JOURNAL OF GEOTECHNICAL GEOLOGY 18 (1) 633–641

Journal of Geotechnical Geology

Journal homepage: geotech.iauzah.ac.ir

Zahedan Branch,
Islamic Azad University

Geo-engineering Properties of subsurface Soils in parts of Northcentral Nigeria: Implications for Construction of Road Pavements

Ernest Orji Akudo *[1], Isaac Oguche[2], Godwin Aigbadon[1], George Ozulu[3]

[1]*Department of Geology, Federal University Lokoja, Kogi State, Nigeria*
[2]*Kogi State Ministry of Water Resources, Lokoja, Kogi State, Nigeria*
[3]*Department of Earth Science, Salem University Lokoja, Kogi State, Nigeria*

ARTICLE INFORMATION

Received 20 March 2022
Revised 12 April 2022
Accepted 17 May 2022

KEYWORDS
Geotechnical properties; Sub-base; Base course; Subsurface Soils; Road Pavement.

ABSTRACT

Due to the persistent failures of road pavements and scarcity of suitable materials for use as fill for road constructions, geotechnical investigations were conducted to characterize and select suitable sites that subsurface soils can be obtained for road construction purposes in the study area. This involved collection of sixteen soil samples from four selected sites. The geotechnical methods deployed include sieve analysis, liquid limit and plastic limit determinations, compaction tests, and, California Bearing Ratio tests (CBR). The particle size distribution curve (PSD) showed ≤35% passing sieve #200. The liquid limit ranges from 22%-47%, the plastic limit from 14%-31%, and the plasticity index range from 6%-18%. The values of the optimum moisture content using the West African Compaction (OMC-WAS) methods ranged from 6.6%-11.5%, with maximum dry density for WAS (MDD-WAS) from 1862 kg/m^3-2061 kg/m^3 while the optimum moisture content using the modified AASHTO methods (OMC-MAS) ranged from 7.0%-11.6% and maximum dry density for MAS (MDD-MAS) from 1932 kg/m3-2174 Kg/m^3 respectively. CBR for unsoaked soil samples ranged from 100%-249% and for soaked samples, 70%-119% respectively. The soils are classified into three groups based on AASHTO classification as A-2-4, A-2-6, and A-2-7 which classifies the soil as gravelly clayey or silty sand. The site investigated is, therefore recommended suitable site for obtaining good to excellent materials for use as fill (bass and sub-base) materials to enhance quality of road pavement construction in the study area.

1. Introduction

The significance of road network to economic and social development of a nation cannot be over stated. They are very crucial physical infrastructures that connect rural communities to cities and accelerate the movement of humans and goods to these locations. However, in most parts of Nigeria, roads are in deplorable states, with very low attention paid to construction of new roads and those constructed unfortunately failing in a short space of time after completion of construction. These failures in road pavements are reflected in presence of pot-holes, discontinuous stretch of asphalt, depressions, deformations, cuts (Ighodaro, 2009; Adiat et al., 2017; Aderemi and Adeola, 2021). Sundry reasons have been suggested to be

* **Corresponding author.**
E-mail address: ernest.akudo@fulokoja.edu.ng
Assistant Professor, Academic Staff.

https://doi.org/10.30495/geotech.2022.691246
Available online 01 June 2022
1735-8566/

responsible for the persistent failure of roads in Nigeria. They include nature of subsurface geology (Prescence of fractures, faults, buried stream channels, weathered bedrock), the subgrade material (topsoil), existence of active and swelling clays beneath, natural of material used as fill (base and sub-base), poor competence of contractors, and poor site investigations prior to construction amongst a host of other causes (Momoh et al., 2008; Oke et al, 2009; Osinowo et al., 2011; Nwankwoala et al, 2014; Adiat et al., 2017; Olubanjo et al. 2018; Dhar and Hussain, 2018; Babadiya and Igwe, 2021).

Soils obtained at or beneath the surface especially lateritic soils have been applied in road construction as fill materials (sub-base and base) for road pavement construction (Lar et al., 2011; Roy and Bhalla, 2017; Vincent et al., 2020). Its wide application is due to its compositional advantage over other soil types used for such purposes. It often consists of a wide range of particle sizes that enhance the binding of the soil when compacted and used as base and sub-base materials, enabling it to bear the imposed load instead of transmitting it completely to the natural sub-surface materials (Oluyinka, 2018). Other advantages of using laterites for construction include the fact that they are cheap alternatives and are often readily available in the environment. They exhibit excellent to good results when compacted. Amadi et al. (2012) are of the view that geotechnical properties of lateritic soils such as Atterberg limit shear strength, bearing capacity, depend on the mineralogical and chemical composition of the soil. In road construction works, especially in coastal regions with soft soils (Dar and Hussain, 2018) and pore spaces saturated with water, the local sub-surface soils possess low bearing capacity, low compaction outcomes, high differential settlement, etc. (Nwankwoala and Warmate, 2014), and often soils that possess the required properties for base and sub-base materials will need to be brought in from other locations. The choice of fill materials to serve as base and sub-base should therefore be able to withstand the pressures from vehicles that ply the road and maintain is stability for many years (Quadri et al., 2012). This will minimize alterations to the shapes and or dimensions of the sub-base thereby ensuring the durability and sustainability of the road pavements. It is therefore imperative that before construction works, detailed and relevant information about the soil properties must be sought and understood (Omotosho, 2010; Didei et al, 2016). If such information is known, it will ameliorate the incessant failure of roads and enhance the construction of sustainable and durable roads and other engineering structures in Nigeria.

Failure of roads characterizes the study area with most of the community road in deplorable state thereby making access to other connecting communities difficult. The geology of the study area consisting mainly of sedimentary soils and soft clays in some parts provides the challenge of finding suitable sites that can provide suitable subsurface soils for use as fills (base and sub-base) materials to aid cost effective means of construction of road pavements. Published reports indicates that the area is prone to and seriously under the influence of gully erosion with most of the overburden soils collapsing under the influence of heavy precipitation because of its weaknesses (Omali et al., 2010; Imasuen et al., 2011; Ile et al., 2015). These highlighted shortcomings, encourage the scarcity of suitable materials that possess the engineering properties to be used as fill materials in the study areas. The aim of this research; therefore was to characterize a selected site through geotechnical investigation methods to ascertain its suitability for use as fill materials for construction of road pavements.

