Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 5 (8): 1479-1483, 2005
ISSN 1812-5654

Analysis of California Bearing Ratio Values of Lime and Wood Ash Stabilized Lateritic Soil

O.O. Amu, I. K. Adewumi, A.L. Ayodele, R.A. Mustapha and O.O. Ola
Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract: This study on stabilization was meant to analysis the California Bearing Ratio (CBR) of lateritic soil when stabilized with lime and wood ash. The aim was to evaluate and provide information for adequate and economical design during stabilization procedures. Classification tests including the moisture content, specific gravity, Atterberg limit and grain-size analysis were performed on the samples in the natural state and when stabilized with lime and wood ash. CBR tests (both soaked and unsoaked) and compaction tests were carried out to establish the analysis parameters needed for the study. Lime and wood ash were added in 2, 4, 6, 8 and 10% by weight of sample. Controls were made at 0% lime and wood ash and another at 2% each of lime and wood ash. The optimum percentage of stabilization was obtained at 6% for both stabilizers while results also indicated that 10% lime sample had the highest optimum moisture content at maximum dry density. The value of CBR at 2% lime + 2% wood ash was found to be lower than stabilizations at 4% lime and 4% wood ash and that soaking generally lowered the CBR values for all the samples. The results revealed that the CBR values of the soil samples were generally better when stabilized with lime, while MDD of the samples were better with wood ash stabilization.

Key words: California Bearing Ratio, lime, wood ash, stabilization, lateritic soil

INTRODUCTION

Structures of all types (buildings, bridges, highways, etc.) rest directly on soil, hence, proper analysis of soil and design of foundations are necessary to ensure that these structures remain safe especially in terms of unequal settlement and collapse.

Materials selected for use in the construction of flexible pavements must be evaluated to provide information for adequate and economical design. The materials selected must be added to ensure the quality and compaction requirements.

Laterites are very important soil resources in civil engineering; they are generally used as materials for construction purposes in the construction industries as well as providing support to various kinds of superstructures. They are used as subgrade, sub base and base materials beneath pavements of roadway and airfields in transportation engineering.

However, to determine the suitability of any soil type for use as a subgrade, sub base or base material in highway construction, the parameter normally used is the California Bearing Ratio (CBR). It was developed by the California Division of Highways Department in 1929 as a means of classifying the suitability of a soil for use as a subgrade, sub base or base material in highway construction.

Apart from its usefulness in the determination of suitability of materials in the highway engineering, the CBR is also used in pavement design, especially flexible pavement to determine the thickness of asphalt or bituminous layer, road base and sub base courses. There are two types of CBR assessment test, the soaked and the unsoaked CBR tests. The unsoaked test was developed to cater for the strength condition of the soil in the natural state while the soaked one was designed to cater for the strength reduction which the soil is likely to suffer due to the ingress of water.

The introduction of lime and wood ash are to serve as stabilizers or conditioners for the lateritic soil type. Soil conditioners or stabilizers are materials that measurably improve the physical and strength characteristics of the soil. The various physical effects and changes associated with lime and wood ash variation in lateritic soils are very important.

In practice, the soil engineer has many diverse and important encounters with soils; soil may be used as construction materials or as foundation materials to support superstructures and embankments. Structures are designed from time to time to retain soils from excavation and underground openings.

One of the problems often faced by the transportation engineers is the selection or determination of appropriate materials for the various layers in the

Corresponding Author: Dr. O.O. Amu, Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria
Tel: 0803 5188 646

construction of road and airway pavements. One of the laboratory tests designed to cater for this particular problem of highway and airfield construction is the California Bearing Ration (CBR) test.

Laterites: According to the Lexicon University Encyclopaedia[1], laterite is a variety of red and reddish-brown soil that occurs in wet equatorial and tropical forest being the principal plant communities. Such soils are characterized by the intense weathering of bedrock into clays and contain a variety of oxides, including iron. On exposure, such soils tend to harden and produce laterite, which is a red, yellow, or rusty-coloured clay-containing iron[2].

According to Robert and Richard[3], laterite is a soil formed by decaying rocks, weathered by tropical heat and centuries of heavy rain. This process strips the soil of all the nutrients except oxidized iron. On land, plants cannot grow in this type of soil, but in tropical Asia, laterite runoff is found in waterways, providing iron to aquatic plants. The term laterite and clay are not the same, but are often confused.

Laterite and lateritic soils have over the years been given an increased attention by soil scientists than other tropical soils. This is because of their wide spread distribution and engineering applications. They are full of cavities and pore and contain a very large quantity of iron in the form of red and yellow ochre. In Latin, the word laterite means brick. Buchanan[4] suggested the name laterite for a highly ferruginous deposit, which was first observed in Malabar during his journey through the countries of Mysore, Canada and Malabar in 1800-1801[5].

