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Strength Developed by Hydrated Lime-Stabilized Lateritic Soil

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ABSTRACT

Soil stabilization is usually carried out to improve weak soils by reducing its plasticity and increasing the strength before they can be used for civil engineering constructions. The additives used for this study is lime for improvement of the quality of the test soil. The test was carried out in accordance with the tests procedures specified in BS 1377: 1990. Soil was classified as A-7-6 and CL according AASHTO and USC systems respectively. It is a poorly drain soil with a liquid limit of 47% and requires a form of stabilization before it could be used for construction purpose. From the compaction test, the natural soil has an OMC of 15.3% and MDD of 1.91g/cm^3. A CBR value of 6.04% and unconfined compressive strength (UCS) of 377.32 kN/m^2 was obtained for the natural soil. The test sample was found to have an activity value of 0.35 which implies it contains kaolinite mineral predominantly. Lime stabilization greatly improved the CBR and strength of test soil by 975% (from 6.04% to 58.9%) and 162% (from 377.32 kN/m^2 to 611.30 kN/m^2) respectively and there was an overall reduction in the plasticity index of the soil at 8% addition of lime. For construction purpose 8% lime is recommended as it increases the soil strength and reduces its plasticity.

Keywords: *California Bearing Ratio, Lateritic Soil, Lime, Optimum Moisture Content, Plasticity.*

1 INTRODUCTION

The improvement of the engineering properties of soil is one of the major professional tasks to every civil engineer involved in engineering practice that has to do with soil (Sotoudehfar *et al.*, 2016). Targeting strength gain is also one of the reasons why a particular method of soil improvement for engineering use is adopted. Unlike manufactured products, some soils have to be improved to meet the engineering specifications for the intended use, this is because they come with some deficiencies due to the geologic processes the soil has undergone during formation (Jayanthi and Singh, 2016). Effective utilization of local weak soils by imparting additional strength using stabilization materials enable reduction in construction cost and improved performance for roads (Vora *et al*., 2018).

Ratna *et al.* (2018) studied the use lime from 0% to 5%. Laboratory tests reveal that the ideal level of lime as 4% which show there is an improvement of properties of black cotton soil by adding lime up to 4% by weight of dry soil to utilize them as an engineering material for various purposes such as foundation soil and pavement sub grade.

Natural soil has a liquid limit of 33.33 a plastic limit of 17 and percent passing sieve#200 is 80.85%. Both of these parameters show that soil fulfills the criteria for soil to be suitable for lime stabilization (clay content>25% and PI>10). The increase in OMC can be related to hydration reaction of water with soil due to pozzolanic activity of lime while decrease in MDD was due to flocculation and agglomeration reaction of soil lime. (Adnan *et al.*, 2019).

The proportion of clay mineral flakes (<2mm size) in a fine soil affects its current state, particularly its tendency to swell and shrink with changes in water content. The degree of plasticity related to the clay content is called the **activity** of the soil and is given by equation 1. Activity values of clay minerals are presented in Table 1 and the classification of soil based on its liquid limit is also presented in Table 2.

$$\text{Activity of soil} = \frac{\text{Plasticity Index(Ip)}}{\text{\% clay particles}} \qquad (1)$$

Activity < 0.75 = Non active soil

0.75 – 1.25 = Normal soil

> 1.25 = Active soil

Table 1: Activity values of Clay Minerals (Skempton(1953).

Minerals	Activity value
Na - monmorillonite	4-7
Ca - monmorillonite	1.5
Illite	0.5 – 1.3
Kaolinite	0.3 – 0.5
Halloysite (Hydrated)	0.1
Calcite	0.2
Quartz	0

Table 2: Classification of clay based on plasticity (John, 2000).

