Suitability of Nigerian Standard Specifications for Evaluation of Composite Lateritic Gravel-Fine Soils for Road Base

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Abstract

Five fine lateritic soils collected from five different areas within the suburb of Minna, Niger State, Nigeria were sieved through BS sieve 0.425mm each. Fractions the fine soils passing through the sieve were mixed with lateritic gravel, at 0, 10, 20, 30, 40 and 50 % by mass of the gravel. Index properties, compaction characteristics and California Bearing Ratio of all the mixtures were evaluated. The results showed that the fine soils used, classified under A-2-6 to A-7-6 according to AASHTO soil classification system. The mixtures that gave the minimum 80 % CBR required by Nigeria General Specification for Roads and Bridge Works, for soil to be used for road base were isolated, and their index properties reevaluated. From the five fine soils studied, it was observed that 36 % maximum percentage passing BS sieve 0.075mm, 39 % maximum liquid limit and 14 % maximum plasticity index were adequate to give the 80 % minimum CBR, and can therefore be recommended for materials to be used for road base course as against the 35 % maximum percentage passing sieve 0.075mm, 35 % liquid limit and 12 % plasticity index, specified by the Nigerian General Specification for Roads and Bridge Works.

Keywords

Californian Bearing Ratio; Lateritic fines; Lateritic gravel; Maximum dry density; Optimum moisture content.

1. Introduction

Laterite soil consisting of gravelly, sandy and fine materials for pavement use, occurs widely in many African sub-regions including Nigeria. The main groups of these road making materials include the concretionary gravels, residual gravels and sands as well as transported gravels and sands (Gidigasu, 1976; Ola, 1980 and Yohanna et al, 2015). Lateritic gravely paving materials constitute the major materials belonging to the concretionary gravel group. These laterite gravels are formed by in-situ tropical weathering, which involves partial and complete alteration of the original mineralogy, geochemistry, texture and structure of fabric of the parent rock. Nearly all kinds of rocks can be deeply decomposed by the action of high rainfall and elevated temperatures. The percolating rain water causes dissolution of primary rock minerals and decrease of easily soluble elements of sodium, potassium, calcium, magnesium and silicon. This process, which is known as laterization, gives rise to a residual concentration of more insoluble elements, predominantly iron and aluminum. Laterite therefore, consists mainly of the minerals kaolinite, goethite, hematite and gibbsite, which are form in the course of these weathering processes. Laterization is the most important factor in the formation of laterite ores deposits (Nwaiwu et al., 2006; Osinubi and Nwaiwu, 2006).

Gravelly soils consisting of gravel-size particles, in a matrix of optimum finer materials have proved to be satisfactory construction material for several large earth dams and road pavement structures. The gravel fraction of these soils impacts a relatively high shear strength, high compacted density and low compressibility, while the permeability of the soil is governed by the properties of the matrix of the fine material. However, AASHTO (1986) soil classification system shows the quality of subgrade soil material decreasing from excellent to good for A-1, A-2 and A-3 subgroups to fair and poor for A-4, A-5 A-6 and A-7 subgroups which, among other factors, are functions of the amount of fines in the soils. The A-1, A-2 and A-3 subgroups soils have less fine content with up to 35% as maximum, while the A-4, A-5 A-6 and A-7 subgroups have more than 35 % fine content. Carter and Bentley

(1991) presented a correlation between AASHTO soil classification and Californian Bearing Ratio (CBR), which showed the value of the later decreasing across the table from A-1 to A-7 subgroups. Results of a study by Talukdar (2014), of correlation between CBR values with other soil properties, showed the CBR values decreasing with increase in fine content. Naveen and Santosh (2014) presented results of a study which shows decrease in CBR value with increase in fine content. Bera (2011) also presented results of a study which showed increase in CBR value with decrease in fine content. In another study by Siswosoebrotho et al. (2005), on the influence of fines content on the strength of base course material, it was shown that addition of fines initially increases the value of CBR, but with further increase in the fine content, the value decreases.

It was as a result of these that Nigerian General Specification for Roads and Bridge Works (1997) specified limits for the maximum percentage of fine, maximum liquid limit and maximum plasticity index for soils to provide minimum CBR (strength) to be used for various components of road pavement. The specifications are shown on Table 1. It is believed that soils that satisfy these specifications will achieve the minimum strength specified by the standard for the respective pavement layers to withstand the anticipated axle load.

