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LIME STABILIZATION OF LATERITIC SOILS

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ABSTRACT

The paper audits lime adjustment of lateritic soils and shows that all Bhubaneswar lateritic soils from A-1-a dirt to A-7-6 soil utilized in the examination, further developed their designing attributes significantly by the expansion of lime. The versatility records of the soils were diminished while as far as possible expanded; as far as possible expanded somewhat, the most extreme dry thickness diminished and the ideal dampness content expanded. From the consequences of Durability and CBR tests, just the A-1 soil and A-2 soil have any potential as skilled base materials and hence just these require any further field tests.. 6% lime is suggested for these field tests. Different soils that don't fit the bill for bases might be used as sub-base materials.

INTRODUCTION

This paper mainly describes the work carried out to assess the potentials of lime in the stabilization of soils for use as road bases or sub-bases for lateritic soils. Portland cement has always been preferred for soil stabilization, but due to its scarcity in some countries, and the fact that portland cement cannot stabilize certain categories of soils and in view of the possibility of local and small-scale manufacture of hydrated lime, the probable use of lime as a stabilizer has been enhanced, particularly in both America and Africa.

The objective of this paper was to study the effect of lime-stabilization on at least one soil from each of the major lateritic soil groups in Nigeria, to make a short review of some of the major work on lime stabilization of lateritie soils and finally to draw relevant conclusions on the potentials of lime for the stabilization of lateritic soils.

PREVIOUS RESEARCH ON SOIL-LIME STABILIZATION

The review of previous research is presented in Table I.

TABLE I

Review of previous research

Year	Author	Author's finding
1925	McCaustland	Reported the use of hydrated lime for soil stabilization in America in 19 24.
1948	Aaron	Reported the first large scale use of lime in pavement construction when 29o of hydrated lime was used to reduce the plasticity index of a ealiehe gravel in Texas in 1943.
1952	Levchanovskii	Suggested the following optimum lime contents: for sandy clay soils, and mechanically stable soila 4—She; light and medium textured silty and elayey soils 6—7 7 and for heavy silty and clayey soils 7—8fio of lime.
1954	National Lime Association of America	Issued a booklet describing how to evaluate mixtures of soil and lime in the laboratory and how to construct lime-stabilized soil roads.
1957	Clare and Crunchlay	In Zambia, low-grade lateritic gravels were used in road bases by adding from **2—39• of** lime.
1958	Road Research laboratory	Reported a linear relationship between the ratio of unconfined eompreeeive strength and CBR values for stabilizing lateritic soils after 7 days curing.
1962	Kassif	
1968	Bhatia	

1958	Irwin	Within the range normally utilized, the strength of stabilized gravels with cement are about 2—4 times higher in strength when compared to lime.
1962	Xassi£	
1959	Brand, Wand, Schoenberg	Reported how quick-lime was used to improve the pro- perties of a highly water-sensitive, clay-bearing loess soil.
1959	Lund and Ramsey	Reported both increases and decreases in the liquid limit
1960	Taylor and Arman	depending on the type of soil.
1959	Lund and Ramaey	Addition of lime to a plastic soil results in a reduction of the plastieity index. Both the plastic limit and the liquid limit of the soil are af tected.
1963	Wang, Mateoa and Davidson	
1963	Jan and Walker	
1972	Arman and Mun fakh	
1960	Hilt and Davidson	Increase in plastic limit after the addition of lime varies directly with the lime content up to some limiting amount referred to as the “lime fixation point”.

TABLE I (continued)

Year	Author	Author's finding
1961	Remus and Davidson	Compactive effort influences **strength** greatly. When the compactive effort waa increased from standard to modified ASTM—AASHO, the compreaaive strength of the soil-lime mixtures increased by 50—250Po for both 7 and 28 days curing periods.
1964	Mateos	This increase in strength was obtained by an increase in maximum dry density of about 10P».
1962	Dumbleton	Concluded that for road construction in the United Kingdom, elayey gravels are likely to be suitable for stabilization with hydrated lime to form road basea on lightly trafficked roads.
1962	lolkov	Reported substantial increases in liquid limit after addition of lime.
1968	Wang, Mateos, and	Reported decreases in liquid limit after addition of lime.
1963	Jan and Walker	