Liquid Limit	Clay classification
LL = < 35%	Clay of Low Plasticity (CL)
LL = 35 – 50%	Clay of Intermediate Plasticity (CI)
LL = 50 – 70%	Clay of High Plasticity (CH)
LL = 70 – 90%	Clay of very High Plasticity (CV)
LL = >90%	Clay of Extremely High Plasticity (CE)

In order to increase the workability and strength and for reducing the plasticity index and swell, lime is added to subgrade soil. Kaolinite reacts slowly with lime as compare to montmorillonite. Depending on the soil type, amount of lime vary from 4 to 6 %.The greater percentage of lime should be used for low quality subgrade soil (Arif *et al.*, 2019). Overall, lime in road construction can result in reduction of the cost of due to reduction in pavement layer thickness. And it can also save the economy of replacing the weak subgrade soil with high strength material (Adnan *et al.,* 2019).

This study will be concerned with the evaluation of the effect of using lime for soil stabilization. This would be achieved by adding the lime in percentages of 2%, 4%, 6% and 8% by weight of the lateritic soil. The present study was made according to the BS 1377 part 2: 1990.

2 MATERIAL AND METHODS

In this study the sample collected was treated with lime at various percentages in the laboratory according to the BS 1377 part 2: 1990.

2.1 Material

Soil

The soil sample used for this research was collected from Dibbo borrow pit in Minna Niger state. The sample was collected in their disturbed state from a depth of 2.0m below the ground surface.

Lime

The lime used for this research was obtained from Kaduna state. It was taken in powder form. Depending on the soil type being tested, the optimum lime content usually vary from 4 to 6%. The greater percentage of lime should be used for low quality subgrade soil (Arif et *al.*, 2019). The use of quicklime is generally preferred to hydrated lime $Ca(OH)_2$, however due to its vulnerability in exposing the user to skin and eye burns, the type of lime used during this study is hydrated lime. The lime percentage adopted are 0%, 2%, 4%, 6% and 8%.

2.2 Methods

The lime was added to the soil in dry condition, mixed thoroughly to get a uniform mixture. Then the required amount of water was added and mixed, and then the samples prepared and tested.

2.2.1 Index properties

The grain distribution/sieve analysis test and Atterberg limits test were conducted in accordance with tests procedures specified in BS 1377: 1990. Specific gravity test was also conducted for the soil. The results are presented in Table 4.

2.2.2. Compaction characteristics

Compaction test of the samples were conducted in accordance with the guidelines specified in BS 1377 (1990) to compute for the dry density and moisture content. British Standard Heavy (BSH)/Modified compaction was adopted for this test.

2.2.3 California Bearing Ratio Test

This is a penetration test used to assess the strength of the soil for construction purpose. This was also conducted according to the BS 1377 (1990) standard.

2.2.4 Unconfined compressive strength (UCS)

The test was conducted according to procedure described in BS, 1377: (1990). The specimens were prepared at optimum moisture contents (OMC) obtained from the compaction test and compacted at 10 blows and 3 layers. The compacted specimens were then tested at a regulated strain of 0.02 %/min. Samples used had a height to diameter ratio of 2:1. The crushed specimen was recorded and used for the computation of the unconfined compressive strength.

3 DISCUSSION OF RESULTS

The result obtained from the data gotten from the laboratory tests conducted for the untreated soil sample and the treated samples are presented in this section.

3.1 Result of the properties of the untreated soil sample

For the untreated soil sample the results obtained are given below in this section.

3.1.1 Index properties of the natural lateritic soil

The index properties of the natural soil are shown in Table 5. The fraction passing No 200 sieve (75µm) is 61.2 % (see Figure 1), with clay contents of 60.3 %. The soil was classified as A-7-6 according to AASHTO soil classification system (AASHTO, 1986) and CL or CI according to Unified Soil Classification System, USCS (ASTM, 1992). Further, the mineralogical characterization of the natural soil and lime additive was conducted using the X-Ray Diffraction (XRD) technique. Result obtained shows that predominant clay minerals found in the soil are Kaolinite, Illite and Quartz (Figure 2) while the lime contains Portlandite and Calcite (Figure 3). The percentage oxide composition of the soil is also summarized in Table 3.