2. Material and Methods

2.1. Study Area Description

Ankpa is located between latitudes 7022′30″N - 7025′30″N and longitudes 7036′0″E - 7039′0″ E (Fig. 1). It is a town situated within Ankpa Local Government Council and bounded in the North by Opulega, to the Southwest by Ogodo, and Southeast by Abache village respectively, all in Kogi State North Central Nigeria. The main occupation of the people of this town and surrounding areas is Cashew and palm nut farming (Ile et al., 2015). The area is drained by the Anambra River which dissects the town from the Northeastern portion to the south. The town just like most parts of the Central part of Nigeria experiences two climatic seasons: the rainy season which is short starts from May through September with most rains in August and September and a long dry season that starts from October through April every year. According to Iwena (2012), the area has maximum temperatures of 34^{o}C and minimum temperatures of 17^{o}C, and it is classified among the Guinea Savannah vegetation belts of Nigeria. It is characterized by the presence of shrubs, grasses, and scanty trees with stunted growth arising from an insufficient supply of water to the soil and near semi-aridity characteristics.

2.2. Geology of the Area

Geologically, the Ajali formation underlies Ankpa (Fig. 1) which is part of the Anambra Basin. The geology of the basin has been discussed by several authors (Du Preez, 1945; Reymont, 1965; Murat, 1972). According to Obaje (2009), its origin and formation are assigned to the Benue trough believed to have started during the mid-Santonian deformation, replacing the key depositional axis westward, thus leading to the formation of the basin. Stratigraphy of the basin was first described by Du Preez (1965) to be of marine and fluviatile sequences consisting of poorly cemented to friable sands, clays, shales, and limestone which is sometimes found in association with thin non-continuous lignite, and peat coal deposits. Ajali sandstone in the study area is overlain by an appreciable thickness of red earth material characteristically referred to as lateritic

