Characterisation of Lateritic Soil from Selected Locations along Ibadan – Oyo Expressway for Highway Pavement Construction

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Abstract

A good understanding of the engineering properties of lateritic soil is highly essential for effective use of the soil for highway pavement construction. The alarming rate of highway pavement failures within the study area has been attributed to paucity of information on the properties of the soil within the study zone. Therefore, the lateritic soils along selected locations along Ibadan - Oyo were characterised for their suitability for highway construction. Ten (10) lateritic soil samples were collected and they were labelled Trial Pit (TP) 1 to 10. The samples were subjected to the following laboratory tests: Sieve analysis, Liquid Limit (LL), Plastic Limit (PL), and Shrinkage Limit (SL), British Standard (BS), West African Standard (WAS), Modified AASHTO compaction and California bearing ratio. The samples were classified using AASHTO classification system. The results of the sieve analyses for percentage passing the 75 μ m ranged from 15.6 - 33.7%, LL, PL and SL ranged from 30.1 - 39.2%, 2.6 - 23.1%, and 2.1 - 9.3%, respectively. The maximum dry density (MDD) and optimum moisture content (OMC) for British, West African and Modified AASHTO compaction ranged from (1.48 - 1.94 g/cm³ and 10.40 - 16.40%), (1.69 - 2.40 g/cm³ and 9.60 - 14.40%) and (1.79 - 2.60 g/cm³ and 6.60 - 11.60%), respectively. The ten samples are classified as A-2-6 soil. Based on the characterisation, all the samples are only suitable for fill and subgrade except sample TP2 that is also suitable for subbase and base course construction in highway pavement.

Keywords: California bearing ratio, Characterisation, Highway pavement, Lateritic soil, Liquid limit, Plastic limit.

Introduction

Lateritic soils are products of complex physical and chemical weathering process that occurred over millions of years as a result of physiography, geology and climatic agents. They are described as tropical or sub-tropical residual soils and are rich in Aluminium oxide (Al₂O₃), Silicon oxide (SiO₂) and Iron oxide (Fe₂O₃). The iron oxide is responsible for the characteristic reddish or reddish brown colouration of lateritic soils, although they may also come in other shades of reddish colouration (Gidigas, 1976). The constituent materials of lateritic soil vary from clay to gravel (Amu *et al.*, 2011; Oyelami and Van Rooy, 2016). Lateritic soils had been chemically classified by Joachin and Kandiah in 1941 using the silica-sesquioxide ratio (SiO₂/(Fe₂O₃ + Al₂O₃)) as a standard. Laterite soils with a ratio of less than 1.33 while those with a ratio ranging between 1.33 and 2.00 are lateritic soils, and a ratio greater than 2.00 indicates non-lateritic soil (Adebisi, *et al.*, 2013). Laterites are coarse-grained with insignificant clay or fine particle contents whereas lateritic soils have more fine particles. Both soils are useful for engineering purposes (Scullion *et al.*, 2005).

A good understanding of the engineering properties of lateritic soil is pertinent for its proper usage in highway pavement construction. Lateritic soil has found wide usage because of its availability and abundance in the tropics and it is used in the construction of earth dams, bricks and blocks for low-cost houses, railway tracks, liners and covers for landfill, and highway pavement layers (Osuolale *et al.*, 2012; Osuolale *et al.*, 2016). The highway pavement has been divided into subgrade, subbase, base and surfacing course. The first three layers are mostly constructed using lateritic soil in the tropics because of its availability and distinctive properties, except for high-density traffic roads that the base course are constructed using crushed stones (Agbede and Osuolale, 2005; Garber and Hoel, 2009).