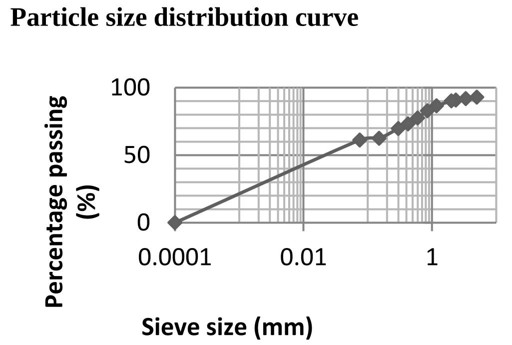

Figure 1: Particle size distribution curve of the natural soil

Table 3: Oxide Composition (%) for the Natural Soil and the Lime

OXIDE	Concentration (%)	
	Lateritic Soil	Hydrated Lime
Cu	0	0
NiO	0	0
Fe_2O3	20.726	0.286
MnO	0.053	0.012
Cr_2O3	0.06	0.0099
TiO2	2.164	0
CaO	0.89	95.33
Al_2O3	16.29	1.451
MgO	1.03	0
ZnO	0.013	0.001
SiO_2	58.75	2.91
SiO_2	58.75	2.91

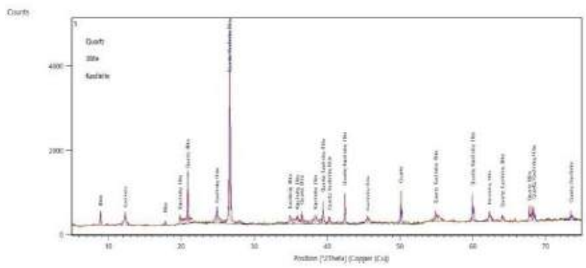

Figure 2: X-Ray Diffractogram of the natural soil

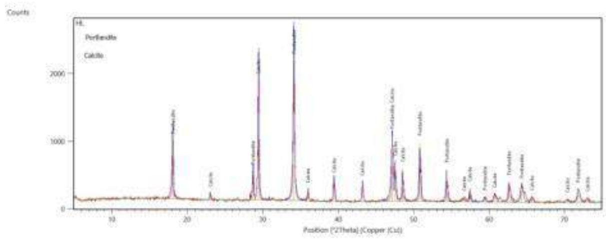

Figure 3: X-Ray Diffractogram of the hydrated Lime

Atterberg Limits: The Atterberg limits (i.e. Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI)) are used to evaluate the plastic behaviour of soils. These are presented in Table 4 and Figure 4.

Table 4: Liquid Limit for Natural soil

Penetration (mm)	% Moisture Content
58	29.55
99	39.22
118	41.07
134	41.67
196	45.76
228	46.51

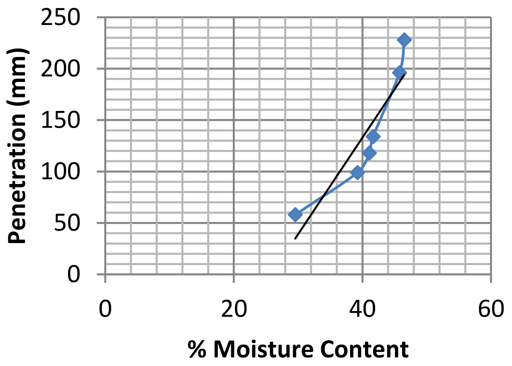

Figure 4: Penetration against moisture content

Liquid Limit = 47%, Plastic Limit = 26.14 and the Plasticity Index (PI) = 20.9

The plasticity of the soil is found to be greater than 10 hence there is need to reduce the plasticity of the soil.