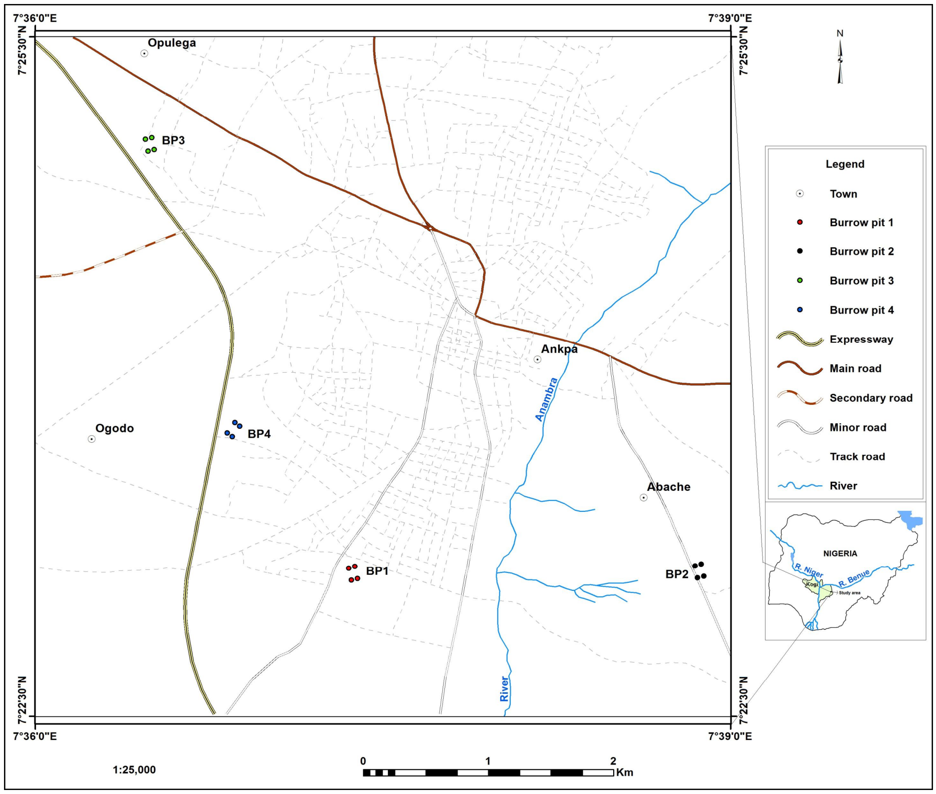

Figure 1. Location of the studied area

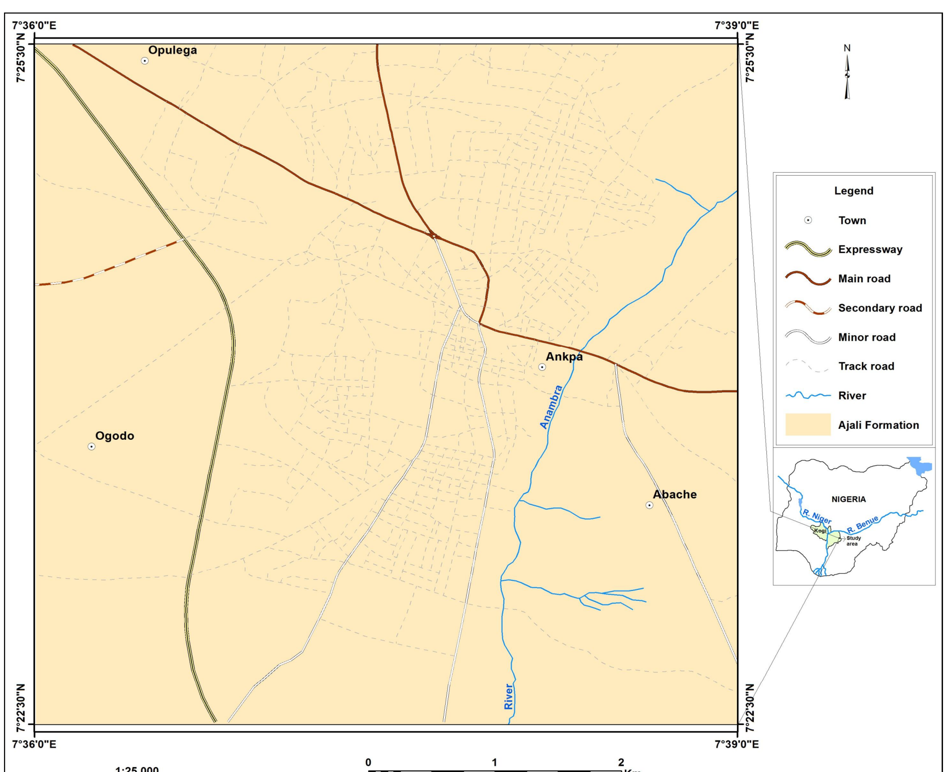

Figure 2. Geological map for studied region

soil which receives its reddish color during weathering resulting in enrichment with ferrous oxides (Ile et al., 2015). The prolific aquifers of the basin are confined to the Ajali sandstones, providing over three hundred meters (300m) of thick sequences of sandstone for citing boreholes for water supply (Offodile, 2002). Nwajide (2013) described the topography of the basin to be gently undulating or flat plains truncated by inselbergs which are shreds of evidence of the resistance of those parts of the landform to erosion. Such inselbergs are located southwards of the basin and are referred to as the Ankpa plateau.

2.3. Sample Collection and Preservation

Sample collection was achieved by digging trial pits or trenches for near-surface soil materials using a shovel. Four borrow pits were identified and selected for sample collection during the reconnaissance stage of this research. In each of the borrow pits, four trial pits were dug resulting in the retrieval of a total of sixteen soil samples (Table 1). The trenches were dug and an appreciable quantity of representative samples was retrieved at a depth range of 0.15m -2.0 m after the removal of a light portion of the surface soil. The samples were carefully examined visually and described in terms of color, presence of organic matter, presence of foreign matter, and geologic history. The log of each trial pits meant to reveal the lithologic succession was described and the samples were put in polythene bags well labeled with permanent marker ink. The samples were then conveyed to the laboratory for geotechnical tests: Sieve analysis, Atterberg limit tests (liquid and plastic limits), compaction tests, moisture content, and california bearing ratio (CBR).

2.4. Laboratory Analysis

The grain size analysis was performed in the laboratory to determine the distribution of the grain sizes that make up the samples. The oven dried samples were poured into a set of sieves and mechanical sieving done according to ASTM D422 methods. The percentage retained on each sieve were calculated and recorded. For the Atterberg limit determination, a portion of the fines were air-dried and sieved through sieve #40. A portion of the samples passing the sieve #40 was formed into a paste by varying the amount of water added to it. The liquid limit and plastic limit was then determined from the samples. Details of the procedures adopted in this study to determine the Atterberg limit is as outlined in ASTM D4318 methods and reported in published sources (Atterberg, 1911; Cassagrande, 1952; Blackall, 1952). Two compaction tests were performed namely: West African (sub-base) and modified AASHTO (Base). The West African method requires the application of compaction effort (number of blows per layer) of 5/25 blows and compacted in three layers. The Modified AASHTO (Base) requires the application of compaction effort of 5/61 blows and compacted in 5 layers. The compaction properties of the samples were determined following ASTM D7380 methods. The sample for CBR determination was compacted to the required optimum moisture content (OMC) and maximum dry density (MDD). For the soaked CBR analysis, the samples were soaked for 9hours to allow the samples to be completely saturated and assume a worst-case scenario (Cabalar et al., 2016a), and then compacted in line with ASTM D1883 describe in published sources (Bishop, 2000; Osinowo et al., 2011; Cabalar et al. 2016b).

3. Results and Discussions

Particle size distribution curves for the four burrow pits (BP1-BP4) consisting of each four trial pits (TP1-TP4) are presented in Figs. 3 to 6 and discussed accordingly. Table 2 shows the percentage passing each of the sieves for all the samples sieved. The percentage passing sieve #200 is less than 35% in all the 16 samples analyzed. Federal Ministry of Works and Housing (FMWH, 1997) specified that for a soil sample to qualify to be used as base and sub base, the percentage passing sieve No. 200 must be less than or equal to thirty- five percent (≤35%). Given this specification, all samples analyzed met the requirement for use as sub-base and base materials respectively. Table 2 contains the results of LL, PL, and PI respectively. The liquid limit ranges from 22%-47% with the lowest value (22%) and the highest value (47%) found at BP4 (TP1) and BP2 (TP1) respectively. The plastic limit ranges from 14%-31% and the plasticity index from 6%-18%. The values of liquid limit and plastic limit should be less than or equal to fifty percent (≤50%) while the plasticity index should be less than 20% for such soils to be suitable for use as base and sub-base materials respectively (FMWH, 1997; Wright, 1986; Adeyemi, et al., 2014; Olubanjo et al., 2018). According to Aghamelu et al. (2011), soils with liquid limit and plasticity index of >35% and >12% respectively, are characteristic of silty soils. For the present study, samples from all four borrow pits sampled falls within the safe threshold for soils that is recommended for use as base and sub-base materials for construction of road pavements in the study area.