A survey conducted in 2010 revealed that most of the roads within the study area were constructed by local, state and federal governments using lateritic soils. The roads were in deplorable conditions especially the local government roads and this was attributed to lack of knowledge and understanding of the geotechnical properties of the laterite deposits around the study area. In addition, there is a great need for infrastructural development within the study area because of the rapid population increase and migration from Ibadan city centre to the suburb. Therefore, the engineers working around the study area need information on the properties of the lateritic

soils for the preliminary and final highway route location and design, however, there is a paucity of information on these properties. Hence, the urgent need to investigate and characterise the lateritic soils deposits within the study area. Therefore, in this study characterisation of lateritic soil at selected locations along Ibadan - Oyo expressway was done in order to ascertain their suitability for highway pavement construction.

Materials and Method

Materials

The major materials used for this study are lateritic soil and water. The lateritic soil was obtained as disturbed samples from ten different locations along new Ibadan-Oyo expressway from chainages 7 + 750 to 27 + 200 around Fiditi interchange. The soil samples were collected at a depth of about 3 m below the natural ground level. The samples were kept in polythene bags before air drying for 48 hr to remove the natural moisture that can affect laboratory analyses. The soil samples were pulverised in order to remove lumps.

Method

The soil samples were subjected to geotechnical laboratory tests: Sieve analysis, Liquid, Plastic, and Shrinkage limits, British Standard (BS), West African Standard (WAS), Modified AASHTO compaction and California bearing ratio (CBR) in accordance with BS 1377 (1990) and Nigerian specification for roads and bridges FMWH (1997).

Sieve analysis

500 g of the dried lateritic soil sample was soaked in water for about 24 hr. The soil was backwashed using BS sieve No 200 (75mm) until it is clean. The soil sample was oven dried for 24 hr at a temperature of 110°C and was allowed to cool before sieving through a set of sieve with different diameters using electromechanical sieve shaker. Soil sample retained on each was collected and measured and the percentage retained and passing each sieve was determined. The percentage passing each sieve was plotted against the sieve size. The procedure was repeated for all the ten lateritic soil samples.

Liquid limit

150 g of air-dried lateritic soil sample passing sieve No. 40 (425mm) was placed on the cleaned flat glass plate, and a considerable amount of distilled water was added and mixed thoroughly with a spatula until a uniform paste is formed. A portion of paste was placed on the Casagrande device using a spatula and a groove was made which divided the soil paste into nearly two equal halves inside the bowl of Casagrande apparatus. The crankshaft of the apparatus was turned to give blows to the soil paste until the two halves nearly closed. The number of blows which closed the groove was recorded. A small portion of the soil in the apparatus was taken for moisture content determination. The water used for mixing was subsequently increased such that the number of blows which closes the groove is within the range of 10 – 15, 15 – 20, 20 – 30, 30 – 40 and 40 – 50. The graph of moisture content against number of blows was plotted and the liquid limit was recorded as moisture content corresponding to twenty-five (25) blows. The procedure was repeated for all the ten lateritic soil samples.

Plastic limit

50 g of the soil sample passing sieve No. 40 (425mm) was mixed with sufficient water until a paste of good consistency was formed. This was kneaded between the palms of the fingers, moulded and rolled until a thread of 3 mm in diameter was formed in accordance to BS1377 (1990). The soil was kneaded together to form a uniform mass and rolled again. The process of alternative kneading and rolling continued until the thread crumbles and the soil can no longer be rolled into a thread. The pieces of crumbled soil thread were collected for moisture content determination. The plasticity index was determined as the algebraic difference between the liquid limit and the plastic limit. The procedure was repeated for all the ten lateritic soil samples.

Linear shrinkage limit

100 g of the soil sample passing sieve No. 40 (425mm) was mixed with sufficient water until a paste of good consistency was formed. The paste was packed into the shrinkage mould of known internal diameter and length and this was placed inside the oven for 24 hr. The length of the resultant gap after shrinkage was measured. The linear shrinkage was the change in length divided by the original length of the sample. The procedure was repeated for all the ten lateritic soil samples.