1965	Diamond and Kinter	Detected two reaction stages: a rapid process during which the plastic properties improve, but little permanent strength develops, and a later elow process of strength development with the formation of eementitious products.
1965	Thompson	The maximum dry density decreases typically by 32“ ’ to 80 kg/m° (2 to 5 pet) and the optimum moisture content increases by 1 to 5&•.
1966	Dumbleton, Sherwood and Besaey	In Africa, the soils available and other conditions like high temperature make lime stabilization an economical and appropriate iiiethod of road baie construction.
1968	Thompson	All fine-trained soils react with lime to effect beneficial changes in yorkability, plasticity, and swell properties.
1969	De Graft-Johnson and Bhatia	An unconfined compreeoive strength of 1034 kN/m' (150 pai) was recommended by the Central Road Research Institute of India for baaes in the tropics.
1971	Bulman	Recommended the use of the wetting and drying test as a check for the a• ¡tability of a aoil for stabilization because it bears a closer relationship to the tensile strength of the material.'
197 1	Odier et a1.	Writing on low cost roads suggested that with lime stabilization 1§Po fines panning BS **sieve** and having a plasticity index of at leaet 10P• ahould be used. They suggested CBR values of 8W100& and uneonfined compression strength ot 35Wl700 kN/m' (50—250 {fsi) udiiig BS compaction effort.

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TABLE I (continued)

Year	Author	Author's finding
1971	**Levinson,** and Castel	**The change in compaction** characteristics of three **lateritic gravels stabilized with** lime were similar to the **changes reported** for temperate zone materials, the maximum **dry density** decreased and the optimum **moisture content** increased with an increase of lime content.
1971	Lyon Associates	Discovered that even with 8% lime, most of the ten **lateritic soils** investigated did not meet the PCA wet-dry **criteria.**
197 5	Ola	The results of the lime stabilization of an A-7-6 lateritic soil showed an **increase** in strength properties of between 70 and 30Po. However, it was concluded that the stabilized soil is only adequate as a sub-base.

DEFINITION OF LATERITIC SOILS

There is controversy about the exact definition of lateritic soils. Maignien (1966) and others used the silica/sesquioxide ratio in conjunction with other criteria for the definition. The following has been suggested (Lyon, Associates, Inc. 1971):

SiO, _ SiOt 1.33 laterites
R, O3 * Fe O, + Al 0 3 - l.33—2.00 lateritic soils
> 2.00 non-lateritic soils

However, the silica/sesquioxide ratio itself has been the subject of some controversy, and from an engineering point of view this definition is not convenient where there is a lack of adequate laboratory facilities. Therefore this investigation has adopted local terminology which regards as lateritic soils all products of tropical weathering with red, reddish brown or dark brown colour, with or without nodules or concretion and generally (but not exclusively) found below hardened femiginous crusts or hard pan.

SAMPLE PREPARATION

Generally, tests were performed in accordance with ASTM specifications, although a few modifications were made because of the lateritic nature of the soil.

For water up to the plastic limit for about 5 min. and left overnight for 24 h, then mixed for another 5 min. before testing.

For grain-size distribution, the samples were air dried then wet sieved through a No. 200 BS sieve with a No. 52 sieve placed on top for protection.

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The samples were then oven dried at 60° C. In the hydrometer tests, sodium hexametaphosphate was used as dispersant.

The mixing procedure prior to compaction was as recommended by Portland Cement Association (1959) for soil-cement. The soils were air dried, pulverized, and divided into batches before each batch was thoroughly mixed with lime to uniform colour. Water then was added as rapidly as practicable before compaction. The soil-lime webdry test also was conducted according to the recommendation of Portland Cement Association (1959) for soil-cement. All tests including the CBR, moisture density, and unconfined compression were performed using the standard Proctor eompactive energy.

DESCRIPTION OP SOIL SAMPLES

All the soil samples in these tests were obtained from the peneplain (primary) laterite in the **Zaria** area. The laterite consists chiefly of the concretionary dark-brown type, hard and porous on exposed surfaces, grading downwards, through yellowish brown ochreous and mottled lateritic soils into the deeply weathered, kaolinized and iron-stained zone overlying the bed rock. Field observation around the location of these samples showed quartz lenses and veins running more or less undisturbed from the granite parent rock into the laterite above. The angular and subrounded quartz pebbles bearing laterites indicated an in-situ/replacement process.