Table 1 General requirements for subgrade, sub-base and base course in Nigeria

Property	Subgrade	Sub-base	Base Course
Portion Passing BS sieve No. 200 (%)	≤ 35	≤ 35	≤ 35
Liquid Limit (%)	≤ 80	≤ 35	≤ 35
Plasticity Index (%)	≤ 55	≤ 12	≤ 12
24 hours Soaked CBR (%)	NA	≥ 30	≥ 80
Relative Compaction (%)	≥ 100	≥ 100	≥ 100

Source: Nigerian General Specification for Roads and Bridge Works (1997)

However, it is observed that most of these specifications were adopted from America and our Colonial Master - the Great Britain, which are all temperate countries, where the Geology, soil type and weather conditions are completely different from that of Nigeria, which is a tropical country. This work is therefore intended to study the suitability of some the specifications in the Nigerian General Specification for Roads and Bridge Works (1997) in evaluating residual lateritic gravel mixed with fines for road use.

2. Review of Relevant Literature

A lot of work has been done to study the effect of fines on various geotechnical properties of lateritic soils. Some of these works include study by Ayodele et al. (2009), on the effect of fines content on some engineering properties of lateritic soil in Ile-Ife. The researchers used soil, washed through British Standard sieve 0.075mm as fine, which was reconstituted with the coarse fraction, at ratio 0:100 to 100:0 at 10 % intervals. Statistical models were developed and tested to ascertain effect of the fines on the lateritic gravelly soil. The result revealed that increase in fines content resulted to decrease in Maximum Dry Density (MDD) and increase in Optimum Moisture Content (OMC). Both soaked and unsoaked CBR values decrease with increase in fines content. Unconfined Compressive Strength (UCS) however, increased with increasing fines content to about 60 %, after which the values dropped to zero.

Osinubi et al. (2012) worked on reddish brown lateritic soil, mixed with 0, 20, 40, to 90 % fines, by determining the engineering properties of the mixtures. They observed that the plasticity properties increased with increase in fines content. MDD and OMC decreased and increased respectively, with increase in fines content. UCS and angle of internal friction (ϕ) both decreased, while cohesion (c) increased with increase in fines content.

Effect of clay content on shear strength and compressibility characteristics of a lateritic soil was studied by George (2014). The result showed that cohesion (c), Plasticity Index (PI) and compressibility index (c_c) are directly proportional to clay content, while angle of internal friction (ϕ) and initial void ratio (e_o) are inversely proportional to the clay content. Studies on effect of fines on cohesion (c) and angle of internal friction (ϕ) of soils were also carried out by Adenoye (2014a) and Adenoye (2014b), by mixing lateritic gravely soils with fines, from 10:100 to 100:0 at 10 % increments. Unconsolidated undrained triaxial tests were conducted on the mixtures. The results revealed that cohesion increased with increase in fines content, while ϕ decreased.

Study on effect of soil parameters and moisture content on stiffness of unsaturated blended laterite, using triaxial test for rural roads was carried out by Varghese et al. (2011). The researchers dealt with experimental investigation on unsaturated lateritic soils blended with varied percentages of fines. The results showed increase in OMC and e_o with increase in fines content. The MDD reduces with increase in fines content from 10 to 92 %.

Bajaj et al. (2013), work on effect of percentage of fine and fly ash on engineering properties of soils, by conducting index properties, compaction and strength properties tests on remolded soils. They observed that the grading modulus and specific gravity decreased with higher percentage fine, while Atterberg limits and plasticity parameters increased with increase in fine content.

Effort was made by Ettu et al. (2013) to replace fine aggregate in structural concrete with lateritic soil. The average density of the resultant concrete was observed to be 22.81 kN/m^3, which is slightly lower than the 24 kN/m^3 for normal concretes. Similar effort, on the use of laterite in concrete production was made by Santhiyaa and Ramasundaram (2015). The work evaluated the strength and durability of lateritic-sand mixtures. Replacing sand, the laterite was mixed from 0 to 100% replacement. The result showed increase in density with increase in percentage laterite. The tensile and flexural strength of the concretes was also observed to increase with increase in percentage of the laterite.