Plots of dry density against average moisture content are displayed in Figs. 7 to 10 while the optimum moisture content and maximum dry density values retrieved from the figures are shown in Table 3. The results are presented based on the West African system (WAS) also called sub-base and Modified AASHTO (MAS) known as base specifically given the number of efforts applied during compaction. The OMC-WAS range from 6.6%-11.5%, MDD-MAS range from 1862 Kg/m^3 -to 2061 kg/m^3 while the range of OMC-WAS is between 7.0%-11.6% and MDD-MAS is between 1932 Kg/m^3 - 2174 Kg/m^3 respectively. In each of the samples, there is a noticed

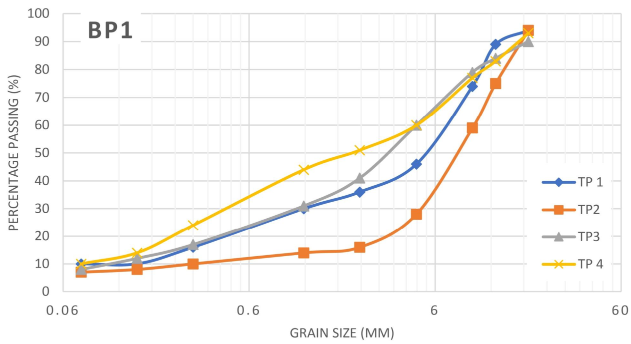

Figure 3. Particle size distribution curve of Pit 1 samples

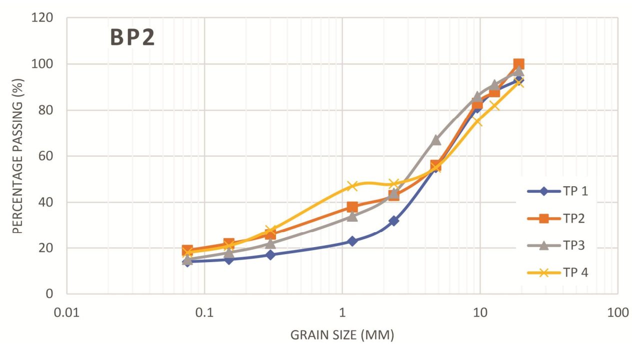

Figure 4. Particle size distribution curve of Pit 2 samples

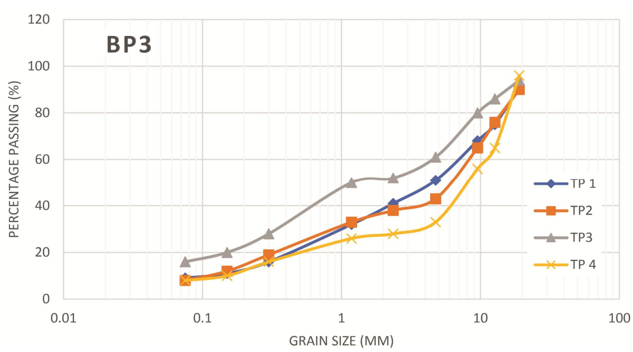

Figure 5. Particle size distribution curve of Pit 3 samples

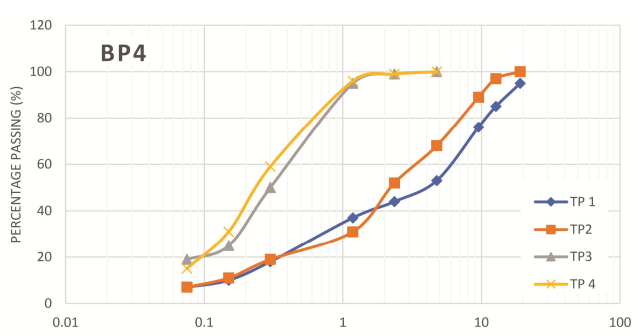

Figure 6. Particle size distribution curve of Pit 4 samples

lower OMC-WAS as compared with that of OMC-MAS which is in accord with published reports suggesting that OMC decreases with an increase in compaction efforts (Osinubi, 1998, 2000).