The properties of the soils utilized are shown in Table II. Por most of the

TABLE II

Properties of some Nigerian lateritic soils

Test	Results				
	A-1-a	A-2-4	A-4	A-6	A-7-6
Liquid limit (to)	non-plastic	39	35.5	36	42.5
Plastic limit (%)	non-plastic	32	26	18.2	18.1
Plasticity index (7o)	non-plastic	7.0	9.5	17.8	24.4
Specific gravity	2.7	2.73	2.63	2.64	2.65
Percentage passing No. 200 BS **sieve**	3.8	31.3	48	37.5	65
Group index	0	o	6.4	2.0	12

work the American Association of State Highway Officials (AASHO) method of classification was utilized. Most lateritic soils used for road construction fall within the A-2, A-4, A-6 and A-7 groups. Of 221 lateritic soils analyzed by Lyon Associates (1971), 52Po fell into the A-2 groups, 28Po into A-4, 13% in A-6. groups and none in the A-3 or A-Mr groups.

The hydrated lime used in all the tests is the imported white non-hydraulic hydrated lime which is commercially available in Nigeria.

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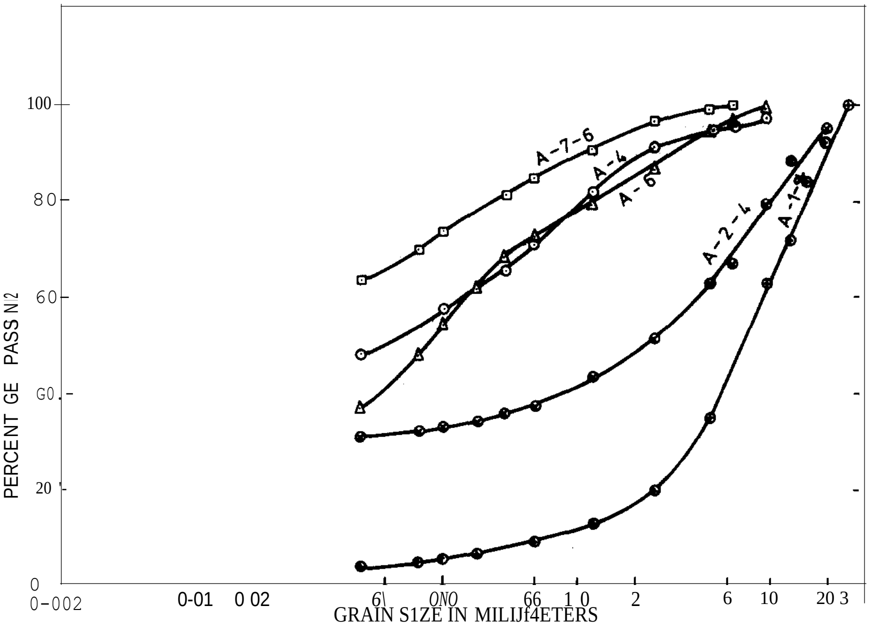
TEST RESULTS AND ANALYSIS

Mineralogy

The grain-size distribution curves for the soils used in the investigation as a result of wet sieving are shown in Fig.1.X-ray diffraction analysis of the fraction of the A-7-6 lateritic soil passing No. 200 sieve, shows that most of the lateritic soil in this area is predominantly kaolinite with some quartz (Ola, 1974).

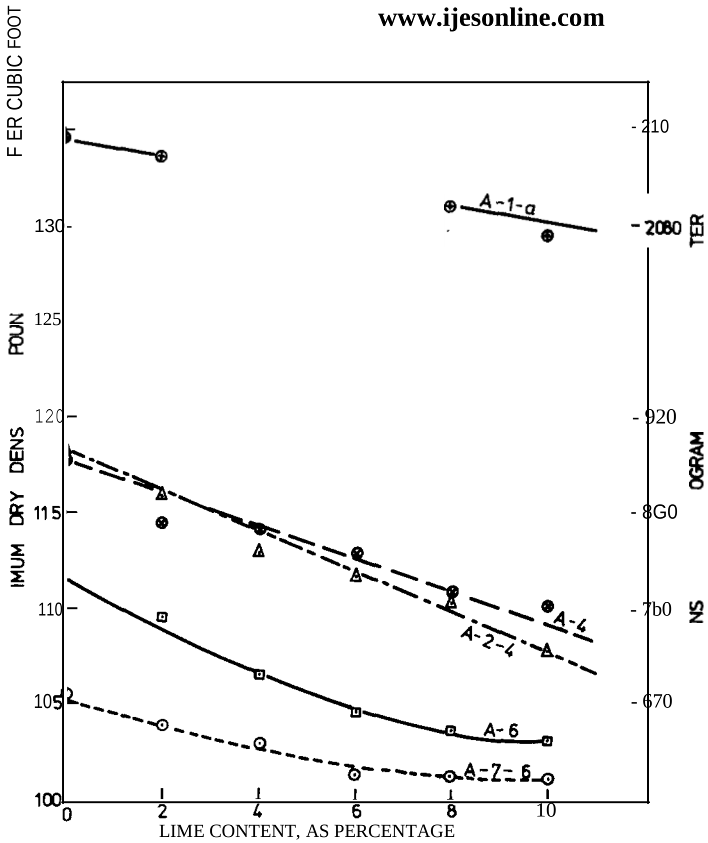


Pig.1. Particle-size distribution curves for lateritic soils used in the investigation.