3. Location, Climate and Geology of Study Area

All the soils used for this study were collected from the suburbs of Minna in Niger State of Nigeria. The lateritic gravel was collected from a borrow pit after Maikunkele, a distance of about 15km from Minna. The first lateritic fine was collected from a borrow pit after Chanchaga, a distance of about 7 km from Minna, along Minna-Suleja road. The second fine lateritic soil was collected from a borrow pit at Kateregi, a distance of about 50 km from

Minna, along Minna-Bida road. The third lateritic fine was collected from a borrow pit at Kuta, a distance of about 55 km from Minna. The fourth fine lateritic soil was collected from Sabon Daga, a distance of about 30 km from Minna, along Minna-Bida road. The fifth fine lateritic soil was collected from a borrow pit in Talba farm, a distance of about 5 km along Minna-Birgi road. All the locations lie between longitude 6°E and 8°E and latitude 9°N and 12°N. A study of the soil map of Nigeria (Areola, 1982) reveals that the residual soil in this area is under laid by a Granite Basement and is surrounded to the North and South by Older Basement rocks of the Precambrian to Upper Cambrian age and Illo group formation to the North-west (Wright, 1989). This area is drained by several rivers, which are tributaries of River Niger. The maximum rainfall per year, in this area, varies from 1000 to 1500mm for different locations.

4. Methodology

The five collected fine soils of varied consistency were sieved through British Standard sieve 0.425mm and the fractions passing the sieve was used as fines for each of the locations. The lateritic gravel was also sieved through sieve 0.425mm and the portion retained on the sieve was used as the lateritic gravel. Index properties, including hydrometer tests were conducted on each of the natural fine soils before sieving through the 0.425mm sieve. Sieve analysis test was conducted on the lateritic gravel. Each of the lateritic fines was replaced with the gravel at 0, 10, 20, 30, 40 and 50 %. Tests including specific gravity, sieve analysis, compaction and unsoaked CBR were carried out on the gravel-fine mixtures. The method of maximum CBR and OMC was used to carry out the CBR test. This method involves carrying out compaction in CBR mold at increasing moisture content and conducting CBR test on each compacted soil. The CBR values are then plotted against the moisture contents to obtain the maximum CBR and OMC. This process was repeated for all the lateritic gravel–fine mixtures. The result of the index properties were compared with the values specified in the Nigerian General Specification for Roads and Bridge Works (1997).

5. Results and Discussion

5.1 Index Properties

Result of index properties of the five fine soils is presented on Table 2. The gravel content are generally low with values ranging between 0.5 and 7.2 %, except for the fine soil, collected from Sabon Daga, which has a relatively high gravel content of 20.4 %.

Liquid limit of the fine soils ranges from 33.7 % for Chanchaga soil to 43.7 % for Talba farm soil, while the plasticity index ranges from 10.6 % for Kuta soil to 16.5 % for Kateregi soil. Only Chanchaga and Kuta soils meet the 35 % maximum liquid limit specified by Nigerian General Specification for Roads and Bridge Works (1997). Similarly, only Kuta soil meet the 12 % maximum plasticity index specified by Nigerian General Specification for Roads and Bridge Works (1997). Only soil from Sabon Daga which has 34.4 % passing sieve 0.075mm meet the 35 % maximum required, with the remaining four soil samples not meeting the requirement. From these results, it was observed that all the five fine soil samples are deficient in one specified parameters or the other. None of the soil samples satisfy all the three parameters specified by the Nigerian General Specification for Roads and Bridge Works (1997).

The trend of the specific gravity with increase in fines content is shown on Figure 1. The values of the specific gravities increased from 2.73 at 0 % fine to 2.84 at between 10 to 20 % fines after which the values reduced to minimum value of 2.65.

Table 2 Index properties of the five fines of varied consistency

Properties	Quantity				
	Chanchaga	Sabon Daga	Kateregi	Kuta	Talba farm
Gravel (%)	0.6	20.4	0.5	7.2	0.5
Sand (%)	33.2	45.2	42.3	42.3	30.7
Silt (%)	48.4	27.2	42.6	38.0	50.2
Clay (%)	17.7	7.2	14.6	12.5	18.6
Liquid limit (%)	33.7	38.9	41.2	35.5	43.7
Plasticity Index	14.8	15.8	16.5	10.6	14.1
Specific gravity	2.55	2.62	2.64	2.52	2.64
USCS	CL	SC	CL	ML	ML

AASHTTO	A-6	A-2-6	A-7-6	A-4	A-7-6

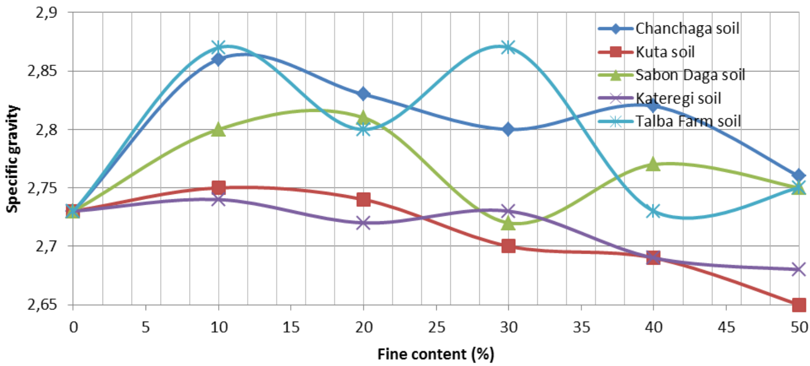

Figure 1 Variation of specific gravity of lateritic gravel with increase in percentage of the fine soils

