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EFFECTS OF COMPACTION DELAY ON STRENGTH OF CEMENT STABILIZED LATERITIC SOILS

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Abstract

Most laterite requires some forms of stabilization before been effectively used in road construction to improve the bearing capacity. However, due to shortage of machine parts, machine breakdown, negligence of workers and company policy, the laterite might not be compacted immediately. Three laterite samples were collected from three different pits to investigate the effect of compaction delay on cement stabilized lateritic soil. The samples were subjected to laboratory tests; (all tests were carried out at the Geotechnic Lab. Ladoké Akintola University of Technology, Ogbomosho) Grain Size Analysis, Natural Moisture Contents, Atterberg Limit Tests (liquid limit and plastic limit), Specific Gravity, British Proctor Compaction test, California Bearing Ratio and Unconfined Compressive Test. Deduction from laboratory tests revealed that sample A, B and C are A – 2 – 6 (0), A – 2 – 6 (0) and A – 7 – 6 (0) respectively. The A and B soils were stabilized with 3%, 4% and 6% cement of dry mass of soil sample while sample C soil was stabilized with 6%, 8% and 10% cement of dry mass of soil sample. The stabilized samples were delayed for 1, 2 and 3 hours before compaction. The California Bearing Ratio soaked test showed a strength reduction of between 4.16% and 12.1% for an hour delay for the A and B soil, while it was 4.3% to 21.4% for the C soil. The CBR unsoaked for soil sample C had the least drop of 2.5%, 5.5% and 12.6% for 1, 2 and 3 hours delay period respectively, while samples A and B had maximum decrease of 6.49%, 13.74% and 23.86% for similar delayed periods. The unconfined compressive strength showed that the highest strength decrease for A and B Soils ranges between 14.9% and 38.7%, while that of C soil is 38.63% for three hours delay period. Delay in compaction reduces the strength of different samples of stabilized lateritic soils.

Key words: stabilized, lateritic soil, California bearing ratio, compaction delay, moisture content.

Introduction

In tropics and sub tropics, laterite is the most common materials for road construction and it is residual in nature. Some lateritic soils do not require treatment to give sufficient load bearing capacity; but, most laterites require stabilization for effectiveness in road construction. Stabilization implies a process of improving the properties of a soil materials and its stability. Soil stabilization had been used in the building of roads and bridges, earth dams and embankments for erosion control. The strength and durability properties of natural soils can be improved by both mechanical and chemical means of stabilization (Osinubi, 1998). The goals of stabilization are therefore; to improve the soil strength, bearing capacity and durability of a soil under adverse moisture and stress condition, and improve the volume stability of soil mass. The tendency for lateritic gravel to be gap – graded with depleted sand – fraction, contain variable quantity of fines, and had coarse particles of variable strength, easily break down, limits their usefulness as pavement materials; especially on roads with heavy traffic and adverse moisture conditions. To improve the above deficiencies, there is need for stabilization (Bell, 1994).

Strength and durability of soils can be improved by mechanical means using compaction without the addition of any foreign matter. Water is added during compaction in order to displace air and facilitate movement of the fine grained particles past one another so as to achieve densification. Depending on the type of soil sample, 3% - 10%

of cement by weight of dry soil mixed with the soil hardened in and gives compact mass that will not soften in the presence of water. Cementation is based on hydration of cement. The major hydration products are series of calcium silicate hydrate ($C_3H_6Si_2O_9$) and hydrated lime [$Ca(OH)_2$]. Reactions of the soil with cement includes replacement of Ca^{++} , adsorption of $Ca(OH)_2$ by particles and cementation at inter particles contacts by the $C_3H_6Si_2O_9$ gel. When clay minerals are present in excess of about 30%, it is more difficult to achieve economic stabilization by the use of cement due to great difficulty in pulverizing and mixing (Gillot, 1987).