Baver[6] discussed the chemical and mineralogical nature of laterites, while Mallets[7] described laterite as a ferruginous, vesicular, unstratified and aluminous in nature with insignificant content of silica and high content of aluminium in hydroxide form, comparable to the composition if bauxite.

Several efforts were made to define lateritic soils in terms of its structure, Pendleton and Sharasuvara[8] defined laterites as profiles in which a true laterite horizon is found and lateritic soils as profiles in which there is an immature horizon from which a true laterite will develop if appropriate condition prevail long enough.

According to Alexander and Cady[9], laterite can be defined as a highly weathered material, rich in secondary oxides of iron, aluminium or both. It is nearly void of basic and primary silicates, but may contain large amount of quartz and kalonite, it is either hard or capable of hardening on exposure to wetting and drying which contains grains in a particular size range.

Soil stabilization: Soil stabilization is a term used for the improvement of soils either as they exist in-situ or when laid and densified as fill[10]. Soil stabilizers are materials that measurably improve the physical characteristics of the soil[11].

It could also mean the improvement of soil in order to reduce its susceptibility to the influence of water and water ingress[12]. This process might be performed in-situ or applied to soil before or after being placed in a road or an embankment.

The purpose of stabilization is to make a soil less pervious, less compressible and stronger. They are used for erosion control, prevention of surface scaling and improvement of water infiltration and drainage.

Mechanical stabilization is the most widely used method which relies on the inherent properties of the soil material for stabilization, usually accomplished by compaction[10]. There are two types of mechanical stabilization these are compaction and consolidation.

Consolidation is associated with increase in weight due to expulsion of water from the pores. Consolidation is achieved by preloading the soil prior to the construction of an embankment and allowing time for the soil to be partially or completely consolidated under induced load. If properly carried out, it will result to an increase in bearing capacity of the underlying soil and decrease in the amount of settlement[10]. In suitable soils, stabilization may be achieved by introducing admixtures, for examples, improving clay soils by mixing it with a few percent by weight of quicklime, hydrated lime or Portland cement. The functions of the admixture are: To modify the soil properties by chemically changing the soil gradation and they may also cause the soil to harden to a compact mass.

Slaking of weak soil aggregates, according to McGraw-Hill[11], leads to the formation of finely divided material that is deposited on the surface of the soil, forming seals and blocking soil pores. This impedes water infiltration runoff and erosion.

Overland water flow applies shear forces to soil surface, when shear forces exceed the stress required to overcome cohesive force between the soil particles, the particles are detached and suspended in the flow, thus causing erosion[13]. Soil stabilizers are good erosion controllers.

Lexicon[1] stated that chemical systems have been developed and used in the stabilization of highways and embankments; commercial products include lime, calcium chloride and magnesium chloride for dust control in road stabilization. Wood ash has also been found to contain these qualities[1].

Lime: According to the Microsoft Encarta Encyclopaedia[14], lime can be defined as a caustic solid substance, white when pure, obtained by calcining limestone and other forms of calcium carbonate. Pure lime, also called quicklime, burnt lime and caustic lime, is composed of calcium oxide (CaO) but commercial preparations usually contain impurities, such as the oxides of aluminium, iron, silicon and magnesium. When treated with water, lime liberates large amounts of heat and forms calcium hydroxide, sold commercially as a white powder called slaked lime or hydrated lime.

Lime is used in the preparation of cement and mortar and as a neutralizer of acidic soils in agriculture. It is also used in the manufacture of paper, glass, whitewash, in leather tanning, sugar refining and as a water-softening agent.

Limewater, which is an alkaline solution of slaked lime in water, is used principally in medicine as an antacid, as a neutralizer for acid poisoning, or for treatment of burns.

Wood ash: Samson[15] indicated that wood ash is the inorganic and organic residue remaining after the combustion of wood or unbleached wood fibre. In the Microsoft Encarta Encyclopaedia[14], it is the solid residue of combustion. If combustion has been completed, the ash will be entirely inorganic.

The ash from wood or similar plant material consists principally of sodium and potassium carbonate[1]. For centuries, wood ash was the principal source of potassium for making such chemical as salt-petre. As recently as World War 1, it was an important potassium source for the United States[14].

The physical and chemical properties of wood ash vary significantly depending on many factors. Hardwood usually produces more ash than softwood, the bark and leaves generally produce more ash than the inner woody parts of the tree[12]. On the average, the burning of wood results in about 6-10% ashes.

When ash is produced in industrial combustion systems, the temperature of combustion, cleanliness of the fuel wood, the collection location and the process can all have profound effects on the nature of the ash material. Therefore, wood ash composition is a variable depending on geographical location and industrial processes. This makes testing of the ash extremely important.