From equation (1) the acivity of the soil is given as;

$$\text{Activity of soil} = \frac{\text{Plasticity index(Ip)}}{\text{\% clay particles}} = \frac{20.9}{60.3} = 0.35 \quad (1)$$

The activity value 0.35 is less than 1.25 the limit for active soil which shows that the soil is an inactive soil type and does not belong to the swelling type of soil according to Skempton's classification of soil base on its activity value. Since it lies between 0.3 and 0.5 it indicates the presence of kaolinite mineral in the clay soil whose activity value lies within this range as shown in Table 1 above.

3.1.2 Compaction Results

The values of the dry density and the corresponding moisture content for the natural soil are given in Table 5 and the Maximum Dry Density of 1.91g/cm^3 and optimum moisture content (OMC) of 15.3% was also obtained from the graph of the dry density vs. moisture content as shown in Figure 5.

Table 5: Compaction Test Results

Dry Density (g/cm$^{3)}$	Moisture Content (%)
1.763	6.91
1.836	11.67
1.904	15.35
1.814	18.215
1.693	21.66

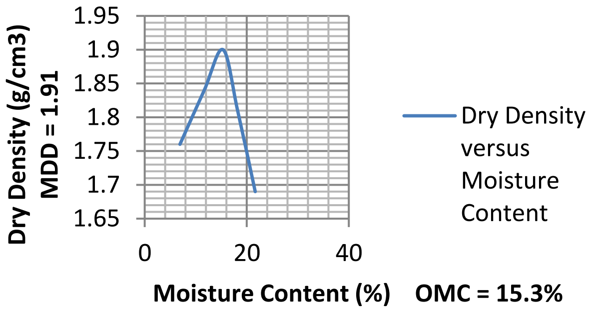

Figure 5: compaction curve for the natural soil at 0% lime

3.1.3 CBR test result

The %CBR value obtained for the natural soil shows it has a low bearing capacity and is unsuitable for use as a subgrade material or for other construction purpose. Hence there is the need for stabilization of the soil to improve its strength.The graph of Load vs. Penetration curve for the soil test conducted at 0% lime is presnted in Figure 6. The % CBR values obtained at 2.5mm and 5.0mm penetrations are 5.34% and 6.04% respectively. Hence the higher % CBR of 6.04% at 5.00 mm penetration was selected for the untreated soil.

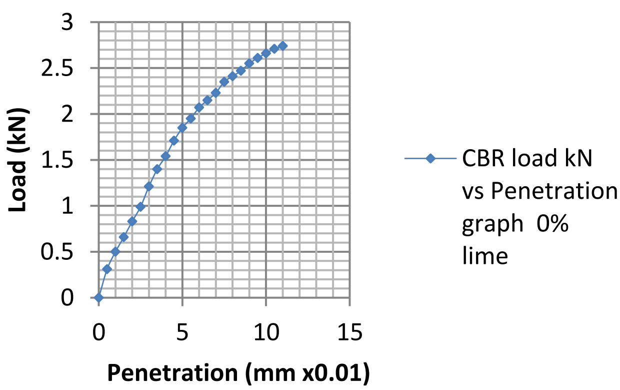

Figure 6: Load-penetration curve for natural soil

3.1.4 Unconfined Compressive Strength test Result

The graph of the axial stress vs. axial strain obtained from the result of unconfined compressive strength test conducted in the laboratory is presented in Figure 7.

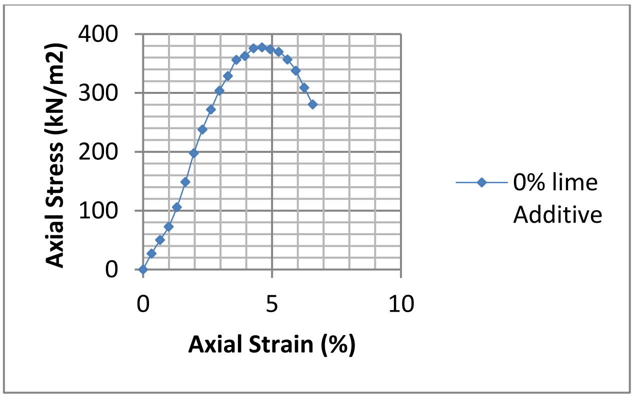

Figure 7: Axial stress – Axial strain curve for the natural soil

The peak Axial stress which gives the Unconfined compressive strength (q_u) =377.32kN/m^2 while the undrained shear strength is given as;