When lime is added, it reduces the Maximum Dry Density (MDD) and increases the Optimum Moisture Content (OMC) of clayey soils at a given compactive effort (Ladd, *et al*, 1960). The swelling characteristic of the soil is reduced and the shrinkage limit is increased when lime is added (Marks *et al*, 1970). The amount of cement for stabilizing lateritic soils normally ranges between 1–8% (Okonkwo, 2009, Nigerian General Specifications, 1997). Most laterite gravels are gap – graded with a deficiency of sand and silt – size particles. Addition of sand may improve the grading curve with a subsequent improvement in the compaction characteristics of the laterites, reduction in the plasticity of fines and swell characteristics (Ashworth, 1970). When the road base is stabilized with base seal, road wearing surfaces remain stable and durable. The base seal is approximately 100 times expensive per square yard when compared to lime stabilization. It contains a revolutionary cohesive agent that forces a lighter bond on the soil and requires any 15% fines passing sieve No. 200. Colloidal materials are bond together during cementation action creating larger particle sizes that contribute to the reduction in plasticity index. Scientific studies revealed that when base seal reaches maximum viscosity, the colloidal soil produce a gel, which polymerizes. The result is a strong bond and the base becomes impermeable preventing action of sub – grade water. Compaction and bonding create greater soil bearing capacity, stability of at least 6 inches allows for heavy traffic (Nigeria General Specifications, 1997). The surface soil containing active clay minerals and with acidic reactions are suitable for lime stabilization, while the lower zone with illite and kaolinite as principal components respond better to cement stabilization, horizons containing large amounts of montmorillonite with acid reaction are not suitable for stabilization (Locat, *et al*, 1990). Laterite soils with relatively low silica – sesquioxides ratio pulverize more readily and react more favorably with cement than podzolic or chemozem clay soils which have a relatively high silica – sesquioxide ratio (Ornsby and Kinter, 1972). Laterite soils have high concentration of sesquioxide (Fe_2O_3 and Al_2O_3). Because of the sesquioxide content, these soils can be effectively stabilized with small amount of lime and cement. This is considered to be due to the reaction of lime with iron and aluminum oxide (De Graft – Johnson *et al*, 1969). Laterite soils containing high content of aluminum oxide show a decrease in strength with time when stabilized with cement or lime. This was attributed to the formation of a compound with poor cementing properties. Organic cement hinders the development of high strengths in laterite soils (Ladd, *et al*, 1960). Lateritic soils have been shown to be stabilizable with any of the additives with the improved soil produced being used as sub – base and base course of road. The strength of a stabilized soil is dependent on many variables such as soil type and properties, additive content, type of additive, curing time and method, water content, unit weight and time elapsed between mixing and compaction (Olaobaju, 2003). Portland cement have been used to appreciably improve the properties of soils (Ola, 1975; 1983; Osula, 1989; Scullion and Harris, 1998; Berthelot *et al.*, 2005; Gadzama, 2009). Bello (2011) reported that compaction delay influence the measured value of CBR and UCS of yellow soil. Gadzama (2009) also established that 4% cement can be recommended as an optimal content to stabilize soil from parts of Northern Nigerian. This work focused on the effects of delay in compaction on strength of cement stabilization of lateritic soils from different sources.

Methods

Samples were taken from three different locations. The depth of the trial – pits was 1.2m. No variation was observed in the soil profile with depth at each location. Soil identification and description was carried out by visual observation and physical feeling. The laboratory tests carried out in order to investigate the effects of compaction delay on cement stabilized lateritic soils includes: sieve analysis, Atterberg limits (liquid and plastic limits), Moisture content, British proctor compaction, California bearing ratio and unconfined compressive strength. All tests were carried out in accordance with BS 1377 (1975) of the method of testing soils for Civil

Engineering purpose at Ladoke Akintola University of Technology Geotechnical Laboratory, Ogbomoso, Oyo State, Nigeria.

