = Linear Shrinkage, **SG** = Specific Gravity, **K** = Kaolinite , **I** = Illite, USCS =Unified Soil Classification System, **AASHTO** = American Association of State Highway and Transportation Officials, **CL** = Low compressibility, **CI** = Intermediate compressibility , **MI** = Intermediate Silt, **Mn** = Mean, **SD** = Standard Deviation

Strength Properties

California bearing ratio (CBR) has been correlated with pavement performance and has been used to generate design curves for pavement thickness (Wignall et al., 1999). The result of the California bearing ratio test ranges from (Tables 2). The Federal Ministry of Work and Housing (FMWH, 1997) recommended California

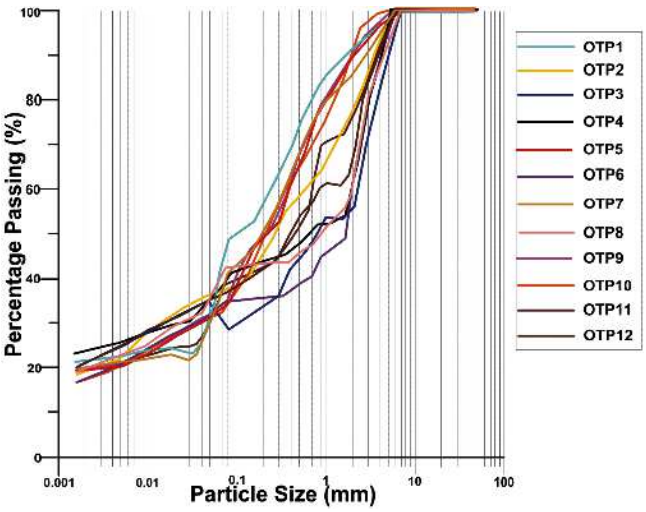

Fig. 4: Grain Size Analysis of the 12 soil samples from Oboto, Ondo East, Nigeria

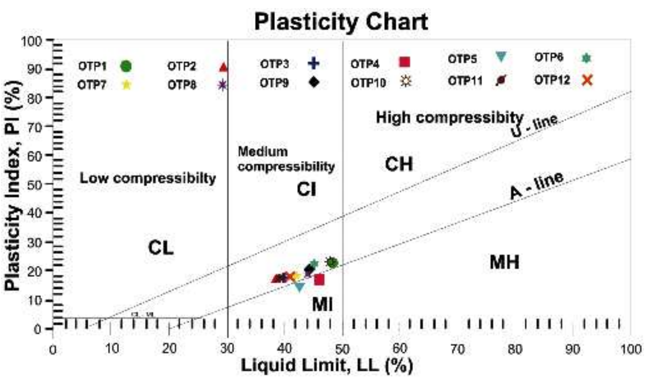

Fig. 5: Plots of the twelve soil samples on the Casagrande Plasticity chart (ASTMD 2487)

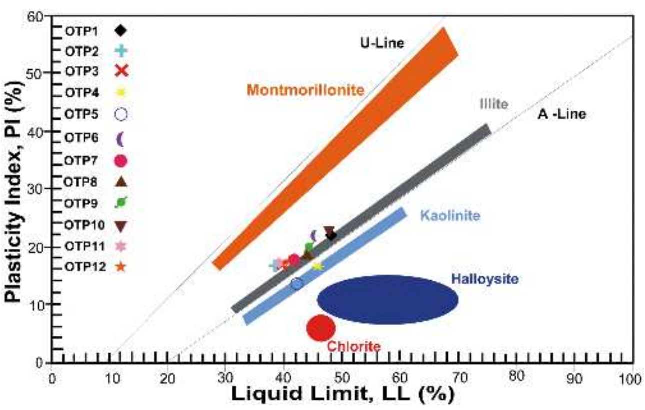

Fig. 6: Plots of the twelve sampled soils from Erusu Akoko on the activity chart

bearing ratio values of 80%, 30% and 5% for base, subbase and subgrade soil materials respectively. None of the soil samples met the specification of base soil material; seven soil samples from locations OPT1, OTP2, OTP3, OTP7, OTP9, OTP11 and OPT12 met the requirements of subbase material; while all the soil samples met the requirements of subgrade material. The