S_u = Cohesion (C) = $\frac{qu}{2} = \frac{377.32}{2}$ = 188.66 kN/m^2

The summary of the test result obtained for the untreated soil sample tested with 0% lime additive is given in Table 6. The specific gravity of the plastic material obtained from the analysis is 1.055 which is less than that of the soil 2.63.

Table 6: Properties of the Natural Lateritic Soil

Characteristics	Description
Natural moisture content	18.27
% passing B.S sieve No. 200	61.2
% clay	60.3
Liquid Limit LL	47
Plastic Limit PL	26.14
Plasticity Index PI	20.86
Activity (A) of soil	0.35
AASHTO Classification	A-7-6
USCS Classification	CL
MDD (g/cm3)	1.91
OMC (%)	15.3
Specific Gravity	2.63
CBR (%)	6.04
Unconfined Compressive stress(kN/m^2)	377.32
Shear strength (kN/m^2)	188.66

3.2 Result of the soil sample treated with lime

3.2.1 Plastic limit Characteristics

The addition of lime to the soil resulted in the increase of plastic limit from 26.14 to 29.167%. Also the Variation of the percentage of lime in the soil with Liquid limit, Plastic limit and the Plasticity index are presented in Table 7.

Table 7: Variation of the percentage of lime in the soil with Liquid limits (LL), Plastic limits (PL) and the Plasticity Index (PI)

Material	LL (%)	PL (%)	PI
Soil + 0% lime	47	26.14	20.86
Soil + 2% lime	46	26.96	19.04
Soil + 4% lime	45	27.63	17.36
Soil + 6% lime	46.5	28.96	17.54
Soil + 8% lime	47.9	29.17	18.83

The graph of variation of the plastic limit of sample with different lime content is presented in Figure 8.

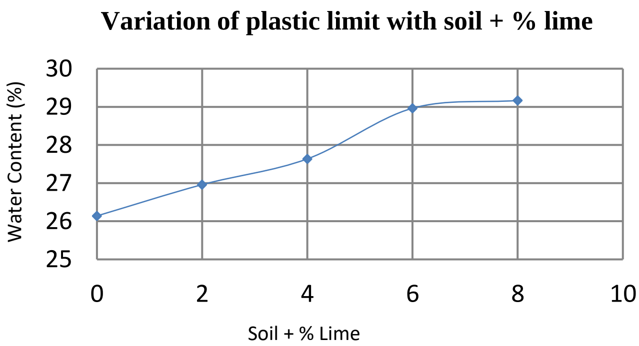

Figure 8: Variation of plastic limit with soil + % lime

3.2.2 Liquid Limit Characteristics

From the graph shown in Figure 9, the liquid limit is seen to decrease up to 4% addition of lime to the soil. Further addition of lime resulted in increase of the liquid limit.

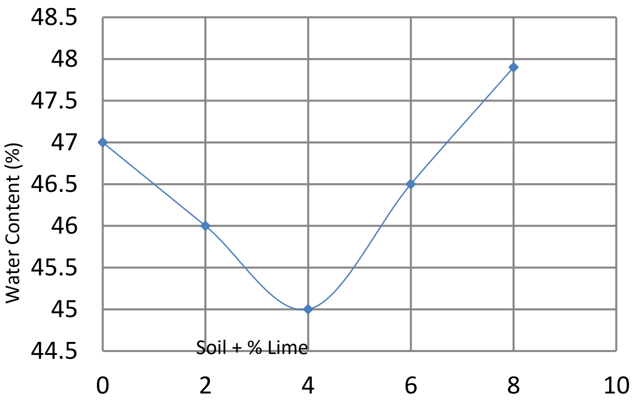

Figure 9: Variation of Liquid Limit with Soil + % lime

3.2.3 Plasticity Index

From the graph in Figure 10, it is seen that there was an overall decrease in the plasticity index of the soil.