Laboratory test

Sieve analysis

The apparatus used include; set of sieves, weighing balance, mechanical sieve shaker, wash bottle, measuring can, porcelain dish and mortar and pestle. A representative samples of 200g was placed on sieve No 800 and the system was shaken for 15minutes. The sieves were removed and carefully weighed with its contents. The weight of material passing (g) and percent passing were estimated from;

$$\text{Weight of material passing} = \text{weight of dry sample} - \text{Weight retained on the sieve}$$

$$\% \text{ Weight retained} = \frac{\text{Weight retained}}{\text{total dry weight of sample}} \times 100\% \dots\dots\dots 1$$

$$\% \text{Weight passing} = 100\% - \text{percent retained} \dots\dots\dots 2$$

$$\text{cumulative \% Weight retained} = \frac{\text{Cumulative weight}}{\text{total dry weight sample}} \times 100\% \dots\dots\dots 3$$

Liquid limit test

A sample weighing 20g was taken from the material passing through 425mm BS test sieve. The sample was mixed with drinkable water to a consistency of a thick paste and allowed to stand in an airtight container for 24hours to allow the water to permeate throughout the soil mass. A portion of the mixed soil was placed in the cup of liquid limit apparatus and level, after which the grooving tools were used to divide the sample along the diameter through the centre of the hinge. The crank was turned at the rate of two revolutions per second, the cup was lifted and dropped until the two part of the soil came into contact at the bottom of the groove along a distance of 13mm. the number of blows with which this occurred was recorded. A little extra of the soil mixture was added to the cup and mixed with thw soil in the cup. The operation was repeated until two consecutive runs give the same number of blows for closure. A quantity of soil from the sample that flowed together was removed with spatula and placed in container and the moisture content was determined.

Plastic limit test

A sample weighing 20g was taken from the material passing through 425mm BS test sieve. The sample was mixed with water to make a malleable but not sticky ball. This was rolled between the palms of the hand until it began to dry and crack. Half of the sample was rolled further to a a length of 5cm and thickness of 6mm. the thread formed during this process was rolled between the tip of the finger of one hand and the surface of the glass plate. The thread was rolled to about 3mm in five to ten complete (forward and backward) movement of the hand. The soil was formed into a thread and rolled out again. The procedure was repeated until the thread sheared both longitudinally and transversely whe it had been rolled to about 3mm diameter. The portion of crumbled soil thread was gathered together and transferred immediately to the containner for moisture determination

California bearing ratio test (CBR) (Unsoaked)

The test established a standard grading of crushed rock compacted under specified condition as a standard for measurement of bearing capacity of soil. In this test, a calculated bulk mass of soil (from compaction test) was tested as well as water content. The sample was then filled to the mould in five layers by a 4.5kg rammer. The weight of the soil plus mould was measured and the dry density was calculated. The sample was tested for strength

in the mould by the application on a bearing surface at the ratio 0.5, 2.00mm/min. load reading were taken at 0.5mm, 1.0mm... penetration. Finally the CBR was calculated from the equation

$$CBR = \frac{\text{measured load} \times 100\% \text{ for the Top and bottom}}{\text{Standard load}} \dots \dots \dots 4$$

The procedure were repeated for 4.5% and 6% of dry mass of soil for sample A and B while 6%, 8% and 10% of dry mass of soil was used to stabilize sample C

California bearing ratio test (CBR) (Soaked)

In this test, the calculated dry mass of samples was taken and mixed with water to the optimum moisture content (OMC) of the soil as predetermined by compaction test. The sample was then filled to the mould and rammed. The soil with a surcharge of 2.5kg was now soaked for 24 hours. The soaked sample was tested for strength in the mould with the surcharge load still in place by application on a bearing surface at the rate of 1.00mm/mm. CBR was calculated from the equation 4. The procedure was repeated for samples A and B with 3%, 4.5% and 6% cement (stabilized) and for sample C, 6%, 8% and 10% cement content

Unconfined compressive strength test (UCS)