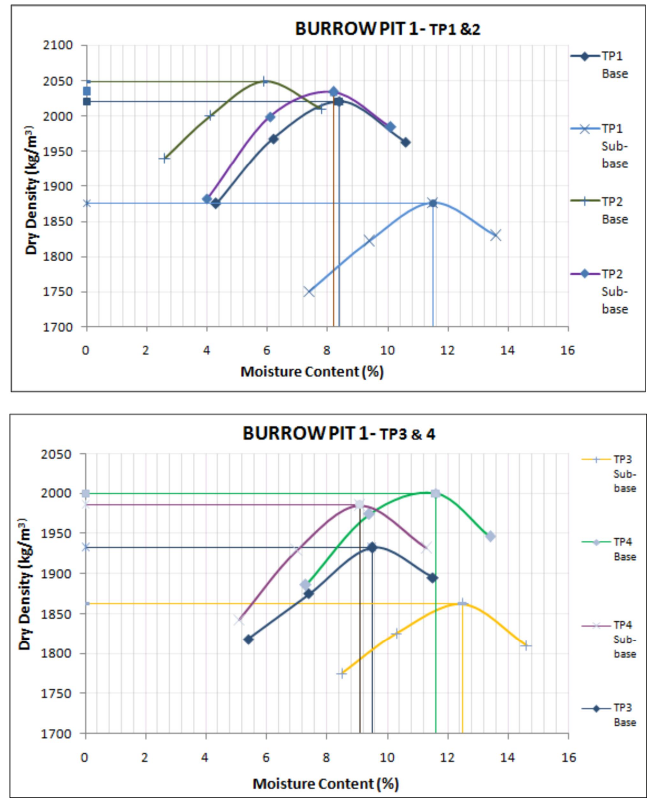

Figure 7. Compaction curves for samples from Burrow Pit 1

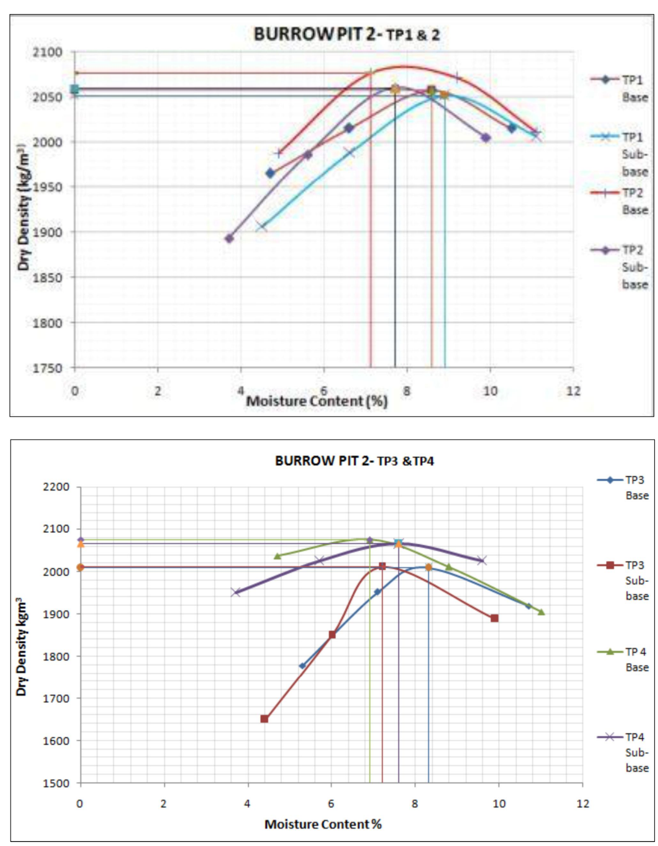

Figure 8. Compaction curves for samples from Burrow Pit 2

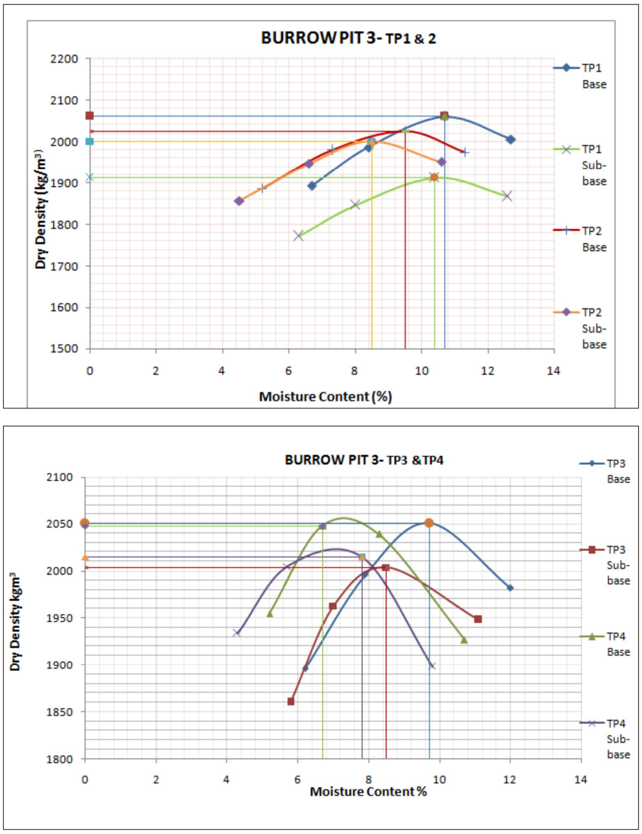

Figure 9. Compaction curves for samples from Burrow Pit 3

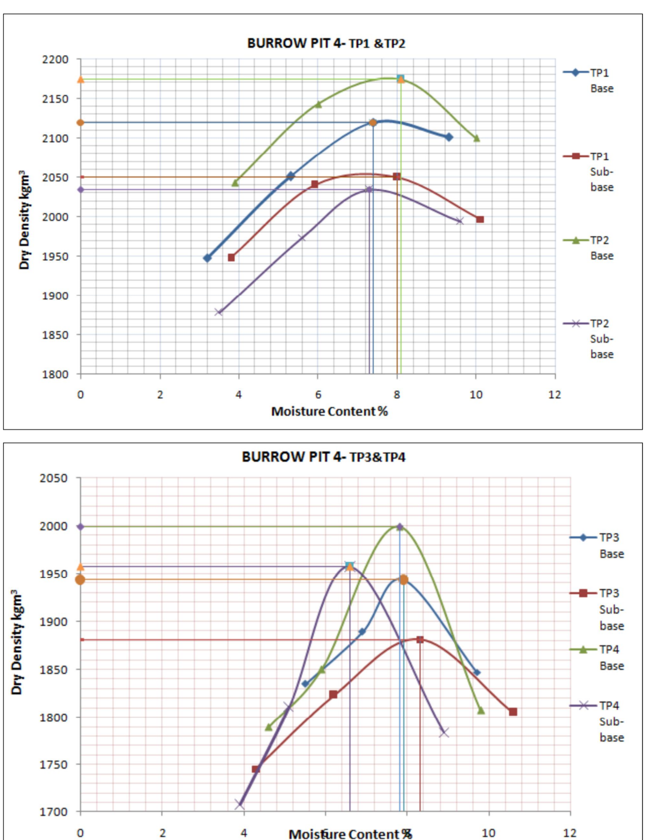

Figure 10. Compaction curves for samples from Burrow Pit 4

Table 1. Sampling field data

Burrow Pit No.	Pit No.	Latitudes (N)	Longitudes (E)	Elevation (M)	Sampling Depth (M)
BP1	TP1	7°23'9.669"	7°37'21.055"	348	0.20 - 2.0
	TP2	7°23'9.669"	7°37'22.706"	345	0.18 - 2.0
	TP3	7°23'5.896"	7°37'21.762"	352	0.15 - 2.0
	TP4	7°23'6.132"	7°37'23.649"	361	0.20 - 2.0
BP2	TP1	7°23'10.37"	7°38'50.417"	373	0.18 - 2.0
	TP2	7°23'10.84"	7°38'52.303"	385	0.16 - 2.0
	TP3	7°23'7.075"	7°38'51.596"	386	0.20 - 2.0
	TP4	7°23'7.547"	7°38'53.246"	388	0.20 - 2.0
BP3	TP1	7°25'2.609"	7°36'28.476"	351	0.24 - 2.0
	TP2	7°25'3.552"	7°36'29.890"	354	0.22 - 2.0
	TP3	7°24'59.77"	7°36'28.947"	375	0.20 - 2.0
	TP4	7°25'0.487"	7°36'30.598"	369	0.25 - 2.0
BP4	TP1	7°23'47.86"	7°36'52.290"	376	0.30 - 2.0
	TP2	7°23'47.15"	7°36'52.761"	385	0.26 - 2.0
	TP3	7°23'45.74"	7°36'49.696"	385	0.30 - 2.0
	TP4	7°23'43.62"	7°36'51.346"	372	0.28 - 2.0