5.2 Compaction Characteristics

Variation of MDD of the lateritic gravel with increase in fines content is presented in Figure 2. It was generally observed that MDD of the lateritic gravel increased with increase in percentage fine to between 10 and 20 % fines content, after which the values decreased to 50 % fines content. This implies that lateritic fines content between 10 and 20 % is required to fill the pores of the lateritic gravel to form a dense mass. Beyond 20 % fines content, the fines, with lower specific gravity, began to predominate the mixture, thereby reducing the MDD. This observed trend is similar to the trend reported by Alhaji and Sadiku (2015). Lateritic gravel, mixed with varied percentage of fines from Kateregi recorded the least MDD of 2.11 Mg/m^3, while lateritic gravel, mixed with varied percentage of fines from Chanchaga gave the highest MDD of 2.20 Mg/m^3.

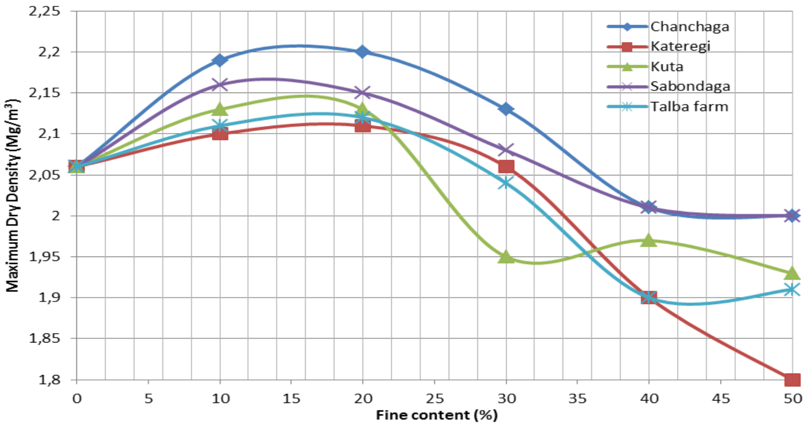

Figure 2 Variation of MDD of lateritic gravel with increase in percentage of the fine soils

Variation of OMC with increase in fines content is presented in Figure 3. The result shows general increase in OMC with increase in fines content to 50% fines content for all the five fines considered in this study. This is because fine soils absorb more water than coarse grained soils due to the affinity of clay minerals to water. This result is in agreement with Ayodele et al. (2009) and Osinubi et al. (2012), who studied effect of fines content on geotechnical properties of reddish residual soils, and reported increase in OMC with increase in fines content.

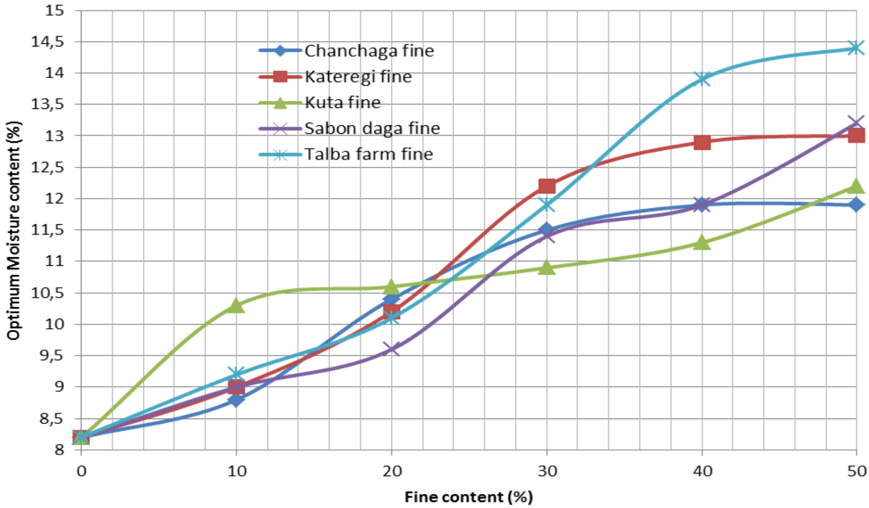

Figure 3 Variation of OMC of lateritic gravel with increase in percentage of the fine soils