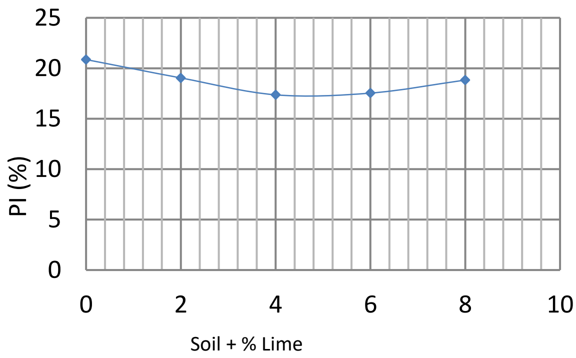

Figure 10: Variation of plasticity index of soil + % lime

From this result obtained it can be seen that the plasticity of the soil was reduced which is an improvement in the soil for construction purpose.

3.2.4 Compaction Characteristics

Compaction result for soil with lime of different combinations is presented in Figure 11.

The result obtained from the compaction test indicates that the optimum moisture content of the soil increases from 15.3% to 19% with the increase of lime content from 0% to 8% while there was an overall decrease in the maximum dry density values from 1.915g/cm^3 to 1.825 g/cm^3 at 8% lime. The values are presented in Table 8. The effect of variation of the percentage lime content on soil is shown in Figures 12 and 13 for the optimum moisture content and the maximum dry density respectively. This result shows that the maximum dry density is reduced with increasing lime content. The increase in OMC can be related to hydration reaction of water with soil due to pozzolanic activity of lime while decrease in MDD was due to flocculation and agglomeration reaction of soil lime.

Table 8: MDD and OMC of Soil with carried % of Lime

Material	Maximum Dry Density MDD (g/cm^3)	O.M.C (%)
Soil + 0% lime	1.915	15.3
Soil + 2% lime	1.87	16.5
Soil + 4% lime	1.845	17
Soil + 6% lime	1.9	18.5
Soil + 8% lime	1.825	19