British standard compaction

3 kg of the lateritic soil sample was weighed and divided into five portions, each portion was mixed with water to make the sample increasingly moist. The percentages of water to soil were 4, 8, 12, 16 and 20. The moist soil was compacted in a BS compaction mould in 3 layers with 2.5 kg rammer evenly distributing 27 blows per layer. The water contents were determined for each compaction. The wet densities of the compacted soil samples were determined and hence its dry densities. A plot of dry densities against the corresponding moisture content was done on a normal-normal scale to obtain a parabolic curve. The maximum dry density and the optimum moisture content was determined from the plot.

West African standard compaction

The procedure was similar to that of British standard compaction except that 6 kg of the lateritic soil sample was used. The percentages of water to soil were 3.5, 7, 10.5, 14 and 17.5%. The CBR compaction mould was used in 5 layers with 4.5 kg rammer evenly distributing 27 blows per layer. The maximum dry density and the optimum moisture content was determined from the compaction curve. The procedure was repeated for all the ten lateritic soil samples.

Modified AASHTO standard compaction

The procedure was similar to that of West African standard compaction except that the percentages of water to soil were 3, 6, 9, 12 and 15. The CBR compaction mould was used in 5 layers with 4.5 kg rammer evenly distributing 62 blows per layer. The maximum dry density and the optimum moisture content were determined from the compaction curve. The procedure was repeated for all the ten lateritic soil samples.

California bearing ratio

The CBR was evaluated using static compaction. The maximum dry density, optimum moisture content, compaction volume along with the air-dry moisture content were used to compute the mass of soil and volume of water required for the static compaction. The CBR of the subgrade was evaluated after soaking the compacted soil for 48 hr, for the subbase, the evaluation of CBR was after 24 hr while the CBR of base was evaluated without soaking the compacted soil.

Results and Discussion

Sieve analysis

The particle size distribution for the ten soil samples is as shown in Figures 1 and 2. All the samples can be described as gravel sandy soil with fewer clay particles and the samples are well graded. The percentage of each soil sample passing the 75 μm is less than 35%. These results are in agreement with the Nigerian Federal Ministry of Works and Housing specifications for road works and bridges. This indicates that the samples contain less fine particles, which make them less susceptible to swelling when in contact with water. From the sieve analysis results, it can be inferred that the ten soil samples are suitable for highway pavement construction but it cannot be concluded without the result of LL, PI and CBR (FMWH, 1997).

Figure 1: Particle size analysis graph for samples TP1 to TP5

Figure 2: Particle size analysis curve for TP6 to TP10

Consistency limit

The results of the LL, PL, PI and LS are presented in Table 1. The LL, PL, PI and LS ranged from (30.1 - 39.2, 2.6 - 23.1, 12.4 - 37.3 and 2.1 - 9.3)% respectively. Based on FMWH, 1997 general specifications for roads and bridges, all the ten samples are suitable for fill and subgrade pavement layers construction because the LL and PI are less than 50 and 30% (Desired limits), respectively except TP10. From the same specifications, only sample TP2 is suitable for both subbase and base pavement layer construction, the remaining nine samples can only be used as fill and subgrade materials. The linear shrinkage results reveal that all the samples are suitable for subgrade, subbase and base layer construction except samples TP5 and TP8 because their LS limits are greater than 8%. However, since their LL and PI limits are above 35 and 12% respectively, only sample TP2 can be inferred to be suitable for subbase and base course construction.

Table 1: Consistency indices for the lateritic soil samples

Sample ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
TP1	39.2	20.5	18.7	5.7
TP2	34.3	21.9	12.4	7.1
TP3	39.2	23.1	16.1	6.4
TP4	39.1	21.7	17.4	6.7
TP5	32.5	17.5	15.0	8.6
TP6	36.5	18.7	17.8	6.4
TP7	38.2	17.1	21.1	5.0
TP8	37.0	19.4	17.6	9.3
TP9	30.1	16.5	13.6	5.4
TP10	39.0	2.6	37.3	2.1

Soil classification

Soil samples were classified using the AASHTO classification method and all the samples were classified as A-2-6 as presented in Table 2. The A-2-6 are rated as good subgrade material and their major constituent are silty or clayey gravel and sand (Garber and Hoel, 2009).