5.3 California Bearing Ratio

Variation of CBR with increase of fines content for the five fine soil samples is shown in Figure 4. The trend shows general decrease in CBR with increase in fine content. The CBR of 148 % recorded for lateritic gravel at 0 % fine, decreased to a minimum of 36 % at 50 % fines content for Chanchaga fine, while for Kateregi fine, the CBR reduced to a minimum of 61 % at 50 % fines content. This trend is in agreement with Alayaki and Bajomo (2011). The results obtained are also in agreement to those obtained by Alao (1983), who stated that as the fines content increases, the water content of the soil increases, causing a decrease in the CBR values after peak strength is reached due to the adverse effect of water on the bonding forces between particles. Nishimura and Fredlund (2000) also stated that the unconfined compressive strength is a function of the water content in the voids of the soil.

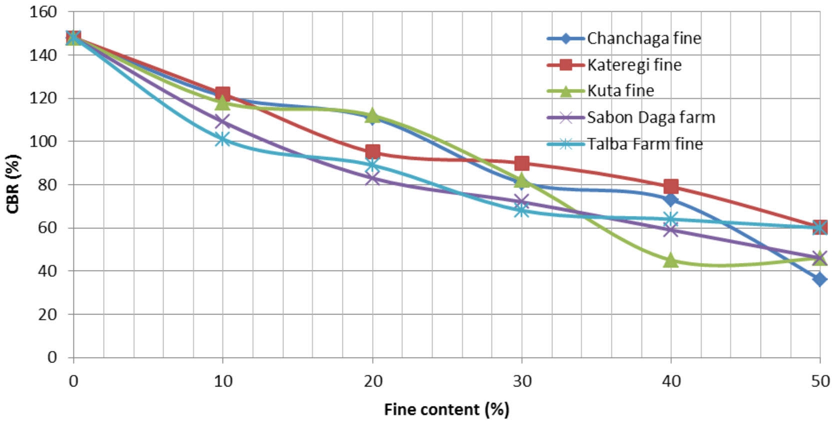

Figure 4 Variation of CBR of lateritic gravel with increase in percentage of the fine soils

5.4 Properties of the Mixtures that gives the 80 % Minimum CBR

After mixture of the five fines with the lateritic gravel, at the varied percentages of 0, 10, 20, 30, 40 and 50 %, grain size analysis was carried out on each of the mixtures and the percentage passing sieve 0.075mm were determined. Summary of the Atterberg limits, the fines content that gave the 80% minimum CBR, the specific gravity, MDDs and OMCs at these mixtures are shown on Table 3.

From the table, it is observed that the fines, collected at Kateregi, Sabon Daga and Talba farm, with maximum liquid limit of 39 %, gave the 80 % minimum CBR. Similarly, the fines collected from Kateregi, Sabon Daga, Chanchaga and Talba farm indicated that maximum plasticity index of 14 % gave the 80 % minimum CBR recommended for material to be used as Base course for road structures. Percentage fine of 36 % also gave minimum CBR of 80 % based on the results revealed by fines from Sabon Daga and Talba farm. All these results were obtained within MDD values of between 1.900 and 2.130 Mg/m^3 and OMC of between 9.6 and 12.9 % at British Standard Heavy compaction energy level. The specific gravity of these samples ranges from 2.69 to 2.81.

Table 3: Summary of index properties of mixtures that gave the 80 % minimum CBR

Location of Fine	Liquid Limit (%)	Plasticity Index (%)	% Fines	CBR value (%)	MDD	OMC	Specific gravity	Gravel (%)
Kuta fines	35.5	10.6	30.0	82.2	1.950	10.9	2.70	28.2
Kateregi fines	41.2	16.5	33.4	79.0	1.900	12.9	2.69	23.8
Sabon daga fines	38.9	15.8	36.3	83.4	2.100	9.6	2.81	19.7
Chanchaga fines	33.7	14.8	33.2	81.0	2.130	11.5	2.80	30.6
Talba Farm fines	43.7	14.1	37.7	89.0	2.060	10.1	2.80	18.8

6. Conclusion

From the study, the following conclusion is drawn:

The lateritic gravel used for this study falls under A-1 soil, while the five fines fall under A-2-6 to A-7-6 according to AASHTO soil classification system.

Based on the 80% minimum CBR specified by the Nigerian General Specification for Roads and Bridge Works (1997), for soils to be used as road base materials, maximum fine content of 36 %, maximum liquid limit of 39 % and maximum plasticity index of 14% are adequate for these Nigerian residual soil mixtures as against the 35 % fines, 35 % liquid limit and 12 % plasticity index specified in the standards.

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