Compae fiori *characteristics*

The variation of maximum dry density with lime is shown in Fig.2. The results in all cases show that addition of lime causes a decrease in the dry density. Similar results for temperate zone soils were obtained by Dum- bleton (1962), Diamond and Kinter (1965), Arman and Munfakh (1972), Thompson (1965), Mateos (1964). Similar results were.presented for lateritic soils by Cartmell and Bergh (1968), Hayter and Cairns **(1966),** De Graft- Johnson and Bhatia **(1969),** Levinson and Castel (1971) and Lyon Associates (1971). The explanation for this is twofold. Primarily the lime causes aggregation of the particles to occupy larger spaces and hence alters the effective gradings of the soils. Secondly, the 2:2 specific gravity of lime generally is lower than the specific gravity of most lateritic soils.

Fig.3 shows that the optimum moisture content increased with increasing



F'ig. 2. Variation of maximum dry density with lime content.

lime content. Similar results were obtained by most previous writers, for both temperate and lateritic soils. It appears that a pozzolanic reaction between the clay present in the soils and the lime is responsible for the increase in optimum moisture content. This is clearly illustrated in the section on mechanism of lime stabilization.

Strength characteristics

For the purpose of this analysis, a soaked CBR of 80 is regarded as acceptable for base construction for the standard Proctor (AASHO) com- paction. On the other hand for the modified Proctor (AASHO) compaction, a soaked CBR of 180 is accepted; whereas for the Ghana compaction*
a soaked CBR of 120 is utilized. Although results of compressive strength, and wet-dry test have been reported in this investigation, the criteria which were applied for soil-cement were found to be much too conservative in analyzing these soil-lime results.

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*The Ghana compaction uses 25 blowa of a 4.5 kg (10 lb.) rammer dropping 0.46 m (18 inches) on each of the five **layers in a standard CBR** mould.

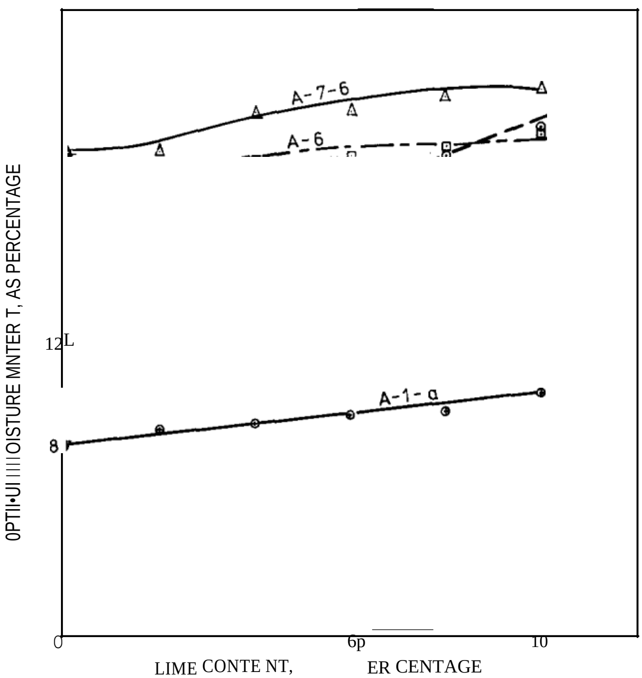


Fig.3. Variation of optimum moisture content with lime (Standard Proctor).

The results of the CBR are shown in Fig.4. Again the results are consistent with the AASHO soil groups except the A-4 soil which plots below the A-6 instead of above it. This could be because A-4 has much higher fines than A-6. Using a soaked CBR of 80Po, only the A-1-a soil satisfies the CBR criterion with about 67o of lime. The A-2-4 has a maximum CBR of 76Po at 7Po lime content. This may be considered as marginally acceptable depending on field tests. The other soils fail to satisfy this CBR criterion and conse- quently are unlikely to be useful as base materials in the field. They can of course be utilized as sub-base materials.