Maximum dry density and optimum moisture content

The results of the compaction test at British, West African and Modified AASHTO standard energy are presented in Table 3. The maximum dry density (MDD) and optimum moisture content (OMC) for British, West African and Modified AASHTO standard energy efforts ranged from (1.48 - 1.94 g/cm³ and 10.40 - 16.40%), (1.69 - 2.40 g/cm³ and 9.60 - 14.40%) and (1.79 - 2.60 g/cm³ and 6.60 - 11.60%) respectively. The MDD increases and OMC decreases with changes in compaction energy as shown in the result. The increase in MDD is due to increase in weight of the rammer and its falling height which caused the soil particles to be closely packed and reduction in voids within the particles thereby increasing the soil density. The decrease in OMC is equally due to the increased weight and falling height of the rammer, these factors cause heat to be generated within the soil mass and it caused the water to evaporate thus decrease in OMC.

Table 2: AASHTO classification of the lateritic soil samples

Sample ID	Percentage Passing No 200 (%)	Liquid Limit (%)	Plasticity Index (%)	AASHTO Classification
TP1	20.8	39.2	18.7	A-2-6(0)
TP2	17.7	34.3	12.4	A-2-6(0)
TP3	30.2	39.2	16.1	A-2-6(1)
TP4	25.3	39.1	17.4	A-2-6(0)
TP5	30.7	32.5	15.0	A-2-6(1)
TP6	31.3	36.5	17.8	A-2-6(2)
TP7	34.3	38.2	21.1	A-2-6(3)
TP8	15.6	37.0	17.6	A-2-6(0)
TP9	20.5	30.1	13.6	A-2-6(0)
TP10	33.7	39.0	37.3	A-2-6(0)

Table 3: Maximum dry density and optimum moisture content

Sample ID	MDD _(OBS) (g/cm ³)	OMC _(OBC) (%)	MDD _(WAS) (g/cm ³)	OMC _(WAS) (%)	MDD _(AASHTO) (g/cm ³)	OMC _(AASHTO) (%)
TP1	1.75	14.80	1.98	12.40	1.89	11.60
TP2	1.94	12.80	2.40	10.20	2.60	8.00
TP3	1.70	13.30	1.96	12.00	2.70	8.00
TP4	1.70	10.40	1.87	10.60	2.00	6.60
TP5	1.56	15.40	1.80	14.60	1.92	10.40
TP6	1.75	13.40	1.70	12.40	1.85	10.40
TP7	1.64	16.40	1.69	15.00	1.79	14.00
TP8	1.48	12.40	1.98	10.60	2.13	10.40
TP9	1.68	13.20	2.04	9.60	2.04	8.40
TP10	1.70	13.30	1.98	12.50	2.10	10.80

Strength characteristics of soil samples

The California bearing ratio (CBR) value represents the bearing capacity of the lateritic soil sample to withstand load. The CBR at British, West African and Modified AASHTO standard energy are presented in Figure 1. The CBR at British, West African and Modified AASHTO standard energy ranged from 12.17 - 35.17%, 31.11 - 74.77% and 81.61 - 149.55% respectively. The results show that all the samples are suitable for subgrade, subbase and base course layers in highway pavement construction because the values are above the minimum specified by Federal Ministry of Works and Housing specification for road and bridges (FMWH, 1997). These indicate that subgrade and subbase can withstand moist infiltration and load and the base material can withstand load without deformation when compacted at MMD and OMC.

Figure 3: CBR values at OBS, WAS and MAASHTO compaction

Conclusion

Based on the study, the following conclusions were drawn:

1. All the samples contain less fine particles and percentage passing sieve No. 200 is less than 35%.
2. The samples are classified as A-2-6 soil based on the AASHTO soil classification system and their GI ranged between 0 and 3.
3. The samples are suitable for construction of subgrade and fill in highway pavement.
4. Only sample TP2 is suitable for fill, subgrade, subbase and base course construction in highway pavement.

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