The UCS test is a special type of unconsolidated undrained test commonly used for clay specimens. The sample was taken as calculated from the dynamic compaction and water was added appropriately. It was thoroughly mixed and placed into the BS mould (of known height and diameter) and compacted in three layers applying 27 blows of 2.5kg rammer drop from 300mm height in each layer. The top of the mould was scraped off to remove excess soil after compaction. The compacted soil is removed from the mould with the aid of hydraulic jack. This was then taken to the UCS machine for test. The procedure was repeated for 3%, 4% and 6% for samples A and B, 6%, 8% and 10% for C. the samples were cured for seven days

Results and discussion

Soil Identification

Table 1 shows that the three representative soil samples had virtually similar physical properties. The various engineering properties of soil samples A and B were very close. The difference in their maximum dry density (MDD) is 0.03kg/dm³ and that of optimum moisture content (OMC) is 1.78%. while sample C has its OMC and MDD that is appreciably far from the other two.

Engineering Properties of Unstabilized Soil

The results of moisture content, Atterberg limits, specific gravity, plasticity index, optimum moisture content, maximum dry density, sieve analysis, AASHTO classification, CBR(%) of both soaked and unsoaked and UCS (qu) (P/A) kpa tests carried out on the samples were shown in Table 2. The plasticity index (PI) of sample C almost double that of sample A and B, while there was negligible difference between the PI of sample A and B, Ditto for Liquid limit (LL). The specific gravity was however too close as it ranges between 2.48 and 2.50. Their unconfined compressive strength (UCS) range between 51.88 and 55.37 for the three samples. The California bearing ratio result showed that samples A and B are much stronger and structurally desirable than sample C. Therefore, the classification of the laterized samples followed the Atterberg limits and sieve analysis results according to AASHTO (1945) system of classification grouped samples A and B with A- 2 – 6 (0) and sample C as A – 7 – 6 (0).

Sieve Analysis

The result of the sieve analysis for the three soil samples were presented in Table 3.(The analysis was carried out in accordance with BS1377 Part 2, 1990) The percentage of particles that passes sieve No. 200 for the three samples were greater than 35% (Olaniyan *et al*, 2017). These values were higher and require that the soil be stabilized for use as base and sub-base courses in highway applications.

Effect of compaction delay on Stabilized Soil Samples

The results of the California Bearing Ratio (CBR) and the unconfined compressive strength (UCS) tests on the stabilized soil samples 0 – 3 hours delay periods were presented in Tables 4, 5 and 6. The CBR (soaked) of the stabilized A – 2 – 6 (0) soil samples decreased by a minimum of 4.16% and a maximum of 12.1% in value for an hour delay period. Alas that of A – 7 – 6 (0) soil decreased by lowest 4.3% and highest 21.4% for the same delay period. The CBR (unsoaked) of the stabilized A – 7 – 6 (0) soil minimally decreased in value by 2.5%, 5.5% and 12.6% for 1,2 and 3 hours delayed periods respectively, while that A – 2 – 6 (0) soils had maximum decrease of 6.99%, 13.14% and 23.86% for similar delay periods. The UCS values obtained after varying the compaction delay periods revealed a notable drop in strength. For the A – 2 – 6 (0) soil the worst strength drop was 69.20%, while the minimum reduction for A – 7 – 6 (0) soil was 38.63% for three hour delay period. The noticed decrease in strength could be as a result of the fact that in the presence of water cement hydration commenced immediately which resulted in hardening of the stabilized soil. As a result of delay in compaction this process is disrupted by compaction at a later time thus weakening the soil (Okonkwo, 2009).

Table 1: Soil Physical Description

Representative Samples	Soil Physical Description
Sample A	Reddish brown gravelly clay granular soil
Sample B	Reddish brown gravelly clay granular soil
Sample C	Reddish brown gravelly clay granular soil

Table 2: Engineering Properties of Natural Soil Samples (A, B, C)

	A	B	C
Natural Moisture (%)	12.34	11.6	12.49
Liquid Limits(LL) %	36.00	36.70	71.75
Plastic Limits (PL)%	18.88	18.91	35.98
Plastic Index (PI)%	17.12	17.09	35.97
Optimum Moisture Content (%)	9.98	8.20	16.50
Maximum Dry Density (kg/dm ³)	2.05	2.02	1.78
Specific Gravity	2.50	2.48	2.50