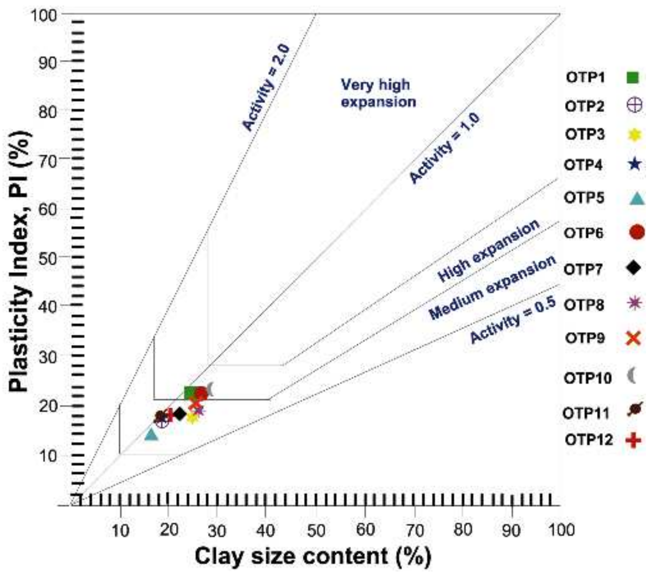

Fig. 7: Plots of the twelve trial pits soil samples from Oboto, Ondo East, Nigeria on the activity chart

soil sample with CBR value lower than 30% should be improved upon by adding stabilizers.

The strength Properties of subsoil is vital to the success or failure of any pavement or road construction. The maximum dry density (MDD) of soil samples range from 1590Kg/m^3 to 1804Kg/m^3 (mean & standard deviation values of 1687.5Kg/m^3 ± 72.4) while the optimum moisture content (OMC) ranges from 10.4% to 14.4% (mean & standard deviation values of 12.8% ± 1.35) (table 2). Soil sample from location OTP11 has the highest maximum dry density and lowest optimum moisture content while soil sample from OTP8 has the lowest maximum dry density and highest maximum moisture content (Table 2). Going by the preposition of Woods (1937), soil samples from locations OTP1, OTP4, OTP5, OTP6, OTP7, OTP8, OTP9, OTP10 and OTP12 fall into poor rating group (<1602 Kg/m^3 - 1762.2Kg/m^3). Locations OTP2, OTP3 and OTP 11 soil samples have fair ratings (<1762.2Kg/m^3 to 1922.4Kg/m^3) in Wood (1937) preposition. The subsoil material must have sufficient shear strength to support both their own weight and external loads such as foundation, foundation with buildings and moving vehicles.

According to the Federal Ministry of Works and Housing (FMWH, 1997) specifications MDD values for base/subbase and subgrade soil materials must not be less than 2000 kg/m^3 and 1760 kg/m^3 respectively. Comparing the MDD values of the soil samples obtained from the 12 locations with FMWH (1997); only three soil samples from locations OTP2, OTP3 and OTP11 met the specification of subgrade material while none met the requirement of subbase/base material. In a similar comparison with O' Flaherty (1988) proposition; the range of values fall into sandy clay and silty clay classifications of MDD values of between 1750kg/m^3 and 2165kg/m^3 and optimum moisture content of between 8% and 15% and between 1600kg/m^3 and 1845kg/m^3 and optimum moisture content of between 15% and 25% respectively. Other soil samples whose MDD values fall below 1700 Kg/m must be improved upon by increasing the level of compaction to close up the voids in the soils and adding of stabiliser.

The Coefficient of consolidation values (Cv), coefficient of volume compressibility values (Mv) and settlement (S) values with their mean and standard deviation values range from 0.1847 to 0.2594 (0.2216± 0.0224) , 0.2194 to 0.3921 (0.3068± 0.0518) and 0.7652 to 1.2428 (0.979± 0.1434) respectively (Table 2). Soil samples from locations OTP1, OTP2, OTP3 OTP7, OTP11 & OTP12 have medium degree of compressibility and also have settlement values lesser than 1 mm/year (very low settlement rate) while the other samples have high degree of compressibility and settlement values greater than 1(which implies that there is possibility of settlement). Authors like Abeele (1985), Coduto (1999), Prakash and Jain (2002) and Bell (2007) noted that a significant drop in groundwater level is a major cause of settlement; soil particles under the influence of water when submerged are supported by buoyancy. This is not a possibility in the study area because of the low population of people in the area. The settlement rate in the study area can be as a result of afforestation activities which can reduce groundwater yield through interception and transpiration (Allen and Chapman, 2001) and vibrations that lead to densification of soils and subsequent settlement (Laskar and Pal, 2012). Despite the level of consolidation achieved on the field, engineers should give allowance in time and design for consolidation to take effect. Consolidation in clayey soil may take several months to respond to applied initial load (foundation, foundation with buildings, pavement and vehicular movement). Coduto (1999) noted that consolidation in sandy soil is more severe than in clayey material. The MDD, OMC and CBR values present the same interpretation of not adequately sufficient to satisfy base, subbase and subgrade materials which are similar to the soil values obtained by Ogunribido et al (2015) and Ale et al (2022) and must be improved upon.