The aim of this study was to analyse the California Bearing Ratio values of some lateritic soil samples when stabilized with lime and wood ash, indicating the optimum percentage of stabilizer, the point of the highest optimum moisture content, the effects of soaking on the CBR values, observing the effects of the stabilizing combination of 2% lime + 2% wood ash and observing a general effect of stabilization by using the two stabilizers.

MATERIALS AND METHODS

This study was conducted between April 2001 and May 2002 in the Transportation Laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

The Mica Schist lateritic soil formation at the Obafemi Awolowo University, Ile-Ife, Campus gate, was used for this study. The lime used was obtained from Ibadan, a town in Osun State Nigeria, in the form of hydrated lime, while wood ash was got from the bread bakeries along Ondo road in Ile-Ife. Portable water for mixing and curing was obtained directly from the university water supply.

During the collection of the laterite soil samples, care were taken to avoid top soils which may adversely affect the results and as such, all samples were taken at a depth of 0.5 m from the ground level. To aid in the determination of the natural moisture content, samples were taken in airtight polythene bags. Vegetable matters in the samples were removed and the samples were air dried for about ten days. The soil samples were then passed through Sieve No. 4 (4.75 mm) that was used for the soil samples throughout this study.

The lime had already been finely prepared from the manufacturer, it is therefore, not necessary to be passed though any sieve. The wood ash was also sieved and air-dried for about five days.

Classification and identification tests, for example, the moisture content, specific gravity, Atterberg limits, linear shrinkage, grain size analysis and sieve analysis tests were conducted on the laterite soil samples.

The samples were also subjected to Compaction and California Bearing Ratio strength tests. All the types and methods of test used for this study were done to conform to the West African Standards for Soil Testing and Methods for Civil Engineering Purposes[15] also the classification methods adopted shall be that of the American Association of State Highways and Transportation Official (AASHTO).

Compaction test: The apparatus are sample tray, 0.002124 m^3 capacity mould, sample extruder, measuring cylinder, moisture content tin, hot-air oven, weighing balance, 4.5 kg rammer.

The empty mould was weighed together with the base and the weight recorded. Six kilograms of the soil sample was weighed and 6% by weight of water was added and thoroughly mixed. The mixed soil was compacted in five layers in the mould. The rammer used was 4.5 kg dropping at a height of 450 mm. The collar of the mould was removed after compaction and the top of the mould was trimmed and scarped with iron rod. The compacted sample was weighed and the weight recorded.

The compacted sample was extruded from the mould using the sample extruder and the soil sample broken into pieces. Samples were taken for the determination of moisture content at each point. The procedure was repeated with the addition of 3% weight of water each time to the sample until the weight of the compacted soil starts falling. The moisture content samples were taken at each point.

California Bearing Ratio test: The apparatus are, a cylindrical metal mould of volume capacity 0.00212 4 cm^3, sample extruder, 4.5 kg rammer, measuring cylinder, sample tray and the California Bearing Ratio testing machine.

The method of Section 5.1.3.3, method 1 of BS 1377[16] was used. The mould was assembled with its base plate and collar fitted to the mould. Four kilograms of the soil sample was weighed and the volume of water calculated for 100% of soil sample at maximum dry density of the soil. The soil was then compacted into the mould with the collar attached in five layers using the 4.5 kg rammer. Each layer was given sufficient evenly distributed blows over the surface to ensure that the layer of the soil was just above the top of the mould. The collar was removed and the soil trimmed flush with the top of the mould, using a steel straight edge.

The mould, containing the specimen, with the base plate in position, but top face exposed, was place on the lower plate of the testing machine. Readings of the force were taken at intervals of penetration of 0.25 mm to a total penetration not exceeding 7.5 mm.

The base plate was removed from the lower end of the mould and fixed on the upper end; the mould and the contents were inverted. The testing procedure described above was then repeated for the other end of the specimen. The whole process above was performed with lime and wood ash added to the soil sample in 2, 4, 6, 8 and 10% each.

RESULTS AND DISCUSSION

The average natural moisture content was found to be 5.84% and the ordinary moisture content was 3.71% (Table 1). The value of the natural moisture was more than that of the ordinary moisture content because, in the ordinary moisture content, the soil has been exposed to air before the experiment was carried out, while in the natural moisture content the soil was preserved.

The specific gravity of the soil sample was found to be 2.70, while that of the wood ash was 2.04. The specific gravity of the soil sample was higher than the wood ash, since soil is denser than wood ash (Table 1).

The results of the Atterberg's limits for the sample gave the liquid limit as 37.7%, plastic limit as 30.5% and the plasticity index, which is the difference between the liquid limit and the plastic limit was calculated as 7.2% (Table 1).