The results of compressive strength are shown in Fig.5. None of the soils achieved the minimum acceptable value of 103 kN/m' (150 psi). The results show the A-l-a with compressive strength values far below those of other soils, even though it has the best **CBR** values. Bhatia (1968) suggested that whereas the use of unconfined compressive strength test as a criterion for the design of soil cement mixes is quite justified in clays and clay soils, it can be ve'ry misleading for granular soils. A material with only cohesion and no internal fnction shows little increase in strength when tested under con- fined conditions, whereas a material with internal friction shows considerable increase in strength. This explanation can be extended to soil-lime mixes since the first reaction of the lime is to flocculate and agglomerate the soil particles into granular fractions.

Fig.6 shows an increase in strength with time for lateritic soils stabilized

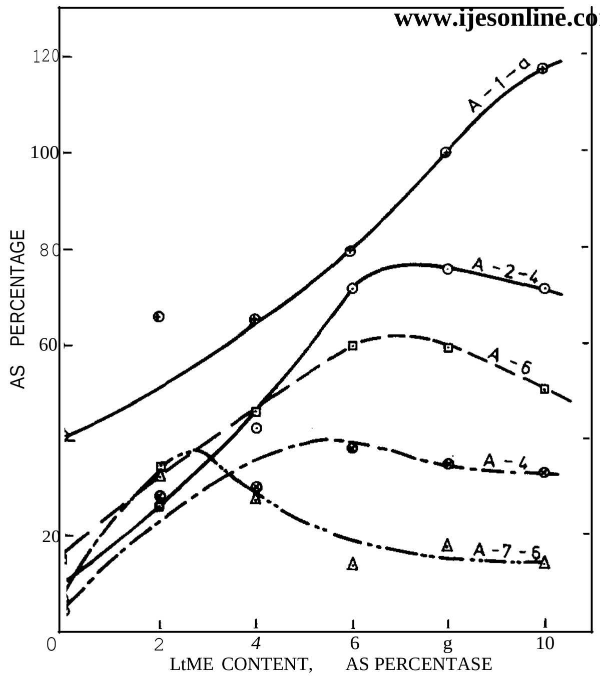
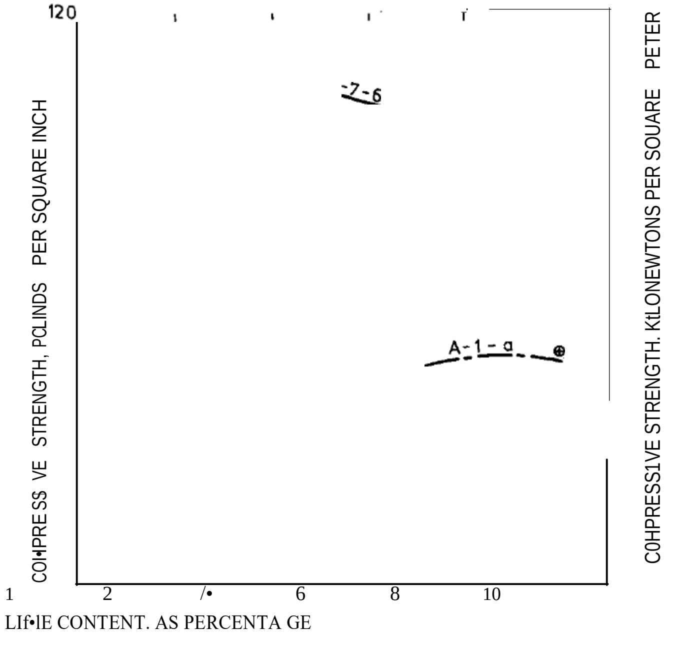


Fig.4. Variation or CBR with lime content.



Pig. 5. Variation of compressive strength with lime content.