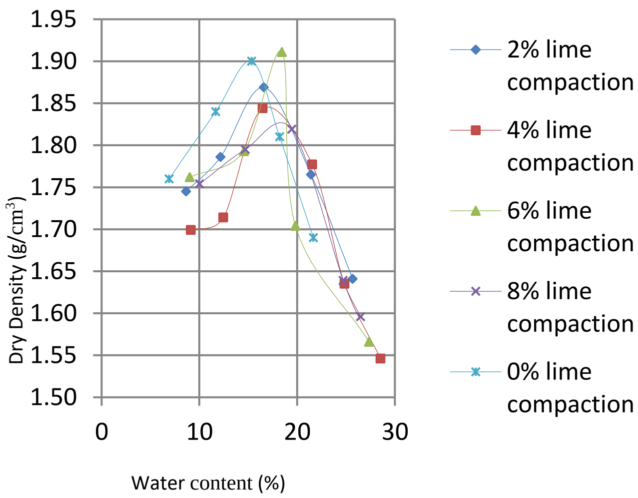

Figure 11: Compaction values of soil + % lime

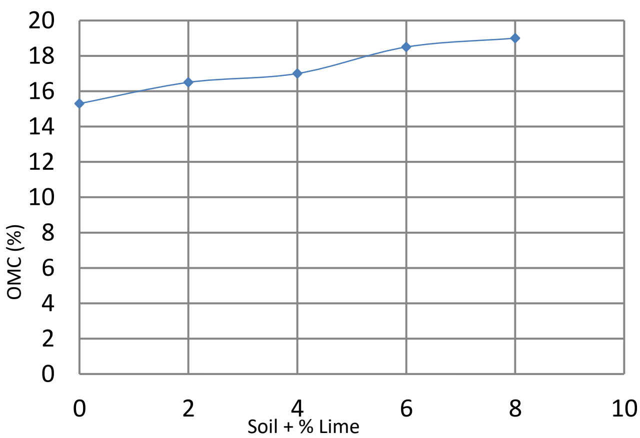

Figure 12: Variation of OMC of stabilized samples

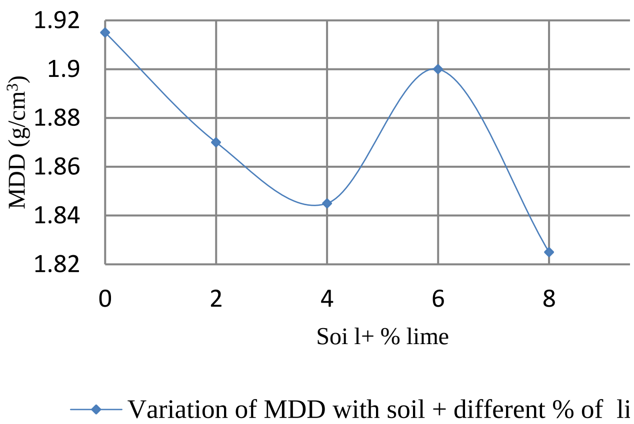

Figure 13: Variation of MDD of stabilized samples

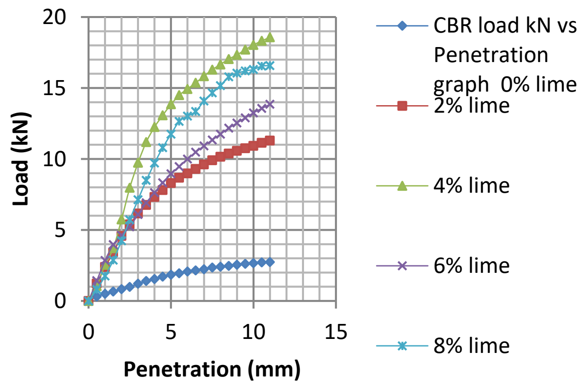

Figure 14: Load – penetration curves for stabilized soil

3.2.5 California Bearing Ratio of samples

From the data obtained from the laboratory, the load vs. penetration curves were drawn for various percentage of lime in the soil and are presented in Figure 14 while the variation of the CBR values with increase in the lime content are tabulated in Table 9 and plotted in Figure 15. Result shows that the % CBR value of the soil increases with increase in lime content hence improvement in the bearing capacity of the soil.

Table 9: Values of CBR with Soil + Different Percentages of Lime

Material	CBR (%)
Soil + 0% lime	6.04
Soil + 2% lime	41.58
Soil + 4% lime	69.4
Soil + 6% lime	44.92
Soil + 8% lime	58.9