Table 2. Index properties of subsurface soil samples

Burrow Pit No.	Pit No.	LL	LP	PI
BP1	TP1	33	20	12
	TP2	34	19	15
	TP3	39	25	14
	TP4	31	18	13
BP2	TP1	47	31	16
	TP2	40	25	15
	TP3	40	22	18
	TP4	38	28	10
BP3	TP1	36	21	15
	TP2	28	17	11
	TP3	26	19	7
	TP4	27	15	12
BP4	TP1	22	14	8
	TP2	26	15	11
	TP3	24	16	8
	TP4	24	18	6

A published report (O'Flaherty, 1988) suggested different ranges of OMC and MDD for different soil types for soils subjected to compaction using standard proctor analytical procedures. The findings show OMC ranging from 20%-30% and MDD ranging from 1440 kg/m^3 - 1685 kg/m^3 for clay and OMC ranging from 15%-25% and MDD ranging from 1600 kg/m^3- 1845 kg/m^3 for silty clay. OMC ranging from 8%-15% and MDD ranging from 1760 kg/^{m3}- 1845 kg/m^3 for sandy clay. A careful look at the results retrieved from the analysis of the soil samples revealed that the soils are sandy with some amount of clay and silty contents. Vincent et al. (2020) opined that compaction aims to maximize the shear strength and reduce compressibility and permeability of soils. According to the Federal ministry of works and housing, FMWH (1997), documented in published sources (Oyelami and Alimi, 2015; Tsado et al., 2018), OMC and MDD values of ≤18% kg/m^3 for OMC and ≥1700 kg/m^3 for MDD is recommended for materials to be used as pavement sub-base. The results from this current research shows that samples, possess excellent to good characteristics to be used for filling (base and sub-base) in road pavement constructions. The CBR is an experimental approach for establishing the shear strength of soils (Mendoza and Caicedo, 2017) especially for its use as base and sub-base materials in road construction works (Oluyinka and Olubunmi, 2018). As shown in Table 3, the unsoaked CBR values range from 100% to 249%, on the other hand, the CBR for soaked samples ranges between 70% to 119% respectively. A CBR value for sub-grade (≥10%), for sub-base (≥30%), and base (≥80%) is recommended (FMWH, 2010) for road construction purposes. Because of the results obtained from the CBR test, the samples exhibited good shear strength and can all serve as excellent soils for use as sub-base and base materials in road construction. Plasticity chart (Fig. 11) is meant to present the percentage of fines (clay and silts) in a soil sample; in this case, the sample passing sieve #200 is ≤18%. From the chart and Table 4, samples from BP1 (TP1-TP4) all plot above the A-line and are largely lean clays (CL) to intermediate clays (CI), for BP2 TP1 and TP4 are intermediate silt while TP2 and TP3 are intermediate clays respectively. BP3 (TP1-TP4) samples are intermediate clays, for BP4 samples from TP1 and TP4 are intermediate silts while TP2 and TP3 are intermediate clays respectively. It, therefore, means that the fines are largely lean clays with some proportion of silts

The classification of soil based on the AASHTO system depends on the liquid limit, plasticity index, percentage passing sieve #200 Most samples fall within the A-2-6 group except BP2 (TP1) which is in the A-2-7 group and BP3 (TP3), BP4 (TP1 and TP4) which fall within the A-2-4 group respectively (Table 4). The soil sample can therefore be said to be silty or clayey gravel and sand as is shown also in the well logs (Appendix A). The sample is rated as excellent to good concerning its use as base and sub-base materials (AASHTO, 1993).

For classifying sands with a little quantity of fines and gravels, the coefficient of uniformity (C_u), the coefficient of Concavity (C_c), the percentage passing sieve #200, and the plasticity index group symbols are applied to correctly provide a group name for the sample. Cu and Cc are obtained from the particle size distribution curve drawn for each sample using the equations below (Handy. 1995). Soil Samples from BP1 (TP1-TP4), BP3 (TP1 2 and 3), and BP4 (TP2), (having Cu ≥6 and 1≤Cc≤3, percent passing sieve No.200 is 5-12%) fall within the group symbol SW-SC and are classified as well-graded sand with clay and <15% gravel. Soil Samples of BP2 (TP1 and TP4) and BP4 (TP4) are of group symbol SM (>12% pass sieve No. 200) meaning that they are Silty Sand with <15% of gravels. The other group symbol SC (BP2-TP2 &3, BP3-TP3 and BP4 –TP3) is clayey sand with gravels.

Table 3. Compaction and CBR laboratory analysis results

Burrow Pit No.	Pit No.	OMC (%)	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)	Soaked	Unsoaked
BP1	TP1	11.5	1876	8.4	2021	86	108
	TP2	8.2	2034	5.9	2049	91	92
	TP3	12.5	1862	9.5	1932	101	215
	TP4	9.1	1985	11.6	2000	103	155
BP2	TP1	8.9	2051	8.6	2057	92	215
	TP2	7.7	2060	7.1	2076	119	134
	TP3	-	-	8.3	2010	88	100
	TP4	7.6	2060	7.0	2070	90	106
BP3	TP1	10.4	1912	10.7	2060	87	106
	TP2	8.5	2001	9.5	2025	114	178
	TP3	-	-	9.7	2051	85	105
	TP4	-	-	6.7	2048	115	138
BP4	TP1	8.0	2051	7.4	2057	95	106
	TP2	7.3	2034	8.1	2174	101	249
	TP3	8.3	1881	-	-	60	107
	TP4	-	-	-	-	70	98

Based on this classification scheme, the bulk of the soils in the study area are largely gravelly, clayey, or silty sand. Sowers et al. (1979) and Handy (1995) classified soils based on group symbols (Table 4). They classified soils in terms of compaction characteristics, value as a fill material, value as pavement sub-grade, and value as a base course for pavement. Soils with the symbol SW have good compaction characteristics, are very stable when used as fill materials, are good if used as pavement sub-grade, and fair when used as a base course for pavement.SC refers to soils that possess good to fair compaction characteristics, are reasonably stable when used as fill materials, good to fair when used as pavement sub-grade, and fair to poor if used as a base course for pavement. SP refers to soils that have good compaction characteristics, are reasonably stable when dense if used as fill material, good to fair when used as pavement sub-grade, and poor when used as a base course for pavement while SM means soils with good compaction characteristics, reasonably stable when dense if used as fill material, good to fair when used as pavement sub-grade and poor when used as a base course for pavement. Based on the soil samples in the study area, they largely fall within the SW group symbol meaning that they are good for use as sub-base and base materials respectively.