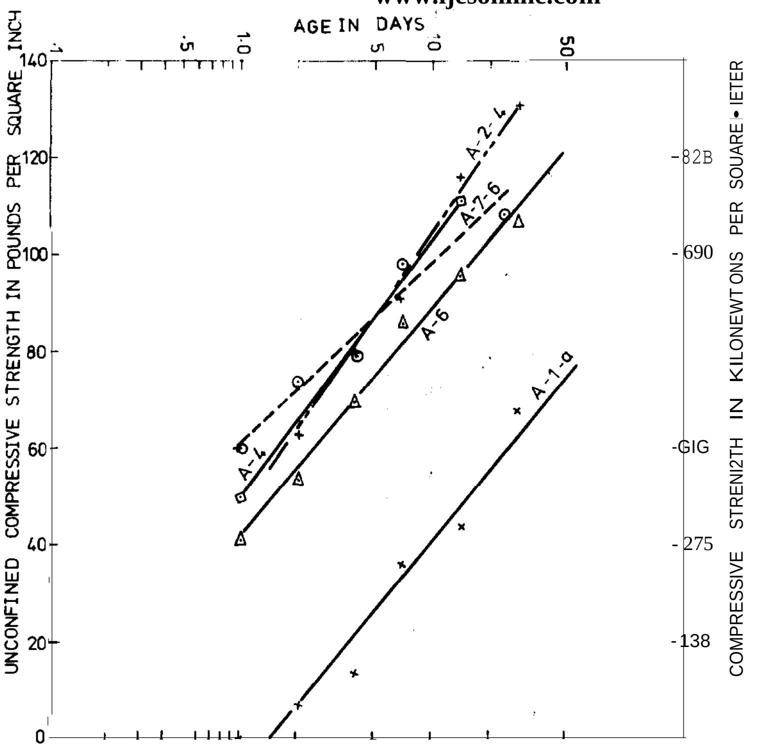


Fig.6. Strength—Age relation for lateritic soils stabilized with 69o lime.

with 6P» of lime. The plot shows that none of the samples was able to achieve the 1034 kN/m' (150 psi) strength in 28 days.

Durabilit y

The maximum swell for all the soils is negligible. for the maximum weight loss in the wet-dry durability test, complete failure of the A-l-a soil stabilized with 6% lime was obtained. Failures were also recorded for A-4 soil. For the A-7-6 soil, complete failure was recorded for 0, and 2Po lime. A marginal pass of 6&o loss was recorded for 6Po lime, while the weight loss for the A-2-4 stabilized with g&o lime was 10Po. A-1-a soil with very small cohesive strength failed very badly.

A tterberg limitc

Table III shows that the PI of the A-6 soil decreases as the percentage lime increases. These results are consistent with the work of other researchers. In our investigation the liquid limit increased only slightly. In Table III, for instance, each additional increase of 2&o lime caused a corresponding increase of 0.5, 0.7, 0.8, 0.5&» in the moisture content respectively up to 8Po lime.

TABLE III

Effects of lime on Atterberg limits for A-6 soil

Lime (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
0	36.0	18.2	17.8
2	36.5	22.8	13.7
4	37.2	28.0	9.2
6	38.0	31.8	6.2
8	38.5	36.5	2.0
10	41.5	40.2	1.3

These are very small but consistent increases in the liquid limit. This compares with the results of Zolkov (1962) and other workers like Lund and Ramsey (1959), Taylor and Arman (1960), and Mateos (1964), who found increases and decreases depending on the type of soil; e.g. Mateos (1964) found that increases in liquid limit occur for illitie clay soils whereas decreases in liquid limits occurred for montmorillonitie clay soils.

***Mechanism** of' **soil-lime** stabilization*

In white lime stabilization, there is no direct hydration of the lime to form cementitious compounds as in the cement stabilization. However, other physical and chemical reactions occur when lime is mixed with clay. The physical reaction is one of cation exchange: calcium first replaces any other ion present as a base-exchange ion; this is followed by floeculation into groups of coarse particles which produce an immediate increase in strength (Ola, 1975), Moh (1962) has suggested that the chemical reaction occurs as in soil-cement hydration.

Thus the addition of lime to a soil causes an immediate increase in the PH of the molding water due to the partial dissociation of the calcium hydroxide. The calcium ions in turn combine with the reactive silica or alumina or both, present at soil surfaces, to form insoluble calcium silicates or aluminates or both which harden on curing to stabilize the soil. This process continues for some months. This then is responsible for the increase in strength with time of lime-stabilized soils as shown in Fig.6.

CONCLUSIONS

The results presented show that all Nigerian lateritic soils from A-l-a soil to A-7-6 soil used in the investigation improved their engineering characteristics substantially by the addition of lime. For example, the PI of the soils decreased, the PL increased and the LL of the Nigerian kaolinized lateritic soils increased slightly. The addition of lime decreased the maximum dry density and increased the optimum moisture content of the soils for the same compactive effort. The durability tests show that only soils with a significant proportion of fine-grained constituents can pass the wet-dry test. From the results of durability and CBR tests, only the A-1 soil and A-2 soil have any potential as competent base material and consequently only these require any further field tests. 6P» lime is recommended for use in the first instance. However, the other soils may be utilized as sub-base materials.

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