Table 1: Geographi

Test	OTP1	OTP2	OTP3	OTP4	OTP5	OTP6	OTP7	OTP8	OTP9	OTP10	OTP11	OTP12	Mn ± SD
MDD (Kg/m³)	1724	1768	1782	1624	1686	1654	1633	1590	1682	1592	1804	1711	1687.5 ± 72.4
OMC (%)	11.7	11.6	11.0	13.6	13.7	13.8	13.6	14.4	13.8	14.0	10.4	12.2	12.8± 1.35
(CBR) (%)	32	34	31	18	27	22	30	24	32	24	31	33	28.4 ±4.6
Cv	0.2323	0.2392	0.2289	0.2124	0.1847	0.1942	0.2369	0.2087	0.2144	0.2022	0.2458	0.2594	0.2216 ± 0.0224
Mv	0.2821	0.2661	0.2899	0.3281	0.3921	0.3702	0.2714	0.3366	0.3235	0.3517	0.2509	0.2194	0.3068 ± 0.0518
S	0.9029	0.8649	0.9225	1.0265	1.2428	1.1617	0.8773	1.0521	1.0131	1.0993	0.8305	0.7652	0.979 ± 0.1434

CBR = California Bearing Ratio, **MDD** = Maximum Dry Density, **OMC** = Optimum Moisture Content, **Cv** = coefficient of consolidation, **Mv** = coefficient of volume compressibility, **S** =settlement

Conclusion

The geotechnical properties of the twelve subsoils in Oboto, Ondo East, southwestern Nigeria were carried in accordance with British standard code of practice (BS1377: (1990). Index and strength tests were carried out on the soil samples. These tests include natural moisture content, liquid limit, plastic limit, plasticity index, linear shrinkage, specific gravity, grain size analysis, California bearing ratio, compaction and consolidation tests. The values of the natural moisture content range from 10.2% to 14.4% (mean and standard values of 12.4% ± 1.42) which fall under marginal engineering material. The liquid limit, plastic limit and plasticity index values with their mean and standard deviation values for the twelve soil samples range from 39.0% to 48.4% (43.5% ± 3.23), 22.1% to 29.4% (24.9% ± 2.37) and 13.9% to 22.7% (18.6% ± 2.64) respectively. Soil samples met the requirement for subgrade soil. The coarse contents and fine contents of the soil samples with their mean and standard deviation values range from 57.8% to 77.7% (63.9% ± 6.45), and 22.3% to 42.2% (36.1% ± 6.45) respectively. Only three soil samples from locations OTP2, OTP10 & OTP11 met the specification of FMWH (1997). Ten soil samples fall within the clay medium compressibility except for OTP4 and OTP5 that have silt medium compressibility. The linear shrinkage values of soil samples with their mean & standard deviation values range from 7.9% to 9.3% (8.4% ± 0.46) which are all good for subgrade, subbase and base materials. The specific gravity shows that the soil is within sandy and silty sand. Three soil samples from locations OTP2, OTP11 & OTP12 have good ratings of A-2-6 or A-2-7; soil sample from location OTP3 has fair rating while the remaining soil samples have A-7-6 rating. The CBR values of 18% to 34% (mean & standard deviation values of 28.4% ± 4.6) show that the soil samples are good as subgrade material. The MDD and OMC values show that the soil samples have fair to poor ratings. Soil samples from locations OTP1, OTP2, OTP3 OTP7, OTP11 & OTP12 have medium degree of compressibility and have settlement values lesser than 1 mm/year (very low settlement rate) while others have settlement value greater than 1.

Recommendations

Engineers should drain water to a safe location during construction works.

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.

Abeele, W.V. (1985) Consolidation and Shear Failure Leading to Subsidence and Settlement Part I, Los Alamos National Laboratory, Los Alamos., New Mexico 87545.

Adekeye, A.M., Olofinyo, O.O. and Ale, T.O. (2021). Engineering Properties and Strength Evaluation of Subsoil in Ede North, Southwestern Nigeria: Its Competence for Foundation Purposes. Engineering Heritage Journal, 5(2):58-64. DOI: http://doi.org/10.26480/gwk.02.2021.58.6412.

Ademila, O. (2017). Engineering geophysical investigation of some unstable sections of Ibadan-Iwo-Osogbo Highway, Southwestern Nigeria. University of Ibadan, Ibadan, Nigeria [unpublished PhD thesis]

Ademila, O., Olayinka, A.I. and Oladunjoye, M.A. (2020). Land satellite imagery and integrated geophysical investigations of highway pavement instability in southwestern Nigeria. 46(2):135-157. DOI 10.7494/geol.2020.46.2.135

Akinseye, S.T. (2010). Climate variability and effects of weather elements on cocoa and cashew crops in Nigeria, M.Tech Thesis, Unpublished.