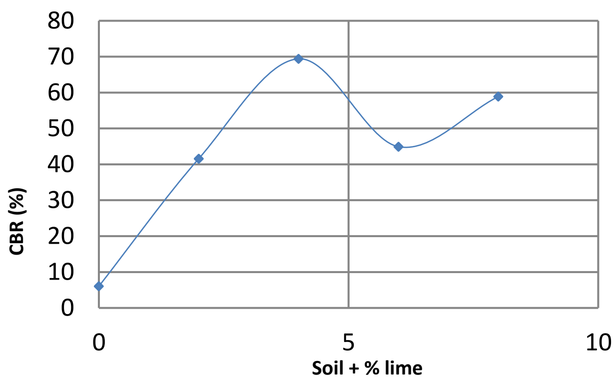

Figure 15: Variation of CBR values of soil + % lime

3.2.6 Unconfined compressive strength of samples

The result obtained from the test shows that increment in lime content resulted in increase of the UCS value and hence increased strength of the soil which is an improvement in the soil. Graph of the Results obtained from the unconfined compressive strength test is presented in Figure 16. It shows that as the percentage of lime increased up to 8% lime additive, there was an overall increase in the UCS value. Increase in UCS can be associated with the hydration and pozzolanic reaction between soil and lime and water forming Calcium Silicate Hydrate and Calcium Aluminate Hydrates and fill the void space, and flocculate particles together improving the strength of the whole mix. The variation of the UCS value with percentage of lime content in the soil, which must have resulted from increased bonding and adhesion of intermolecular particle by the hydration process of lime is presented in Figure 17 and tabulated in Table 10.

Table 10: UCS of stabilized soil samples

Material	UCS (kN/m^2)
Soil + 0% lime	377.32
Soil + 2% lime	508.44
Soil + 4% lime	550.17
Soil + 6% lime	504.61
Soil + 8% lime	611.30

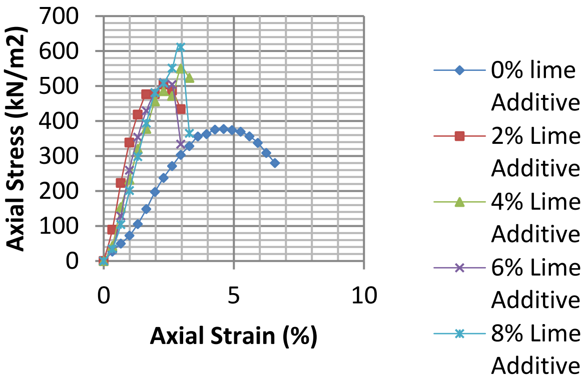

Figure 16: Axial Stress – Axial Strain of stabilized soil

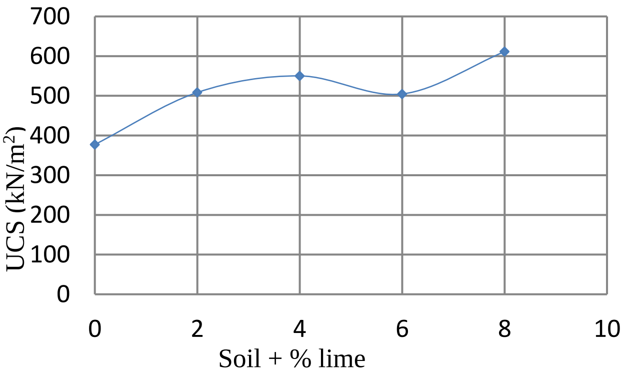

Figure 17: Variation of UCS values with soil + % lime

The study shows that there was great increase in the CBR values from 6.04% to 58.9% and the UCS values from 377.32 kN/m^2 to 611.30 kN/m^2 as the percentage of lime increased to 8% in the soil.

Also there was an overall decrease in the plasticity index from 20.86 to 18.83 at 8% lime content in the soil.

Increase in UCS, CBR and OMC was observed while decrease in MDD and plasticity index was observed.

4 CONCLUSION

From the study carried out on Strength development in lateritic soil stabilized with hydrated lime, the following conclusions were drawn;

1. There was an overall reduction in the plasticity of the clay soil and improvement in the strength of the soil at 8% hydrated lime content thereby enhancing its suitability for use as an engineering material for various construction purposes such as foundation soil and subgrade of pavement.
2. Lime stabilization greatly improved the CBR and strength of test soil by 975% (from 6.04% to 58.9%) and 162% (from 377.32 kN/m^2 to 611.30 kN/m^2) respectively and there was an overall reduction in the plasticity index of the soil at 8% lime.
3. 8% hydrated lime is therefore recommended as optimum for stabilization of A-7-6 lateritic soil.

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