The sieve analysis result indicated that the percentage finer than No. 4 sieve was 100% while the one finer than No. 100 sieve was 54.40% (Table 2). The soil sample is more sandy than clayey.

It was observed that the wood ash-stabilized sample had the highest MDD of 1790 kg m^{-3} at 2% additive, while the maximum OMC of 18.2% was observed at 6% stabilization (Table 3). In the lime stabilized sample, the highest MDD of 1670 kg m^{-3} occurred at 2 and 4% additive, while the maximum OMC of 19.5% occurred at 10% stabilization (Table 3 and 4). The MDD at 100% (unstabilized sample) was found to be 1820 kg m^{-3} at OMC of 15.0% (Fig.1).

The results of unsoaked CBR values for samples stabilized with lime and wood ash indicated that the highest CBR of 110.73% for lime and 92.26% for wood ash

Table 1: Result of identification tests on natural soil sample

Test	Value/Unit
Natural moisture content	5.84%
Ordinary moisture content	3.71%
Specific gravity	2.70
Liquid limit	37.7%
Plastic limit	30.5%
Plasticity index	7.2%
Maximum Dry Density (MDD)	1820 kg m^{-3}
Optimum Moisture Content (OMC)	15.0%
Average CBR	33.07%

Table 2: Result of sieve analysis on natural soil sample

Sieve No.	Wt. retained (g)	Retained (%)	Finer (%)
4	0.00	0.00	100.00
8	18.56	3.71	96.29
16	15.25	3.05	93.24
20	38.63	7.73	85.51
30	68.16	13.63	71.88
40	46.99	9.40	62.48
50	18.10	3.62	58.56
100	22.28	4.46	54.40
Pan	6.26	1.25	53.15

Table 3: Variation of MDD and OMC with wood ash stabilization

Wt. of additive (%)	MDD (kg m^{-3})	OMC (%)
2	1790	13.8
4	1720	14.6
6	1680	18.2
8	1670	18.0
10	1690	16.8

Table 4: Variation of MDD and OMC with lime stabilization

Wt. of additive (%)	MDD (kg m^{-3})	OMC (%)
2	1670	14.0
4	1670	18.0
6	1660	16.5
8	1630	17.8
10	1630	19.5

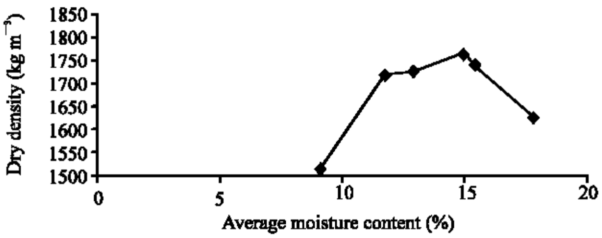

Fig. 1: Compaction curve for 100% (unstabilized) soil sample

Table 5: Variation of unsoaked California Bearing Ratio with lime and wood ash contents

Additive by wt. (%)	Type of additive	CBR (%)
2	Lime	18.54
	Wood ash	13.28
4	Lime	71.65
	Wood ash	54.11
6	Lime	110.73
	Wood ash	92.26
8	Lime	109.65
	Wood ash	82.42
10	Lime	92.26
	Wood ash	74.40

Table 6: Variation of soaked California Bearing Ratio with lime and wood ash contents

Additive by wt. (%)	Type of additive	CBR (%)
2	Lime	13.78
	Wood ash	10.02
4	Lime	20.54
	Wood ash	22.42
6	Lime	51.98
	Wood ash	44.09
8	Lime	44.38
	Wood ash	39.58
10	Lime	40.58
	Wood ash	33.57

were observed at 6% stabilization for both lime and wood ash (Table 5). The CBR values were increasing as the lime and wood ash percentages were increasing up till 6% beyond which they started to reduce. Stabilization with lime and wood ash would therefore be recommended at 6% levels. However, the value of CBR at 2% lime+2% wood ash was found to be 29.44%, a value lower than stabilizations for both 4% lime and 4% wood ash. This shows that stabilization is not preferred with the combination of lime and wood ash.

The trend was the same for the CBR values of the soaked samples, the highest values for both the lime and wood ash were obtained at 6% stabilizations as 51.98 and 44.09%, respectively (Table 6). The value of CBR at 2% lime + 2% wood ash was found to be 19.42%, a value lower than stabilizations for both 4% lime and 4% wood ash. However, it was observed that soaking generally lowered the CBR values for all the samples.

The results revealed that the CBR values of the soil samples were generally better when stabilized with lime, while MDD of the samples were better with wood ash stabilization.

ACKNOWLEDGMENTS

The authors wish to express thanks to the wife of the corresponding author, Eyitope Oluseyi and the children, for their spiritual and moral supports given during the preparation of this manuscript. Thank you all.

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