Ale, T.O., Ogunribido, T.H.T., Olatunji, Y.I., Faseki, O.E., Olomo, K.O., Ajidahun, J., Olofinyo, O.O., Johnson, T.D. and Asubiojo, T.M. (2022). Engineering properties of soil samples from stable and failed sections: An example of Akure-Idanre road, Southwestern Nigeria. Journal of mining and Geology, 58(1):123-128

Ale, T.O. (2021). Engineering properties of sub-soils along Akungba-Ikare road, Southwestern Nigeria: Appraising the effect on road construction. Journal of mining and Geology, 57(2):513-520

Ale, T.O. (2022). Effect of Drying Temperature on The Engineering Properties of Stabilised and Natural Soils For Road Construction. *Engineering Heritage Journal, 6(1):19-26*. Pp. 58-64. DOI: http://doi.org/10.26480/gwk.01.2022.19.26

Allen, A. and Chapman, D. (2001). Impacts of afforestation on groundwater resources andquality. Hydrogeol. J. 9 (4), 390–400. https://doi.org/10.1007/s100400100148.

Bell, F.G. (2007). Engineering geology, 2nd edn. Butterworth-Heinemann Publishers, Oxford, Pp. 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, Pp. 378.

British Standard, B.S. (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.

Coduto, D.P. (1990). Geotechnical engineering, principles and practices. Prentice-Hall, New Jersey, 759p.

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

Emmanuel, U.O., Ogbonnaya, I. and Uche, U.B. (2021). An investigation into the cause of road failure along Sagamu-Papalanto highway southwestern Nigeria. Geoenvironmental Disasters, 8(3):1-19 https://doi.org/10.1186/s40677-020-00174-8

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

Federal Ministry of Works and Housing (FMWH) (2010). General specification of roads and bridges, 2, Pp. 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.

Ighodalo, C.A. (2009). Transport Infrastructure and Economic Growth in Nigeria. Revised Paper Submitted for Presentation at the First International Conference on Transport Infrastructure (ICTI 2008), Beijing, China.

Laskar, A. and Pal, S.K. (2012). Geotechnical characteristics of two different soils and their mixture and relationships between parameters. EJGE, vol. 2821-2832.

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

Meshida, E.A. (2006). Highway failure over talc–tremolite schist terrain: A case study of the Ife to Ilesha Highway, Southwestern Nigeria. Bull Eng Geo & Environ. Vol. 65:457–461.

O'Flaherty, C.A. (1988). Highway Engineering. Vol. 2, Edward Amold Publishers, London UK.

Ogunribido, T.H.T., Mohammed, M.Z. and Adesuyi, A.R. (2015). Effect of Engineering Properties of Soil on Pavement Failures in Ogbagi - Akoko Area, Southwestern, Nigeria Journal of Environment and Earth Science, 5(4):39-42

Olofinyo, O.O., Ale, T.O., Odebode, O.S. and Esan, D.S. (2022). Effect of Compaction at different energy levels on the geotechnical properties of stabilized soils. Malaysian Journal of Geosciences, 6(2):38-44 DOI: http://doi.org/10.26480/mjg.02.2022.38.44

Olofinyo, O.O., Olabode, O.F. and Fatoyinbo, I.O. (2019). Engineering properties of residual soils in part of Southwestern Nigeria: implication for road foundation. SN Appl Sci., 1, Pp. 507. https://doi.org/10.1007/s42452- 019-0515-32.

Prakash, S. and Jain, P.K. (2002). Engineering Soil Testing, Nem Chand & Bros, Roorkee.

Rahaman, M.A. (1988). Recent Advances in the Study of the Basement Complex of Nigeria. In Precambrian Geology of Nigeria, Geological Survey of Nigeria, Kaduna South. pp. 11-43.

Ramamurthy, T.N. and Sitharam, T.G. (2005). Geotechnical engineering. S. Chand, New Delhi, p 28

Simon, A.B., Giesecke, J. and Bidlo, G. (1973). Use of Lateritic Soils for Road Construction in North Dahomey, Engineering Geology, Amsterdam, 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.F. (1979). Introductory Soil Mechanics and Foundations: Geotechnical Engineering, 4th edition, Macmillan, New York.

Underwood, L.B. (1967). Classification and identification of shales. J. soil Mech. Found. Div. ASCE, 93 (11):97-116

Wignall, A., Kendrick, P.S., Ancil, R. and Capson, M. (1999). Roadwork; theory and practice. 4th ed. Butterworth-Heinemann, Oxford, 309p.

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