4. Conclusion

This study assessed some geotechnical characteristics (Sieve analysis, LL, PL, PI, Compaction, and CBR) of soils from Ankpa. The results of the PSD showed that soils are largely sands and met the requirements for use as sub-base and base courses having <35% of the soils passing the sieve No. 200. The liquid limit, plastic limit (≤50%), and plasticity index revealed low to medium plasticity. The optimum moisture content and maximum dry density for both WAS and MAS all showed good values while the CBR both soaked and unsoaked satisfied the requirements of the federal ministry of works and housing. The site investigated is, therefore recommended suitable site for obtaining good to excellent materials for use as fill (bass and sub-base) materials to enhance quality of road pavement construction in the study area. This research finding will serve as guide in selection of suitable borrow pits in the study area.

Acknowledgements

The authors are grateful to the staff of Civil Engineering Laboratory, Kaduna Polytechnic, Kaduna State for carrying out the laboratory tests. The authors have no relevant financial or non-financial interests to disclose. Also, there is No funding was received for this research.

References

Aderemi F.L., Adeola R.O., 2021. Geophysical Investigation of Causes of Road Failure along Abadina Community Road, University Of Ibadan, Nigeria. *Journal of Research in Environmental and Earth Sciences*, 7(1): 1-5.

Adeyemi G.O., Oloruntola M.O., Adeleye A.O., 2014. Geotechnical Properties of Subgrade Soils along Sections of the Ibadan-Ife Expressway, South-Western Nigeria. *Journal of Natural Sciences Research*, 4(23): 67-76.

Adiat K.A.N., Akinlalu A.A., Adegoroye A.A., 2017. Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. *NRIAG Journal of Astronomy and Geophysics*, 6: 244-255.

Aghamelu O., Odoh B., Egboka B.C., 2011. A geotechnical investigation on the structural failures of building projects in parts of Awka, southeastern Nigeria. *Indian Journal of Science and Technology*, 4(9): 1119-1124.

Amadi A.N., Eze C.J., Igwe C.O., Okunlola I.A., Okoye N.O., 2012. Architect's and geologist's views on the causes of building failures in Nigeria. *Modern Applied Science*, 6(6): 31-38.

ASTM D1883, 2016. *Standard test method for California Bearing Ratio (CBR) of laboratory-compacted soils*. ASTM International, West Conshohocken, PA.

ASTM D4318, 2020. *Standard test method for laboratory determination of Atterberg Limit of soils*. ASTM International, West Conshohocken, PA.

ASTM D698, 2012. *Standard test methods for laboratory compaction characteristics of soil using standard effort*. ASTM International, West Conshohocken, PA.

Atterberg A. 1911. Uber die physicalische Bodenuntersuchung und uber die plastizitat der tone (On the investigation of the physical properties of soils and on the plasticity of clays). *Internationale Mitteilungen fur Bodenkunde*, 1: 10-43.

Babadiya E.G., Igwe E.O., 2021. A geotechnical investigation on the failure of road Pavements in Abakiliki, Southeastern Nigeria. *Journal of Mining and Geology*, 57(1): 177-191.

Bishop E.C., 2000. *Guidelines on materials and Borrow pit management for low-cost Roads*. Roughton International, United Kingdom.

Blackall T.T., 1952. A.M. Atterberg 1846-1916, *Geotechnique*, 3: 17-19.

BS1377, 1990. *Method of tests for soils for civil engineering purposes*. British Standards Institution, (BSI) London, UK.

Cabalar A.F., Abdulnafaa M.D., Karabash Z., 2016a. influence of various construction materials on the behavior of clay. *Environmental Earth Sciences*, 75: 841-850.

Cabalar A.F., Hassan D.I., Abdulnafaa M.D., 2016b. Use of waste ceramic tiles for road Pavement subgrade. *Road Materials*, 18(4): 882-896.

Casagrande A., 1952. Classification and identification of soils. *Transactions of the American Society of Civil Engineering*, 113: 901.

Dar S., Hussain M., 2018. The strength behavior of lime-stabilized plastic fiber-reinforced clayey soil. *Road Materials and Pavement Design*, 20(8):1757-1778.

Dhar S., Hussain M., 2018. The strength behaviour of lime-stabilised plastic fibre-reinforced clayey soil. *Road Materials and Pavement Design*, 20(8): 1757-1778.

Du Preez, J.W., 1945. Geology of the Aba and Nnewi Lignite Deposits, Onitsha Province. *Geological Survey Nigeria Bulletin*, 26: 35.

Du Preeze J.W., Barber W., 1965. The distribution and chemical quality of groundwater in northern Nigeria. *Geological Survey Nigeria Bulletin*, 36: 93.

Federal Ministry of Works and Housing, 2010. *General Specification for Roads and Bridges*. Federal Highway Department (FMWH), Lagos, Nigeria, II: 317.

Ighodaro C.A., 2009. Transport infrastructure and economic growth in Nigeria. J. Res. National Dev., 7(2): 1-15.

Ile U.C., Mahi S.A., Nda A.I., 2015. Geotechnical Assessment of Gully Erosion at Ankpa Area, North Central Nigeria. *IOSR Journal of Applied Chemistry*, 8(12): 36-48.