% Passing Sieve No. 200	20.36	4.96	23.77
AASHTO Classification	A- 2 -6 (0)	A – 2 – 6 (0)	A – 7 – 6 (0)
CBR Soaked (%)	9.40	10.22	6.12
CBR Unsoaked (%)	8.57	8.11	4.72
UCS (qu)(P/A) kpa	53.44	55.37	51.88

Table 3: Sieve Analysis Result of Samples A, B, and C

Sieve Size or No.	A	B	C
0.8mm	96.18	97.85	98.28
5.6mm	91.72	93.73	94.97
4.0mm	83.57	87.69	90.13
2.0mm	68.00	71.75	77.35
710µm	51.60	49.07	59.16
500µm	43.72	39.84	15.71
355µm	38.68	31.68	45.21
250µm	34.04	25.23	40.04
63µm	27.71	16.17	32.77
<63µm	20.36	4.96	23.77
PAN	0.11	0.02	0.00

Table 4: Properties of Stabilized Sample A Soil

Cement Content (%)	Delay Period (Hr)	CBR Unsoaked (%)	CBR Soaked (%)	UCS (qu) (P/A) kpa
3	0	16.39	11.69	799.19
4.5	0	16.57	12.80	830.53
6	0	17.00	14.90	852.88
3	1	15.92	11.30	780.00

4.5	1	16.15	12.22	810.16
6	1	16.03	13.94	820.26
3	2	15.54		699.09
4.5	2	15.62		714.57
6	2	14.95		789.50
3	3	14.77		246.19
4.56	3	14.62		306.05
	3	13.28		485.78

Table 5: Properties of Stabilized Sample B Soil

Cement (%)	Content	Delay Period (Hr)	CBR (%)	Unsoaked	CBR Soaked (%)	UCS (qu) (P/A) kpa
3		0	13.62		12.05	658.16
4.5		0	16.38		14.09	761.02
6		0	19.87		15.53	941.38
3		1	12.95		11.65	601.22
4.5		1	15.44		12.56	745.70
6		1	18.58		13.65	761.23
3		2	11.75			630.73
4.5		2	13.67			778.32
6		2	17.14			884.63
3		3	10.48			354.38
4.56		3	12.14			571.97
		3	15.30			721.46

Table 6: Properties of Stabilized Sample C Soil

Cement (%)	Content	Delay Period (Hr)	CBR (%)	Unsoaked	CBR Soaked (%)	UCS (qu) (P/A) kpa
3		0	10.27		11.06	761.23

4.5	0	10.35	12.27	766.28
6	0	10.92	12.53	916.58
3	1	9.44	8.69	548.46
4.5	1	10.09	10.53	652.48
6	1	9.82	11.99	699.09
3	2	9.07		548.46
4.5	2	9.78		576.67
6	2	9.14		653.45
3	3	8.31		466.06
4.56	3	9.05		470.12
	3	9.08		982.46

Conclusion

Cement stabilized lateritic soil could gain more compressive strength of up to 77% of the original strength. However, the increase in bearing capacity could be as much as 100% but 60% in soaked condition. The influence of compaction delays which is almost inevitable on construction sites, is devastating as reasonable amount of strength and bearing capacity are lost in the cause of delay. The compressive strength of the cement stabilized laterite is drop by a maximum of 23.7% if delayed beyond 3 hours and the bearing capacity of the mixture can also reduce to 23.9% for the same time delay period.

Recommendations

Based on the laboratory findings, the following recommendations are made to maximize the benefits from road lateritic earthworks:

- The soil cement mixture should be compacted as soon as the desired mixture is accomplished.
- In case of inevitable delay from construction intricacies, it is advisable to stabilize the soil until the laying and compaction materials are readily available.
- Delay should be minimized to less than one hour to avoid greater loss of soil strength.
- Higher mixing percentage of cement should be chosen to achieve meaningful increase in strength of the stabilized soil

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