Imasuen O.I., Omali A.O., Ibrahim I., 2011. Assessment of environmental impacts and remedies for gully erosion in Ankpa Metropolis and Environs, Kogi State, Nigeria. *Advances in Applied Science Research*, 2(5): 372-384.

Iwena O.A., 2012. *Essential geography for senior secondary schools*. Tonad Publishers limited, Lagos, Nigeria, 352 p.

Lar U.A., Wazoh H.N., Mallo S.J., Chup A.S., 2011. Geotechnical Characterization of Lateritic Soils in Jos and Environs, North Central Nigeria. *Nigerian Mining Journal*, 9(1): 9-19.

Mendoza C., Caicedo B., 2017. The elastoplastic framework of relationships between CBR and Young's modulus for granular material. *Road Materials and Pavement Design*, 19(8): 1796-1815.

Momoh L.O., Akintorinwa O., Olorunfemi M.O., 2008. Geophysical Investigation of Highway Failure -A Case Study from the Basement Complex Terrain of Southwestern Nigeria. *Journal of Applied Sciences Research*, 4(6): 637-648.

Murat R.A., 1972. *Stratigraphy and Palaeogeography of the Cretaceous and Lower Tertiary in Southern Nigeria*. University of Ibadan Press, Nigeria, pp. 251-266.

Nwajide C.S., 2013. *Geology of Nigeria's sedimentary basins*. CSS Press, Lagos, 565 p.

Nwankwoala H.O., Amadi A.N., Ushie F.A., Warmate T., 2014. Determination of Subsurface Geotechnical Properties for Foundation Design and Construction in Akenfa Community, Bayelsa State, Nigeria. *American Journal of Civil Engineering and Architecture*, 2(4): 130-135.

Nwankwoala H.O., Warmate T., 2014. Subsurface Soil characterization of a site for infrastructure Development Purposes in D/Line Port Harcourt, Nigeria. *American International Journal of Contemporary Research*, 4(6): 139-148.

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

Obaje G.N., 2009. *Geology and Mineral Resources of Nigeria: Lecture Notes in Earth Sciences*. Springer, Heidelberg, 221 p.

Offodile M.E., 2002. *Groundwater study and development in Nigeria*. Mecon Geology & Eng. Services Ltd., Nigeria, 453p.

Oke S,A.,Okeke O.E., Amadi A.N., Onoduku U.S., 2009. Geotechnical Properties of the Subsoil for Designing Shallow Foundation in some selected parts of Chanchaga area, Minna, Nigeria. *Journal of Environmental Science*, 1(1): 45-54.

Olubanjo A.N., Ogunribido T.H.T., 2018. Geotechnical Properties of subgrade soil along failed portions of Akunbga-Ikare Road stabilized with Rock Fines. *Asian Journal of Geological Research*, 1(2): 1-9.

Oluyinka L.G., Olubunmi O.C., 2018. Geotechnical Properties of lateritic soil as Subgrade and base material for road construction Abeokuta, Southwest Nigeria. *International Journal of Advanced Geosciences*, 6(1): 78-82.

Omali A.O., Imasuen O.I., Musa K., 2010. Geotechnical Investigation of Gully Erosion Sites in Ankpa Metropolis, Kogi State, Central Nigeria. *Journal of Environmental Sciences and Resources Management*, 2: 1-10.

Omotoso, O.A., 2010. An Investigation into the geotechnical and engineering Properties of some laterites of Eastern Nigeria. *Journal of Nigeria Mining Geology and Metallurgical Society*, 1: 10-110.

Osinowo O., Oladunjoye M.A., Olayinka I.O., 2011. Integrated Geophysical and Geotechnical investigation of the failed portion of a road in Basement complex terrain, Southwestern Nigeria. *Materials and Geoenvironment*, 58(2): 143-162.

Osinowo O.O., Akanji A.A., Akinmosin A., 2011. Integrated geophysical and geotechnical investigation of the failed portions of a road in Basement Terrain Southwest Nigeria. *Geoenvironmental*, 58(2): 143-162.

Osinubi K.J., 1998. Influence of compactive efforts and compaction delay on Lime-treated soil. *Journal of Transportation Engineering*. 124(2): 149 -155.

Osinubi K.J., 2000. Influence of Compaction Energy levels and Delays on Cement Treated Soils. *Nigerian Society of Engineers Technical Transaction*, 36(4): 1-13.

Oyelami C.A., Alimi S.A., 2015. Geotechnical investigation of some failed sections along osogbo-awo Road, Osun State, Southwestern Nigeria. *Ife Journal of Sciences*, 17(1): 87-95

Quadri H.A., Adeyemi O.A., Olafusi O.S., 2012. Investigation of the Geotechnical Engineering Properties of Laterites as a subgrade and Base Material for Road Construction in Nigeria. *Civil and Environmental Research*, 2(8): 23-32.

Reyment R.A., 1965. *Aspects of Geology of Nigeria*. Ibadan University Press, Ibadan, Nigeria, pp.145-147.

Richard L.H., 1995. *Introduction to Geotechnical Engineering (3rd Edition)*. Mc Graw-Hill, New York.

Roy S., Bhalla S.K., 2017. Role of geotechnical properties of Soil on Civil engineering Structures. *Resources and Environment*, 7(4): 103-109.

Sowers G.F., 1979. *Introductory Soil Mechanics and Foundations: Geotechnical Engineering (4th Edition)*. Macmillan, New York.

Tsado R., Adejumo T.W., Aguwa J., David B., 2018. Geotechnical Analysis of Lateritic Soil from Selected Borrow Pits in Minna Metropolis. In: *Proceedings of the 16th International Conference and Annual General Meeting of Nigerian Institution of Civil Engineers*, February 2018.

Vincent E., Domnic D., Kure M.M., 2020. Assessment of Geotechnical Parameters of Lateritic Soil of Jos and Environs for Civil Engineering Construction, North Central Part of Nigeria. *Annals of Pure and Applied Science*, 3(3): 222-239.

Wright P.H., 1986. *Highway Engineering (6th Edition)*. John Willey and Sons, New York.